The Dyslexic User's Interface Support Tool (DUIST)

- A framework for performance enhancing interface adaptation strategies for dyslexic computer users

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Abstract

Due to the nature of the symptoms experienced by dyslexic individuals (e.g. defective visual processing, short term memory deficit and motor control problems) an investigation into support strategies to aid persons suffering from the condition seems strongly justifiable.

As such, an extensive review of existing support techniques for dyslexic computer users are explored leading to the formulation of four central research models; dyslexia symptoms, symptom alleviating interface strategies, adjustable interface components and a dynamically adaptable interface preference elicitation mechanism. These models provide the foundation for the design of the Dyslexic User's Interface Support Tool (DUIST) framework.

Using a user centred design approach, the support framework is developed, tested and subsequently evaluated with positive results. Performance gains for dyslexic subjects in reading speed and reading accuracy exemplify the apparent benefits of framework utilisation (e.g. dyslexic mean reading speed increased by 4.98 wpm vs. control gains of 0.18 wpm; dyslexic mean reading errors reduced by 0.64 per 100 words vs. control reductions of 0.06 fewer errors per 100 words).

Subsequent research into the long-term impact of framework utilisation; the perceived benefits of applying research formulated models to interfaces designed for dyslexics; and alternative strategies to portability; all now seem justified. That said, the findings presented thus far warrants investigation by any reader actively interested in dyslexia; strategies for dyslexia symptom relief; support environments for dyslexic computer users; applications of adaptive interfaces; and all potential system designers who may be considering developing any type of graphical interface for a dyslexic user group.

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Chapter 3: Interface Design for the Dyslexic Computer User

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Chapter 1: Introduction to the Dyslexic User's Interface Support Tool (DUIST) Framework

1. Introduction

Human-Computer Interaction (HCI) is one of the most widely researched areas in the field of computing. Since the early 1970s, when the commercial use of computers became prevalent, considerable research has been conducted into the development of strategies to facilitate effective, efficient and usable computer interfaces. Since Hansen's seminal work on design principles in 1971, through to Shneiderman's work on graphical user interfaces and direct manipulation in the 1980s, progress in the field has been significant (Hansen, 1971; Shneiderman, 1983).

Now, at the beginning of a new century, considerable effort is being channelled into the investigation of HCI strategies designed to support users with a wide range of disabilities. With an estimated 5-10% of the world's population suffering from some form of physical or cognitive disability (UN Statistics Division, 1993) the development of interface technologies that facilitate usability and accessibility for disabled computer users is certainly justified for many reasons; including:-

a) **Ethical**: In a world that offers a plethora of opportunities for individuals via the technological advancements of the previous decade (i.e. the Internet, mobile communication devices, entertainment system, etc.) the pursuit of strategies for universal inclusion seems morally justified.

b) **Commercial**: Regardless of ethical considerations involved, commercial organisations that fail to develop inclusive technologies run the risk of alienating their potential disable client base and subsequently may loose out on a significantly sized market demographic.

c) **Legal**: As a direct result of recent legislation in several countries (e.g. the Disability Discrimination Act (UK) and the Americans with Disabilities Act (USA)) organisations utilising technology to provide services to the public, have certain legal obligations to ensure, or at least actively pursue, usability and accessibility for all potential disabled users (ADA, 1990; DDA, 2005).

1.1 Research Rationale

As a direct result of the impetus generated by the imperatives outlined above, significant work has been carried out into the design and development of Universally Accessible Interfaces, intended to meet the needs of all possible potential user groups (Goette, *et al.*, 2006; Keates, 2006; Savidis, *et al.*, 2006). Unfortunately, due to the vast diversity in disabilities, the construction of one generic interface solution, that meets the requirements of all types of disabled users, presents a significant challenge (Maybury, 2001). With this consideration in mind, there is strong justification for the separate analysis of interface requirements for specific disabled user groups, especially when failure to provide suitable support mechanisms could significantly disadvantage the group.

One disabled group that is especially disadvantaged when using conventionally designed interfaces is the Dyslexic user group. Due to the nature of dyslexia, common interface operations such as text interpretation, data entry and application navigation are extremely difficult. With an estimated 10% of the UK's population suffering from dyslexia, an investigation into improved interface design for these potential users is justified (British Dyslexia Association, 1999).

Surprisingly, relatively little research has been carried out into the design of interfaces for dyslexic users. Even less research has been carried out into the construction of software interface support environments for individuals suffering with dyslexia. With the growing trend in increased computer usage, especially within web-based systems, an investigation into the design of a generic interface support framework for dyslexic computer users is desirable. To this end, the design, development and evaluation of the Dyslexic User's Interface Support Tool (DUIST) framework for portable, performance enhancing, interface modifications will be discussed in this document.

1.2 Project Aims and Objectives

With the design, development and evaluation of the DUIST framework representing the fundamental objective of the proposed research, the identification of implicit research goals is appropriate. These research goals include: -

1) Identification of the design limitations of conventionally built interfaces for dyslexic users.

2) The formulation of a set of design principles for the effective construction of interfaces for dyslexic users.

3) An examination of emergent interface technology, including adaptive interface techniques, for evaluation and possible utilisation within the DUIST framework.

4) The formulation of a strategy to facilitate framework portability, for derived interface modifications

5) The design of suitable underlying models of dyslexia symptoms and interface specific symptom alleviation strategies.

6) The derivation of a suitable strategy for interface performance evaluation.

7) The development of a robust, reliable, user-friendly software environment to support dyslexic computer users and facilitate the evaluation of the performance impact of the previously formulated embedded system models

1.3 Overview of Thesis

As an overview of the research conducted, Table 1.1 outlines the contents of each of the chapters and provides a concise summation of some of the key observations, findings and conclusions presented.

Table 1.1 "Thesis Overview"

Chapter Summary	Key Findings/Observations/Conclusions
Chapter 2: Examines dyslexia and the many proposed classifications of dyslexia. Causality theories are reviewed and experimental evidence for each proposed theory presented. The chapter concludes by acknowledging the most widely accepted causality theory and comments on the validity of visual processing models of dyslexia.	• Expert opinion is fundamentally divided as to the precise nature of dyslexia. • As causality cannot be established, research efforts should be focused on condition symptom characteristics, where consensus amongst experts can be found. • Models of dyslexia, formulated for the purpose of this work should be based on condition characteristics and suitable symptom alleviation strategies, not theoretical causality or classification.
Chapter 3: Introduces the concept of Disabled Human-Computer Interaction (DHCI), followed by an exploration of the limitations of conventionally designed interfaces for dyslexic users. Existing dyslexic support tools and environments are examined leading to the formulation of a comprehensive set of design principles for the development of interfaces for dyslexic users. Intelligently adaptive interface strategies are reviewed with a view to their potential utilisation, as a vehicle for bringing about desired interface adaptations within interfaces for dyslexic users.	• A consensus based model of symptoms is formulated, to include:- a) Reading errors/difficulties b) Poor phonological skills c) Poor spelling performance d) Short term memory deficit e) Defective visual processing f) Motor control problems g) Defective sequence recollection • The strengths and weaknesses of existing Support Tools and Environment are reviewed for subsequent assimilation into any solution system or alleviation strategy. • A comprehensive set of interface design principles are complied from previous research findings and are used as a basis for subsequent framework models and system infrastructure development. • Recommendations address the use of:- a) Colour and Contrast b) Interface Typography c) Screen Layout d) Titles and Headings e) Interface Consistency f) Readability g) Navigation h) Web-specific Design Considerations i) Customisation • Adaptive Interface Technology and Techniques are examined as an appropriate strategy for the facilitation of automated system customisation.

Chapter 4: Outlines the development of the DUIST framework including the specification, analysis and design of the overall system architecture. This is followed by the development of four fundamental framework models; the Dyslexia Symptoms Model (DSM); the Symptom Alleviating Adaptations Model (SAAM); the User Profile Model (UPM) and the Elicitation Preference Selection Mechanism. Strategies to facilitate the portability of extracted user interface preferences are examined leading to the selection of the Cascade Style Sheet (CSS) as a suitable medium for display preference portability.	• The formulation of the specification of the DUIST framework, including:- a) adaptable interface components; b) expert user model of dyslexia; c) symptom alleviating interface adaptations; d) an automated intuitive elicitation mechanism; e) user profile to interface adaptation translation rule set; f) portability strategy; g) embedded system evaluation mechanisms; h) framework support features; i) administration tools. • The formulation of framework performance requirements, including:- a) distributed architecture; b) system throughput speed; c) input response times; d) system reliability; e) system usability; f) system portability. • The analysis and design of the framework incorporating:- a) underlying framework model synthesis and design; b) adaptable component selection criteria; c) profile elicitation and interface adaptation enforcement; d) attribute refinement algorithms. • An overview of the framework development methodology, inclusive of:- a) Joint Application Development (JAD) deployment; b) programming environment selection and utilisation; c) standalone prototype and subsequent distributed architecture development.
Chapter 5: Explores the suitability of interface performance test strategies, leading to the development of an experimental hypothesis and evaluation mechanism for framework performance. Software acceptance criteria are specified, facilitating the development of a suitable test strategy. Experimental validation and verification procedures are established to ensure the reliability of the extracted system performance data.	• The development of the experimental hypothesis and the frameworks main experimental evaluation policy to include:- a) a focus on the readability of interface text as an essential experimental parameter; b) a discussion of experimental size, subject characteristics, measurable performance indicators, and experimental design; c) a critique of the formulated evaluation strategy; d) experimental verification and validation procedures. • A review of alternative framework evaluation strategies and discussion of the evaluation selection guidelines utilised during the work. • The formulation of the projects ethical policy. • Details of the frameworks test strategy.

Chapter 6: Presents all the experimental results obtained from the DUIST framework trials. All aspects of the environments performance are examined, including; software correctness; software completeness; distributed system performance; system throughput and input response time; system reliability; system usability and preference portability. Evaluation of the experimental performance results provides insight into the suitability of the elicitation strategy, the underpinning system models and patterns in dyslexic user preference selection.	• Testing and evaluation demonstrates that the framework conforms with essential functional and performance benchmarks including:- a) software completeness and correctness; b) no system performance degradation evident during distributed system trials; c) system throughput ⌠ 10 minutes; d) framework usability consistently seen as good by both dyslexic and control user groups; e) system generated display preference settings achieve portability via CSS file utilisation. • Reading performance evaluation of adapted interface display settings against non-modified display settings provides encouraging data including:- a) statistically significant patterns in dyslexic and control group results (p=0.999); b) enhanced dyslexic reading speed performance vs. control (e.g. dyslexic mean reading speed increase = 4.98wpm vs. control 0.18wpm); c) fewer dyslexic reading errors for dyslexic participants (e.g. 0.64 fewer mean reading errors per 100 words for dyslexic subjects vs. 0.06 fewer reading errors for the control). • A review of interface preference selection patterns and the implications for dyslexic interface development.
Chapter 7: Reflects on project findings and presents several project critical conclusions relating to the suitability of adaptive interface technology for dyslexic systems, framework performance, adaptation portability, elicitation mechanics, model validity and the implications of the research on dyslexia causality theories. Subsequent essential research areas are highlighted, as a direct response to research findings.	• Project reflection leads to several recommendations including:- a) the validity of the underlying project models; b) the suitability of the proposed elicitation mechanics for use with dyslexic users; c) the potential benefits of using project formulated design principles for guidance in subsequent dyslexic system construction; d) the implications of the findings in respect to the prevalent causality theory of dyslexia; e) the potential benefits of framework utilisation for dyslexic computer users. • Project limitations and essential avenues of subsequent research are highlighted and include amongst others:- a) the application of framework models to other systems developed for dyslexic participants; b) an examination of alternative permutations of elicitation strategy (e.g. hybrid methods that incorporated automated and manual elements); c) a longitudinal study of framework utilisation; d) an evaluation of the potential benefits of the framework for children; e) an investigation into alternative approaches to framework preference setting portability; f) an exploration of the framework with respects to theorised navigational enhancement for users.

1.4 Overall Summation

While Table 1.1 provides only a brief overview of some of the research findings, the results presented should provide sufficient incentive for interested parties to read the subsequent chapters. As such, it is anticipated that individuals or organisations with interest in the following research areas will find the material beneficial:-

a) dyslexia;
b) strategies for dyslexia symptom relief;
c) applications of adaptive interfaces;
d) all potential system designers who may be considering developing any type of graphical interface for a dyslexic user group.

Chapter 2 Dyslexia: Classification, Characteristics and Causality

2. Dyslexia

The word 'dyslexia' comes from a combination of the Greek words 'dys' and 'lexiocos'. 'Dys' has a meaning of 'difficult' or 'abnormal' and 'lexiocos' can be translated as 'the words of a language'. As such a literal translation for the word dyslexia is 'a difficulty with words'.

As this translation implies the symptoms of dyslexia are not just restricted to reading, rather they extend to all aspects of language processing, including reading, spelling, writing, memory and concentration.

As an understanding of dyslexia is essential to this project, it is imperative that we consider the condition, the theoretical causes of this disability and the symptoms that characterise dyslexia.

2.1 Definition

Despite being one of the most commonly recognised learning disabilities, there is still no universally accepted definition for dyslexia. By 1990, over 43 different definitions of dyslexia and its associated symptoms had been proposed (Doyle, 1996).

The World Federation of Neurology proposed one of the first formal definitions of dyslexia in 1968. It defined dyslexia as:

"a disorder in children who, despite conventional classroom experience, fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities" (World Federation of Neurology, 1968).

The British Dyslexia Association gave the following definition in 1999:

"We define dyslexia as a specific difficulty in learning, constitutional in origin, in one or more of reading, spelling and written language which may be accompanied by difficulty in number work. It is particularly related to mastering and using written language (alphabetic, numerical and musical notation) although often affecting oral language to some degree" (British Dyslexia Association, 1999).

In 1994, the Orton Dyslexia Society provided the following definition:

"Dyslexia is one of several distinct learning disabilities. It is a specific language based disorder of constitutional origin characterised by difficulties in single word decoding, usually reflecting insufficient phonological processing. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalised developmental disability or sensory impairment. Dyslexia is manifest by variable difficulty with different forms of language, often including, in addition to problems with reading, a conspicuous problem with acquiring proficiency in writing and spelling" (Orton Dyslexia Society, 1994).

It is evident, even from the three definitions provided, that disagreement exists between authorities as to the precise nature of dyslexia. As such, this work will attempt to outline the most common classifications, symptoms and causality models.

2.2 Classifications of Dyslexia

Despite the fact that over 30 different terms are used to describe dyslexia, most experts agree that there are two basic types or classification of dyslexia (Doyle, 1996). These two broad classifications are Acquired and Developmental dyslexia.

2.2.1 Acquired Dyslexia (Alexia)

Acquired Dyslexia or Alexia is a condition where the subject loses the ability to process written language. A person suffering from acquired dyslexia will lose a previously well-established reading ability and at worst leave them unable to read even elementary words. The condition usually results from some type of brain trauma. Strokes, drug abuse, psychiatric disorders and brain tumours can all trigger acquired dyslexia.

Recent work into acquired dyslexia has identified at least four possible sub-classifications, with each sub-type having its own individual characteristics and behavioural patterns. These sub-classifications are outlined in the following sections.

2.2.1.1 Surface Dyslexia

Surface dyslexics identify words by sound rather than their written appearance. They have good phonological skills and can effectively read words that have a direct letter-sound relationship (e.g. kill, fill, ship). Surface dyslexics do however have problems with homophones (similar sounding words such as their/there; hole/whole) and particularly struggle with words that can not be read phonologically (e.g. cheque, broad). Sufferers from this type of dyslexia also find it very difficult to spell as they can not effectively visualise words and remember correct letter sequence (Young, 1983).

2.2.1.2 Deep Dyslexia

Deep dyslexic sufferers have little or no phonological skills. They are unable to read words using phonics. They will often read a word incorrectly, but often with a related meaning (e.g. flower read as daisy, town read as Northampton). Words of a similar length and shape are often confused and read incorrectly (e.g. day read lay, sky read why). This is often considered to be the most severe type of acquired dyslexia with several stages of the brains word to meaning translation process being dysfunctional (Bryant, 1985).

2.2.1.3 Phonological Dyslexia

This is a similar, yet less severe type of deep dyslexia. The subjects' phonological skills are usually underdeveloped and they will have difficulty sounding out unfamiliar words. The phonologically lacking dyslexic will rely heavily on the visual recognition of words when reading. They will often make errors with the prefix or suffix of words (e.g. sinking is read sink, covering is read cover). Accurately reading words they have never encountered before is extremely difficult, as letter-sound relationship rules are problematic for the dyslexic to employ (Pumfrey, 1991).

2.2.1.4 Direct Dyslexia

Direct Dyslexia is exemplified by the ability to read words accurately, yet fail to comprehend the meaning of the words read. These severe symptoms are almost exclusively caused by massive damage to the left hemisphere. Due to the nature of this disability, patients suffering from direct dyslexia are very poor readers. Despite extensive remedial therapy, reading skills rarely improve beyond the ability to interpret simple nouns and verbs. Any restored reading skills are often characterised by semantic substitutions (e.g. night for dark). They cannot read phonetically, often opting for a visually similar word to pronounceable non-words. (Coltheart *et al*, 1987).

2.2.1 Developmental Dyslexia (Congenital Dyslexia)

Developmental Dyslexia or Congenital Dyslexia is the condition, initially evident amongst children learning to read, that manifests itself primarily by the subjects inability to learn to read effectively, despite reasonable or even high levels of intelligence.

As with acquired dyslexia, most experts agree that there are several possible sub-types or classification of developmental dyslexia; unfortunately no current agreement exists as to the precise number or names for these sub-types. The most widely referenced classification proposals are outlined below.

2.2.2.1 The Boder Classification (Boder, 1973)

Johnson and Mykelbust first suggested that the identification of patterns in subjects with reading disabilities was essential for the formulation of suitable remediation programs(Johnson & Mykelbust, 1967). With this philosophy in mind, Boder conducted several studies of dyslexic reading performance in the early 1970s and proposed one of the first sub-groupings for developmental dyslexics

The Boder classification of developmental dyslexia is based around an examination of the reading and spelling errors made by dyslexics. Using a combination of reading and spelling tests Boder observed 3 major patterns of behaviour: -

- *Dysphonetic*: These subjects demonstrated they were lacking the conventional phonic analysis or synthesis skills required to decode words not present in their sight vocabulary. They are thought to read exclusively by the visual recognition of words and are unable to read any words they have not encountered previously. A dysphonetic's spelling skills are limited to words stored in their sight library. Over 60% of the subjects tested were classified as dysphonetic.

- *Dyseidetic*: Boder classified this subgroup by its apparent lack of sight vocabulary. Almost all reading was carried out laboriously 'by ear' using phonetic skills. Dyseidetic subjects seemed unable to store a visual representation of previously encountered words. Spelling errors were epitomised by the incorrect phonetic representation of words. Approximately 10% of the subjects analysed were considered to be exclusively dyseidetic.

- *Dysphonetic-Dyseidetic*: The most severally disadvantaged group were the subjects that appeared to display a lack of visual and phonic processing skills. (A total of 22% of the subjects tested were considered to fall into the Dysphonetic-Dyseidetic classification)

Shallice formalised a methodology for the classification of developmental dyslexics based around Boder's observations, which was used extensively in Europe in the 1980s (Shallice, 1988). The use of this method was finally phased out after several authors published criticism of Boder's work. Stanovich and colleagues noted that the Boder and other early classification systems were disappointing, as they were not based around an explicit model of the skilled reading system and as such are descriptive rather then explanatory (Stanovich *et al.*, 1997).

2.2.2.2 Early Neuropsychological Classification

As well as Boder's attempt to identify developmental dyslexia sub-groupings, several other authors proposed alternative classifications based on neuropsychological observations. Table 2.1 provides a summary of three of the most widely published early attempts to classify sub-types of developmental dyslexia.

Table 2.1 - Published early attempts to classify sub-types of developmental dyslexia

Author(s)/Date	Summary of conclusions from work
(Mattis *et al.*, 1975)	• Identified 3 sub-types of developmental dyslexia. • Sub-type 1 – "Articulatory and graphomotor dys-coordination". The group is characterised by problems with speech articulation and poor handwriting motor control. (48%) • Sub-type 2 – "Language disorder". This sub-type is comprised of subjects with naming and labelling difficulties. (28%) • Sub-type 3 – "Visuo-spatial". Subjects with poor visual discrimination and visual memory exemplify this sub-type. (14%)
(Denckla, 1977)	• Identified 5 sub-groups of developmental dyslexia. • Sub-group 1 – Globally poor language skills. • Sub-group 2 – Poor articulation and graphomotor skills. • Sub-group 3 – Anomic repetition deficit. (Naming and semantic errors) • Sub-group 4 – Verbal learning and memory deficits. • Sub-group 5 – Dysphonemic sequencing disorder. (Evident by poor sentence repetition, naming and syntactic errors)
(Doehring & Hoshko, 1977)	• Identified 3 sub-types of developmental dyslexia using factor analysis of three skills. (Oral, Visual and Auditory) • Sub-type 1 – "Severe oral difficulties, contrasting with good visual and auditory skills" • Sub-type 2 – "Limited audio-visual letter association skills" • Sub-type 3 – "Poor audio-visual word/syllable association skills and difficulties with phonic analysis and sequencing"

It is evident from Table 2.1 that there is significant consensus about the neuropsychological behaviour observed in subjects with congenital dyslexia. There is also considerable overlap between some of the proposed sub-grouping/sub-types identified. Despite this seemingly favourable commonality evident in these early studies, later reviews are highly critical of the groupings proposed (Marshall, 1984; Patterson & Marshall, 1985; Stanovich 1997; Castles *et al.*, 1999). Typical limitations identified include: -

- The sub-groupings formulated are inevitably a function of the type of testing used.

- The disciplinary background and/or clinical experience of the researcher is thought to have a heavy influence on the groupings the author proposed.

- The diversity of symptoms, coupled with the varying degrees of severity of each symptom, makes the accurate delineation of sub-groups intrinsically difficult.

- The sub-groupings are derived purely from neuropsychological observations, rather than any proposed model of the processes involved in skilled reading.

2.2.2.3 Skilled Reader Model Classification

With the rejection of the early attempts of congenital dyslexia classification, several leading experts began to propose alternative sub-groupings, based on widely accepted models of the processes involved in skilled reading (Castles & Coltherat, 1993; Coltheart *et al*, 1993; Manis *et al.*, 1996; Plaut *et al.*, 1996). The dyslexia classifications proposed by Castles and Coltheart in 1993 are modelled on the 'dual-route' reading model and they typify many of the developmental dyslexia classifications proposed during the 1990s.

The 'dual-route' model states that a skilled reader has two primary mechanisms for reading. The first mechanism, or 'route', is a lexical or word specific procedure that involves internal access to units representing whole words (complete words are recognised and translated into their associated meaning). The second route, for words that are not internally represented as a single unit in the mind of the reader, is the non-lexical procedure. In this mechanism, a skilled reader uses a system of rules that specify the relationships that exist between a series of sub-word units, graphemes and phonemes, in an attempt to decode the complete word.

Working on the basic assumption that each route works independently and that proficiency in using either mechanism can be developed separately; Castles and Coltheart theorised that two separate patterns in reading deficit should be observed: -

- *Developmental Phonological Dyslexia* – The subject's reading deficit is primarily caused by defective non-lexical processing skills. An inability to read non-words would readily identify subjects suffering from this type of dyslexia.
- *Developmental Surface Dyslexia* –The subject's reading difficulties are primarily due to poor lexical processing skills. A subject's inability to read exception words (i.e. yacht) would suggest limited access to internalised word information and indicate surface dyslexia.

The 'dual model' classification system also allows for subjects suffering from a deficit in lexical and non-lexical processing. As such, the theory predicts that some subjects will demonstrate varying degrees of membership to both classifications.

Early investigation of the symptoms displayed by 53 developmental dyslexics, apparently confirmed the 'dual model' predictions: Roughly 15% of the sample were identified as being pure surface dyslexics; approximately 19% of the sample demonstrated symptoms conforming to pure surface dyslexia; and around 50% of the subjects demonstrated an apparent membership to both classifications (Castles & Coltheart, 1993). Later work by Manis and colleagues support the findings of Castles and Coltheart and added additional weight to the phonological and surface dyslexic classifications. Developmental dyslexic subjects consistently displayed phonological and/or orthographic processing difficulties, in varying degrees (Manis *et al.*, 1996).

The proposal of phonological and developmental surface dyslexic classifications has paved the way to the creation of numerous remedial support programs, targeting the deficiencies experienced by each class (Olson *et al.*, 1997; Castles *et al.*, 1999).

With the classifications suggested by Castles and Coltheart now widely accepted, several theoretical explanations have been proposed for the symptoms displayed by developmental dyslexics from both classifications; these will be examined in the following section.

2.3 Theoretical Causes of Dyslexia

As with many aspects of dyslexia, the actual cause of dyslexia is still a great cause of controversy. Numerous theories have been proposed and these theories have been subject to varying levels of criticism and acceptance. Despite the controversy, most authorities now favour defective neurological development as the most likely cause of developmental dyslexia.

2.3.1 Neurological Basis for Dyslexia

The British ophthalmologist James Hinshelwood first proposed the theory that dyslexia could have a neurological origin in 1895 (Hinshelwood, 1895). This notion was independently collaborated by an English physician Pringle Morgan in 1896 (Morgan, 1896). Morgan identified certain patterns in reading difficulties amongst children suffering with 'visual word blindness'. He suggested that these common symptoms could be caused by a neurological deficiency.

In 1896 Jules Dejerine, a French Neurologist, reported that damage to the left inferior-parieto-occipital region of the adult brain seemingly resulted in reading and writing impairment. Dejerine concluded that the left angular gyrus region seemed to be directly responsible for processing the optical images of characters received by the brain (Dejerine, 1891).

By 1917, Hinshelwood, based on Dejerine's work with the damaged adult brain, theorised that young dyslexic patients could have their symptoms explained by defective development of the left inferior-parieto-occipital (Hinshelwood, 1917).

It was not until 1968, during the first dissection of a brain from a dyslexic boy, that these theories were tested. Pathological examination showed a series of brain malformations, predominantly in the cortical gyri of the left inferior parietal region (Drake, 1968). These findings apparently supported the idea that defective cortical maturation is directly responsible for developmental dyslexia.

The available evidence to support the theory that dyslexia is directly related to the constitution of the brain has increased dramatically over the last three decades and now includes many, widely accepted, supporting studies. Table 2.2 summarises the conclusion from some of these seminal studies.

Table 2.2 - Summary of work supporting constitutional nature of dyslexia

Author(s)/Date	Summary of conclusions from work
(Pennington, 1991; Pennington, 1999)	• Evidence of the Genetic Origin of Dyslexia • Prevalence of dyslexia in families
(Smith *et al.*, 1998; Flint, 1999)	• Identification of specific chromosomes related to dyslexia • Chromosome abnormalities in dyslexic subjects.
(Grigorenko *et al.*, 1997; Castles *et al.*, 1999)	• Chromosome 15 identified as key determinate of reading performance for single words. • Critical involvement of chromosome 6 with phonological awareness • Environmental factors key in dyslexic performance, despite genetic origin.

2.3.2 Defective Neurological Maturation Theories

Despite the fact that almost all authorities would now point to defective neurological development as the root cause of dyslexia, there is still a proliferation of theories attempting to explain the specific neurological dysfunction that causes dyslexia. Table 2.3 provides an elementary summary of the two most widely accepted defective neurological maturation theories.

Table 2.3 Summary of the Most Widely Accepted Defective Neurological Maturation Theories

Author(s)/Date	Summary of Theory
Atypical Lateralisation Theory (Orton, 1925; Orton, 1937; Geschwind & Galaburda, 1987)	• The typical structure of the human brain is non-symmetrical with language processing operations being primarily located in the left hemisphere. • Orton theorised that a symmetrical brain physiology could explain the abnormal patterns in language processing skills evident in dyslexic subjects. • Experimental evidence collected in support of this theory is still inconclusive. • Appendix 22 provides a detailed description of the theory and presents a summary of relevant experimental investigations.
Interhemispheric Deficit Theory (Gross-Glenn & Rothenberg, 1984; Best, 1985; Moore *et al.*, 1995)	• The Corpus Callosum is the primary mechanism for inter-hemisphere signal transfer. • Experts theorise that a defective Corpus Callosum could result in a degradation in inter-hemispheric signal transfer, leading to the symptoms displayed by dyslexic patients • Existing experimental findings relating to the theory are still far from conclusive. • Appendix 23 provides a detailed description of the theory and presents a summary of relevant experimental investigations.

2.3.3 Phonemic Awareness Theory

A phoneme is the smallest unit of sound present in a spoken word. To read successfully the reader must know the phonemes within a word and know how they are pronounced. For example the sentence "A black cat" is made up of three words, three syllables, and eight phonemes (a – b – l – a- ck – c – a – t). The ability to successfully identify and pronounce the sound of each phoneme is called phonemic awareness. As such, the phonological awareness theory states that the dyslexic's main deficit has to do with oral language processing rather than visual perception. It assumes a neurological deficit, which results in a degradation in the translation of auditory signals into their associated visual representation. Several studies have been conducted that seemingly supports this theory; the most critically acclaimed studies are summarised in Table 2.4.

Table 2.4 - Experimental evidence supporting the phonemic awareness theory

Author(s)/Date	Summary of findings from work
(Liberman, 1973; Bradley & Bryant, 1983)	• Several authors have demonstrated that many dyslexic children are unable to identify the syllables and phonemes that make up words, even after acquiring elementary reading and writing skills.
(Werker 1987; Reed, 1989)	• Studies have demonstrated the dyslexic child's inability to differentiate between acoustically similar phonemes (e.g 'ba'and 'da'; 'da' and 'ga').
(Manis *et al.*, 1997)	• Dyslexic's apparent inability to pick out phonemes from non-words or read non-words.
(Taylor, 1995; Kraus *et al.*, 1996)	• Electrophysiological studies of event-related potentials (ERPs) in the brain have demonstrated that many dyslexics suffer from reduced or absent ERPs in regions of the brain where auditory processing is normally performed.
(Witton *et al.*, 1998)	• Many dyslexic subjects have an apparent defect in sensitivity to auditory frequency modulation, which has a strong correlation with the subjects inability to read non-words

Based on the body of evidence collected to date, Manis provides one succinct explanation of the problem encountered by dyslexics: Auditory perception deficits lead to an inadequate representation of phonemic units; this in-turn leads to a lack of phonological processing skills, that ultimately results in the loss of the phonological prerequisites required to read (Manis *et al.*, 1997). The work of Lundberg apparently supports Manis' explanation: As part of a reading support program for preschool children, Lundberg and colleagues focused on teaching children the auditory representation of syllables and phonemes using a series of oral activities. Despite focusing on verbal activities, all of the students involved demonstrated a marked improvement in their reading abilities (Lundberg *et al.*, 1988).

Despite the strong experimental evidence available to support the Phonemic Awareness theory, the most common criticism levied against the theory is the fact that a large proportion of subjects diagnosed with dyslexia do not display a phonological deficit. As previously outlined in Section 2.2.1.3 the phonemic awareness theory can only fully explain the symptoms of the patients suffering from the phonological classification of dyslexia. The obvious implications of this fact is that neurological auditory perception deficits may explain some of the typical behaviour evident amongst dyslexics but it can not fully account for all the symptoms displayed by sufferers of dyslexia. As such, alternative theories must be considered, either in conjunction with the phonemic awareness theory or in isolation, as a means of fully explaining the diversity of symptoms displayed by dyslexics.

2.3.4 Visual Processing Deficit Theories

All of the visual processing deficit theories assume that the symptoms displayed by people suffering from dyslexia are caused by problems in the domain of visual perception. To support these arguments, supporters of such theories cite numerous apparent visual impairments evident amongst dyslexic patients. Table 2.5 summarises the most commonly referenced visual deficit characteristics.

Table 2.5 - Summary of visual deficit characteristics commonly observed amongst dyslexics

Author(s)/Date	Summary of findings from work
(Boder, 1973)	• Confusion between symmetrically similar letters (e.g. "p" and "q", "b" and "d"). • Incorrect recognition of characters that have a similar shape (e.g. "m" and "n" and "w" and "u"). • Word reversals (e.g. "saw" and "was").
(Lovegrove *et al.*, 1980a; Valdois *et al.*, 1995)	• Reduced visual information processing speed. (Exemplified by slow reading speeds)
(Lovegrove *et al.*, 1980a; Lovegrove *et al.*, 1980b)	• Contrast Sensitivity Deficit. An estimated 75% of all dyslexics have difficulty in identifying spatial frequency contrast differences.
(Denckla, 1977)	• Deficit in graphomotor skills. (As exemplified in poor hand-writing skills common in dyslexic patients)
(Livingstone *et al.*, 1991)	• Lack-of or unexpected electrophysiological responses to different high spatial frequency and low contrast visual targets. • Non-dyslexic subjects produce expected event-related potentials (ERPs) as an indication of cortical cognitive processes, as the subject recognised the spatial frequency/contrast differences in the visual targets they observed.

The characteristics presenting in Table 2.5 cannot easily be explained by a phonological impairment, rather a visual processing defect seems more plausible. To this extent a variety of visual processing defect theories have been proposed; the most commonly referenced of these theories are outlined in the following sections.

2.3.4.1 The Magnocellular System (Magnosystem or M-system) Theory

Human vision is made possible by two fundamental pathways leading from the retina to the brain. These two pathways are known as the magnocellular pathway and the parvocellular pathway. At an elementary level, the two pathways are responsible for transmitting different types of visual information to the brain. The composite result of the processed information sent via the two pathways results in normal vision, including visual word recognition.

The magnocellular pathway is primarily responsible for transmitting coarse-grain information and information about movement. (Magnocellular retinal ganglion cells are found predominately in the non-foveal region of the retina.) The parvocellular pathway is responsible for transmitting fine-grain highly detailed information. (Parvocellular retinal ganglion cells are found mainly in the foveal region of the retina.)

The M-system theory, as proposed by Stein and Walsh in 1997, in part, explains dyslexia in terms of a dysfunctional magnocellular pathway (Stein & Walsh, 1997). It assumes that during reading, the magnocellular pathway is responsible for the transient visual information (moving focus on individual letters), while the parvocellular system processes the more sustained channel of information, (line, page and other peripheral data). If the transient channel is inhibited, for whatever reason, visual processing of a given letter within a word is compromised by abnormal persistence of the proceeding letter(s). This results in an increase in the number of fixations that are made per line, in order to gain the same amount of information from the text, it also increases the time taken to read each line)

Pathological examination of several dyslexic brains has identified small anomalies in neuronal organisation in the thalamic relay of the retinocortical pathway, where many magnocellular neurons were abnormally atrophied. (Parvocellular neurons were apparently normal) This is consistent with the M-system theory (Galaburda *et al.*, 1985).

Despite having many supporters, it should be noted that the M-system theory had recently received much criticism from many experts (Johannes *et al.*, 1996; Skottun, 2000). Talcot notes that the most widely used supporting evidence of the M-system, the pathological examination of several dyslexic brains, is fundamentally flawed, as the neuropsychological profiles of the subjects are ill-defined. (There is little detail of the symptoms that each subject displayed prior to death. As such, identifying cortical anomalies that would account for visual dysfunction, when visual dysfunction has not been confirmed, is extremely unsatisfactory) (Talcot *et al.*, 1998).

2.3.4.2 Eye Dominance/Tracking Theories

Non-dyslexic subjects typically favour one eye during normal visual processing; this facilitates normal optical motor control of the eye during reading. The eye dominance theory states that the abnormal visual processing experienced by many dyslexic subjects may be caused by a failure to develop consistent eye dominance. Experts suggest that if eye dominance fluctuates, the dyslexic patient can experience symptoms that include; text convergence; irregular ocular motor control; fixations; and abnormal optical saccade patterns. Stein succinctly describes the probable cause of the deficit as a "failure to develop dependable associations between retinal and ocular motor signals that are essential to fix the true, as opposed to retinotopic, locations of objects in the outside world" (Stein & Fowler, 1982).

As well as the more common eye dominance theories, there has also been a proliferation in work exploring defective eye tracking theories; due in-part to the apparent abnormal fixations, irregular saccades and uneven pursuit observed amongst dyslexic readers (Eden *et al.*, 1994). As it is difficult to argue that these two theories are in-fact mutually exclusive, a review of the most critically acclaimed eye dominance/ tracking studies is presented in Table 2.6.

Table 2.6 - Summary of findings from recent favourable eye dominance/ tracking studies

Author(s)/Date	Summary of findings and conclusion(s) from work
(Stein & Fowler, 1987)	• An investigation of fine binocular control in dyslexic children. • Experimentation presented evidence of control abnormalities amongst dyslexic subjects. • Results included:- a) 67% of subjects exhibit poor dynamic control of optical movements in response to stimuli. b) Subjects with poor vergence control displayed reduced stereo-acuity. c) A six month period of single eye occlusion improved vergence control, stabilising eye dominance and had a positive impact on reading performance • The authors conclude that vergence control is a contributing factor to the symptoms displayed by dyslexics.
(Eden *et al.*, 1994)	• Investigation of eye movement abnormalities for several non-reading tasks. • Measurement of four critical variables: Fixation, vergence amplitude, saccade and smooth pursuit. • Dyslexic subjects compared against aged matched controls. • Performance of dyslexic subjects was significantly worse than controls: - a) Vergence amplitudes lower. b) Worse eye movement during fixation on small targets. c) Fixation instability evidence at the end of optical saccades. d) Poor smooth pursuit when pursing targets left to right. • Authors conclude that oculomotor abnormalities in non-reading tasks suggest a deficit in eye movement control that contributes to reading difficulties.
(Raymond *et al.*, 1988)	• The non-cognitive saccade movements of dyslexic subjects were monitored during a variety of tasks. • The results were compared against a non-dyslexic control group. • Dyslexic subjects demonstrated significantly more regressive saccades when performing sequential-tasks when compared to the controls. • A weak correlation (0.4) was detected between saccadic variables and subject reading ability. • Significant deviations from normal saccadic control levels were evident in 50% of the dyslexic subjects, compared to only 20% in the control group. • The authors conclude that the findings "suggested that reading process and saccade systems are both controlled by visuo spatial attention and fixation systems that maybe impaired or develop slowly in many dyslexic subjects"
(Stein *et al.*, 2000)	• 140 dyslexic children participated in a study to examine a proposed therapy for poor binocular control due to fluctuating eye dominance. • 50% of children given glasses that occlude one eye. (Subjects asked to perform all close visual processing activities, including reading, wearing occluded glasses) • Study carried-out for 9 months. • Reading performance of subjects monitored at regular intervals during the study. • Subjects with occluded glasses demonstrated significant improvements in stable binocular control within 3 months. • All subjects with occluded glasses showed a significant improvement in reading age compared to non-occluded subjects. (+9.4 vs. +3.9 months) • Stein and colleagues conclude that single eye occlusion results in improved binocular control, which in-turn aids reading in dyslexic subjects.

Based on the findings presented in Table 2.6, the reader could conclude that the evidence supporting eye dominance/tracking theories is incontrovertible. Unfortunately, this is not the case. In several comparable studies the findings have been anything but conclusive. Olson *et al.*, in a study of eye movement in dyslexic subjects, presented findings that showed statistically insignificant differences in optical saccades, fixation stability and other oculomotor control variables compared with non-dyslexic subjects. He concluded that the basis for dyslexia was not abnormal eye movements but rather differences in higher cognitive processes (Olson *et al.*, 1983).

Ygge and colleagues, in a study of 86 dyslexic school children in Sweden, concluded that dyslexic children did not significantly differ from the control group in stereo-acuity, vergence or eye dominance (Ygge *et al.*, 1993).

On balance, despite apparent glaring differences between the results from several studies, the weight of evidence for abnormal oculomotor control suggests that eye dominance/tracking theories should not be discounted, for at the very least, explanation of some of the symptoms displayed by dyslexic patients.

2.3.5 The Temporal Rate Processing Theory

Yet another neurologically based causality theory for congenital dyslexia is the temporal rate processing theory. The temporal rate processing theory states that dyslexic subjects suffer from an inability to process rapidly changing (< 40ms) or concurrent stimuli, either via audio or visual channels. Any such condition would account for the phonic and visual deficits common to dyslexics.

Tallal and Piercy provided some of the first evidence for the temporal rate theory when he demonstrated that children with language learning impairments are poor at processing, or even identifying, rapid changes in audio stimuli. A deficiency in audio signal detection was particularly noticeable for changes in the tens of milliseconds time range; where similar rate changes are common in normal speech(Tallal & Piercy, 1973).

Later audio experimentation, based around syllable discrimination testing ('ba' and 'da'), demonstrated that language learning impaired subjects could often not detect changes in syllables played with a 40ms duration, but could identify changes in syllables when they were artificially slowed to 85ms (Tallal & Piercy, 1975).

Ongoing rapid visual and auditory stimuli detection experiments on dyslexic subjects have been carried out extensively over the past two decades. A summary of the findings from a favourable sample of recent studies is provided in Table 2.7.

Table 2.7 - A summary of the findings from a sample of recent favourable rapid visual and auditory stimuli detection studies

Author(s)/Date	Summary of findings from work
(Farmer & Klein, 1995)	• Review of five critically acclaimed temporal studies from the previous two decades. • Based on the ten temporal order experiments conducted in the five studies, Farmer concluded that the vast majority of evidence indicates significant performance differences between control and dyslexic groups.
(Hari & Kiesila, 1996)	• Investigation conducted with 10 dyslexic adults and 20 aged matched controls. • Subjects asked to detect changes in sequences of binary audio stimuli. • In the control group, detection was possible at intervals between 90-120ms. • Dyslexic subjects could not detect changes in the binary pattern until intervals of 250-500ms. • The author concluded that adult dyslexics tested have a deficit in processing rapid sound sequences, which manifest itself via significant delays in conscious auditory perception.
(Rousseau *et al.*, 2001)	• The ability to detect short temporal intervals was examined in a dyslexic adult and six aged match controls. • The subjects were played a series of sequential audio tones, separated by varying periods of silence and asked to determine if the audio gap was shorter or longer than the proceeding audio interval. • The audio gaps ranged in duration from 100 to 1,200ms. • The results demonstrated that the dyslexic subject could only accurately determine a decrease or increase in duration if the gap duration exceeded 800ms. • The authors concluded that the findings supported an apparent temporal processing deficit.
(Van Ingelghem *et al.*, 2001)	• Experimental examination of theoretical temporal processing deficit for audio and visual stimuli in dyslexic children. • Subjects were 10-12 year old dyslexics with age-match controls. • Subjects were asked to detect differences in audio gap duration and identify double or single flash stimuli. • Significant differences were found between control and dyslexic subjects, in both audio and visual tests. • 70% of dyslexic subjects had significantly higher thresholds than controls, for the detection of rapidly changing audio and visual stimuli. • Van Ingelghem and colleagues conclude that the "evidence tends to support the theory of a temporal processing deficit in children with dyslexia."
(Rey *et al.*, 2002)	• A series of experiments were conducted to test the impact of temporal and complex syllable structure adjustment on consonant order judgement. • 13 dyslexic and 10 aged-match control subjects were tested. • Audio sequences of consonant consonant vowel (CCV) or consonant vowel consonant vowel (CVCV) were played to the subjects at varying speeds. • The temporal order judgement performance of the dyslexic subjects was significantly worse than that of the control group. • The performance of the dyslexic subjects did improve as the audio speed was reduced. • The authors concluded that the results support the temporal deficit theory of dyslexia.
(Conlon *et al.*, 2004)	• Several experiments were conducted to test spatial and temporal sequencing performance. • Factors effecting test performance, such as the reading skill, IQ and short-term memory, were all considered when the results were analysed. • Conlon makes several important conclusions from the findings, including- • "The association between temporal sequencing and reading skills may provide a stronger link between neural processing and poor reading skills than basic sensory processing measures alone" • "The problems with rapid sequential processing are predicted to be a generalised problem in poor adult readers, whether they are formally classified as dyslexic or not"

Despite the proliferation of experimental data apparently supporting the temporal processing theory (see Table 2.7), experts are still deadlocked as to the correct interpretation, or even accuracy, of the findings. Supporters of the temporal rate-processing theory have recently been subjected to a barrage of highly critical observations.

Mody and colleagues duplicated the Tallal's early syllable discrimination testing and found, in the majority of cases, very little statistical difference in the performance between control and dyslexic subjects. Only with syllables that were phonetically close together ('f' and 'd') was any significant difference in performance noted. Based on these findings Mody concluded that dyslexic subjects were encountering difficulty with phonetic not temporal processing (Tallal & Piercy 1975; Mody *et al.*, 1997).

McAnally and colleagues conducted consonant-vowel-consonant (CVC) temporal order judgement testing with 15 dyslexic and 15 control subjects. Dyslexic subjects did perform poorly compared to the control group, however performance was not affected by the playback speed of the stimuli. McAnally concludes that differences in performance are not explained by temporal factors, but rather by a phonetic processing deficit evident amongst dyslexic subjects (McAnally *et al.*, 1997).

Similar work by Laasonen *et al.* and Bretherton and Holmes suggests that "correlations between temporal acuity and reading-related tasks suggested that temporal acuity is associated with phonological awareness" (Laasonen *et al.*, 2001; Bretherton & Holmes, 2003).

To summarise, the temporal rate processing theory, as with most other developmental dyslexia causality theories, remains subject to intense debate. Seemingly conclusive studies are often followed by a series of studies that yield results that are bi-polar in nature. Despite this, the merits of the favourable studies observed thus far, compel further experimentation.

2.4 Additional Consideration

The following section presents several additional research critical observations regarding; the relationship between intelligence and reading ability; models of reading; and an assessment of the most prevalent causality theory.

2.4.1 The Relationship between Intelligence and Reading Ability

Although Dyslexia is one of the most widely known and accepted learning disabilities, several authors have recently questioned the fundamental premise behind the condition; namely the validity of the relationship between intelligence and reading ability. By definition, an individual suffering from dyslexia is somebody of above normal intelligence who experiences difficulties in reading and learning to read, that are inconsistent with their age and expected reading skills development.

Thus traditional testing strategies for dyslexia attempted to identify individuals who have below average reading ability, relative to age, who display higher than average intelligence levels, typically measured as an Intelligent Quota factor. This implicitly makes the assumption that intelligence is essential to reading proficiency. Several authors are now challenging this assumption. Table 2.8 provides a summary of several studies that provide evidence that contradicts the intelligence premise.

Table 2.8 - A summary of the findings from a sample of recent studies investigating the relationship between IQ and reading performance

Author(s)/Date	Summary of findings from work
(Wagner & Torgesen, 1987; Wagner & Torgesen, 1994; Farmer & Klein, 1995)	• Meta-analysis on 16 longitudinal studies of reading and phonological performance amongst kindergarten children was conducted. • Wagner and colleagues came up with four fundamental conclusions:- 1) There is no relation between IQ and a child's ability to learn to read. 2) Phonological processing skills are fundamental to reading development 3) Phonological training improved reading skills in all cases. 4) Analysis of words into phoneme segments, the ability to blend phonemes and working memory were all essential skills needed for successful reading development.
(Ellis & Sinclair, 1996)	• Ellis *et al*, conducted extensive tests with diagnosed dyslexic children, with characteristically high IQ levels and non-dyslexic poor readers with low to medium IQ scores. • The battery of tests included, letter matching, word recognition, reading passages of text and reading non-words • After suitable analysis of the results, Ellis concluded that there were no discernable differences between the two groups and thus theorised that IQ is not a significant factor in dictating a child's ability to read.
(Hatcher *et al*., 1994; Hatcher, 2000)	• Hatcher developed a Reading intervention (RI) support system that was trialled in schools within one Local Education Authority area in the UK. • Hatcher made no attempt to differentiate or label poor readers as dyslexic or non-dyslexic. • The RI package focused on phonological training, with an emphasis on making the process of reading enjoyable. • Analysis of the results showed that remedial phonological training significantly enhanced reading performance in all the participants. • The IQ level of the child, did not impact reading performance gains; suggesting that phonological processing skills and not cognitive intelligence is essential to reading.

Though not universally accepted, many subject experts are now revising their understanding of dyslexia to exclude the use of cognitive intelligence levels as a means of identifying or classifying people with poor reading skills as dyslexic.

2.4.2 The Prevalent Theory of Causality

Despite the numerous models of dyslexia (with their associated interpretation of causality) within the last decade a significant number of authors have identified a phonological processing deficit as the most likely cause of the disorder.

In a comprehensive review of specific reading disability in 2004, several leading subject authorities (Vellutino, Fletcher, Snowling and Scanlon) attempted to summarise the evidence that points to a phonological processing deficiency as the most likely cause of dyslexia. Published in the Journal of *Child Psychology & Psychiatry*, the article *"Specific Reading Disability (Dyslexia): What have we learned* *in the past four decades?*", provides a critique of the evidence supporting the auditory processing deficit model of dyslexia (Vellutino *et al.*, 2004). An examination of the evidence presented is obviously fundamental to this work and as such some of the most compelling studies are presented in the subsequent sections.

2.4.2.1 Visual Processing Models Untenable?

As early as the late 1970s Vellutino began to examine the validity of the visual processing deficit model as the likely cause of dyslexia. Using a series of experiments designed to examine how dyslexic children processed printed characters and shapes, Vellutino exposed English speaking dyslexic children to the Hebrew character set. He theorised that if a visual processing deficit was at the root of dyslexia, dyslexic children would encounter significantly more problems when asked to reproduce or match the unfamiliar shapes present in the Hebrew character set. A lengthy series of tests conducted with dyslexic children and a suitable age matched control group of non-dyslexics, found no significant differences in the performance of the two groups (Vellutino, 1977; Vellutino, 1979).

In a comparable study conducted in 1996, Ellis and Sinclair again explored, amongst other issues, the validity of the visual impairment causality theory. In a comprehensive battery of experimental trials that included numerous measures of visual processing ability, Ellis and Sinclair found no significant difference in visual processing performance between dyslexic subjects and the age-matched control (Ellis & Sinclair, 1996).

In 2002, Ramus and colleagues attempted to assess the validity of the three most widely expected developmental dyslexia causality theories; namely phonological, magnocellular (visual) and cerebellar processing deficits. Using 32 university students (16 dyslexic and 16 aged matched control) an extensive series of psychometric, phonological, visual, auditory, and cerebellar tests were conducted in an attempt to identify subject deficiencies and thus likely causality. A detailed assessment of the tests results provided some significant findings, including: -

a) The presence of a phonological deficit in all 16 dyslexic subjects.
b) Evidence of auditory deficit problems in 10 subjects.
c) Only 4 subjects displayed any motor control problems. (These were considered to be minor)
d) Only 2 subjects showed any characteristics consistent with a visual processing deficit.

As a result of the findings, Ramus *et al* concluded that there was a strong case for the phonological deficit theory. "*Results suggest that a phonological deficit can appear in the absence of any other sensory or motor disorder, and is sufficient to cause a literacy impairment... Auditory disorders, when present, aggravate the phonological deficit, hence the literacy impairment*" (Ramus *et al.*, 2002).

Despite the numerous contradictory studies (Tallal & Piercy, 1975; Mody *et al.*, 1997) by 2004, when the article *"Specific Reading Disability (Dyslexia): What have we learned in the past four decades?"* was published in the *Journal of Child Psychology & Psychiatry"*; in excess of 650 independently reviewed studies had been published that directly or indirectly point to the phonological deficit theory as the most likely cause of dyslexia. Vellutino and colleagues conclude that "*there is abundant evidence that difficulty in learning to identify printed words is causally related to significant difficulties in acquiring phonological analysis skills... regardless of whether causes appear to be intrinsic to the individual or reflect environmental/instructional influences*" (Vellutino *et al.*, 2004).

2.4.2.2 Models of Reading Development and Dyslexia

As almost all dyslexic subjects, have fundamental difficulties acquiring the ability to read proficiently; an examination of current reading development theory should prove beneficial to any causality theory validation. Logically, if an understanding of the process of reading is achieved, any causality model of dyslexia should naturally harmonise with the accepted reading model and present insight into reading dysfunction. To this end, several of the most widely accepted reading models are reviewed in the subsequent table.

Table 2.9 - A summary of common reading models

Author(s)/Date	Summary of reading model
(Frith, 1985)	• Frith proposed a three stage model: - • **Stage 1: Logographic** (or whole word skills): The learner memorises important features of the word. The order of letters is typically ignored at this stage. Each word is viewed as a whole and its meaning is decoded without decomposition. This stage relies heavily on memory and difficulties are often encountered when two similar looking words are presented (e.g. house and horse). • **Stage 2: Alphabetic:** The reader starts to develop awareness of phonics (e.g. the relationship between letters and sounds). Once mastered the reader can start to sound out words they previously have not encountered. This process is also known as grapheme-phoneme conversion (GPC) • **Stage 3: Othographic:** The reader develops the skill of automatic analysis of othographic units without phonological conversion. The reader develops the ability to visually perceive the sequences and patterns of individually printed letters within words. Once established the previous strategies become less accessible.
(Coltheart *et al.*, 1987; Coltheart *et al.*, 1993)	• Coltheart developed the Dual Route theory in 1978. • This theory states that individuals learn to read simultaneously via two routes • **Route 1: Lexical**. The reader develops the skill to decode whole words, without any word decomposition. • **Route 2: Grapheme-Phoneme Conversion (GPC).** The reader breaks down words into component letters and translating each letter or grouping of letters to sounds. • The use of the two routes is dictated by the expertise of the reader. • Inexperienced readers rely more on GPC to sound out words. • Expert readers tend to rely almost exclusively on the lexical conversion route and may only employ GPC if they encounter a word for the first time.
(Seidenberg & McClellend, 1989)	• Seidenberg & McClelland developed a print to speech translation connectionist model in the late 1980s. • In the connectionist model, key cogitative processes interact in a series of cooperative and competitive interactions to process printed text into speech. • Neurological groupings deal with specific essential tasks including encoding written words (orthography), encoding the spoken form (phonology) and encoding word meaning (semantics). • These neuron groups work effectively when they establish the appropriate connections between all the relevant groupings. • For a normal reader, if reading is practiced, the neurological connections between the essential task processing clusters are strengthened and reading proficiency increases. • "The connectionist approach attempts to capture the essential computational properties of the vast ensembles of real neuronal elements found in the brain using simulations of smaller networks of more abstract units. By linking neural computation to behaviour, the framework enables developmental, cognitive and neurobiological issues to be addressed within a single, integrated formalism" (Plaut, 2004).

Despite the diversity of reading models, each with their associated merits and limitations, it is clear that all authors accept the importance of phonological processing as one of the key components of reading. This finding does harmonise with those theories of dyslexia that identify a phonological deficit as a root cause of the condition.

2.5 Research Implications

The material presented in this chapter (e.g. a review of dyslexia classification, causality and symptom characteristics) lays the foundation for the subsequent research conducted. With this is mind, the summation of the most relevant findings and their implications to the work should be explicitly stated at this juncture:-

a) Expert opinion is fundamentally divided as to the precise nature of dyslexia. No single classification system or causality theory has been universally accepted and the ongoing debate about causality continues.

b) As classification and causality cannot be definitively determined at this juncture, research efforts should be focused on condition symptom characteristics, where some consensus amongst experts can be found. (See Section 3.2)

c) Subsequent models of dyslexia, formulated for the purpose of this work, should therefore be based on condition characteristics and suitable symptom alleviation strategies, independent of any theoretical causality models.

d) Reflection on possible causality implications of the research may be justified at the conclusion of the work based in the results obtained. For example, if the phonological awareness theory of dyslexia causality is correct, modifications designed to aid the visual recognition of words within an interface should have little or no significant impact on a dyslexic subject.

Chapter 3: Interface Design for the Dyslexic Computer User

3. Disabled-Human-Computer Interaction

Human-Computer Interaction (HCI) is one of the most widely researched areas in the field of computing. Since the early 1970s, when the commercial use of computers became prevalent, significant research has been conducted into the advancement of user centred interface design. Since Hansen's seminal work on design principles in 1971, through to Shneiderman's work on graphical user interfaces and direct manipulation in the 1980s, progress in the field has been significant (Hansen, 1971; Shneiderman, 1983).

Recently the current focus of HCI investigation has become oriented towards the design and development of interfaces for the disabled computer user. With an estimated 5-10% of the world's population suffering from some form of disability, the design of an interface that will allow universal access has become the objective of a considerable number of research projects (Edwards, 1994; Emiliani & Stephanidis 2000; Stephanidis, 2001a).

Inclusive HCI design continues to be motivated by several critical factors, including: -

- The proliferation of computer technology in all aspects of everyday life (e.g. the World-Wide-Web to computerised information kiosks.)

- Recognition of the potential injustice of excluding disabled members of society from access to information, resources and other facilities provided via any computer based medium. (This includes the introduction of legislation to prevent the unnecessary exclusion of disabled citizens in the EU and USA) (Wendy, 1996; Disability Policy Division, 1997).

- The financial implications of excluding potential disable clients from access to services commercially available via computer.

- Increases in the number of disabled people in society due to demographic trends in increasing population age and improved health care.

The gravity of these considerations justifies the continued work in this field.

3.1 Interface Design for the Dyslexic Computer User

One disabled group that is especially disadvantaged when using conventionally designed interfaces is the dyslexic user group. Due to the nature of dyslexia, common interface operations such as text interpretation, data entry and application navigation are extremely difficult. With an estimated 3-10% of global population suffering from dyslexia, an investigation into improved interface design for these potential users is justified (Doyle, 1996; British Dyslexia Association, 1999).

There are however, a number of fundamental difficulties, intrinsic to the development to any computer interface for dyslexic users. The most critical of these considerations can be summarised as: -

1) The precise nature of dyslexia is unknown. The causality and classification of dyslexia are subject to intense on-going debate. (See Chapter 2)

2) Dyslexic subjects display a wide diversity of symptoms, with differing levels of severity evident for each symptom. As such, creating a universally accepted model of typical dyslexic behaviour is extremely difficult.

3) The difficulties encountered by dyslexic subjects do not fall into a single sensory domain. Available evidence suggests multi-sensory deficits are possible in audio, visual and temporal processing. (See Section 2.3.).

4) The validity of an experimentation that explores visual support mechanisms for dyslexic subjects may be flawed, if the prevalent phonological processing causality theories of dyslexia are correct. (See Section 2.4.2.)

In an attempt to minimise the impact of these constraints on this study, the following strategy will be employed.

- A conclusion as to the definitive cause of dyslexia is regarded as beyond the scope of this study. As such, the symptoms displayed by dyslexic patients will be used as the basis for modelling remedial interface characteristics.

- Due to the diversity of symptoms displayed by dyslexic subjects and the controversy over the link between certain symptoms and other learning disabilities; a normalised model of typical dyslexic behaviour, based around expert consensus, will be constructed. Extreme symptoms subscribed by some authors to dyslexia; will be rejected for the purpose of this study.

- Once created, the consensus model of 'typical' symptoms of dyslexia will be used as a basis for the proposal of interface characteristics that will alleviate the problems caused by the symptoms described.

- Upon completion, failure to achieve performance improvements for dyslexic computer users, by means of interface modification, could provide support to claim that dyslexic patients do not suffer from a visual processing deficit and thus validate the current prevalent causality theory.

3.2 A Consensus Based Model of Dyslexic Symptoms.

As previously examined, various authors propose different classifications and subscribe a variety of symptoms to dyslexia (Johnson & Myklebust, 1967; Boder, 1973; Castles & Coltheart, 1993; Snowling, 2000). The following section is an attempt to model a 'typical' set of characteristic symptoms that represent, wherever possible, consensus between subject experts.

Characteristic symptoms are included or excluded from the model based on the following criteria.

1) The level of consensus that exists between subject experts.
2) The frequency of which symptoms are observed in dyslexic subjects.
3) A multi-disciplinary review, across the fields of neurophysiology, neuropsychology, linguistics and educational sciences.
4) Irrespective of the causality model proposed by the author.

Table 3.1 provides a summary of characteristics accepted as being typical of dyslexic subjects.

Table 3.1 - A summary of the characteristic symptoms of dyslexia, to which most experts would subscribe

Key Author(s)/Date	Description of Symptom(s)
(Johnson & Myklebust, 1967; Naidoo, 1972; Boder, 1973; Temple & Marshall, 1983; Snowling & Hulme, 1989; Miles & Miles, 1990; Miles 1993; Mcloughlin *et al.*, 1996; Griffiths & Snowling, 2002)	• **Reading errors/difficulties** as typified by: - a) Visual paralexias ("press" read "pass") b) Derivation errors ("imagine" as "image, "bought" read "brought") c) Logographic reading skills (e.g. read only words encountered previously). d) Inability to read exception words (e.g. "cheque" and "quay") e) Poor reading comprehension f) Slow reading speeds g) Incorrect letter doubling (e.g. "eeg" for "egg" and "piil" for "pill"
(Liberman, 1973; Snowling, 1981; Campbell & Butterworth, 1985; Seymour & Elder, 1986; Werker & Tees, 1987; Miles & Miles, 1990)	• **Poor phonological skills**, as exemplified by:- a) Inability to read non-words. b) A deficit in letter to sound decoding. c) Inability to identify phonemes in spoken words. d) Poor recognition of rhyming words
(Naidoo, 1972; Boder, 1973; Frith, 1985; Olson *et al.*, 1985; Miles & Miles, 1990; Miles, 1993; Mcloughlin *et al.*, 1996)	• **Poor spelling performance,** as typified by: - a) Dysphonetic spelling errors. ("Bump" as "bunt") b) Phonetic spelling errors. ("Knock as "Nock") c) Confusion between symmetrically similar letters (e.g. "p" and "q", "b" and "d"). d) Incorrect recognition of characters that have a similar shape (e.g. "m" and "n" and "w" and "u"). e) Word reversals (e.g. "saw" and "was").
(Miles & Miles 1990; Miles, 1993; Mcloughlin *et al.*, 1996; Snowling, 2000)	• **Short term memory deficit**, as exemplified by: - a) Inability to correctly recite recently presented number sequences (e.g. telephone numbers). b) Poor recollection of sentence structure. (When given a sentence and asked to repeat it word-for-word, dyslexics will often omit words or change the word sequence, while keeping sense of the original sentence)
(Lovegrove *et al.*, 1980a; Lovegrove *et al*, 1980b; Stein & Fowler, 1987; Eden *et al.*, 1994; Cornelissen *et al.*, 1998; Bednarek & Grabowka, 2002; Floyd *et al.*, 2004)	• **Defective visual processing**, as demonstrated by: - a) Contrast sensitivity deficit. b) Difficulty identifying spatial frequency contrast differences. c) Pattern glare. d) Fixation problems. e) Poor vergence control f) Irregular optical saccades
(Denckla, 1977; Everatt *et al.*,1999; Francks *et al.*, 2003; Ramus *et al.*, 2003)	• **Motor control problems**, as typified by: - a) Poor hand-eye coordination b) Deficit in graphomotor skills (irregular hand-writing).
(Boder, 1973; Miles, & Miles, 1990; Miles, 1993)	• **Defective sequence recollection**, as evident by: - a) Difficulty remembering the sequence of days of the week and months of the year. b) Difficulty learning the sequence of letters in the alphabet. c) Problems reciting times-tables.

Some important consideration should be noted when interpreting the consensus model proposed in Table 3.1.

- There is a wealth of literature describing the symptoms observed in dyslexic subjects. The references cited represent only a fraction of the available knowledge to support the behavioural characteristics presented.

- Even though this model attempts to describe 'typical' dyslexic symptoms, it should be noted that due to the nature of dyslexia, it is unlikely that any single dyslexic subject will display all of the symptoms described; and the characteristics that they do display may differ dramatically in severity between subjects.

- The model presented excludes some symptoms that have been proposed where consensus between experts cannot be established (e.g. poor mathematical skills, Meares-Irien Syndrome) (Wilkins & Lewis, 1999 ; Miles & Miles, 2004). See also Appendix 19 for an additional commentary on the relationship between mathematical skills and dyslexia.

- Subsequent references to the symptoms characterising developmental dyslexia will refer to the symptoms outlined in the consensus model in Table 3.1.

3.3 Alleviating the Problems Encountered by Dyslexics via Technology

In the last three decades technological advancements, particularly in the field of computing, have been dramatic. As such, several researchers have attempted to employ technology in an attempt to alleviate the problems encountered by dyslexic subjects (Van Aarle & Van Den Brecken, 1999; Dickinson *et al.*, 2000; Wright, 2001). An examination of the results published thus far, demonstrate the great potential for computer-based support for dyslexics (British Dyslexia Association, 2000).

The following sections will attempt to summarise the most promising examples of technology applied to supporting patients with dyslexia. The findings have been divided into two main categories, support tools and support environments: -

- Support tools are considered to be applications of technology that enhance an *existing* software application or environment, which was not specifically designed for dyslexics.
- Support environments are considered to be *independent* software system solutions, specifically designed for dyslexic subjects.

3.3.1 Support Tools

The dyslexic population has employed the following technology to good effect in a variety of tasks. Table 3.2 summarises key technologies and describes the symptoms that the technology has helped to alleviate.

Table 3.2 - Technological advancement and the perceived benefits for the dyslexic

Device/Technology	Description and Perceived Benefits
Keyboards	• Keyboards have removed many of the hand-eye coordination difficulties experienced by dyslexics using pen and paper. • Poor graphomotor skills are no longer a barrier to legible correspondence (Everatt *et al.*, 1999). • Memory processing requirements are reduced, as subjects do not have to remember the visual representation for each letter.
Operating Systems (Accessibility Settings)	• Most computer operating systems now incorporate accessibility options that allow the user to adjust many of the visual display settings. • Typical option settings include, character set selection, font size, background/foreground colour combinations and display resolution. • Individually tailoring the display settings of the operating system can help alleviate many of the problems associated with contrast sensitivity deficit and pattern glare (Floyd *et al.*, 2004).
Word-processors and associated functionality (Spell checkers, grammar checkers and auto-correction facilities)	• Perhaps the most valued tool available for dyslexics. • Word-processing software allows a dyslexic user to construct error-free documents, by taking advantage of the functionality incorporated into most word-processors. • Spell checkers, grammar checkers and auto-correction facilities support typically bad dyslexic spelling (Miles, 1993). • Sophisticated spell checkers allow for the identification of patterns of regularly misspelled words and incorporate appropriate feedback to support the dyslexic user. • Many spell checkers now identify phonetic spelling errors, which can be particularly useful for dyseidetic subjects (Boder, 1973). • Grammar checkers can help to identify other typical dyslexic errors including; duplicated words, inappropriate use of punctuation and incorrect sentence-syntax.

Word-predictors	• Word-predictors are now often included in software that requires textual input. • The user may input the first letters of a word and the word-prediction software will provide valid suggestions as to the word the user is trying to spell (e.g. the subject enters "de" and the software offers several predictions as to the word the subject is attempting to type: "destruction, describes, detects, deletes etc.). • Word-predicting software is particularly useful for subjects where extreme patterns of incorrect spellings are evident. (Spell checking software alone, may be unable to identify the word the user is attempting to type, if it deviates to extensively from the correct spelling.)
Voice-recognition software	• Voice-recognition software is particularly useful for dyslexic subjects with severely retarded reading and spelling performance (Miles, 1993). • Software can be trained to recognise the voice patterns of the subject and thus translate spoken words into text. • Using voice-recognition software, in-conjunction with a suitable word-processor, the dyslexic subject can dictate the required document without the normal constraints of poor spelling and comprehension. • The subject can usually check the content of the document using text-speaker software (see later) and as such circumvent the usual writing prerequisites of spelling and reading. • Voice-recognition software can be imbedded into or interfaced with a variety of software applications. This can significantly reduce the need for textual-input for the dyslexic computer user.
Text-speaker software	• Text-speaker or text-reader software allows dyslexic subjects to listen to, rather then read, paragraphs of text. • Text-speaker software can considerably increase the comprehension, and dramatically decrease the effort required to read (Leong, 1992; Elkind *et al.*, 1993; Elkind *et al.*, 1996). • As many dyslexic subjects process text very slowly, text-readers can reduce the time needed to read and comprehend passages of text considerably. • Elkind suggests that computer readers can also be used to supplement adult remediation programs, with the text-readers motivating the students to read more and, as a result, to progress more rapidly (Elkind *et al.*, 1996). • Despite the obvious advantages of text-readers, some authors have been critical of the early monotone voice output generated by text-speakers and indicate that comprehension over prolonged periods of use is difficult (Olofsson & Lundberg, 1993). • Recent technological advancements have allowed for more natural speech-synthesis, which again helps to hold the listeners interest and thus improves comprehension.

The application of new technology has significantly improved the lives of many dyslexics, in a variety of everyday tasks (Leong, 1992; Elkind *et al.*, 1993; Miles, 1993; Elkind *et al.*, 1996; Everatt *et al.*, 1999). It should, however, be noted that the tools reviewed represent incidental applications of technology to aid dyslexic computer users. The following section will examine support environments that have been designed exclusively to aid the dyslexic population

3.3.2 Support Environments

Several studies have recently been carried out with the explicit proviso of employing technology to improve the usability of computers for the dyslexic. Results have been varied, but generally, evaluation of pilot system performance has resulted in positive feedback from dyslexic users groups. Table 3.3 provides a summary of some of the recent support environments created for dyslexic computer users and highlights the main conclusions derived from each study.

Table 3.3 - Software environments specifically designed to aid dyslexic subjects

Author(s)/Date	Description of Application/Testing/Conclusions
(Dickinson *et al.*, 2000; Dickinson *et al.*, 2002)	• The development of a highly configurable word-processing environment to alleviate the problems encountered by dyslexic subjects. • System is called "SEEWORD" • Highly customisable interface, due to varying degrees of symptoms displayed by dyslexic subjects. • Key features include: - (a) User manipulation of foreground and background colour. (b) Custom selection of character typeface, font size and line spacing. (c) User adjustment of the colour, font or size of letters that the users are likely to confuse (e.g. 'b' and 'd). (d) User manipulation of the width of the text on the page. (e) Synthesised speech (for audio review of documents). (f) Direct manipulation based interface. (g) Improved usability. • Pilot system evaluation with six dyslexic boys (aged 14-16). • Evaluation based on reading performance (based on the number of errors) with and without customisable components applied. • Evaluation testing results demonstrate a statistically significant reduction in the number of reading errors when the user had customised the system environment. • Key Conclusions: - 1) Optimal interface settings are highly individual. 2) Customisable components are essential for improved performance (comfort and accuracy). 3) Flexible user centred design is critical to the success of interface and its on-going development.
(Wright, 2001)	• Wright and colleagues developed a web-site designed specifically for dyslexic students studying nursing and midwifery at Sheffield University. • The site provides support for dyslexic students, and tutors wanting information about dyslexia. • Constructed inline with design principles specifically tailored for dyslexic users. • Key features include: - (a) Strong focus on interface customisation policy. (Fonts, background colour, foreground colour, character size). (b) Flexible reading modes (on-line or off-line dyslexic friendly output). (c) Well-structured site navigation (avoids semantic net, free surfing approach). (d) Clear delineation between sections for students and tutors. • Pilot system evaluation conducted via online evaluation questionnaire, with 31 dyslexic students responding. • The evaluation questionnaire indicated strong satisfaction levels, with 90% of responses indicating the site was useful and provided the right level of information. • Evaluation of the content, structure and site navigation were all favourable.

<table>
<tr><td>(Van Aarle & Van Den Brecken, 1999)</td><td>

- Van Aarle and Van Den Brecken have developed CONDALS, a knowledge-based decision-support system for diagnosing typical spelling and reading problems, common amongst dyslexic subjects.
- Using a set of established reading and spelling guidelines in a prescriptive framework, the software conducts a decision making diagnostic cycle of experiments with each subject.
- Current knowledge acquisition experiments have resulted in the development of a reliable knowledge-base that can accurately identify patterns in reading and writing errors.
- Appropriate remedial support can be prescribed as a result of the recommendations from CONDALS.

</td></tr>
<tr><td>(Cisero *et al.*, 1997)</td><td>

- Cisero and colleagues developed CAAS (Computer-based academic assessment system) to aid the identification of students with specific reading disabilities (predominately dyslexia) in college.
- CAAS was designed to assess reading skills via a series of computer-presented reading tasks that measure reading speed and accuracy of performance.
- The conclusions of CAAS were validated against four key criteria: -
    (a) The suitability of the test mechanism for identifying reading disability.
    (b) The consistency of the data against established reading disability theories.
    (c) The unique nature of each subjects test results and any subsequent diagnosis.
    (d) The generation of prescriptive information, leading to the development of a program of remedial activities, designed to alleviate the students' learning disability.
- Critical evaluation of the CAAS system demonstrated the value of computerised reading assessment and resulted in the creation of several effective remedial support programs for students identified as having a learning-disability.

</td></tr>
<tr><td>(Richards, 2007)</td><td>

- Richardson and colleagues have developed a series of extensions to the Firefox browser designed to support people with visual processing and reading difficulties (including dyslexic computer users)
- Using a series of dynamic, 'on-the-fly' transformations of web pages the modified browser seeks to enhance the presentation of all content.
- Adjustable attributes include: - text size, image size, text style, line and letter spacing, text foreground colour, text background colour, page background removal and text to synthesised speech features.
- Modifications are made in response to traditionally selected user display selection options (e.g. menus, toolbars etc.).
- Richardson *et al*, achieve page transformation using suitable modifications to the Document Object Model (DOM).
- Provisional trials support the idea that modifications are beneficial.

</td></tr>
</table>

(TechDis, 2002)	• TechDis is an online information repository providing details of support strategies for dyslexic computer users and other user groups with disabilities. • Formed in 2002 and funded by the Joint Information Systems Committee (JISC) TechDis provides online access to:- a) expert advice, guidance and support for institutions in relation to technology and disability; b) information resources detailing strategies to identify and support dyslexic technology users; c) guidelines and advice on the implications of accessibility and disability legislation on institutional technology practice.
(Bartlett, 2002)	• The FUSSY (Free User Style Sheet for You) web-resource provides access to a set of dyslexic friendly Cascade Style Sheets (CSS). • This resource allows users to download one or more predefined CSS suitable for incorporation within web-pages designed for dyslexic users. • CSS attributes have been selected based on existing research into optimal display settings, but no evidence of performance evaluation is presented. • Plans for tool extension are discussed to allow CSS customisation via standard menu-bar/tool palette selection options, but access to this functionality is currently unavailable.
(Textic, 2007)	• The Textic organisation has developed several support tools specifically for dyslexic computer users. • The Textic-Toolbar provides an add-on component for the Internet Explorer browser that allows conventional display attributes such as font, font size and colours to be adjusted by the user, using manually adjustable preference options on the toolbar. • The Textic-Talklets provides an embedded text-to-speech module that can convert standard textual content to synthesised speech. • The tools manufacturer presents no product experimental evaluation findings.
(Barron *et al.*, 1998; Castell *et al.*, 2000; Lynch *et al.*, 2000; Wise *et al.*, 2000)	• Barron and colleagues have successfully developed a remedial reading support environment for dyslexic children. • Using DECtalk, a high-level speech synthesiser, a software environment was designed to help users develop effective letter sound translation skills. • Users were encouraged to develop an accurate understanding of the correct pronunciation of words by concatenating the sounds from each word segment. • Dyslexic subjects trained using the software demonstrated a marked improvement in their reading and consistently found that word recognition improved when words were taught in segments rather than whole words. • Further studies of remedial reading software by Castell *et al.*, Lynch *et al.* and Wise *et al.* (though not specific to dyslexic subjects) have demonstrated that such support environments are particularly effective in developing reading skills in children with learning disabilities.

3.3.3 Interface Design Principles for Dyslexic Specific Applications

During the last decade several authors (and organisations sponsoring research into dyslexia) have proposed a series of generic design principles that should be considered during the development of any computer interface built for dyslexic users (Lovegrove *et al.*, 1980a; Molich & Nielsen, 1990; Bradford, 2002; British Dyslexia Association, 2003; Rainger, 2003). Most of the guidelines proposed have been formulated based on: -

- Evaluation of recent software developed for dyslexic computer users;
- Wider universal accessibility research;
- Expert opinion on the causality and the characteristics of dyslexia.

The following section examines each of the principles proposed, the evidence supporting each guideline and provides examples of the application of each principle.

3.3.3.1 Colour and Contrast

The appropriate use of colour within any interface design is critical. It is even more important for interfaces designed specifically for dyslexic users. Consistently, experiments have shown that dyslexic subjects are particularly prone to contrast sensitivity deficits (Lovegrove *et al.*, 1980a; Lovegrove *et al.*, 1980b). As such, most authors propose colour guidelines that prompt sufficient colour contrast between all visible interface elements (Rainger, 2003).

Certain colour combinations seem particularly inappropriate for dyslexic computer users. As well as the red/green combinations, (which should be avoided due to the confusion they cause colour-blind subjects) many dyslexic subjects have difficulty with extreme colour contrast. Common interface colour combinations like black text on a white background or white characters on a black background consistently cause problems for dyslexic subjects.

Scotopic sensitivity, or Maeres-Irlen Syndrome, describes a condition subscribed to many dyslexic subjects, which is characterised by a difficulty reading text displayed on high contrast backgrounds. Sufferers of scotopic sensitivity find that extreme colour combinations result in several undesirable visual effects. Typically these negative effects include increased fixations, word movement and the blurring or blending of foreground elements with background components. The most common scotopic sensitivity symptom is described as the 'rivers of text effect', where the readers' focus is diverted from the text to the surrounding blank space with the subject perceiving rivers or pathways of space running down the page. Despite the fact that a recent critical review of several scotopic sensitivity studies and the associated use of corrective coloured filters have produced mixed findings, most authors recommend the avoidance of high contrast foreground and background colour combinations (Evans *et al.*, 1996; Robinson & Foreman, 1999; Evans & Joseph, 2002).

Most authorities now reject the idea that a prescribed 'cookbook' combination of interface colours can adequately cater for the individual preferences of every dyslexic interface users. Rather, due to the diversity of symptoms displayed by dyslexic subjects, interfaces should incorporate functionality to allow individuals to adjust colour display settings to meet their unique visual preferences (Wright, 2001; Dickinson *et al.*, 2002).

Where colour customisation options are impractical to incorporate within an interface, designers should select colours combinations that have sufficient colour contrast, while avoiding extreme contrast combinations (e.g. Cream or light yellow background with black or brown foreground text). Where possible, designers should also ensure that backgrounds are a single, solid colour.

3.3.3.2 Interface Typography

The appropriate selection of font type is critical to the usability of any interface designed for dyslexic subjects. With typical behaviour amongst dyslexics including confusion between symmetrically similar letters (i.e. "b" and "d") and incorrect recognition of characters with similar structures (i.e. "m" and "n"), it is imperative that a font is selected that minimises the impact of these symptoms.

Most authorities now agree that the use of character sets that have clearly defined, simple letter shapes, with clear spacing between letter combinations, can improve the legibility of any interface text. Standard fonts such as Arial, Comic Sans, Verdana and Trebuchet MS are all recommended, as they comply with the basic dyslexic legibility criteria (Bradford, 2002; Rainger, 2003). Conversely the use of elaborate character sets such as Monotype Corsiva and Times New Roman, that incorporate purely decorative elements are to be avoided for dyslexic interface designs.

Further interface typography research suggests that the use of commonly used fonts, such as Arial and Verdana, with which users are familiar, is also advantageous. Boyarski *et al* studied the reading speed of users and found that the greatest reading speeds where achieved when users were familiar with the font. Fonts not previously encountered by the interface users apparently took longer to adjust to and consequently increased reading speeds (Bergfeld-Mills & Weldon, 1987; Boyarski *et al.*, 1998; Kahn & Lenk, 1998).

Recently, Frensch (Frensch, 2003), developed 'Read-Regular', the first font specifically developed for the dyslexic reader. Working on the basic assumptions that all characters must be significantly different, typical character features have been simplified or exaggerated to ensure that each new character is clear, simple and unique. Tests with over 100 dyslexic subjects have proved encouraging, with the majority of those tested reporting improved reading performance, in both reading speed and accuracy (Frensch, 2003). Based on the provisional findings thus far, further investigation into the use of bespoken character sets for dyslexic users would seem justified.

Examination of optimum font size has also been considered in a number of studies. Typically researchers working with dyslexic subjects recommend a minimum font size of 12pt or 14pts (Bradford, 2002; Rainger, 2003). A study by Tullis and colleagues conducted in 1995 determined that the readability of interface fonts significantly deteriorates below a 10pt size. Interface users attempting to read information in fonts below 10pts found that reading speeds dropped as the fonts size reduced (Tullis *et al.*, 1995).

The highest font point size a designer should consider is dictated by a number of factors including the physical display area of the screen, the quantity of text required and other related aesthetic considerations. Generally, text used for anything other than headings or titles, that exceeds an 18pt size, quickly becomes unmanageable and should be avoided (Kahn & Lenk, 1998).

All usability and accessibility research based around the dyslexic computer user consistently finds that the use of *italics* is particularly disconcerting for dyslexic readers. Where words need to be emphasised, emboldened characters may be employed to good effect (Bradford, 2002).

3.3.3.3 Screen Layout

Irrespective of the purpose of the interface, be it a web-page or an interactive telephone kiosk, the position of elements within the interface is critical to the usability of the system. Inappropriately placed buttons, hyperlinks, menus, labels, and headings can significantly reduce the usability and in turn the effectiveness of the interface.

The following considerations should aid the successful design of any interface layout.

3.3.3.3.1 Prioritise On-Screen Information and Interface Functionality

The order in which elements are presented within an interface is critical to the successful operation any such interface. Sears demonstrated that users consistently accomplish tasks with greater accuracy and speed when they move through a display in a top-to-bottom sequence, compared to a layout that requires the users focus to move irregularly around the interface (Sears, 1993). In a similar vein, Detweiler and Omanson insist that placing information on screen in a descending order of importance significantly increases the user's ability to assimilate the information presented (e.g. critical information is available first, at the top of the screen; while less important information is available lower down the screen) (Detweiler & Omanson, 1996).

As dyslexic behaviour is characterised by deficits in short-term memory and sequence recollection, it would seem logical to support any cognitive deficiencies by establishing a clear structural hierarchy of importance, typically from top-to-bottom, for any on-screen display. For example, a list of menu options could be prioritised by listing the most widely used options first, at the top, with less critical options being listed in a descending order of importance.

3.3.3.3.2 Ensure Interface Consistency

Establishing interface consistency is critical for any interface design. It is even more critical when designing interfaces for dyslexic users who typically have reduced short-term memory processing capabilities (Miles & Miles, 1990; Snowling, 2000). Early authors of conventional interface guidelines recognised that reducing the cognitive load on working memory was critical to any successful interface development (Hansen, 1971; Baecker & Buxton, 1987). Subsequent studies and subject authorities have consistently demonstrated that this view is correct (Vincow & Wickens, 1993; Dix *et al.*, 1998; Shneiderman, 1998). By placing all interface components, in consistent, on-screen positions, several key benefits are conferred to the dyslexic user; these include: -

a) A dramatic reduction on the users short-term memory load.
b) A reduction in the time taken for the user to feel at 'ease' with the interface.
c) Noticeable improvements in the user operating skills, including speed and accuracy, especially where the interface incorporates multiple screens and/or complex functionality.

Interface components that are particularly important to keep consistent include, all navigational elements, buttons, icons, menus, headers, help facilities, prompts, system outputs, use of colour, fonts, graphics and user feedback. Failure to maintain consistency in all aspects of on screen-display can significantly impede the usability of the interface for the dyslexic user.

3.3.3.3.3 Well-Designed Titles and Headings

Titles and headings are critical to the clarity of any interface. They should provide the user with a concise description of the information and/or functionality the current or subsequent screens provide. The use of well-designed titles and headings is thus of particular importance to dyslexic users as: -

a) Poor spatial awareness/sequential processing skills can quickly leave dyslexic users feeling lost, when navigating around multi-screen interfaces.
b) Failure to provide meaningful titles and headings significantly increases the cognitive load on working memory; something which is often impaired in dyslexic subjects
c) Dyslexic users can quickly start to feel negative emotions including, discomfort, confusion, frustration, even panic, when they feel unsure about their current position or task status in a multi-screen application.
d) Negative feelings can quickly lead to dissatisfaction or indifference with an inadequately labelled interface; this at worst can lead to the cessation of use by the dyslexic subject.

To minimise the impact of these factors, careful design of titles and headings is essential. Designers should ensure that titles and headings are:

- clear and concise;
- provide the user with an unambiguous overview of the contents and/or functionality currently available via the interface;
- support clear interface navigation;
- establish a clear structure for all on-screen information, by classifying the contents of each screen section. (This allows the user to scan the interface for relevant material and will in-turn, reduce the time it takes for a user to locate a specific item);

- give meaning to internet search results when used as part of any web-based site interface. (Appropriately named screen titles also allow users to save pages with meaningful favourite names, when used in a web-based environment.)

Compliance with these rules conforms to many fundamental interface design heuristics including; reduce uncertainty; seek recognition rather than recall; minimise the user's memory load (Molich & Nielsen, 1990; Nielsen, 1994; Gerhardt-Powals, 1996; Wilson, 2002).

3.3.3.4 Readability

When designing an interface that will contain substantial volumes of information in the form of text, readability is critical. Due to the special nature of dyslexia, reading large volumes of on-screen text is especially difficult for most dyslexic subjects. As such every effort must be taken to alleviate the problems experienced by dyslexic interface users when reading text on-screen. With this end in mind, the following design features should be considered.

3.3.3.4.1 Limit Column Width

Usability studies have demonstrated that the readability (including, speed, accuracy and comprehension) of on-screen text is decreased if the column width of text is excessive (Bergfeld-Mills & Weldon, 1987). As such, dyslexic interface design guidelines consistently recommend a short column width (typically between 7 and 12 words per column, dependant on font size and visible screen area) (Bradford, 2002; Rainger, 2003; Marshall, 2004). Limiting the column width for dyslexic subjects has particular benefits, as previously noted irregular ocular-motor control patterns may be exasperated by longer column widths. Dyslexic subjects are likely to have greater difficulties scanning across a long line of text and then accurately moving to the start of the next line, when column widths are excessive (Eden *et al.*, 1994).

When working with web-based interfaces, column width is especially critical as accessibility settings in browsers can increase font size automatically. An increase in the font size may increase the width of the column beyond the originally planned visible screen area and lead to horizontal scrolling, something that should be avoided at all times.

3.3.3.4.2 Avoid Underlined, Moving and Flashing Text

Underlined text should be avoided, as a means of highlighting or emphasising words, in the body of text. It should be avoided as it generally makes reading harder for the dyslexic user and in the case of web-based interfaces may be confused with hyperlinks. By convention, underlined text should only be used to indicate a hyperlink in a web-based interface.

Moving and flashing text are two additional features that should be avoided when designing for dyslexic users. It is particularly difficult for users with reduced ocular-motor control to read either moving or flashing text. Accessibility software such as text-reading and text-resizing tools are also adversely affected by flashing or moving text (Bradford, 2002; Rainger, 2003; Marshall, 2004).

3.3.3.4.3 Use Short Clear Sentences and Paragraphs

As reading is a particularly strenuous activity for dyslexic subjects, and reading from an on screen-display is even more challenging; it is imperative that the structure of the language used is as clear and concise as possible.

Universally, authors writing on the subject of producing documents for dyslexic readers, weather electronic or conventional based material, recognise that the careful use of language is critical to the effective transfer of knowledge to the dyslexic reader. Poorly written or structured text can significantly increase the cogitative loads placed on working memory and significantly reduce the reading speed and comprehension for the dyslexic reader.

To ensure the best possible readability of any information presented on-screen, the following guidelines should be adhered to: -

- Utilise short simple sentences, (between five and 20 words long) constructed in a clear concise manner.
- Use well defined short paragraphs, between two and five sentences long.
- Employ elements that can enhance scanning including, bulleted lists, numbered lists, emboldened keywords, captions, diagrams, tables, section summaries, headings, titles and content listings.
- Exploit graphical elements wisely to reduce the volume of text the dyslexic user has to plough through.
- Use appropriate colour to highlight critical elements within the body of the text.
- Employ left-aligned, unjustified text.
- Avoid unfamiliar terminology and overly complicated language.

(Nielsen, 1994; Morkes & Nielsen, 1997; Busse, 1998; Bradford, 2002; Wilson, 2002; British Dyslexia Association, 2003; Rainger, 2003; Marshall, 2004)

3.3.3.5 Navigation

As already discussed, appropriate screen titles and headings are critical to dyslexic users, as they can quickly become disoriented when navigating around multi-screen interfaces. Due to the poor spatial awareness and sequential processing skills common to dyslexic users, it is vital that other interface navigational aids are employed.

3.3.3.5.1 On-Screen Navigational Elements

Buttons, icons, drop-down menus, hyperlink lists and other typical navigational elements should be grouped together and consistently positioned within any multi-screen interface. This significantly reduces the user's short-term memory load and aids efficient system routing.

When utilising buttons as part of a navigational system they should:

- maintain consistency of style and order;
- have meaningful labels with text and/or symbols;
- be sized consistently to fit the size of the longest label;
- be limited to related groups of six or fewer;
- have pop-up caption labels that indicate function, especially when icons have been used.

(Dix *et al.*, 1998; Thatcher *et al.*, 2002)

The use of icons on buttons can be especially helpful for dyslexic subjects, as they typically favour pictures and symbols over words. It should, however, be noted that despite the obvious advantages of icons over text for dyslexics, most authors state that icons should not be used in isolation (Haramundanis, 1996). Kurniawan and Horton provide additional guidelines regarding the use of icons and review critical issues including the physical and perceptual distinctiveness of icons and the importance of family resemblance amongst related groups of icons (Horton, 1994; Kurniawan, 2000).

When drop-down menus are utilised within an interface it is important to list options appropriately. Options should typically be listed in descending priority order, based on the likelihood of the option being used. Menu options should not be listed alphabetically. Reliance on alphabetical sequence recollection should be avoided when designing systems for dyslexic users, due to the increased cognitive problems most dyslexics will encounter when attempting to remember alphabetical sequences. Alphabetical lists also rely on the user to guess the correct function names in order to locate them accurately within the list (Rainger, 2003).

Navigational elements should be placed in an on-screen position that will minimise the need for complex sequences of hand-eye coordination via the interface input device. For example, Bailey and colleagues found that placing the menu options on the left-hand side of the screen, next to vertical scroll bar, significantly reduced the number of mouse movements and thus the time required to navigate around an

Internet based medical encyclopaedia (Bailey *et al.*, 2000). This is especially important for dyslexic subjects, as poor coordination is common.

3.3.3.5.2 Navigation that Yields Closure

One the most widely referenced general interface design guidelines is 'design dialogs to yield closure' (Shneiderman, 1998). When applied to interface navigation this principle dictates that multi-screen traversal should be organised in such a way that the user has a clear understanding of the sequence of screens that they must access in order to complete a specified task. In addition, once a task is completed the user should be provided with the required feedback to ensure the user achieves task closure and experiences the associated feelings of satisfaction and accomplishment. Many dyslexic subjects will lack confidence when using an application for the first time. As such, positive enforcement of successful interface navigation and task completion is very desirable.

Practical examples of navigation that yield closure include: -

- Placing an order for a product online. (A sequence of clearly labelled interface screens, providing task closure via an authorisation of order screen.)
- Registering for an online service. (A series of sequentially number screens, culminating in a registration confirmation display screen.)
- Updating a record within a database system. (A number of logically sequenced screens that require completion in order to update a database record, culminating in confirmation of the successful update of the record.)

3.3.3.5.3 Internet Specific Navigational Considerations

Due to the unique nature of the Internet and the interface design constraints associated with browser technology and other web-access conventions; (e.g. Hyperlinks, http, data transfer rates, etc.) there are a number of navigational design issues that are specific to interfaces for web-based systems. Table 3.4 provides a summary of these key guidelines

Table 3.4 - Internet specific design considerations for the effective navigation of web-based system for dyslexic users

Author(s)/Date	Description of guideline and associated design rationale
(Shneiderman, 1998; Wright, 2001; Bradford, 2002; Rainger, 2003)	• The inclusion of a site map is critical to the usability of any web-site for dyslexic users. • A graphical or text-based site map can considerably aid navigation as it helps the dyslexic subject to construct a conceptual model of the sites' structure. • As order-processing skills are often retarded in dyslexic users, any tool that can visually represent site navigation should significantly aid the cognitive processes related to successful orientation around the site.
(Shneiderman, 1998; Wright, 2001; Bradford, 2002; Rainger, 2003)	• Use graphical elements and colours to ensure traceability around any web-site. • Change the colour of hyperlinks to ensure that they are visually distinct from unvisited ones. • Ensure that the colour of visited hyperlinks does not conflict with the site background colour and render text unreadable. • Consider a 'breadcrumb trail', either graphical or text based, to give the user a clear understanding of their current position within the site (e.g. Home page > section > sub-section). • Trails should incorporate hyperlinks to allow the rapid retracing of a users forward navigation. This complies with Shneiderman's critical 'reversal of actions' design principle.
(Busse, 1998; Wright, 2001; Bradford, 2002; Rainger, 2003)	• Avoid dead-end links. Ensure that you do not construct sites that lead users to pages that cannot be exited without using the browser 'back' button. • Dyslexic users need increased navigational support, to compensate for poor sequence processing skills. Failure to provide consistent navigation links/options from all pages within the site will cause frustration and confuse users. • Bradford proposes a golden rule for dyslexic user site navigation, namely there should be "a simple list of links on each individual page, linking to every other page or section on the site".
(Spool *et al.*, 1997; Rainger, 2003)	• Use front loaded hyperlinked sentences to enhance scanning and facilitate rapid navigation. • Label links descriptively so that users can discriminate between similar links. Link descriptions should be clear and make effective navigation an intuitive process • This is particularly important as dyslexic subjects can be slowed down considerably, when they must evaluate the differences between similar link labels.
(Nielsen, 1996; Rainger, 2003)	• Provide user friendly, internal search facilities • For sites comprised of multiple web-pages and incorporating a devise range of available resources, an internal search facility is critical. • Dyslexic subjects need additional support to find the information they require within any web-site. The use of an internal search engine can help the user to navigate to the required information in a very efficient manner.
(Bernard, 2002; Rainger, 2003)	• Employ a wide rather than deep hierarchical site structure. • Recent research by Bernard has demonstrated that site users make less navigational errors in sites constructed with a wider hierarchical structure, compared to sites built around a deeper hierarchy of pages. • Bernard suggests that this may be due, in part, to an increased reliance on short-term memory for sites that have a deep rather than wide construction. • As poor short-term memory is typical of dyslexic users, the adoption of a wide hierarchical site design is essential.

3.4 Adaptive Interface Techniques

Clearly, significant research has been conducted into the development of a comprehensive set of design principles that can be employed within most interfaces to enhance the operational experience for dyslexic users. Unfortunately, despite being beneficial, most authors agree that the static application of the previously outlined design principles can only bring limited enhancement because optimal individual visual preference settings vary dramatically between users (Wright, 2001; Dickinson *et al.*, 2002).

In several studies where users have been given the facilities to change display setting such as background colour, foreground colour, font type, font size, line-spacing and paragraph width; no consistent pattern or combination of settings has emerged as being preferred by any single group or type of user. Rather the selection of preferred settings seems to differ dramatically between each individual (Brown & Robinson, 2002; Dickinson *et al.*, 2000; Dickinson *et al.*, 2002; Wright, 2001).

With this conclusion in mind, an understanding of the essential principles behind adaptive interface techniques is fundamental to this work and is presented in the subsequent sections.

3.4.1 Universal Access and Adaptive Interface Technologies.

The concept of adaptive interface techniques is an integral component of the Universal Access philosophy. At its most fundamental level Universal Access seeks to facilitate access to all available system services, from all potential users, despite any functional or situational limitations. Functional limitations can be considered to be the constraints generally refer to as disabilities (e.g. visual, auditory, physical, cognitive, language or learning disabilities). Situational limitations are considered to be environmental or equipment based constraints (e.g. device specific limitations, low technical specifications, slow network connection speeds, etc.).

An alternative definition is provided by Stephanidis:-

"Universal Access refers to the global requirement of coping with diversity in: (i) the target population (including people with disabilities) and their individual and cultural differences; (ii) the scope and nature of the tasks; and (iii) the technological platforms and the effects of their proliferation into business and social endeavours" (Stephanidis, 2001a).

From the definitions provided, it should be clear that the central premise, on which the philosophy is based, is user diversity. At the most fundamental level we can therefore assume that the needs of each potential system user are likely to be different (be it with varying levels of diversity) in all cases. This obviously would include preferred visual display settings within system interfaces.

Logically, by extension, attainment of the goal of developing universally accessible systems facilitated considerable research into adaptive interface techniques. A representative summary of several of the most critically acclaimed adaptive interface research projects is presented in Table 3.5.

Table 3.5 - A Representative Summary of Critically Acclaimed Adaptive Interface Projects

Author(s)/Date	Project Overview, Results and Key Conclusion
(Fink *et al.*, 1997; Kobas, 1999)	• Project Title: **AVANTI Project** • The project aimed to explore generic solutions to support interface adaptations for all potential users. • The project resulted in the development of a framework for adaptable hyper-media content that included: - a) A collection of multimedia databases, which contain the sit information and are accessed through a common communication interface (**Multimedia Database Interface - MDI**). b) A **User Modelling Server (UMS)** that maintains and updates individual user profiles, as well as user stereotypes. c) The **Content Model (CM)** which retains a meta-description of the information available in the system. d) The **Hyper-Structure Adaptor (HSA)** that adapts the information content, according to user characteristics, preferences and interests. e) The **User Interface (UI) component**, which is also capable of adapting itself to the users' abilities, skills and preferences, as well as to the current context of use. • The system dynamically constructs adapted hypermedia documents for each user, based on assumptions about the user characteristics and the interaction situation provided by the User Model Server • Pages were assembled using a set of adaptation rules and the information stored within each users unique profile on the UMS. • The initial profile of the user is acquired through a short questionnaire session during the initiation of the interaction • Adaptations included:- a) Alternative presentation formats using different media (e.g., text, graphics, audio) b) Alternative colour schemes, font types and sizes. c) Additional minor functionality including adaptive "shortcut" links and conditional presentation of technical details. d) Different presentation structures. e) Different levels of content detail. • Evaluation with 180 subjects, including learning efficiency tests, memory load tests, error-proneness testing and overall satisfaction interviews; provided evidence that the users benefited from the adaptive components of the system.
(Brown & Robinson, 2002)	• Project Title: **Web Mediator for Users with Low Vision** • Brown and Robinson developed an access gateway mediator tool that allowed users with impaired vision to adjust the size and colour of on-screen text, from web pages, to aid reading. • Conventional browser settings were to be overridden and text was reformatted to enhance readability. • The tool overcame the problems caused by using the standard accessibility settings within conventional browsers (e.g. the need for horizontal scrolling if font size is large). • Evaluation of the tool was carried out using a variety of different page formats with significant success. (It could handle most common web-page elements including frames, tables, lists, ALT attributes, forms, plug-ins and CSS.) • The authors conclude by acknowledging several technical difficulties with the mediator tool, but state clearly the advantages for supporting users with special needs
(Stuerzlinger *et al.*, 2006)	• Project Title: **User Interface Façades** • The project develops a system that provides users with simple ways to adapt, reconfigure, and re-combine existing graphical interfaces, through the use of direct manipulation techniques. • The project provides a framework for customisation that provides intuitive support for the user to aid the adaptation process. • The support environment provides users with a seamless tool to adjust visual display settings from a central point. • Stuerzlinger *et al* developed several key design criteria that were explored during their development: - a) **Granularity**: Redesigning interfaces necessitates the need for individual elements to be moved around. Under the granularity principle each widget (feature within the interface) can be selected and manipulated. b) **Level of control**: Users should be allowed to reconfigure the interface.

(Stuerzlinger *et al.*, 2006 ctd.)	(Rather than allowing the software to reconfigure display settings automatically) c) **Modify interaction**: The mode of interaction with the interface should also be adaptable • Evaluation of the system and the design criteria proposed, with a suitable user group, yielded encouraging results.
(Bental *et al.*, 2000)	• Project Title: **Adapting Web-Based Information to the Needs of Patients with Cancer** • The project investigated the feasibility of developing a customised interactive hypermedia educational support tool for people diagnosed with cancer. • The tool aims to provide the most appropriative information, at a suitable level of depth, alleviating the need for patients to search through the copious volumes of literature available. • The system develops a user model and suitable processing algorithm that dispenses information aimed at the situational and process-based aspects of the patient's illness and treatment. • Key features include: - a) Natural language generation to present information from a patients own medical records in a personalised manner. b) Summaries of current treatment strategies, specific to the patient. c) Automatic generation of hyperlinks to the most appropriate sources of information d) The development of a **process model** that incorporates **situational variations**, (e.g. types of cancer, severity, course of illness and course of treatment) **dispositional needs** (e.g. the attitude of the patient towards the amount of information they need and their choice of treatment) **patient process-based variations,** (e.g. The patients psychological needs and their ability to deal with information) and established **coping theory**. e) The generation of information, based on the process model, at convenient time intervals during the patient's treatment (e.g. A time-based architecture). f) Adapted hyperlink lists of relevant patient issues based on the individual process model and the time-based architecture). • Online evaluation of the system with patients, members of cancer newsgroups and other relevant individuals; suggested that approximately 33% of trial subjects felt that the tailored information was helpful, while 66% were unsure of the usefulness of the tailored approach to information dissemination.
(Alpert *et al.*, 1999)	• Project Title: **Deploying Intelligent Tutors on the Web** • The project aims to develop an online, one-to-one, tutoring system that responds appropriately to the specific educational needs of each user. • With an initial brief to focus on "elementary high school algebra" the tool provides the following key features:- a) An environment for practicing algebraic skills. b) Support examples and tutorials on specific topics. c) The system to act as a pedagogical partner to existing teaching avenues. • Four distinct components were developed and when combined established a suitable systems architecture; the expert solver model; the student model, the tutorial module and the user interface. • Initial evaluation trials were conducted with suitable subjects locally, using a stand-alone version of the application. • Once satisfactory performance had been achieved as a stand-alone application the system was redesigned to support a distributed architecture. • A HTML-CGI architecture was employed, with HTML entry forms in a Web browser; where information entered by the user is sent to the Web server, forwarded to a CGI (Common Gateway Interface) program, which provided suitable replies as new HTML pages. All tutorial elements being stored on the server (in the CGI program) with all user interaction being facilitated by a standard Web browser. • Successful trials with the system lead the authors to make several important conclusions: - a) The potential for adaptive online tutors is considerable. b) The migration of existing stand-alone applications to multi-user web-based systems is feasible, if not complicated. c) The skills base needed to develop any effective intelligently adaptive system is extensive and should be considered carefully before any project is attempted.

A review of Table 3.5 provides a brief overview of the diversity and potential of adaptive interface technology. Since 1996 alone, this author has found in excess of 350 relevant research projects that incorporate adaptive interface design and development. The most common areas of research include; adaptive navigation support, adaptive medical systems, natural language systems, intelligent tutoring systems, mobile device systems, information retrieval, decision support and most relevant to this work, adaptive disability support systems. Exploration of many of these projects has yielded considerable project critical information. These findings are outlined in the subsequent sections.

3.4.2 Essential Adaptive Interface Technology Concepts

It should be clear to the reader, that there are fundamentally two general categories of adaptable interface. The first category is that of **user-invoked** adaptations (e.g. The user interactively customises the interface using a variety of predefined embedded options, such as colour, visible menu listings and font size; typically using direct manipulation). The main limitation of this type of adaptive interface is that the level of adaptability is fixed, being predetermined by the available customisation options.

The second general category is that of **automatic-adaptations**. In this approach the system itself identifies the events that necessitate adaptation and automatically enforces the modification based on a predefined set of rules. Implicitly, user activity or behaviour must be monitored effectively in order to facilitate the appropriate interface adaptations. The combined user activity collection and monitoring process typically involves several sophisticated stages including; the acquisition of initial user group data; user group adaptation preference assumption formulation; ongoing assumption verification, refinement and revision; and possibly the rejection of previously formulated assumptions based on changing user behaviour.

Systems that use automatic-adaptations employ a variety of techniques to profile user behaviour and facilitate appropriate interface modifications. Some of the most commonly used approaches are outlined below: -

a) Least-recently-used criterion.

One of the most common algorithms for on-screen display management is the least-recently used criterion. In this approach user activity is monitored and on-screen display options, for functionality that is rarely used, are discretely hidden. The Microsoft Office 2000 suite exemplifies this type of adaptation, as the number of drop-down menu options are reduced, as infrequently used menu features are hidden. Functionality is not lost however, as the user can retrieve irregular used menu elements, simply by clicking on the menu expansion option (providing a complete list of the default options).

b) Comparable activity criterion.

In applications that have a significant number of users and the behaviour of each user is monitored, the comparable activity criterion can be employed. This criterion operates on the assumption that groups of users, exhibiting similar behaviour, are likely to want or need the same type of services and/or system functionality. This type of algorithm is most commonly applied within commercial or marketing environments. To illustrate Amazon.com makes product recommendations based on other 'similar' customer purchase profiles. For example, if customer A has purchased products x, y and z; it follows that customer B maybe interested in product z, if he/she have already purchased products x and y.

The comparable activity criterion should however be used with caution, as there is no guarantee that a period of comparable activity, by a group of system users, conclusively means subsequent needs will remain the same. Accordingly adaptations triggered by this criterion should not be overly intrusive or irreversible. Amazon.com complies with this rule by providing product recommendations, derived from 'similar' customer purchases, via unobtrusive advertising adaptations in peripheral parts of the main pages. This type of application of comparable activity criterion is also known as content-based collaborative filtering.

c) Most-frequently-used criterion.

An inverse of the least-recently-used criterion, the most frequently used algorithm makes the assumption that interface elements that are used with the greatest frequency should be the most accessible within any on-screen display. Meaningful applications of this include; (i) the re-sequencing of menu items to place the most frequently used options at the top of listings; (ii) adjusting system navigational routes, via the inclusion of additional hot-links or short-cuts to allow rapid access to the most frequently used parts of the system; (iii) recording file access and making readily available commonly used files, as exemplified by many applications that include easily accessible menu listings of the most recently accessed files.

Microsoft Office 2007 illustrates the potential of the "Most-frequently-used criterion" via its utilisation of Ribbons. Constructed as a graphical widget across the top of the main Office window, the Ribbon automatically adjusts displayed system functionality based on the user's individual operating patterns. Replacing menus and toolbars, the Ribbon adapts to meet the users perceived needs based primarily on functional usage. Its deployment of contextual tabs, (e.g. functional tabs that are only visible to the user, when specific operations are being performed) help to reduce the Ribbons actual display area. Reduced user mouse movements and click overheads, resultant from menu and toolbar removal, also seek to enhance application usability.

d) User-based models

One of the most common techniques used to facilitate appropriate on-screen adaptations is that of user based modelling. In this approach, subject experts with the required knowledge of the potential user-group's behavioural patterns, attempt to select a relevant set of system specific profile characteristics or attributes. There are many potential sources of profile attribute; crucially these will be dependent on the actual functional needs of the proposed system. That said, commonly employed characteristic sources include:

(i) the user's cognitive skills;
(ii) accepted learning strategies;
(iii) educational background;
(iv) existing subject knowledge level (basic, intermediate, advanced);
(v) age;
(vi) geographic location;
(vii) IT experience (novice, intermediate or expert);
(viii) disability;
(ix) language;
(x) gender.

Once selected, profile attributes are typically allocated a set of valid scoring ranges. These range brackets are used to indicate the likely identifiable profile groupings for the system. Subsequent work is then carried out to identify the desired on-screen system adaptations and suitable algorithms are created to map specific profile attribute scores to precise interface modifications. Practical examples of this are seen within the Avanti project, the intelligent web-tutor and the cancer-support system; where the level of detail and language used, within many of the adaptive hypermedia text blocks, varied considerably dependent on the users existing subject knowledge (See Table 3.5).

3.4.3 The Perceived Benefits and Limitations of Adaptive Interface Technology

The field of Adaptive Interface Technology demonstrates considerable potential for subsequent research. That said, a brief critique of both the benefits and limitations of the field should prove advantageous to this work.

3.4.3.1 Adaptive Interface Benefits

a) User Performance Gains

Research has demonstrated that interfaces that facilitate customisation, by means of automatically adaptable or manually initiated adaptations, can improve user performance as measured by user satisfaction, application competency times and task completion times. For example, a comparison of static, user-invoked and automatic-adaptable menus by Findlater *et al*, demonstrated that users could enhance their task performance, if they were aware of the menu customisation options and were provided with an intuitive means of adapting the menus to their specific needs (Findlater *et al.*, 2004) (see also Table 3.5).

b) Enhanced Support Environment for Novice Users and People with Disabilities

A well-designed adaptive system should incorporate functionality that supports novice users and people with disabilities. Implicitly it should increase accessibility and seek to enhance application usability by, amongst other things, reducing the operational memory load of the interface, improving navigation, reducing the likelihood of input errors and presenting intuitive displays to the user (See Table 3.5).

c) Efficient Display Area Management

Typically, conventional applications display all available system functionality on screen simultaneously. In conformance with the established interface design principles of "What You See Is What You Get" (WYSIWIG) and user-centred control. Effective adaptation mechanisms allow infrequently used functionality to be discreetly hidden, significantly improving the workable display area (Kantorowitz & Sudarsky, 1989).

d) Potential Psychological and Physical Benefits

Improvements to the usability of any system, by means of an enhanced user interface, can have considerable psychological benefits on the user. A positive perception of a system can considerably increase the likelihood that a user will continue to use the application. Negative emotions such as uncertainty, confusion and frustration (typically associated with the learning phase of any application) can be lessened by including adaptable interface components. Physical benefits are also theoretically possible as a result of reduced keystrokes and/or mouse moment, for high frequency users who may have been susceptible to repetitive stress injuries (see also Table 3.5).

3.4.3.2 Adaptive Interface Limitations

a) Increases in the Complexity of the Interface

Additional interface elements and interaction techniques must be added to any manually adaptable interface to facilitate the customisation process. The inclusion of additional options, menus and display elements increases the complexity of the interface and can increase the user's memory load and the associated time it takes to become proficient with the application. In many cases these facilities presuppose considerable user familiarity with the application, which theoretically could limit or render void the usefulness of the adaptation options.

It should be noted that there will always be a trade off between enhance user interface performance, by means of customisable features and the increased load on memory, coupled with application proficiency times, when user-invoked adaptation options are deployed.

b) Possible User Confusion/Frustration

If automatic adaptations are deployed inappropriately, users may experience negative emotional effects, when previously visible functionality is either moved or hidden (e.g. an item of functionality is removed from a drop down menu, when a least-recently used criterion algorithm is applied).

c) Limited Level of Customisation

In most applications the level of adaptation is generally above the functionality layer of the system (e.g. the user may modify the appearance, the menu options, even the navigation sequence; but the functionality remains constant). Bentley & Dourish refers to this as surface level customisation. If application behavioural modifications are required (Bentley & Dourish refers to these as deep level customisations) the level of expertise needed by the user is significant and in most cases will inhibit the customisation completely (Bentley & Dourish, 1995).

d) No Universally Accepted Design Methodology or Framework.

The successful integration of adaptable components into any application requires the utilisation of a suitable design methodology that incorporates adaptive interface modelling features. Several design methodologies and/or development frameworks have been developed, including (i) The Unified User Interface Development Methodology (Akoumianakis *et al.*, 2000 ; Stephanidis, 2001b); (ii) Design Rationale (Carroll & Moran, 1996); (iii) Scenario Based Design (Carroll, 1995); (iv) The Web-Modelling Language (WebML.org 2001).

Many of these methodologies have been favourably received, however at the time of writing no single approach has received universal acceptance and as such a standard approach to modelling is not currently available. This fact has several negative implications on the availability of appropriate CASE tools and subject experts; as CASE tools and expert guidance are likely to be limited until one or more of the proposed methodologies become widely accepted. That said, the obvious need and perceived benefits of adaptive interfaces will undoubtedly drive future innovations and standardisation within the field.

e) User Profiling (Modelling) Complexity

When an application's designer plans to employ a user profile as the catalyst for on-screen automatic adaptations, as seen in the Avanti Project (see Table 3.5), several additional layers of complexity are imposed on the project's development: -

(i) Determination of the required profile attributes.
(ii) Selection of a suitable profile data elicitation vehicle.
(iii) Algorithm creation for conversion of profile attributes to on-screen adaptations.
(iv) The need to cater for ongoing profile changes in a seamless manner during everyday application use.

The inclusion of these additional steps, for systems incorporating adaptive technology, may also have a significant impact on other developmental issues, including; project management, resource requirements and component design sequence.

f) Dramatic Increases in the Required System Development Skills Base

As already alluded to in the previous sections, the overall process complexity for the effective development of any system fronted by an intelligently adaptable interface, has increased dramatically; compared to a comparable static system. For any reasonably sized adaptive application, the development expense and skills set required can be daunting. For example Alpert and colleagues identified an extensive list of essential knowledge and skills required to develop their adaptive web-based tutoring system. The list of required skills included; proficiency in cognitive science, programming, software engineering, rule programming, user interface design, computer art skills, client-server distributed application construction, multithreaded socket communication and Internet development skills (Alpert *et al.*, 1999). (See also Table 3.5 for example details of selected project development stages and project deliverables)

Chapter 4: The Development of a Framework for Adaptable Interfaces for Computer Dyslexic Users

4. A Framework for Adaptable Interfaces for Dyslexics

The following chapter presents an overview of the specification, analysis and design process used during the development of the Dyslexic User's Interface Support Tool (DUIST) framework.

4.1 Project Assumptions

An examination of the fields of dyslexia, disabled human-computer interaction and adaptive interface technology leads this work to several critical conclusions that will dictate the direction of subsequent experimentation. Although these conclusions have been highlighted in the previous sections, it is worthwhile reiterating the pivotal findings at this juncture.

1) Despite the variety of proposed causality theories for dyslexia (see Section 2.3), no single theory has been universally accepted at this point in time. Despite the recent swing in consensus towards advocates of the phonological deficit causality theory, this work will make no initial assumption as to the derivation of dyslexia. Instead, any proposed support mechanisms will be developed based on the widely accepted symptoms of dyslexia as opposed to any causality models. (See Section 3.2.)

   Any appropriate findings that are generated as a result of this investigation will be reviewed against the plethora of causality models once the project is complete.

2) Significant experimentation has been carried out to establish a set of design principles (or characteristics) that can usefully be employed to enhance interfaces for dyslexic subjects. (See Section 3.3.3.) That said, research findings suggest that a static application of the aforementioned design

characteristics will not completely satisfy all dyslexic subjects because individual display preference varies considerably amongst dyslexics.

3) Adaptable interface technology has considerable potential for use with a wide range of possible user groups. Despite several current limitations, the benefits of customisable interface components compel suitable experimentation and evaluation with dyslexic users. (See Section 3.4.)

4.2 Existing Domain Observations

With the aforementioned project assumptions in mind, logic dictates that the development of a support tool to facilitate appropriate interface adaptations for dyslexic users is desirable. As static implementations of established interface characteristics do not fully satisfy dyslexic users, a dynamically adaptable alternative could potentially maximise visual display preferences for each unique user.

In the two known previously developed systems that explored the potential of adaptable interface components specifically for dyslexic subjects, both systems deployed user-invoked adaptation mechanisms to enable on-screen modifications (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002). While both systems obtained positive experimental evaluation results, several limitations were identified. These included: -

1) The complexity of the interface was increased by the inclusion of multiple preference setting options and menus. (See Figure 4.1.) This potentially decreased system usability, especially for inexperienced dyslexic computer users.

2) The manual display setting selection process imposed a lengthy trial and error approach for the user, as subjects were required to select, apply and test each display setting attribute iteratively; until their final optimal settings were achieved.

Figure 4.1– Seeword System- Example Manual Preference Setting Tools

(Dickinson, 1998)

3) The user-invoked display setting selection processes used, (using menus and buttons) inhibits simultaneous visual comparison, as the interface only presents one set of display preferences on screen at any one time.

4) Novice dyslexic computer users wanting to tailor an interface to optimise their visual display settings could potentially find the process extremely daunting, due to the non-linear nature of the activity and the infinite number of possible display selections. The complexity of the task could cause the user to avoid customisation entirely or prevent attainment of the individual's optimum settings.

5) Derived preference settings were not portable and thus could only be used within the application in which they were created. This meant that a dyslexic user could spend considerable time finding their ideal preference settings only to realise their settings could not be transferred to other applications. A frustrating system feature and a potential barrier to subsequent attempts at customisation.

6) Although both systems included several adjustable interface components (e.g. background colour, foreground colour, font size, font type, etc.) no guidance was given on which elements should be modified or the sequence in which adjustments should be made. Users were left to experiment and make adjustments based on their existing knowledge and experience. Implicitly this meant that the user could overlook one or more beneficial modifications.

As well as the limitations identified within the work produced by Dickson *et al* and Wright; a detailed investigation in to the validity of the design principles outlined in Section 3.3.3 would be beneficial (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002; Wright. 2001). Any such investigation would be especially useful for comparison against the most prevalent dyslexia causality theory that suggests visual deficits are not the cause of dyslexia and as such display modifications should have little or no impact on dyslexic users

4.3 Project Aims and Objectives

With all project underpinning reviewed and key domain observations highlighted; it now seems appropriate to definitively state (and reiterate in some cases) the core project aims and objectives: -

1) Identification of the design limitations of conventionally built interfaces for dyslexic users

2) The compilation of a comprehensive set of design principles (or characteristics) for use within interfaces specifically designed for dyslexic subjects.

3) An experimental review of the application of the aforementioned design principles to establish their validity, or lack of, as the case may be.

4) An examination of emergent adaptive interface technologies and the evaluation, via a suitable application, of their suitability for use within dyslexic interface design.

5) The development of an intelligently adaptive software tool and/or environment that will enhance a dyslexic user's interface operational experience.

6) The appropriate evaluation of the aforementioned software system, leading to appropriate recommendations regarding the suitability of adaptive technologies for use with interfaces designed for dyslexic subjects.

7) A reflective examination of project findings against dyslexia causality models.

It is envisaged that the attainment of the majority of these project aims and objectives will be accomplished by the successful development and appropriate evaluation of the Dyslexic User's Interface Support Tool (DUIST) framework.

4.4 System Specifications

The following section provides detailed system specifications for all components of the proposed DUIST environment. All specifications are based on the previously stated assumptions, existing domain knowledge and the project aims and objectives.

4.4.1 Functional Requirements

It is envisaged that the DUIST environment will incorporate the following essential functionality and features. (See Table 4.1.)

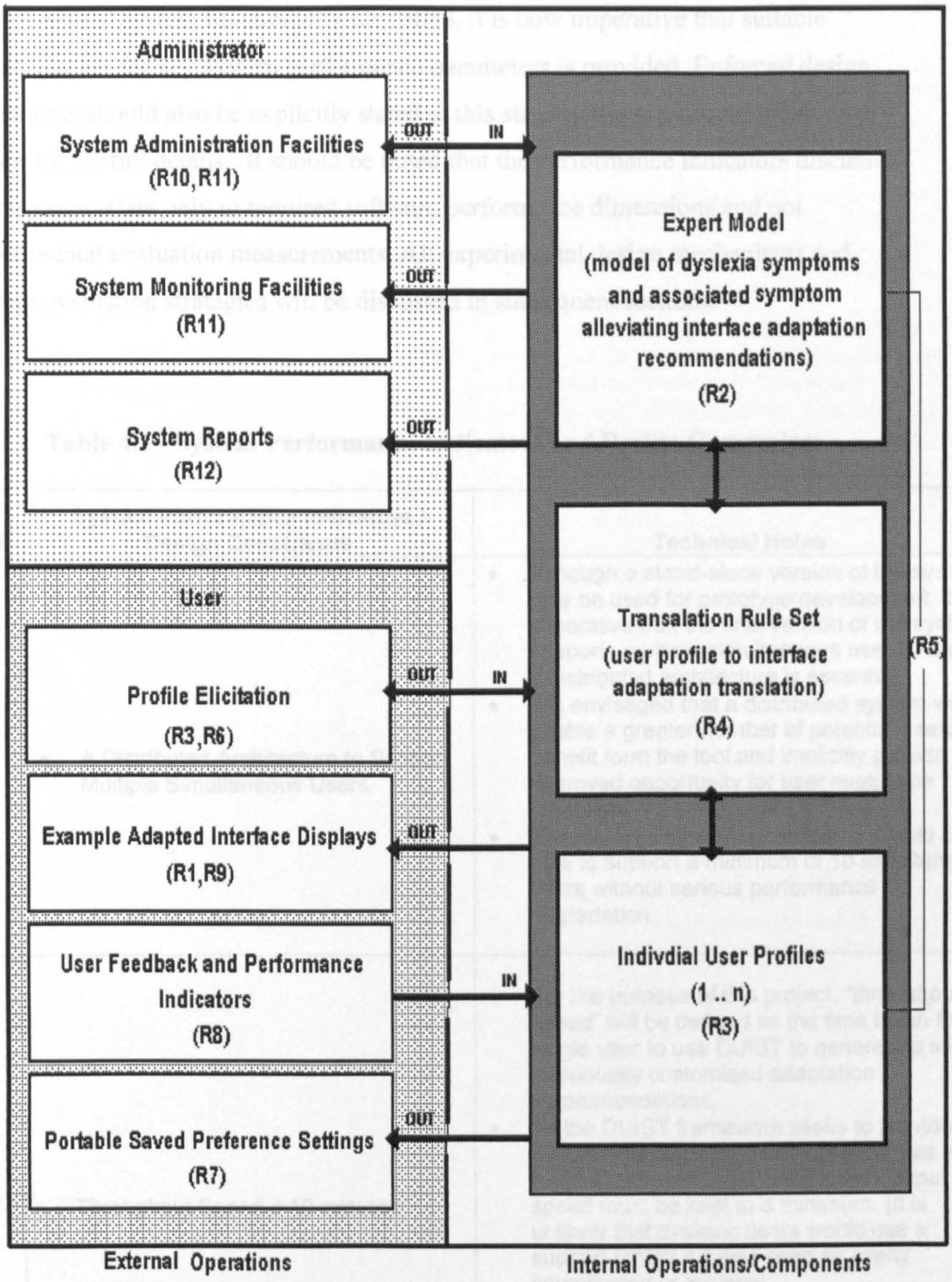
Table 4.1 - Required System Functionality and Features

ID Ref	Required System Functionality/Features	Technical Notes/Justification for Inclusion
(R1)	• Automatically adaptable interface components.	• Existing solutions have incorporated manually adjustable interface features that have significantly increased the complexity of the base interface. (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002) • Increased complexity reduces usability and thus should be avoided.
(R2)	• An expert user model of dyslexia symptoms and associated symptom alleviating interface adaptation recommendations.	• Automatic adaptation of interface components must be based on a suitable adaptation algorithm and/or user model. (See Section 3.4.2.) • The model can be based on the previously formulated lists of dyslexia symptoms (see Section 3.2) and interface design principles. (See Section 3.3.3) • The deployment of a user model that contains a comprehensive set of appropriate interface modifications, to alleviate the symptoms of dyslexia, will act as the central component of the DUIST system
(R3)	• An intuitive elicitation mechanism that will facilitate the collection of individual profile data in a short, intuitive, linear manner; in a system supported environment. • The elicited user profile for each system user must be stored persistently within the system.	• Previous solutions have forced subjects to use lengthy trial and error approaches to customisation (e.g. set attribute, apply, test, iterations). • Existing solutions make the adaptation process non-linear and fail to provide support as to which modifications are appropriate. • The complexity of modification menus/tools in previous manually adjustable systems has not made the process intuitive. (See Section 4.2.)
(R4)	• A user profile to interface adaptation translation rule set.	• An appropriate rule set must be developed to translate individual user profile data to a set of appropriate interface modifications.
(R5)	• Adaptable interface components should be adjusted based on an individual users elicited profile data, the systems model of alleviating modifications and the systems profile to adaptation translation rule set.	• As with the AVANTI Project, the Adaptable Cancer Support System and the Web Tutoring System modifications will be based on: - (i) a suitable expert model of the user; (ii) a profile to adaptation translation rule set; (iii) appropriately collected unique user data. (See Table 3.5.)
(R6)	• The user profile elicitation process should incorporate simultaneous visual comparison.	• One of the major limitations of existing manually adjustable interfaces is that only the currently selected visual display settings can be viewed at any one time. Thus preventing the simultaneous visual comparison of multiple display options. (See Section 4.2.) • The simultaneous visual comparison of interface components is likely to be advantageous to the user when preference settings are being selected.

(R7)	• The system should facilitate the portability of user approved visual display settings between similar media and/or systems.	• One of the major disadvantages of previous systems that incorporated adaptable interface components is that customisable settings were not transferable between other similar systems. (See Section 4.2.) • For this system to be a success, a users formulated optimal display settings should be portable between similar media and/or systems.
(R8)	• Embedded system evaluation mechanisms to: - (a) monitor system user feedback. (b) measure key use and performance indicators.	• The accurate and detailed evaluation of users and their experiences using the tool will be an essential part of the project. • A detailed description and justification of the projects evaluation strategy will be outlined in subsequent sections.
(R9)	• Application user support features including: - (a) intuitive user help facilities; (b) system user guides and operation instruction; (c) example renditions of applied user selected display preferences.	• Embedded user support facilities should be incorporated as an integral part of the design.
(R10)	• System administration facilities to include, auto-create, manual creation, modify and remove functions for: - (a) individual user profiles; (b) adaptation model rules; (c) profile to adaptation translation rules.	• Essential administration features will be required for all major system components.
(R11)	• System administration tools to include: (a) initial system set-up; (b) data back-up facilities; (c) system operation monitoring tools.	• Essential system operations such initial system set-up and back-up of data will be automated where possible.
(R12)	• The generation of essential system reports to include: - (a) user specific information such as profile data, feedback and individual performance indicators; (b) system operational performance reports;	• Reports are likely to be needed in a variety of formats including, on screen displays and externally printed reports.

A simple pictorial representation of the proposed relationships between essential functional components of the DUIST system can be seen in Figure 4.2.

Figure 4.2 - Overview of the Functional Components of DUIST



Key

→	direction of data flow within the system	IN	system input
(Rx)	functional requirement reference	OUT	system output

4.4.2 Performance Requirements and Design Constraints

With essential system functionality identified, it is now imperative that suitable quantification for key system performance parameters is provided. Enforced design constraints should also be explicitly stated at this stage of system development. See Table 4.2 for full details. It should be noted that the performance indicators discussed at this stage relate only to required software performance dimensions and not experimental evaluation measurements. All experimental design mechanisms and system evaluation strategies will be discussed in subsequent sections.

Table 4.2 - System Performance Indicators and Design Constraints

ID Ref	System Performance Indicators / Design Constraints	Technical Notes
(P1)	• A Distributed Architecture to Support Multiple Simultaneous Users.	• Although a stand-alone version of the system may be used for prototype development, it is imperative that the final version of the system supports multiple simultaneous users. As such, a distributed architecture is essential. • It is envisaged that a distributed system will enable a greater number of potential users to benefit form the tool and implicitly provide improved opportunity for user evaluation feedback. • The required system architecture should be able to support a minimum of 10 simultaneous users without serious performance degradation.
(P2)	• Throughput Speed ≤ 10 minutes	• For the purpose of this project, *"throughput speed"* will be defined as the time taken for a single user to use DUIST to generate a set of individually customised adaptation recommendations. • As the DUIST framework seeks to provide a support environment mechanism for use with existing software applications, throughput speed must be kept to a minimum. (It is unlikely that dyslexic users would use a support facility if it was seen as overly complicated or lengthy) • The 10-minute target throughput speed assumes basic IT skills. (Users with no existing keyboard or mouse proficiency may need additional support and thus acceptable throughput times may be modified accordingly)

(P3)	• Input Response Times ≤ 1 second	• For the purpose of this project, "*Input Response Times*" will be defined as the time taken for a single user input action to elicit the required system output response. • Typical system outputs will likely include, adaptation translation rule application and the resultant on screen adaptations, system generation and requested on screen system support. • Failure to comply with the 1 second input response time, with noticeable hang-time being evident, would significantly reduce system usability and in turn impact user performance evaluation.
(P4)	• Data Storage Capacity	• The storage of system data is essential to the project and as such a suitable storage media should be selected for the project. • As primary and secondary data storage is widely available no upper limit on record storage will be enforced.
(P5)	• System Reliability	• Two measures of system reliability will be used to assess the robustness of the environment. • The first measure will suppose a target system error rate of ≤ 0.01% (e.g. less than 1 inappropriate system response per 10000 user interactions). • The second measure will suppose a system availability time of 165 hours per week. (3 hours of system unavailability being reserved for system back-ups and upgrades) • Achievement of these system reliability targets will require an extensive testing program. A suitable test strategy will be formulated in subsequent sections)
(P6)	• System Usability	• As a high level of system usability is essential for this project to be successful, every attempt will be made to incorporate well design interfaced components and navigational mechanisms. • All previously researched "*good practice*" design principles for use with dyslexic subjects will be seamlessly embedded within the DUIST environment. (See Section 3.3.3.) • It is hoped that a dyslexic user, with basic IT skills, will be able to explore the environment for the first time and be able to understand what they need to do, in order to use the tool, within 5-10 minutes.
(P7)	• Portability	• System generated preference settings need to be portable and facilitate their appropriate application to a variety of circumstances. (Technical specifications to be determined later.)

4.5 System Analysis and Design

With the essential functional and performance requirements of the DUIST environment identified, analysis and design of system components is now possible. Due to the diversity of system elements required, no single universal methodology can be employed. Although several approaches to developing adaptable systems have been proposed (e.g. The Unified User Interface Development Methodology, Design Rationale, Scenario Based Design), the unique nature of dyslexic user requirements, the originality of some desired framework features (e.g. the simultaneous visual comparison of customisable elements) and the lack of CASE-tool support for most of the proposed methodologies has resulted in the rejection of any of the currently proposed approaches. As an alternative, the development of this system will employ a variety of well-established analysis and design techniques in a "*tool box*" approach rather then rigidly sticking to the formality of one of the proposed prescriptive "*cake recipe*" methodologies. It is considered that this approach will have several advantages, including; (i) flexibility of technique selection; (ii) wider availability of expert resources (e.g. books, technical guides, pre-existing software components, CASE-tools, subject experts, etc.); and (iii) give opportunity to reflect on the suitability of the techniques employed for future comparable projects.

The analysis and design process will be broken down into four distinct divisions. The first division will deal with the design of the key system models (e.g. the model of dyslexia symptoms, a model of associated symptom alleviating interface adaptations and the user profile model). The second division will attempt to model profile elicitation and interface adaptation enforcement including; user profile to adaptation translation rule set considerations and the effective enforcement of interface adaptations. The third division highlights the steps taken to develop a suitable prototype system. While the fourth division deals with the final distributed system architecture and explores; selection of distributed architecture type; and the mechanism used to facilitate portability.

4.5.1 System Models

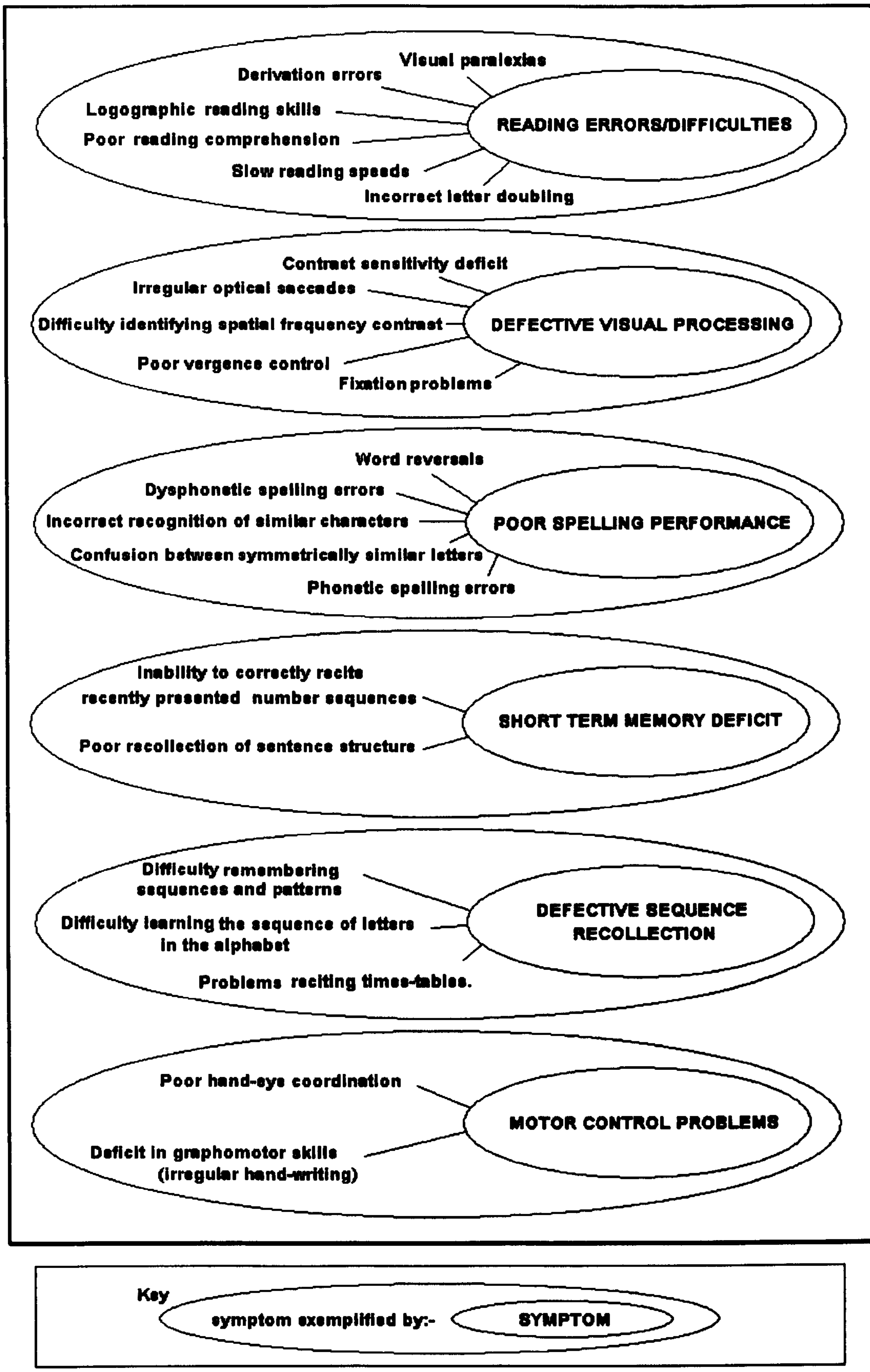
The subsequent section outlines the derivation of the fundamental framework models, and provides justification for their construction.

4.5.1.1 The Dyslexia Symptoms Model (DSM)

In Section 3.2 research was carried out to identify the symptoms that subject experts agreed were associated with dyslexia. Although some authors were found to have differing views on the validity of some dyslexia symptoms, the model developed explicitly rejected symptoms, attributed to dyslexia, that were in major dispute. Thus a consensus-based model of dyslexic symptoms was developed. With this in mind, it seems appropriate to use this model as the foundation for the internal expert user model of dyslexia symptoms within the DUIST system. (See Table 3.1.)

Of the seven general categories of symptom outlined in the original model, all but one (poor phonological processing skills) theoretically can be supported by enhanced interface support; and as such all six of the remaining categories are to be included in the model. See Figure 4.3 for a graphical representation of the most fundamental system model.

Figure 4.3 - The Dyslexia Symptoms Model (DSM)



4.5.1.2 Symptom Alleviating Adaptations Model (SAAM)

With the DSM representing the system expert knowledge of dyslexia symptoms, the Symptom Alleviating Adaptations Model (SAAM) could then be formulated. Based on the research outlined in Section 3.3, the model was developed to include three essential components: -

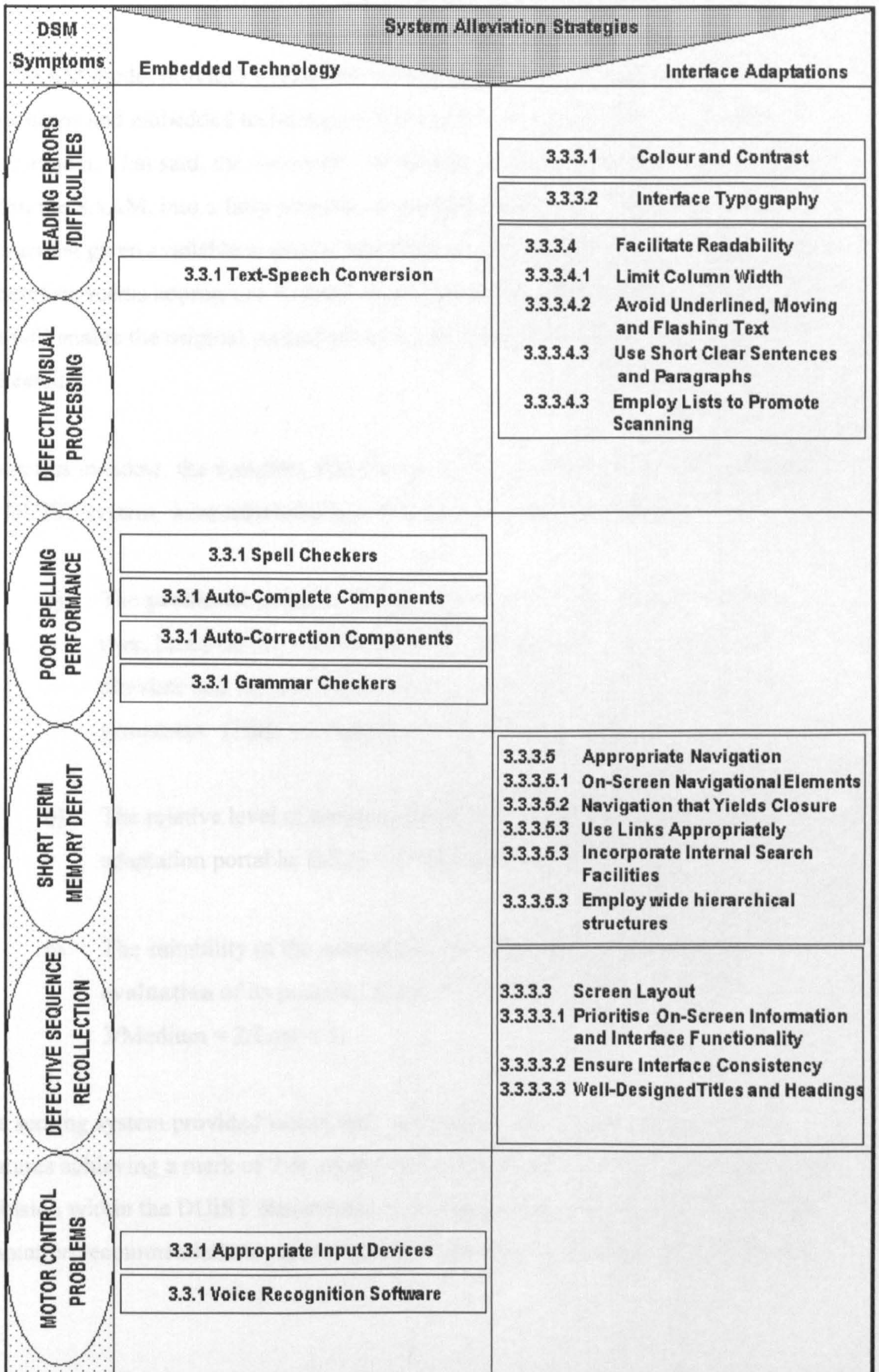
(i) Symptom. (As previously identified in the DSM).

(ii) Symptom Alleviation via Embedded Technologies.
(This division of the model aims to identify appropriate existing software tools/applications that could be embedded (or integrated) into an interface, as a suitable symptom alleviation strategy.)

(iii) Symptom Alleviation via Interface Adaptation.
(This division of the model aims to identify specific interface adaptations that can be incorporated directly into an interface to lessen symptom impact.)

At least one alleviation strategy is available for each recognised symptom and in most cases multiple suggestions are made. See Figure 4.4 for a pictorial illustration of the proposed model.

Figure 4.4 – Symptom Alleviating Adaptations Model (SAAM)



Note : Detailed discussion on each of the symptom alleviation strategies can be found within this document,in the sections referenced in the diagram.

4.5.1.3 Adaptable Components to be Incorporated within DUIST

The SAAM model provides a relatively comprehensive list of possible interface adaptations and embedded technologies that could be utilised within the DUIST environment. That said, the successful incorporation of all the strategies identified within the SAAM, into a fully portable, cross application, software solution; seems impractical given available resources and the enforced time-limitations of this project. It therefore seems appropriate to focus on a subset of adaptations, from the SAAM, that will enable the original project aims and objectives to be most proficiently addressed.

Given this mandate, the symptom alleviating adaptations that were to be used within the DUIST system, were selected based on the following three criteria: -

a) The **predicted benefits** that the adaptation would have on a dyslexic user, based on the number of symptoms the adaptation would help alleviate and the perceived significance of the targeted symptom or symptoms. (High =3 /Medium = 2/ Low = 1)

b) The relative level of **technical sophistication** needed to make the adaptation portable. (High = 1/Medium = 2/Low = 3)

c) The suitability of the adaptation with respects to **experimental evaluation** of its potential benefits for the dyslexic user. (High = 3/Medium = 2/Low = 1)

The scoring system provided would thus yield marks between the range of 3 to 9. Features achieving a mark of 7 or greater would be presumed to be ideally suited for inclusion within the DUIST framework. The application of the above criteria to the adaptation recommendations presented within the SAAM is illustrated in Table 4.3.

Table 4.3 – DUIST Adaptation Feature Selection Matrix

Potential DUIST Features	Predicted Benefits	Technical Sophistication	Experimental Evaluation	Total
Colour and Contrast	3	3	3	**9**
Interface Typography	3	3	3	**9**
Readability of Text	3	3	3	**9**
Use Links Appropriately	3	3	2	**8**
Limit Column Width	2	3	3	**8**
Avoid Underlined, Moving and Flashing Text	3	3	2	**8**
Well-Designed Titles and Headings	2	3	2	**7**
Employ Lists to Promote Scanning	2	3	2	**7**
Ensure Interface Consistency	3	1	2	**6**
Text-Speech Conversion	3	1	2	**6**
Employ Wide Hierarchical Structures	3	1	2	**6**
Use Short Clear Sentences and Paragraphs	3	1	2	**6**
Appropriate Navigation	3	1	2	**6**
Navigation that Yields Closure	3	1	2	**6**
Prioritise On-Screen Information/Functionality	2	1	2	**5**
Spell Checkers	2	1	2	**5**
Auto-Complete Components	2	1	2	**5**
Auto-Correction Components	2	1	2	**5**
Grammar Checkers	2	1	2	**5**
Appropriate Input Devices	3	1	1	**5**
Voice Recognition Software	2	1	2	**5**
Incorporate Internal Search Facilities	3	1	1	**5**

Key

Predicted benefits (3 = High /2 = Medium/1 = Low)

Technical sophistication of making feature portable (1 = High/ 2 = Medium/3 = Low)

Suitability of feature for experimental evaluation (3 = High /2 = Medium/1 = Low)

An inspection of Table 4.3 highlights several critical points related to adaptation feature selection for the DUIST framework.

Firstly, to comply with the system specification for portability (see Table 4.1) and implicitly with the original project aim to facilitate portability; some desirable interface features simply could not be included within the DUIST framework. For example, navigation routes, presented functionality sequence and screen layouts are intrinsically built into software systems at a very deep level. The practicality of developing a means to support the portability of such system components is considered, at present, impractical. The inclusion of this type of adaptable interface feature must be designed and built into the system as part of the standard software development process.

Any characteristic that achieved a score of 3 (high) in the bracket "suitability of feature for experimental evaluation", was also given selection priority. Features scoring "high" were considered especially suitable as few existing studies with dyslexic subjects were currently available and it was felt that suitable empirical experiments could be designed to measure feature significance within the DUIST environment.

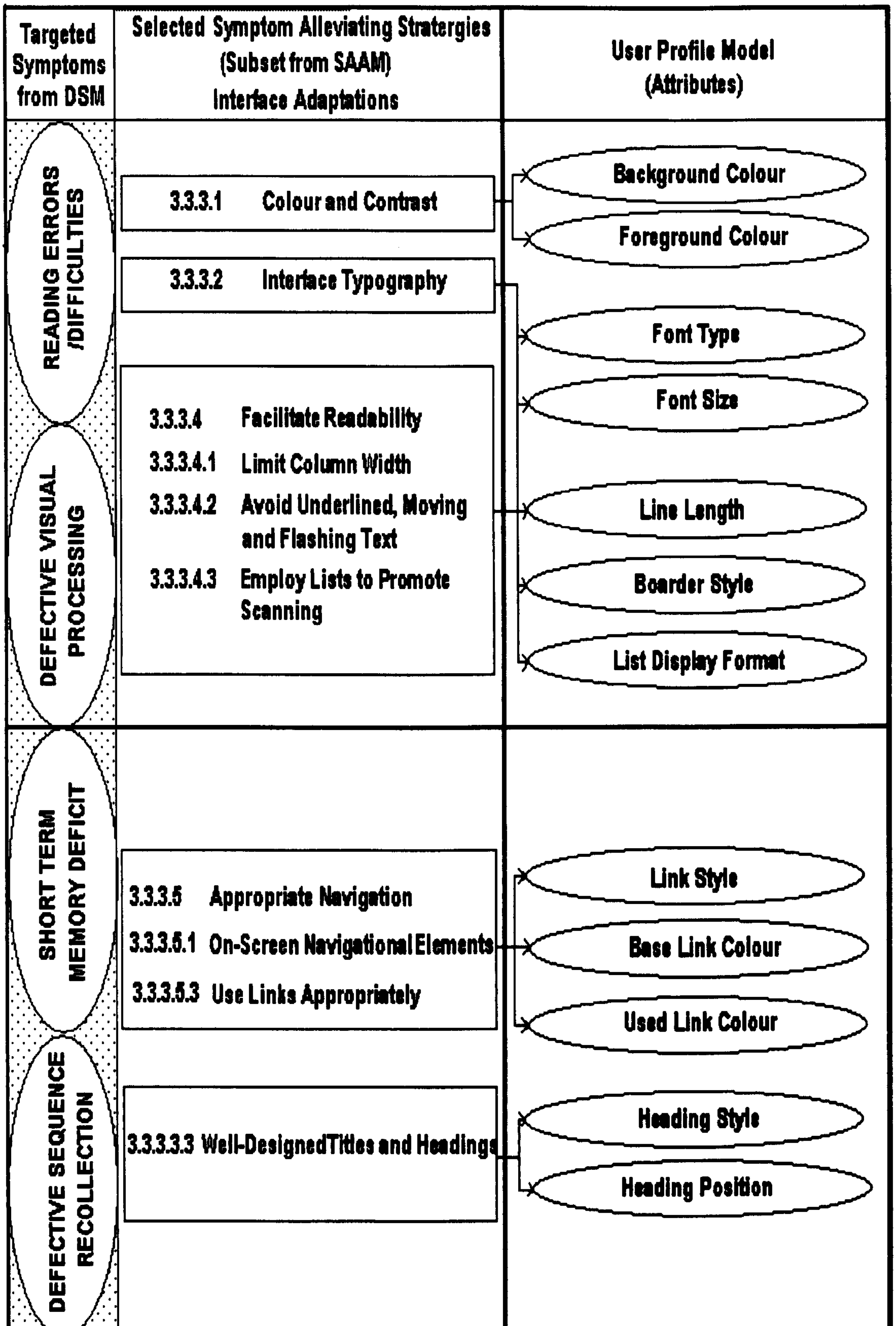
All embedded technology adaptation recommendations were also disregarded for use within the DUIST framework, as these features were considered to be more static in nature than other candidate interface adaptations (e.g. Spell checkers, text to speech synthesisers and input device selection, could not easily be tailored to unique user preference). Figure 4.5 summaries the adaptable components that were finally selected for utilisation within the DUIST framework.

4.5.1.4 The User Profile Model (UPM)

With a subset of suitable adaptations selected from the SAAM, the User Profile Model (UPM) could finally be developed. This model would hold details of the attributes that each system user would be allowed to adjust in order to generate a uniquely tailored interface display. Final profile attribute selection was made using the basic assumption that selected attributes must facilitate the prescribed symptom alleviating adaptations, selected for DUIST, from the SAAM (e.g. the modification of screen colour and contrast could be facilitated by adjustment of the display attributes foreground and background colour). See Figure 4.5 for a graphical representation of the UPM.

In addition to the attributes selected for the UPM, Figure 4.5 illustrates the symptoms that the DUIST environment will aim to alleviate (taken from the DSM); the symptom alleviating strategies that DUIST will employ (taken from the SAAM); and the underlying relationship between the three models.

Figure 4.5 - The User Profile Model (UPM)



4.5.2 Profile Elicitation and Interface Adaptation Enforcement

With the central system models designed an effective strategy for the elicitation of user profile attributes was required.

4.5.2.1 Profile Elicitation Mechanism

Development of an efficient profile elicitation mechanism is fundamental to the success of the project. Failure to develop an effective strategy for profile collection would seriously diminish the value of any subsequent interface adaptations. Previous strategies for collection of user preference data (e.g. font, font size, background colour, etc.) have employed user-invoked adaptation menus that have been criticised for their complexity, non-linear nature and lengthy trial and error mechanics.

With system requirement R3 and R6 dictating two elicitation specific system needs; compliance is essential (see Table 4.1): -

- R3: "An intuitive elicitation mechanism that will facilitate the collection of individual profile data in a short, intuitive, linear manner; in a system supported environment."
- R6: "The user profile elicitation process should incorporate simultaneous visual comparison."

The elicitation vehicle should therefore be designed to incorporate the following qualities: -

(i) **Short in length** (System performance requirement P2 requires a throughput Speed $\leq$ 10 minutes.)

(ii) **Intuitive in nature** (The actions required to complete the process should be obvious to the user.)

(iii) **Linear in sequence** (The process should comprise of several logically sequenced steps.)

(iv) **Provide expert support** (The process should give the user direction as to what modifications should be made in order to enhance their viewing experience. Existing strategies fail to provide users with guidance on what interface adaptations may be beneficial.)

(v) **Allow simultaneous visual comparison**. (Allowing simultaneous visual comparison provides an extremely intuitive way of determining user preference.)

(vi) **Dynamic in nature**. (The process should be dynamic in nature, with each successively displayed selection option, incorporating previously acquired knowledge.)

In an attempt to comply with the desired process characteristics outlined above, the following elicitation mechanism was developed (See Figure 4.6).

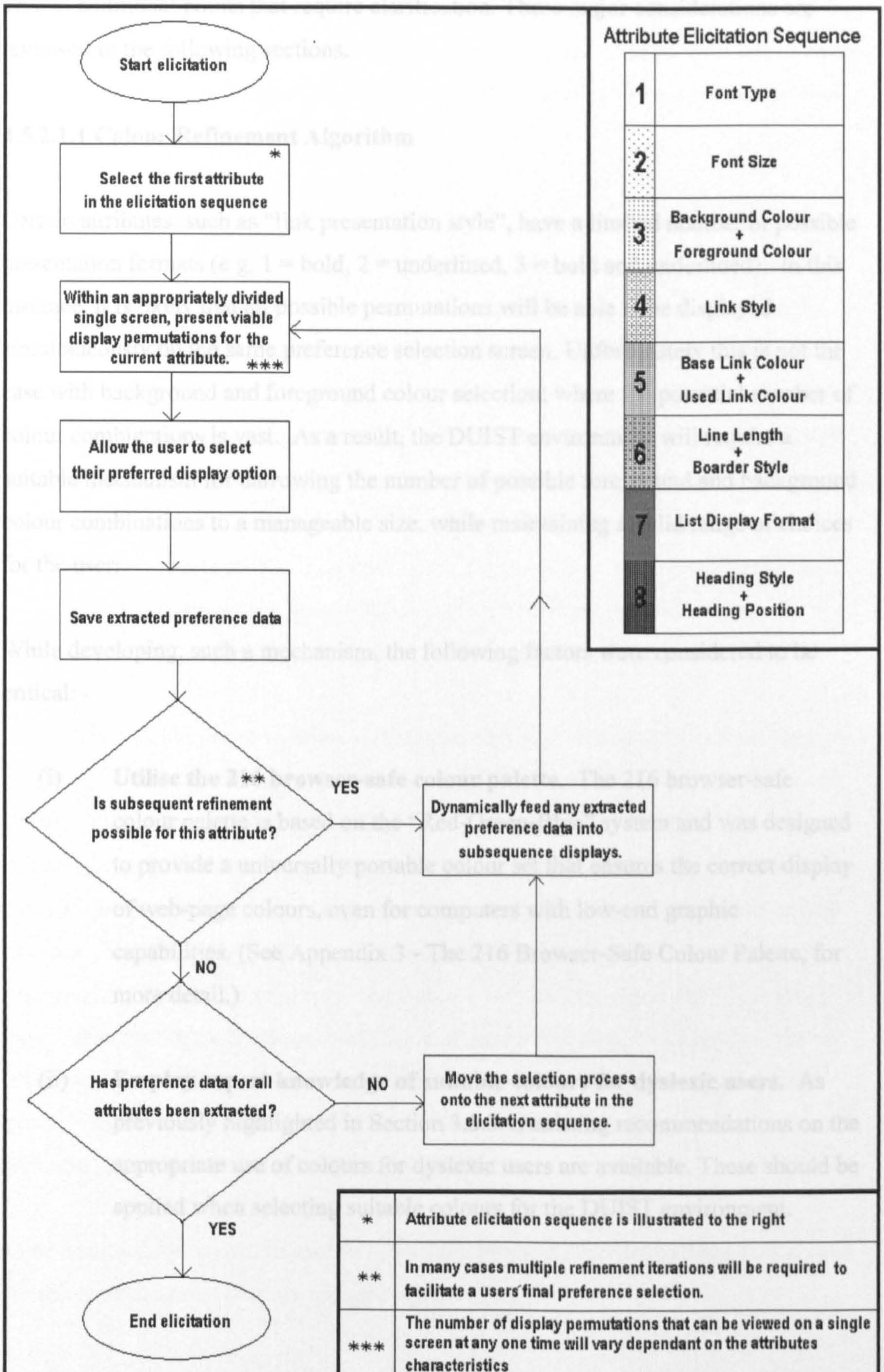
It is believed that the proposed elicitation mechanism has a number of advantages over conventional user-invoked customisation menu pallets and/or toolbars, including: -

1) Even though the mechanism includes several attribute refinement iterations (e.g. for foreground and background colour), these loops are hidden from the user with the process seeming completely linear.

2) The system seamlessly provides the user with expert advice as to what modifications they should make to enhance their viewing experience.

3) The deployment of simultaneous visual comparison is an extremely natural, intuitive, approach to preference selection. At its most fundamental level the user is simply being asked "of the display choices currently presented, which display looks best to you?" Answers provided by the user are acknowledged and subsequent displays modified to incorporate responses, iteratively, until the users preferred settings are found. An appropriate analogy could be made with the process preformed by an optometrist to find a patient's prescription.

Figure 4.6 - Overview of the DUIST Elicitation Mechanism



An inspection of the elicitation mechanisms illustrated in Figure 4.6, highlights several additional points that require clarification. These major considerations are reviewed in the following sections.

4.5.2.1.1 Colour Refinement Algorithm

Certain attributes, such as "link presentation style", have a limited number of possible presentation formats (e.g. 1 = bold, 2 = underlined, 3 = bold and underlined). In this instance, it is likely that all possible permutations will be able to be displayed simultaneously on the same preference selection screen. Unfortunately this is not the case with background and foreground colour selection; where the potential number of colour combinations is vast. As a result, the DUIST environment will require a suitable mechanism for narrowing the number of possible foreground and background colour combinations to a manageable size, while maintaining a valid range of choices for the user.

While developing, such a mechanism, the following factors were considered to be critical: -

(i) **Utilise the 216 browser-safe colour palette.** The 216 browser-safe colour palette is based on the "Red-Green-Blue" system and was designed to provide a universally portable colour set that ensures the correct display of web-page colours, even for computers with low-end graphic capabilities. (See Appendix 3 - The 216 Browser-Safe Colour Palette, for more detail.)

(ii) **Employ expert knowledge of suitable colours for dyslexic users.** As previously highlighted in Section 3.3.3.1, existing recommendations on the appropriate use of colours for dyslexic users are available. These should be applied when selecting suitable colours for the DUIST environment.

(iii) **Ensure a balance between choice and process length.** As the number of colour combination options presented to the users increases, so to does the potential length of the elicitation process. As the process must be relatively short, a legitimate balance between colour choice and process length must be achieved.

(iv) **Consider colour grouping.** The selection process may be made easier if the user reviews natural groupings of colours separately. The preferred selections from each grouping then being compared cumulatively at the conclusion of the process to ascertain the overall "best" combination.

(v) **Refinement is essential.** To make the mechanism as efficient as possible it is important to allow for subsequent colour refinement, as a direct response to indicated preferences provided by the users (e.g. if a user was to indicate an initial preference for a blue/yellow foreground/ background combination, the system should offer subsequent refinement by providing subtlety different permutations on the users base selection).

With these considerations in mind, a representative selection of colours from the 216 browser-safe palette were arranged into seven blocks of colour. (Violet/Purple, Blue, Green, Yellow/Orange, Red, White/Light-Grey and Dark-Grey/Black). The colours from each block were carefully selected to comply with the previously reviewed contrast recommendations (e.g. significant contrast, yet not extreme). Careful colour selection also maximised the number of effective permutations for block-to-block combination, for use as foreground and background colours. Figure 4.7 illustrates the typical structure of each colour block, while Figure 4.8 demonstrates how blocks can effectively be combined to create multiple foreground and background options for user selection. A complete listing of each colour block and their internal structure can be found in Appendix 4 - Colour Blocks Structure.

Once designed, the colour blocks were utilised within the foreground and background selection mechanisms outlined in Figure 4.9.

Figure 4.7 – Example Colour Block Blue

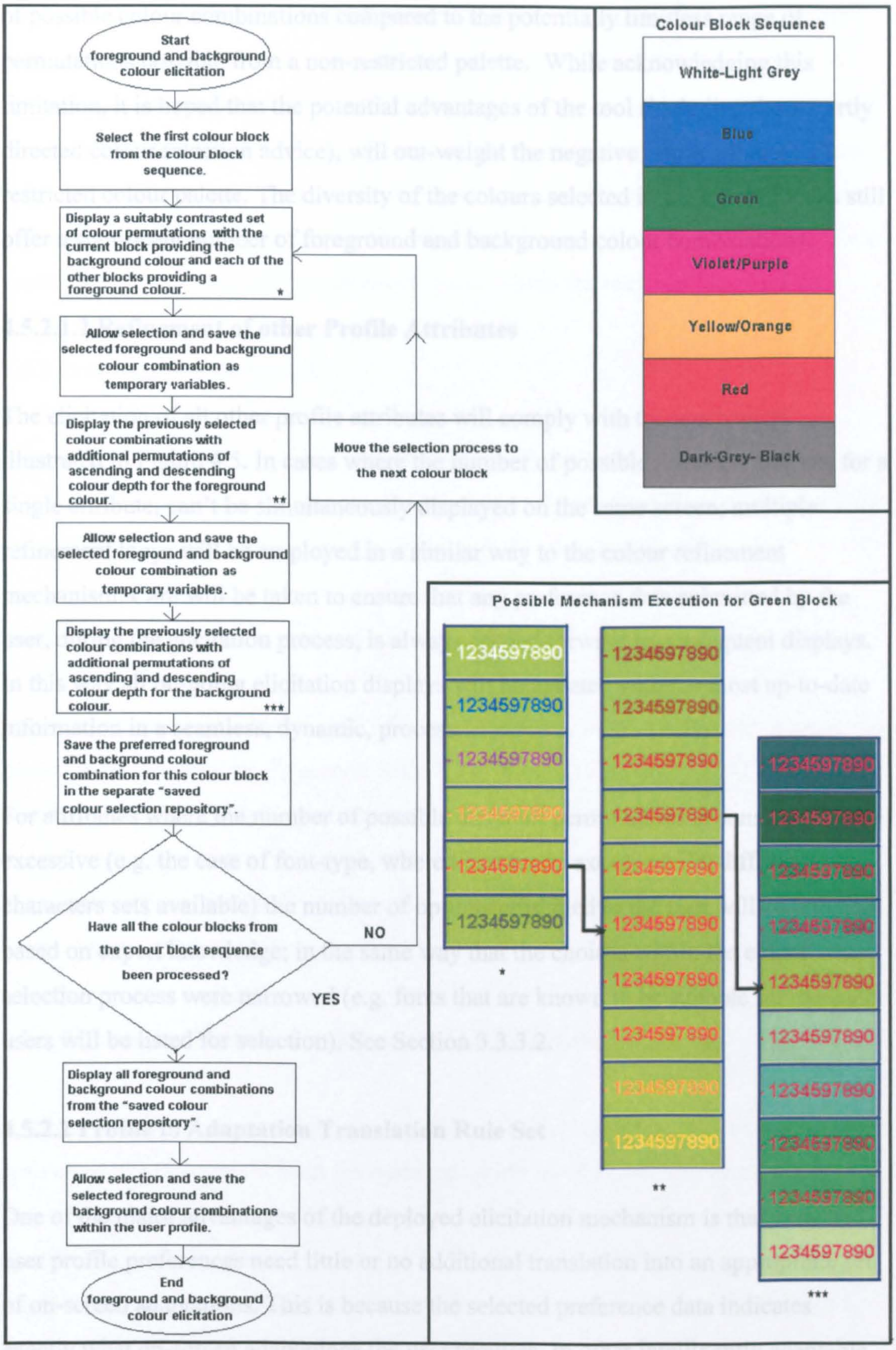
330066	
000099	
3300CC	
3333FF	
0066FF	
0066CC	
3399FF	
99CCFF	
33FFFF	
CCFFFF	

Fig 4.8 – Example foreground-background permutations

Background / Foreground	White/ L. Grey	Blue	Green	Violet/ Purple	Yellow/ Orange	Red	Dark Grey/ Black
White/ Light Grey		Example Contrast	Example Contrast	Example Contrast	Example Contrast	Example Contrast	Example Contrast
Blue	Example Contrast		Example Contrast	Example Contrast	Example Contrast	Example Contrast	Example Contrast
Green	Example Contrast	Example Contrast		Example Contrast	Example Contrast	Example Contrast	Example Contrast
Violet/ Purple	Example Contrast	Example Contrast	Example Contrast		Example Contrast	Example Contrast	Example Contrast
Yellow/Orange	Example Contrast	Example Contrast	Example Contrast	Example Contrast		Example Contrast	Example Contrast
Red	Example Contrast	Example Contrast	Example Contrast	Example Contrast	Example Contrast		Example Contrast
Dark Grey/ Black	Example Contrast	Example Contrast	Example Contrast	Example Contrast	Example Contrast	Example Contrast	

NOTE : Only one colour from each colour block is used to illustrate the potential of the block-to-block combinations – In no way, is it designed to illustrate all possible permutations.

Figure 4.9 – Overview of the Foreground and Background Colour Selection Mechanism



The obvious major criticism of the colour selection mechanism is the significant loss of possible colour combinations compared to the potentially limitless range of permutations possible from a non-restricted palette. While acknowledging this limitation, it is hoped that the potential advantages of the tool (including the expertly directed colour selection advice), will out-weight the negative implications of a restricted colour palette. The diversity of the colours selected in the colour blocks still offer a significant number of foreground and background colour combinations.

4.5.2.1.2 Refinement of other Profile Attributes

The elicitation of all other profile attributes will comply with the mechanism illustrated in Figure 4.5. In cases where the number of possible selection options, for a single attribute, can't be simultaneously displayed on the same screen; multiple refinement loops will be employed in a similar way to the colour refinement mechanism. Care will be taken to ensure that any preference data submitted by the user, during the elicitation process, is always carried forward to subsequent displays. In this way all on-going elicitation displays will be updated with the most up-to-date information in a seamless, dynamic, process.

For attributes where the number of possible different permutations is considered to be excessive (e.g. the case of font-type, where there are in excess of 500 different characters sets available) the number of options presented to the user will be reduced based on expert knowledge; in the same way that the choices within the colour selection process were narrowed (e.g. fonts that are known to be suitable for dyslexic users will be listed for selection). See Section 3.3.3.2.

4.5.2.2 Profile to Adaptation Translation Rule Set

One of the major advantages of the deployed elicitation mechanism is that extracted user profile preferences need little or no additional translation into an appropriate set of on-screen adaptations. This is because the selected preference data indicates exactly what on-screen adaptations the user requires. In other intelligently adaptable systems, reviewed in Section 3.4, complex translation algorithms had to be developed to convert observed system behaviour into appropriate modifications. In the DUIST system the user profile can be directly translated into appropriate interface adaptations, with little possibility of inference errors. A review of other adaptable systems provided no alternative non-user-invoked elicitation strategies for the extraction of profile data such as background and foreground colour (e.g. predicting a user preferred background and foreground colour combinations by observed system behaviour and/or extracted socio-economic data is highly implausible). Enforcement of on-screen adaptations within the DUIST environment will thus be based on a direct application of extracted user preferences stored within the user profile.

4.5.3 Prototype Development

With all essential system models and mechanisms formulated, it seemed prudent to develop a standalone prototype system to test the validity of the ideas developed thus far. Although a standalone solution would not fulfil all the required system specifications, a working prototype would give considerable insight into the suitability of the developed models and the proposed elicitation mechanics.

Rapid Application Development (RAD) was seen as the most appropriate approach to prototype development with several Joint Application Development (JAD) workshops being conducted with a group of dyslexic volunteers who were happy to contribute to the development process. Although most of the systems functionality had provisionally been specified, potential user group involvement was seen as invaluable to help shape interface construction and validate preliminary software specifications.

4.5.3.1 Joint Application Development (JAD) Workshops

As an essential part of the initial system prototype development, JAD workshops were seen as an effective mechanism for ensuring a high level of end user engagement with the developmental process. Implemented over a three day period, workshop membership constituted an experienced facilitator/scribe and five diagnosed dyslexic panel members. Panel member profile details can be found in Appendix 20. Prior to the commencement of the workshop, each panel member was briefed in accordance with essential JAD protocols, these being:-

- Overall aims and objectives of the workshops.
- Workshop daily agenda and proposed deliverables.
- Member equality status and disagreement resolution strategy.
- An overview of key workshop resources/tools (See Section 4.5.3.2)

The daily agenda including, primary goals/activities and daily deliverables for the JAD workshop is illustrated in Figure 4.10. Examples of material and notes produced at the JAD are summarised Appendix 20.

Figure 4.10 - Joint Application Development Workshop Agenda/Activities

Day 1: Problem Domain Understanding and Preliminary Software Specification

Primary goals/activities:

a) **Problem domain exploration**: A discussion of the existing problems experienced by dyslexic computer users (i.e. what problems did the panel members experience while using conventionally designed interfaces?) See Appendix 20.

b) **Review of existing techniques/strategies**: A review of previously formulated interface design strategies for dyslexic interface development. Panel members briefed on existing technology and techniques and asked to comment on illustrative examples (i.e. do the panel members concur with the existing recommended strategies?)

c) **Draft preliminary framework specification**: Formulation of a preliminary specification for the DUIST software. (What behaviour, performance and system constraints should the proposed DUIST system incorporate?)

Day 2: System Interface Preliminary Design

Primary goals/activities:

a) **System wireframes**: Based on the preliminary specification developed in day one, paper-based wireframe diagrams for the proposed DUIST interface were developed. Panel members were encouraged to either draft rough wireframes for key framework screen layouts themselves or use the facilitator to help them realise their conceptual layouts. See Appendix 20

b) **Interface feature selection**: Using the wireframes developed by the panel, the group reviewed the proposed layouts. Positive features were extracted from the set of wireframes and compiled into a single set of more detailed digitally produced screen mock-ups. See Appendix 20

c) **Preliminary design heuristic evaluation**: Using the set of existing design principles formulated for dyslexic interface design. The draft screen mock-ups developed by the panel were critically reviewed. (A list of the heuristics used at this stage can be found in Appendix 20.) Where heuristics were found to be compromised, modifications were made and the resulting layouts were re-evaluated iteratively.

Day 3: Provisional Interface Development

Primary goals/activities:

a) **Provisional interface construction**: Using the screen mock-ups formulated after the post heuristic evaluation refinement, the facilitator, with panel member input, developed the provisional system interface using a suitable CASE tool. (See Section 4.5.3.2)

b) **Interface walkthroughs**: Once complete, the interfaces developed for the system were used to conduct simple system user-group walkthroughs. Although system functionality was not implemented, system navigation, screen feature location and aesthetic considerations could be reviewed. User-group feedback was noted and identified problems were corrected immediately.

4.5.3.2 Programming Environment Selection

Eiffel (the object-oriented programming language) with its associated CASE tools (Eiffel Build and Eiffel Studio) was selected as a suitable vehicle for prototype construction. The use of Eiffel during prototype construction had several advantages including: -

(i) High quality CASE-tool support, to facilitate the JAD workshops: Eiffel Build offers a drag-and-drop screen builder tool, which was used in conjunction with the dyslexic volunteers present at the JAD workshops; to rapidly model provisional interface layouts. Layouts could be developed interactively with continual feedback from the dyslexic volunteers present at the sessions, being incorporated into the design process.

(ii) Access to extensive programming library resources: Eiffel Studio provides access to an extensive collection of Eiffel classes that facilitate the rapid development of software, via the reuse of high quality software components.

(iii) Comprehensive modelling facilities: Eiffel Studio provides an excellent support environment for the development of system designs using either Business Object Notation (BON) or Unified Modelling Language (UML) notation standards. Prototype designs can be graphically developed and then engineered forward to produce sections of system code, saving considerable development time.

(iv) Significant expert resources: As an established programming language access to expert support is widely available from existing practitioners, technical guides, books, journals and embedded Eiffel environment support facilities.

(v) Adherence with object principles: As a "pure" object language Eiffel offers a full range of object-based benefits including; multiple inheritance, polymorphism, data encapsulation, developmental seamlessness, design-by-contract and system extendibility.

(vi) Potential for reuse and extension: The development of a prototype using Eiffel presents numerous opportunities for software component reuse and/or system extensions for subsequent versions of DUIST.

As part of the RAD design process, several object analysis and design techniques were utilised to ensure the prototype system was robust and could potentially be reused. The object elicitation techniques Textual Analysis (TA) and Commands, Queries and Constraints (CQC) were used to design the internal system architecture of the system. Design documentation was produced in conformance with the Business Object Notation. (BON) See Appendix 5 - Prototype System Design Documentation

As part of the prototype development, an appropriate investigation of system data storage requirements was conducted. Although an Eiffel solution could be constructed to store all system data requirements (e.g. user profiles, system performance data, user feedback data, etc.) it was felt that an independent data repository would be more advantageous to the overall project goal of a distributed infrastructure.

A review of available database technology highlighted several potential solutions but the benefits of the post-relational database Matisse were considerable for the DUIST project. These benefits included:-

(i) Native Object Support: As a post-relation database Matisse supports the majority of object-oriented languages (including Eiffel, C++, Java, C# and VB.NET). Essential object principles such as object persistence, inheritance, encapsulation, object identifiers, polymorphism, and bi-directional link features are available within the Matisse data model.

(ii) Seamless System Development: With the class as the central modelling unit of Matisse, conventional object analysis and design approaches can be utilised to model the persistent system classes to be stored within Matisse. System designs developed using BON or UML notations can thus be seamlessly deployed within Matisse and the central prototype application.

(iii) Implementation Benefits: The utilisation of prototype development tools that use a single implementation vehicle, (e.g. the class) should also decrease code complexity and size by eliminating the overhead, and performance limitations, of object-relational mapping.

(iv) Potential for Extension and Reuse: As Matisse supports almost all object languages the subsequent extension and/or reuse of the central system data repository within later versions of DUIST is entirely possible. (Even if the currently selected prototype development language is changed, persistent data storage components of the system will be available for use with almost no database modifications required.)

(v) Data Interrogation Options: Full support for ANSI SQL and programmable object enquiry routines, allows for the widest possible range of system interrogation options.

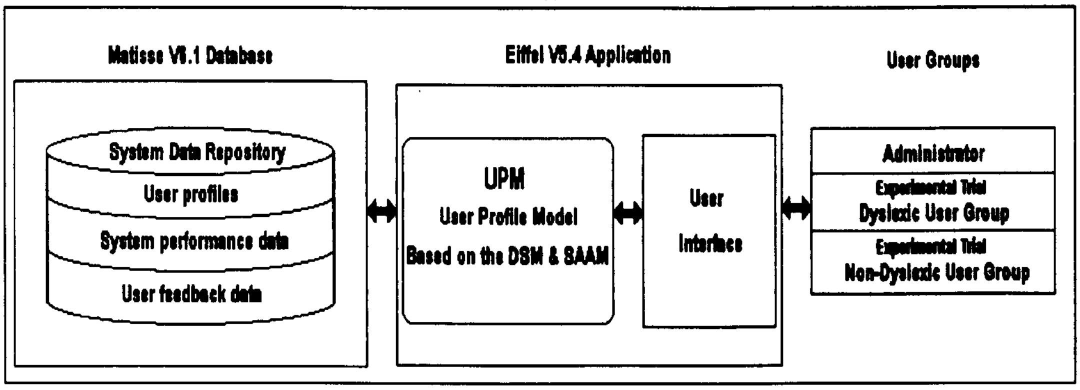
(vi) Effective Modelling of Real World Entities: Matisse supports the object data model and facilitates the effective modelling of real-world entities. The abstraction limitations of the relational model (e.g. the table) are improved on significantly by allowing the creation of non-primitive complex objects. The intuitive nature of the object data model is likely to be beneficial to the design process.

(vii) Facilitation of RAD methodology: As the rapid iterative development of working system components is fundamental to the RAD approach to software development; CASE-tool support is essential. Matisse includes several tools specifically designed to facilitate rapid system development including forward engineering code generators and dynamic schema evolution.

(viii) Comprehensive Administration Features: An extensive range of high quality embedded administration facilities should ensure that system data is stored securely. Key application components include: database mirroring; data partitioning; versioning engine and suitable recovery features.

With these design considerations in mind, a standalone version of the DUIST environment was developed with the essential components illustrated in Figure 4.11.

Figure 4.11 - DUIST Prototype Architecture



4.5.4 Final System Architecture

Development of the prototype system concluded with suitable software testing and interface performance evaluation. (See Chapter 5 - Formulation of an Experimental Evaluation Strategy for DUIST, for full details of the testing and evaluation strategies employed within the project.) With project feasibility established, based on positive results from the usability evaluation trials conducted with the prototype system, project development moved on to the design of a distributed version of the DUIST environment that would support the portability of derived user preference settings.

4.5.4.1 Distributed Architecture

Previous work has highlighted the limitations of standalone support environments and tools that were specifically developed for dyslexic users (Dickinson *et al.*, 2000;

Dickinson *et al.*, 2002). One of the most fundamental drawbacks of any such standalone system is that user efforts to customise visual display settings are not transferable between other applications. System users are either required to spend considerable time manually adapting each application with their desired preference settings or reject global customisation. As a direct response to this problem, system requirement R7 and design constraint P1 were proposed for the DUIST framework. (See Table 4.1 and Table 4.2.)

- R7: "The system should facilitate the portability of user approved visual display settings between similar media and/or systems."
- P1: The system should deploy "a distributed architecture to support multiple simultaneous users."

Adherence to these two edicts is also fundamental to the original project aims and objectives. (See Section 4.3.)

As a distributed framework architecture would naturally facilitate preference portability, initial research was carried out into the variety of distributed architectures available. Of the approaches reviewed, the utilisation of a web-enabled hypermedia solution stood out as the most viable means of developing a distributed framework for DUIST. Key selection criteria included: -

(i) Availability of Technology: With an estimated 1.018 billion users world-wide having access to the Internet in 2005 (CIA, 2005), making use of this widely available technology seems the most logical way of maximising the potential of the DUIST system.

(ii) Existing Conventions and Standards: Although not always universally accepted many standards and conventions have been established to facilitate the World-Wide-Web. Network topologies, data transfer protocols, browser components, hypertext mark-up languages and web-server configurations have all become widely accepted de-facto standards that support global data transfer. It would seem highly appropriate to utilise these existing, tried and tested technologies, to precipitate the DUIST framework.

(iii) Exemplified Project Success: As previously reviewed in Table 3.5, several comparable studies have employed adaptive-hypermedia technology to great success. Systems ranging in diversity from adaptive personalised tourist information advisors, to intelligent tutoring systems, have all used the Internet and its associated technologies to achieve distributed architecture goals.

(iv) Proliferation of Expert Resources: Due to its extensive use, access to expert support is widely available from existing practitioners, technical guides, books, journals and other expert resources for the development of systems using adaptive-hypermedia. The availability of such resources should prove invaluable to the DUIST project.

With the overall distributed architecture determined as a web-based approach, the precise implementation strategy for the DUIST framework had to be decided. Again multiple architectural paths were reviewed, with a representative sample of several of the most suitable being outlined in Table 4.4.

Table 4.4 - Possible Web-Enabled Architectural Solutions

Architectural Solutions	Technical Notes
Client-Side - Java Applet Solution	• All components of the DUIST system that interact with the potential user are coded as a Java applet. • The applet is freely available as a download, via a specified URL. • Once downloaded, all functionality runs on the client machine. • System performance data and user feedback is uploaded to the server at convenient intervals.
Distributed Client-Server Architecture	• A downloadable Java applet contains only the adaptable user interface part of the framework. • The downloaded, client applet, communicates with the server directly during system operation using a socket connection or other inter-program communication mechanism. • The interface behaviour resides on the client, while all other functionality resides on the server. • System performance data and user feedback is collected simultaneously, during normal system interaction.
HTML-Common Gateway Interface (CGI)-Architecture	• The user interacts with suitably designed dynamically adaptable HTML rendered pages via a web-browser. (Java-Script, Perl or other dynamic HTML language can be used) • Preference selections entered by the user are sent to the Web-server, which forwards it to the CGI program which then replies with newly adapted HTML rendered pages. • All system functionality resides on the server side (in the CGI program) with all user interaction made possible via a conventional web-browser.
Server Side Scripting Languages	• A server side scripting language such as PHP, ASP or ASP.NET can be used to develop dynamically adaptable pages running on the server without the need for a CGI layer. • Server compatibility with the scripting language is essential, but the removal of the CGI layer of script processing is seen as advantageous. (Most servers can readily be configured with the associated extension modules to run the required server side scripting language) • System performance data and user feedback is collected simultaneously, during normal system interaction.

After suitable deliberation, PHP was selected as a suitable vehicle, with which to implement a server-sided scripting framework architecture, for the distributed version of the DUIST environment. Leading factors in this decision included: -

(i) Download Efficiency: Several of the strategies outlined in Table 4.4 involved initial applet downloads. As the applet file size was likely to be considerable (≥ 1Mb) and user connection speeds are unknown; a possibly lengthy, single block download, was rejected. An approach that allowed the incremental, staged download, of single modified displays, was considered to be more efficient and engaging for the potential user group.

(ii) Server Side Application Residence: Utilising a server sided scripting framework architecture enables all major system components to be located on the server. System maintenance and the implementation of any essential upgrades can be carried out centrally, with universal, immediate effect; compared to other approaches that require update applet downloads.

(iii) Script Language Selection: PHP is a widely used, well supported, server side script language. Later versions of PHP, (e.g. PHP 4.3 onwards) support object-oriented system development. With the existing prototype system modelled as an object-based solution, the seamless integration of any new web-based components could be made easier by adherence to an object implementation strategy. PHP 4.4 onwards, is also fully compatible with Matisse and the previously developed prototype data repository.

(iv) Suitability for Adaptive Applications: Server side scripting languages such as PHP were specifically designed to facilitate highly customised, dynamic web-page generation, based on the premise of continually changing user needs.

(v) Availability of Data: A server sided scripting framework architecture implicitly elicits regular responses from the user in order to facilitate dynamic adaptation. This intrinsically has two major benefits for the DUIST framework. Firstly, all required system performance data can be continually collected, stored and processed. Secondly, the nature of dynamic script processing harmonises with the elicitation mechanism formulated for the DUIST environment. (See Figure 4.6.)

4.5.4.2 User Preference Setting Portability

Undoubtedly one of the most challenging aspects of the DUIST project is the implementation of display preference portability. As the majority of software applications have interface display formats intertwined with system functionality at the code level; cross application modifications at such a deep level seem highly impractical. With this key consideration in mind, investigation was conducted into screen modification strategies that could be utilised, without software intervention at a source code level.

4.5.4.2.1 Gateway Web-Mediators

One effective solution, researched by Brown and Robinson was the use of a gateway web-mediator for the pre-display processing of HTML. (Brown and Robinson, 2002) Specifically designed for web-users with impaired vision, the web-mediator functions by parsing downloaded HTML and reformatting the content by suitable adjustment of selected parameters within the mark-up text. Evaluation of the web-mediator, demonstrated the potential of customisation of hypermedia content for people with visual disabilities. It did however have several limiting factors, including: -

(i) It only supported user-invoked, conventional interface modification strategies employing menus, toolbars and palettes to facilitate adaptation.

(ii) Certain pages, including those with secure components could not be processed correctly due to page encryption and concerns over lose of security.

(iii) The mediator regularly re-sequences content in-order to display pages that comply with the users desired display characteristics. Some system processing heuristics can result in meaningless content displays, which can be confusing for the user (e.g. the web-mediator attempts to provide a textual description for unhelpful or missing ALT attributes using a simple system heuristic; this regularly generates meaningless or inaccurate titles).

(iv) In certain instances, typically to comply with the users selected display preferences and screen resolution issues, content is re-sequenced using a system heuristic based on link density. The current algorithm can currently result in inappropriately sequence pages (e.g. A table is presented to the user, before the explanatory text).

(v) As the mediating gateway requires the entire page to be downloaded, (before the page can be reformatted and possibly re-sequenced) final display times can be considerably slower then those evident in conventional browsers, especially in cases where a user only has a low bandwidth connection.

Other web-mediator/gateway tools such as "Muffin" and "Shodouka" have been developed, but these display similar strengths and weakness to the system developed by Brown and Robinson (Boyns, 2003; Yee, 2006).

4.5.4.2.2 Cascade Style Sheets (CSS)

Possibly the most widely used hypermedia customisation mechanism is that of Cascade Style Sheets (CSS). CSS allow for web-page designers to specify the style of a page (e.g. the font type, font colour, line spacing, margin size, etc.) separately from the structure and content of the document (e.g. headings, body text, links, etc.) Used in conjunction with a compatible web-browser the presentation characteristics of most HTML based documents can be modified to meet a users' individual display preference needs.

From the inception of HTML in the early 1990's, Berners-Lee *et al.* identified one of the key goals of HTML as the appropriate separation of document structure from layout (Berners-Lee, *et al.*, 1992). This goal was extolled in the format known today in 1996, with the publication of the first version of "Cascading HTML Style Sheets, Level 1" by Lie and Bos (Lie & Bos, 1996). Shortly thereafter, the two industry leading browser developers adopted many of the CSS recommendations and released CSS compliant browsers (e.g. Microsoft's Internet Explorer 3 and Netscape Navigator 4). The endorsement of CSS recommendations by the World Wide Web Consortium

(W3C) ensured that CSS standards were developed and widely enforced in subsequent browser versions (Lie *et al.*, 1996; Lie & Bos, 1999).

The current version of CSS standards, published by the W3C, includes 3 levels of recommendation for efficient desktop browsers deployment. Each incremented level incorporates additional, successively sophisticated features, some of which are currently under-development. By means of an overview, level 1 outlines the most fundamental CSS attributes (e.g. fonts, margins, colours, etc.). Level 2, envelops all level 1 features and extends attributes to include amongst others; absolutely positioned elements, automatic numbering, page breaks, right to left text. Level 3, seeks to extend current provision to include; fancy borders and backgrounds, vertical text, user interaction and speech (W3C, 1999).

Utilisation of CSS technology within the DUIST framework offers significant benefits over other possible display preference portability mechanisms, for several important reasons:-

(i) **Established Infrastructure**: As an industry standard for almost all current browsers, existing accessibility features allow for the adoption of a user specified set of display preferences via CSS file selection. This established infrastructure facilitates the quick and easy application of previously derived display settings and seems ideally suited to DUIST portability aspirations.

(ii) **Standards and Expertise**: With widely accepted industry standards and extensive technical resources available, any use of the CSS model within the DUIST framework should be more than adequately supported.

(iii) **Reduced System Build Time**: For preference portability solutions such as the web-mediator (outlined above) considerable effort must be expended on the bespoken development of the software. Use of the CSS model within the DUIST framework should significantly reduce system development time, as a significant part of the preference portability framework has already been developed. Use of the CSS model within DUIST would require the development of software to generate appropriately constructed CSS preference files; but no software development would be required to implement the generated CSS files, as existing browser technology would facilitate screen adaptations.

(iv) **CSS to UPM Translation**: As previously discussed in Section 4.5.1.4, the UPM seeks to model screen preference characteristics that can be adjusted to enhance the dyslexic users interface viewing experience. An examination of the attributes formulated in the UPM and of those contained within the CSS standards exhibit a significant level of compatibility.

(v) **Existing User Knowledge**: Although not fundamental or essential, some potential users of the DUIST tool may have existing knowledge of and/or experience using browser accessibility features. In instances where this is the case, use of the existing accessibility browser components within the DUIST framework should make the process more intuitive for new users.

Despite the significance of the outlined benefits of deploying CSS to facilitate the DUIST framework, using CSS may have some drawbacks. Potential limitations of a CSS solution include: -

(i) **Non-CSS Compliance in Certain Browsers**: Even though adherence to W3C CSS standards is now extensive, some browsers do not fully support all level 2 features. CSS containing features that aren't supported by certain browsers may find that pages are displayed incorrectly. (Typically this will be minor formatting errors.) As any page abnormalities are to be avoided, (especially for dyslexic users who may become quickly confused or disoriented by page rendering errors) any CSS feature selection will be made in compliance with UPM and level 1 CSS features that are almost universally complied with by current browsers. (See Appendix 6 - W3C.org List of CSS Compliant Browsers and Technology.)

(ii) **Technical Problems with the CSS Language**: Current versions of the CSS language do contain several limitations including; vertical control page location limitations; multiple properties performing the same function (e.g. position, display and float); unexpected margin collapse; and lack of float containment. That said, display-formatting issues relating to these identified problems are unlikely within the DUIST framework, based on the set of desired UPM adaptations.

(iii) **Limited Scope of CSS**: The level 1 version of the CSS specifications contained a number of characteristics that limited the potential scope of the model. Key limitations included; lack of advance support for table formatting; limited font configurations; and lack of media types (e.g. it was designed as a screen-device language for monitor resident interface displays). These limitations are being, or have been, addressed in level 2 and level 3 versions of the CSS specifications. That said, even though only level 1 recommendations are deployed within the DUIST system, the scope provided in CSS1 is more than adequate for the build, as:-

- The attributes identified for modification within the User Profile Model (See Section 4.5.1.4) are totally compatible with CSS1.

- The vast majority of current browsers are fully compliant with CSS1.

Reflection on potential strengths and weaknesses of a CSS deployment, for preference settings portability, led to the acceptance of the CSS approach for use within DUIST.

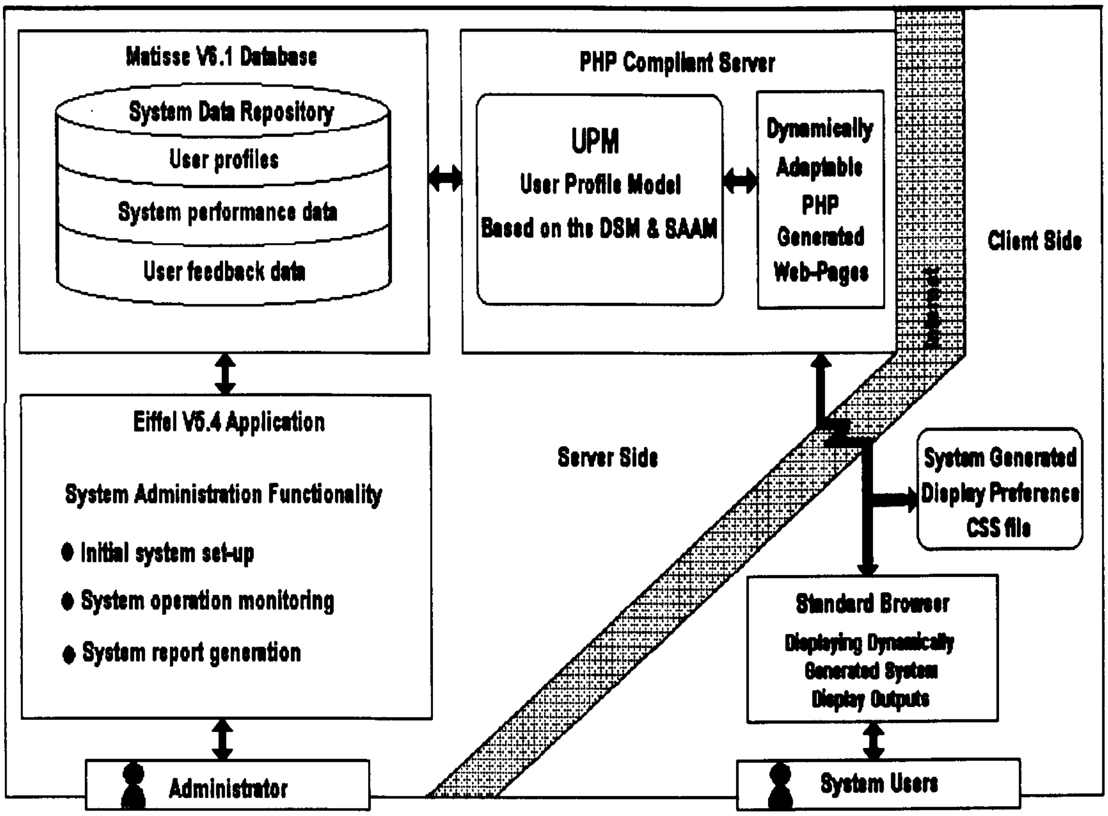
4.5.4.3 Standalone Prototype to Distributed Version Migration

With all essential decisions related to system architecture and preference portability made, a strategy could then be developed to support the migration of useable components from the standalone prototype to the distributed version of the system. Due to the strengths of the object-design approach employed for the development of the prototype, several major software components could be reused within the final distributed version of the system. In particularly, all Eiffel resident administration functionality and the Matisse based system database could be used with only minor modifications for the final distributed system. At the highest level, standalone to distributed version migration would require the following steps: -

- Keep the previously developed Eiffel based system to provide administration support for the DUIST environment. (Ensure the existing connectivity between the administration system and the data repository is retained)
- Remove the embedded GUI from the prototype Eiffel system
- Using the previously tested models from the prototype interface, redesign and re-implement the GUI as a series of PHP pages that facilitate the dynamic elicitation process outlined in Section 4.5.2.1.
- Set-up a PHP compliant server to hold and process the reworked GUI.
- Ensure connectivity between the existing system data repository and the newly developed PHP interface.
- Write and test the PHP software components that will generate the appropriate CSS file for subsequent user browser deployment.

A graphical representation of the revised distributed system architecture is presented in Figure 4.12.

Figure 4.12 - DUIST Distributed System Architecture



Throughout the migration process, object-modelling techniques continued to be used to ensure that the system remained fundamentally object-based in nature. It should however, be noted, that some deviation from a pure object development strategy was necessary during the development of the PHP Interface, due to the limited object-support features available within the version of PHP available at the time (e.g. PHP 4.4 does not fully support all of the object principles used elsewhere during system development. PHP 5+ uses an enhanced object model that complies more efficiently with standard object conventions).

Final system interface designs were developed using a variety of techniques. Initial prototype layouts developed during the JAD workshops were used as a starting point for development of the final interface designs. These designs were subject to heuristic evaluation based on a compiled set of conventional usability and accessibility criteria. Considerations such as the level of feedback, system consistency, perceived stability, the level of user control, forgiveness and the appropriate use of metaphors were all assessed. Where violations of criteria were detected, designs were reworked and modifications reviewed iteratively until all heuristics were met. All interface designs were also reviewed against the dyslexic specific design principles presented in Section 3.3.3, to ensure compliance. Examples of the finalised interface designs and supporting technical notes are provided in Appendix 7 - DUIST Interface Designs and Supporting Technical Notes.

Chapter 5: Formulation of an Experimental Evaluation Strategy for DUIST

5. Experimental Evaluation of DUIST

With the specification, analysis and design of the DUIST framework complete, the formulation of a suitable experimental evaluation strategy for the DUIST framework was required. This chapter will detail the experimental strategies utilised within the work and provide appropriate justification for deployment.

5.1 Experimental Hypothesis

Before any experimental evaluation strategy can be developed, clarification of the experimental objectives must be achieved, via the formulation of a suitable project hypothesis. Based on the original aims of the work, the following central hypothesis was developed: -

"The use of the DUIST framework, by a dyslexic computer user, will result in interface performance gains, as exemplified by statistically significant increases in reading accuracy and speed"

with the corresponding NULL hypothesis being: -

"The use of the DUIST framework, by a dyslexic computer user, will result in no interface performance gains, as exemplified by statistically insignificant changes in reading accuracy and speed".

Implicitly the appropriate experimental evaluation of the formulated hypothesis should help address several other essential project objectives, including: -

(i) The validity of the model of dyslexia symptoms used.

(ii) The legitimacy of the previously formulated interface design principles utilised.

(iii) The validity of the elicitation mechanism deployed.

5.2 Experimental Parameters

The central project hypothesis has already alluded to the need to measure predicted interface performance gains for dyslexic subjects using DUIST. Thus, the appropriate selection of techniques to evaluate user application performance is essential. After an extensive review of previously deployed interface evaluation strategies, utilised within similar systems (see Table 3.5 and Table 3.3), certain essential parameters were determined.

(i) **Laboratory Conditions**: Although the DUIST framework was developed to work as a distributed system, (with potential users utilising the tool remotely through the Internet) it was decided that for the preliminary trials of the system, the need for specialist equipment and the potential benefits of observing user interactions with the system, dictated a laboratory approach. (The potential lack of context for the subject and the presence of the evaluator during system trials were considered unavoidable experimental constraints)

(ii) **Sample-Size**: Several of the comparable systems previously reviewed had used a relatively small sample size. (Seeword = 6 dyslexic subjects and 5 control; Dyslexic nursing support system = 31 dyslexic subjects and no control. (Dickinson *et al.*, 2000; Wright, 2001; Dickinson *et al.*, 2002)) Although findings from these studies were valid, it was felt that a larger sample-size would add to the validity of any results and subsequent conclusions. With this in mind, at total sample-size of 100 experimental participants was derived; 50 dyslexic subjects and a control group of 50 non-dyslexic volunteers.

(iii) **Subject Characteristics**: All dyslexic participants would be asked about their dyslexic status, with formal diagnosis of their condition being a prerequisite. All participants would need to be over the age of eighteen. Other characteristics would be noted (e.g. age, gender) but would not result in exclusion. Factors such as IT competency, social grouping, educational background or other such demographics were not considered relevant as the DUIST environment is theoretically designed for all dyslexic computer users, irrespective of any social or economic factors.

(iv) **Measurable Performance Indicators**: Previous comparable studies have employed a variety of performance indicators to measure user performance. Typically a mixture of subjective and objective quantifiable indicators are used to extract a multi-facetted model of performance. Typical indicators include: -

- **Satisfaction Levels** (extracted by post-event questionnaires, or interviews)

- **Application Competency Speeds** (elicited by measuring the period of time taken for a user to achieve a predefined level of application competency)

- **Task Completion Times** (derived by recording the time taken to perform a predefined task or set of tasks)

- **Reading Accuracy and Speed** (measured by recording reading performance in terms as errors per 100 words and words per minute, respectively)

- **Psychological Impact** (elicited by post-event walkthrough, interviews, thinking-aloud techniques and observation)

Compliance with the central project hypothesis dictates that reading accuracy and speed must be evaluated as a measure of interface performance. Additionally, user satisfaction levels will be assessed by means of suitable post-event questionnaires. This combination of subjective and objective indicators should provide a rich source of data with which to assess the success of DUIST.

5.3 Experimental Design

With several of the key experimental parameters identified, the design of an appropriate experiment to facilitate the collection of the required data (e.g. reading accuracy, speed and user satisfaction levels) is now required.

The experimental design developed by Dickinson, for the comparable system SEEWORD, would seem appropriate for use with the DUIST framework. (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002) Dickinson argued that one of the most significant performance indicators for any interface developed for dyslexic subjects is its ability to facilitate effective reading. This harmonises with the Dyslexia Symptoms Model (DSM) developed during this project. (See 4.5.1.1 - The Dyslexia Symptoms Model.) Consequently, if an interface could be modified in such a way that reading performance for the dyslexic subject could be enhanced; then the applied screen adaptations could be considered to be successful. To test this assumption, Dickinson deployed the following experimental strategy.

- Allow the subject to select their preferred interface display settings. (Dickinson employed a conventional, manually adaptable, approach to customisation.)

- Using a set of screen rendered textual passages with comparable reading difficulties, (Flesch Reading Ease = 50-60 and Flesch-Kincaid Grade Level = 10) randomly apply user preference modification to half the screen displays, while keeping a base screen presentation style for the remaining half. (See Appendix 8 - Flesch/Kincaid Reading Scales.)

- Ask each experimental participant to read aloud from the passages of text embedded within each screen display. (Those modified and those unmodified.)

- For each textual display, record the number of reading errors the subject makes and the time taken to read each passage. Reading errors are considered to be mispronunciations, substitutions, refusals, additions, omissions, and reversals.

- Using the number of words from each screen display, the time taken to read the text and the number of reading errors recorded; the following performance variables can be derived:

    - **Mean Reading Errors (as a % of words)**
    - **Mean Reading Speed (words per minute)**

- Perform a statistical comparison of the participant's reading performance, with and without their user-preference settings applied, to determine the significance, if any, of the screen modifications.

Although this approach may be subject to some valid criticism (see Section 5.5) the objective nature of the generated results and the readily repeatable format of the technique make it suitable for use within the DUIST project.

As well as the objective performance measures obtained from the reading experiments, subjective performance indicators will be sought using a post-event questionnaire. After using the DUIST environment all experimental participants will be asked to complete a system embedded electronic evaluation questionnaire. The questionnaire will be divided into four distinct categories as illustrated in Table 5.1.

Table 5.1 - Post-Event Evaluation Questionnaire Categories and Question Examples

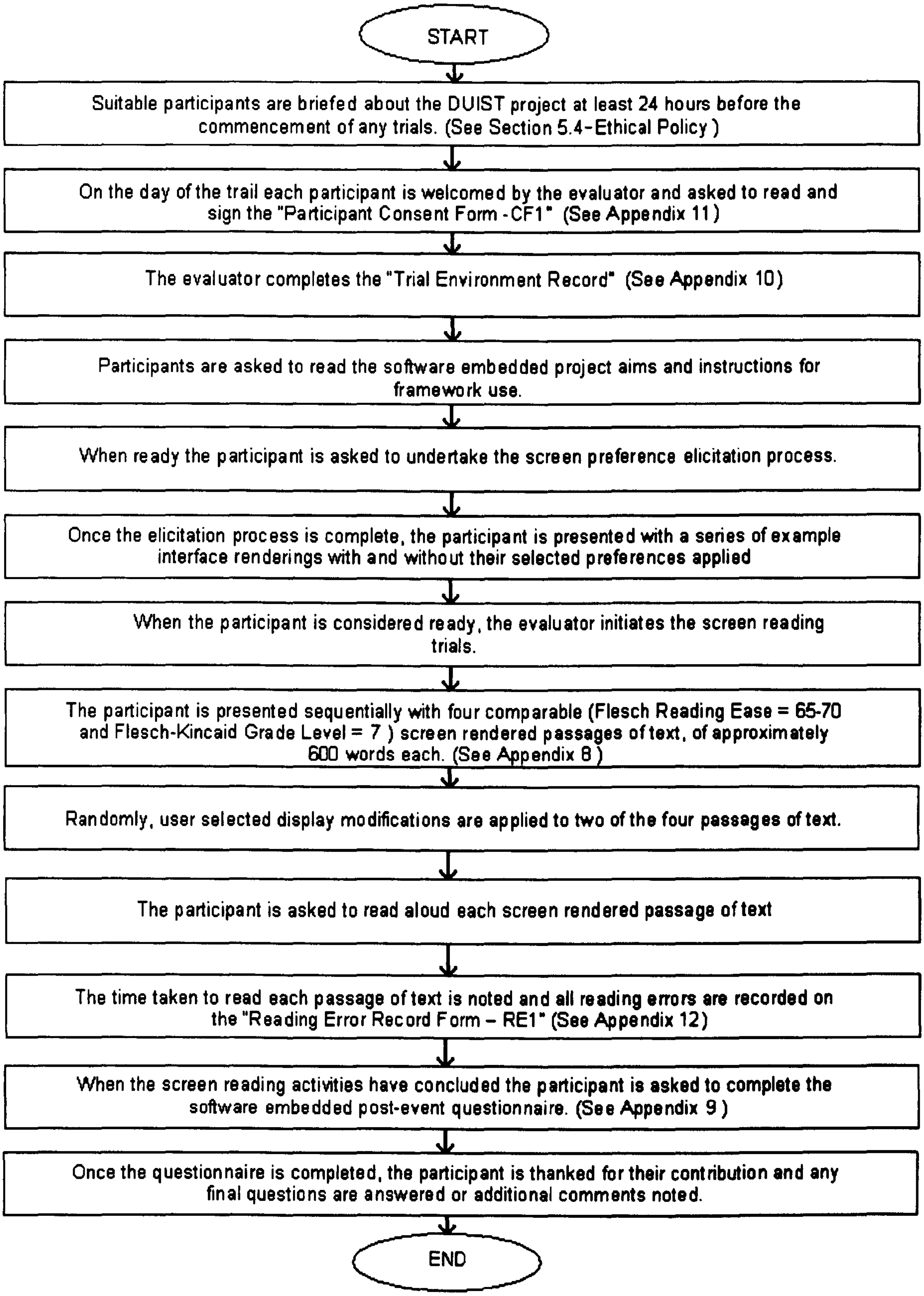
Question Category	Example Questions
• Basic information about the subject	■ Age ■ Gender ■ Dyslexic Status (Dyslexic/Not Dyslexic)
• The subjects view of the preference elicitation process	■ How simple, quick and intuitive was the preference elicitation process?
• The impact of the applied modification on the subjects interface experience	■ Did the subject experience benefits once preference settings were employed? ■ Would the subject like to apply their extracted preference setting to other applications?
• The subjects view of the DUIST environment	■ Did the DUIST environment provide enough information about the project? ■ How easy was the tool to use, including navigation, layout, presentation and help?

It is hoped that these subjective indicators will be complimentary to data extracted during the reading performance trials, with the analysed results being sufficient to address the original project hypothesis. (See Appendix 9 - DUIST Post-Event Questionnaire.)

A number of other potentially significant observations will be recorded prior to the commencement of each system trial. Firstly environmental factors such as trial location, time and lighting conditions will be noted. (Any abnormalities in the results obtained may be explained by non-conducive environmental parameters.) Secondly any other relevant subject comments or evaluator observations will be recorded. (See Appendix 10 - Experimental Trial Environment Form.)

With the proposed experimental approach outlined, system specific implementation details for the complete experimental process, are graphically represented in Figure 5.1.

Figure 5.1 - The Experimental Evaluation Process



5.4 Experimental Critique

By way of a critique, it is worth reviewing the potential criticisms that could be levied at the proposed experimental methodology.

Reading Aloud vs. Non-verbalised Reading: It is fair to say that the cognitive processes involved in reading aloud may differ slightly from those used when a subject reads to themselves; with articulated reading typically including the additional processes of motor plan production, subsequent muscle moment and the preceding sound generation (Colteart *et al.*, 1993, Levelt *et al.*, 1999). That said, the validity of the experiment can still be justified as the decoding processes involved in reading shouldn't be compromised by the additional stage of verbalising decoded words (e.g. words must still be internally decoded even if they are subsequently verbalised or not). Any results obtained should give an indication of the impact of the screen modifications on the fundamental translation and interpretational processes being performed by the reader (Borowsky & Besner, 1993; Rapp, 2001).

Reading Aloud vs. Mean Reading Speed: As a direct result of reading aloud, it is likely that average recorded reading speeds for all participants will be reduced, compared to potential non-verbalised reading speeds (e.g. verbalising translated words will slow down the overall reading process). This however, is not considered to be a significant problem, as participants will be reading all passages of text aloud, hence all comparisons should be meaningful.

Standardisation of Experimental Texts: Critics of the evaluation methodology used, may question the validity of the standardised text. Arguably, even though the texts have been normalised using Flesch Reading Ease and Flesch-Kincaid Grade Level scales (See Appendix 8 - Flesch/Kincaid Reading Scales) theoretically the content of the passages could influence reading speed (e.g. A participant that is interested in the text they are reading, may increase their reading speed; whereas a subject finding the text disinteresting may slow down). As a direct response to this, texts were selected that typically would be considered interesting to the expected target population (e.g. adults). Topics such as money, relationships and family were included. More importantly, random selection would be enforced to ensure that no single text would be displayed consistently as either a modified or unmodified page. With 100 trial participants, any unexpected abnormalities in reading speed, induced as a response to content for a specific text, would have little significance to the overall data set.

Standardisation of Environmental Factors: Certain environmental factors such as available light, the position of the screen within respects to the light source, the time the experiment was conducted, etc; could all potentially influence the subjects reading performance and on screen preference selection. Although a standard experimental trail location could not be guaranteed, every effort was made to ensure that the impact of environmental factors was minimised. Considerations such as providing ample lighting, positioning the screen so as to avoid glare and conducting the trial at a time convenient for the subject were all enforced. As an additional precaution, all relevant trial environmental factors were recorded for subsequent review on the Trial Environment Record sheets. (See Appendix 10 "Experimental Trial Environment Form")

Human Factors: Human factors such as nervousness, embarrassment and project interest level, could all potentially impact reading performance. As dyslexic subjects can often suffer from low self-esteem, especially when asked to read aloud, this consideration is valid and is addressed in detail in Section 5.6.

Identification of the Cause of Potential Failure: The null hypothesis makes clear that statistically insignificant changes ($p < 0.05$) in reading accuracy and speed will demonstrate the failure of the DUIST framework to enhance interface performance for dyslexic subjects. Should this be the case, one potential drawback of the evaluation method deployed is that is does not give an indication of the reason for potential failure. As the DUIST framework represents a conglomeration of formulated theories (e.g. models of dyslexic symptoms, symptom alleviating strategies and a newly developed elicitation strategy, etc.) isolating the specific causality of system failure would potentially be very difficult. That said, it is believed that the research methodology employed is still justified for two legitimate reasons: -

(i) There is significant research to support the validity of each of the component parts of the DUIST framework.

(ii) The overall framework warrants investigation as a conglomeration of theories, models and techniques in order to evaluate the full potential of the proposed tool (e.g. the validity of each component part of the framework could be explored separately, but the potential combined benefits of the conglomeration of underpinning ideas, within the integrated system, justifies the investigation).

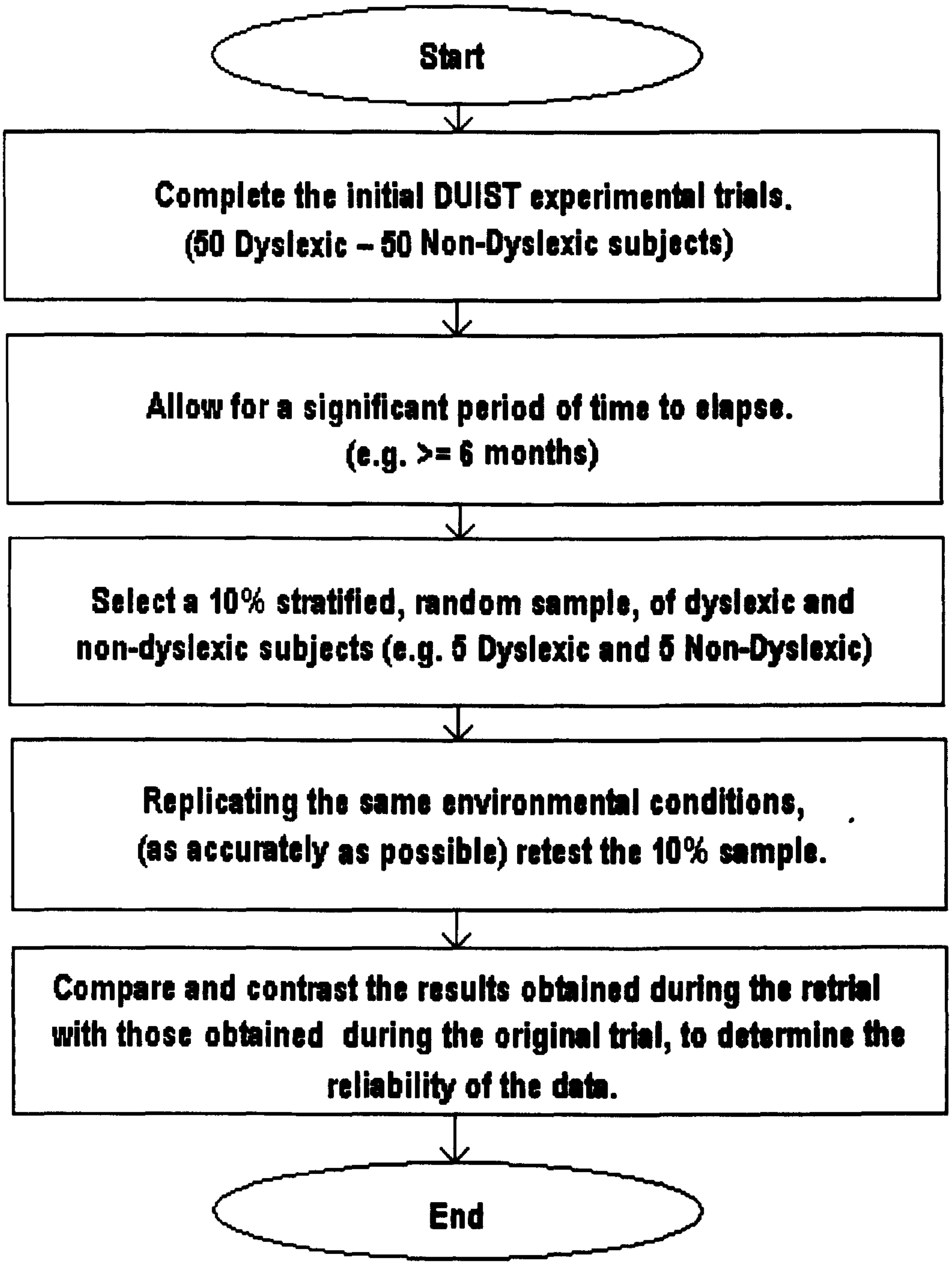
Should the overall framework fail to deliver a statistically significant improvement ($p < 0.05$) in reading performance; the exploration, in isolation, of the component theories behind DUIST would be justified.

5.5 Experimental Validation and Verification

To ensure the validity of the results obtained from the evaluation process, a suitable verification mechanism must be employed. As the proposed experimental evaluation method is readily repeatable, the use of verification retrials should help to ensure result validity. Figure 5.2 illustrates the proposed experimental results validation strategy.

The strategy includes a gap between the original trials and the retrials in an attempt to minimise the impact that the subjects short-term to medium-term memory would have on the experimental results (e.g. close proximity between trial and retrial could potentially lead to familiarly with the tool and textual passages, resulting in a possible bias). With the minimum 6-month gap period enforced, subject recollection is likely to be limited and logically retrial results subject to less bias.

Figure 5.2 – Experimental Results Verification Mechanism



5.6 Alternative Evaluation Strategies

Although the experimental design and evaluation strategy utilised within this work mimicked the one employed by Dickinson and colleagues (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002), it should be noted that alternative evaluation strategies for the research were also considered. The following table briefly summarises the alternative evaluation strategies/techniques considered, highlights where certain techniques were deployed within this work and gives an indication as to some the strengths and weaknesses of each approach.

Table 5.2 Alternative Evaluation Strategies/Techniques Considered

Technique Author(s)/Date	Evaluation Strategies/Technique Overview
Cognitive Walkthrough (Polson *et al.*, 1992)	• Polson and colleagues developed an analytical evaluation technique based on the expert psychological analysis of the perceived impact of a given interface design on the proposed target user group. • Detailed psychological behavioural profile knowledge about the target user group is required, with the expert attempting to predict the interfaces impact on the user, the cognitive processes required and any learning problems that may occur. • Analysis is typically centred on the likely operational goals of the user. • Although this technique could potentially provide some invaluable insight into theorised system usability, the level of analytical skills required to effectively utilise this technique were unavailable for this work.
Pluralistic Walkthrough (Bias, 1994)	• Teams of developers and usability experts walkthrough system execution scenarios using a series of hard-copy screen mock-ups or storyboards illustrating system execution pathways. • All members of the team individually record their observations on the systems perceived usability, identifying issues that may potentially detract from interface efficiency for each execution pathway. • Once all of the navigational/execution pathways have been examined by the members individually, the group discuss their findings/observations as a collective. • Design limitations are highlighted and fault alleviation strategies are formulated • The technique itself generates high volumes of quantitative data, but requires significant expertise and resources.
Heuristic Evaluation (Nielsen & Molich, 1990)	• Nielsen and Molich proposed the use of known usability criteria (or heuristics) to use as an evaluation technique for the assessment of interface designs. • Using a predetermined, previously researched set of usability principles, interfaces can be assessed for criteria compliance. Where criteria are violated, the evaluator can suggest suitable adjustments to the designs. • As a relatively simple evaluation technique, a set of dyslexic specific heuristics were created and deployed during the initial JAD workshop and then subsequently used throughout the development of the pilot DUIST system. (See Section 4.5.3.1 and Appendix 20)

Review Based Evaluation (Dix, *et al.*, 1998)	• As there is a proliferation of literature and research available on interface development and dyslexic-computer-interaction (DCI) a review of previously compiled empirical evidence is an effective way to support (or refute) the deployment of a specific feature within any interface. • This technique, namely Review Based Evaluation (RBE), utilises existing research and can be applied directly to newly designed systems. • In the case of the DUIST project, RBE was indirectly carried out in two ways:- 1) Previous DCI research was deployed to create the criteria used for the Heuristic Evaluation technique (See Appendix 20) 2) An examination of previously developed dyslexic based interfaces (e.g. SEEWORD, Avanti, etc) presented an excellent opportunity to allow comparative evaluation of similar systems with DUIST. (Fink *et al.*, 1997; Kobas, 1999; Dickinson *et al.*, 2000)
Observational Techniques (Dix, *et al.*, 1998)	• Observational techniques such as "Thinking Aloud" and "Post Event Walkthroughs" offer excellent insight into the user's interactive operational experience either during or after interface use. • With the "Thinking Aloud" technique, users are encouraged to vocalise their reactions to the interface, while actually using the system. By recording the users comments, emotional responses, body language, facial expression and noting pauses in operation, the evaluator can achieve good insight into the interfaces overall performance. • In the case of the "Post Event Walkthrough" approach, the evaluator allows the user to perform a series of operations using the system interface. Once complete, the evaluator discusses the user's experiences with each screen in a sequential walkthrough of the interface displays the user visited. • In both cases, the presence of the evaluator could potentially influence the participant's reactions and/or responses; but the richness of the possible information extracted justifies the use of this technique for many projects.
Interviews (Preece, *et al.*, 1994; Preece, *et al.*, 2002)	• Offering a potentially rich source of evaluation data, user interviews are invariably used in most software development projects. • Unstructured interviews typically don't include a script, they are not replicable but they are the most flexible type of interview. • Structured interviews in general follow a tight script and are similar in nature to a verbalised questionnaire. • Semi-structured interviews provide some general predefined questions for discussion, but deeper, follow-up questions can be used where appropriate. • Group interviews, are typically deployed where a consensus of opinion is required. They open the way for debate on a topic, but are implicitly harder to facilitate. • Simple, unstructured questioning was used throughout DUIST experimental trials, with each participant being asked for their reaction to the framework after they had completed the formal experimentation. Typical questions included:- "How easy did you find the tool to use?" "Was there anything you didn't like about the framework?" "Would you like to use the tool personally?" • Unexpected comments or reactions were noted on the "Trial Environment Details form", under "other observations". (See Appendix 10)

Questionnaires (Preece, *et al.*, 2002)	• Providing a relatively inexpensive, simple and fast way of collecting evaluation data from a large number of users, questionnaires provide a powerful tool for the evaluator. • Supporting multiple styles of question (e.g. yes/no, scale, open-ended responses, checklist, ranked order, etc.) questionnaires provide the evaluator with a means of collecting large volumes of quantitative data. • Although an effective questionnaire (including appropriate structure, layout and content) requires considerable skill to develop, significant literature is available on the subject. • The main limitations of using questionnaires include inflexibility and possible low response rates. • An embedded software questionnaire was deployed to gather evaluation data from the DUIST trial user group. (See Appendix 9)
User Testing (Preece, *et al.*, 1994; Rubin, 1994; Preece, *et al.*, 2002)	• User testing attempts to utilise one or more experiments to measure user performance in someway or another • Experiments will typically seek to measure certain performance variables to evaluate the overall performance of the interface. Typical measures include:- a) Task or activity completion times. b) Selected navigation pathway sequences. c) The number and type of errors made by the user. d) The number of errors per unit of time. e) The number of times a user accesses an application support feature such as help. f) Learning competency times (e.g. the time it takes to train a new user to be able to use the interface to performance a specific task to a predetermined level of competency) g) Memory load testing (e.g. the users ability to remember interface feature location and or sequence) • Within the DUIST project, critical interface performance measurements centred on, core task (i.e. training) completion times; interface attribute selection preference; and reading performance variables. (See Sections 5.2 and 5.3)
Predictive Modelling Evaluation Techniques (Fitts, 1954; Card, *et al.*, 1980; Card, *et al.*, 1983)	• Predictive Modelling evaluation techniques attempt to evaluate designs without direct user involvement. • By modelling anticipated user behaviour, the need for real user group interaction is removed. • The major limitation of predictive models is that only system interfaces incorporating predictable tasks are suitable for this type of evaluation. • Several well established predictive modelling techniques exist, including:- a) Goals, Operators, Methods, Selections (GOMS) rules (Card, *et al.*, 1983): By modelling knowledge and cognitive processes of users interacting with a system interface, efficiency between alternative implementation strategies can be evaluated. b) Keystroke Level Model (KLM) (Card, *et al.*, 1980): Providing actual numerical predictions of user performance levels, the KLM technique is invaluable for comparing theoretical timings for system operation. c) Fitt's Law (Fitts, 1954). : Used to estimate the time a user will take to physically locate an object on a screen in direct-manipulation based interface environments, the law predicts the time taken as a function of the distance from the target and the object's size. • Although powerful evaluation techniques in their own right, the use of predictive models as part of the DUIST evaluation program was seen as inappropriate due to the lack of predictability of the tasks users were expected to perform.

Although not exhaustive, Table 5.2 gives some indication of the wide range of evaluation techniques available for use within any software engineering development project. As interface usability is fundamental to the success of any software development, careful selection of the most appropriate evaluation methods, for use throughout a projects lifecycle, is critical.

Final research selection of project evaluation needs (e.g. which technique should be used? When should each approach be applied? With whom should the technique be used with? Etc.) were made based on the expert practitioner guidance supplied via several leading subject authors. Figure 5.3 illustrates the evaluation technique selection guidelines utilised within this work.

Based on the guidelines extolled in Figure 5.3 and an examination of comparable projects, (e.g. Fink *et al.*, 1997; Kobas, 1999; Dickinson *et al.*, 2000) it became clear that several evaluatory techniques must be incorporated into the DUIST project lifecycle. Figure 5.4 provides an overall summary of the evaluation mechanisms deployed throughout the DUIST project.

Figure 5.3 - Evaluation Technique Selection Guidelines Utilised

Based on the work of Rubin, Dix *et al.* and Preece *et al.*, the following evaluation technique selection guidelines were utilised throughout the research. (Preece, *et al.*, 1994; Rubin, 1994; Dix, *et al.*, 1998, Preece, *et al.*, 2002)

+ Clearly determine the ultimate goals of the evaluation.

+ Define the questions that are to be addressed during the evaluation.

+ Deploy evaluation techniques at appropriate stages throughout the projects lifecycle.

+ Use analytical, review and model based approaches to evaluate systems at the design stage.

+ Use empirical techniques such as experimentation, observation and query methods to evaluate developed interfaces.

+ Contrast the strengths and weaknesses of laboratory vs. field evaluation. (Consider a combination of both approaches where appropriate.)

+ Consider the subjectivity (or objectivity) of the technique to be deployed

+ Consider combinations of techniques that yield qualitative and quantitative data, so comparative evaluation of results is possible.

+ Assess the resources and equipment available for evaluation utilisation.

+ Quantify the intrusiveness of the technique and theorise on its possible impact on findings.

+ Ensure the experimental participants used in any evaluation stage are suitable (i.e. comparable age, educational background, socioeconomic profile and technical expertise with the target user group).

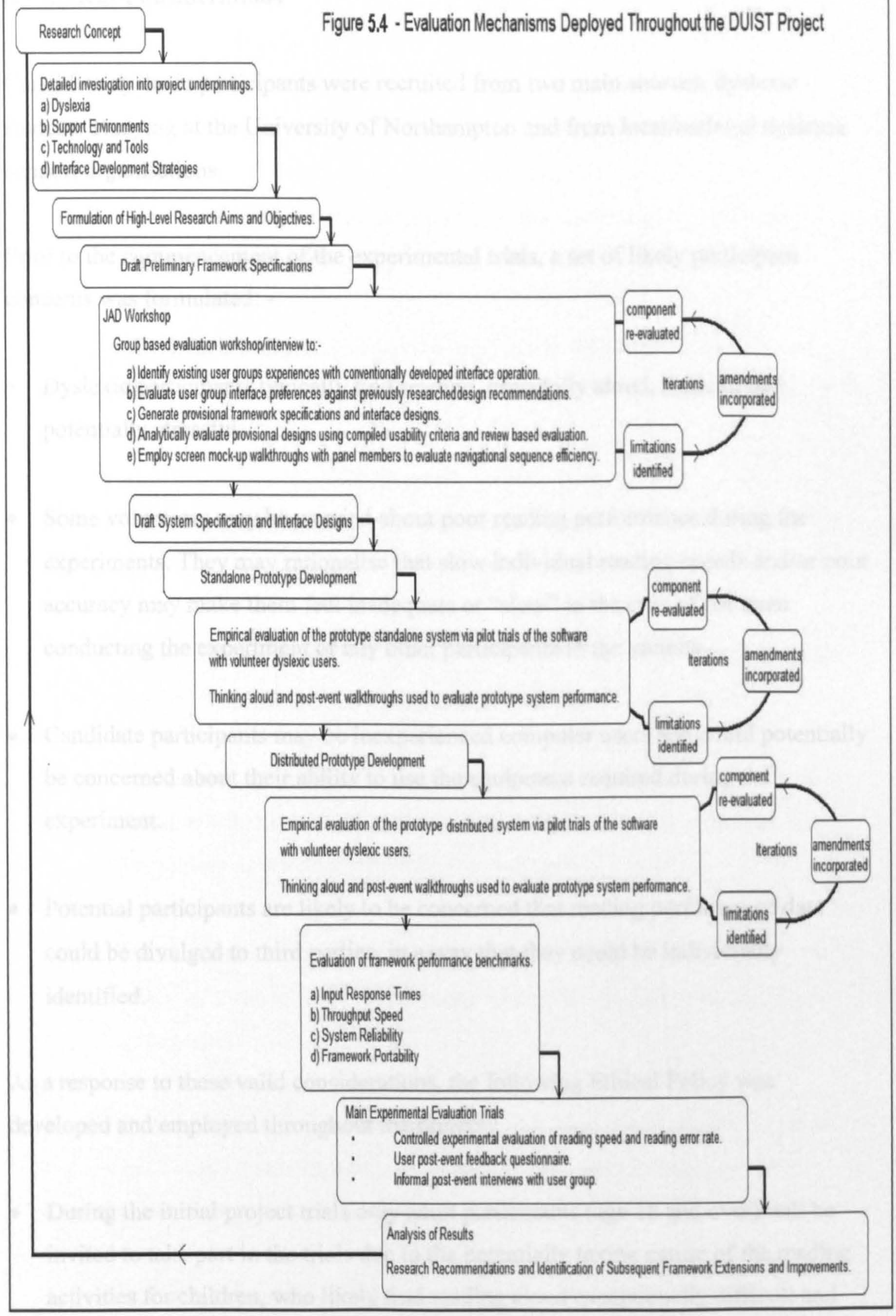
+ Address the ethical issues the research may infringe upon.

+ Deploy formative evaluation to address interface usability throughout system development.

+ Utilise summative evaluation strategies to assess the quality of the final interface solution.

+ Assess the validity, reliability and any potential biases that any results may include.

Figure 5.4 - Evaluation Mechanisms Deployed Throughout the DUIST Project



5.7 Ethical Considerations

Candidate dyslexic participants were recruited from two main sources, dyslexic students studying at the University of Northampton and from local/national dyslexia support organisations.

Prior to the commencement of the experimental trials, a set of likely participant concerns was formulated: -

- Dyslexic participants typically find reading, especially aloud, difficult and potentially stressful.

- Some volunteers may be worried about poor reading performance during the experiments. They may rationalise that slow individual reading speeds and/or poor accuracy may make them feel inadequate or "slow" in the eyes of the team conducting the experiment or any other participants in the vicinity.

- Candidate participants may be inexperienced computer users and could potentially be concerned about their ability to use the equipment required during the experiment.

- Potential participants are likely to be concerned that reading performance data could be divulged to third parties, in a way that they could be individually identified.

As a response to these valid considerations, the following Ethical Policy was developed and employed throughout the project.

- During the initial project trials only adult participants (age 18 and over) will be invited to take part in the trials due to the potentially taxing nature of the reading activities for children, who likely find reading aloud exceptionally difficult and potentially distressing.

- All candidate participants will be fully informed about the projects aims, purpose, research method, likely duration, potential consequences, and the likely publication of findings; before they are asked to participate in the study.

- A full description of all the experimental tasks, the candidate will be asked to perform will be outlined before any candidate can participate in the study.

- Experimental trials will be conducted in accordance with those originally developed by Dickinson and colleagues in 2000 and 2002 (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002).

- Candidates will be informed about the environment in which the experiments will be conducted. This will help alleviate the typical concerns identified above: -

    a) All experiments will be conducted in private with the participant and the researcher only.

    b) To conform to health and safety regulations, an additional research team member will be available outside the laboratory, should either the participant or the researcher require assistants.

    c) Inexperienced computer users will be given the required IT training, in order for them to feel "comfortable" using the equipment during the experiment.

    d) Participants will be assured that apparently slow reading speeds or high reading error rates might be expected. (The participant should not feel inadequate or "slow" regardless of reading performance.)

    e) All data collected during the experiments will be recorded in such a way that only the researcher conducting the experiment has access to the personal details of the participant. Any results presented, will have all identifying features (e.g. names) removed, to ensure that experimental results can not be traced back to individual participants.

f) All paper-based records from the experiments, which include personal data, will be stored securely by the researcher (a suitably locked filing cabinet should be sufficient).

- Care will be taken to be sensitive to the individual needs and potential embarrassment that a dyslexic participant may experience while reading text aloud from the interface screens presented.

- The participant will be made aware that they have the right to withdraw from the study at any point, even during the experiment, should they become unhappy, confused, embarrassed or frustrated with what they are being asked to do.

- Each participant will be asked to sign a consent form agreeing to participate in the study, before they will be allowed to participate in any project experimentation. (See Appendix 11 - DUIST Project Trials – Participant Consent Form (CF1).)

- All participants will be given at least 24 hours notice, from the point of initial recruitment, to the point at which they are asked to participate in any experiment. This will provide participants a 'cooling-off' period within which they may decide to withdraw from the study.

- Each participant will be given the opportunity to see his or her individual experimental results.

- All project results and conclusions will be made available to the projects participants.

5.8 Software Testing Strategy

As well as the experimental evaluation methodology outlined above, DUIST also required a suitable software testing strategy to ensure all software components comply with the formulated system specifications. (See Section 4.4.)

Any proposed strategy should ensure: -

a) Correctness – behave in a predictable manner in compliance with the functional requirements outlined in Section 4.4.1.

b) Completeness – exhibit all the required functionality described in Section 4.4.1.

c) Efficiency – execute system operations using system resources in an economical manner.

d) Reliability – comply with the performance indicators and design constraints outlined in Table 4.2.

e) Portability – comply with the fundamental project objective of user preference portability.

f) Usability – enforce established interface design principles to facilitate accessibility and usability for all potential dyslexic users.

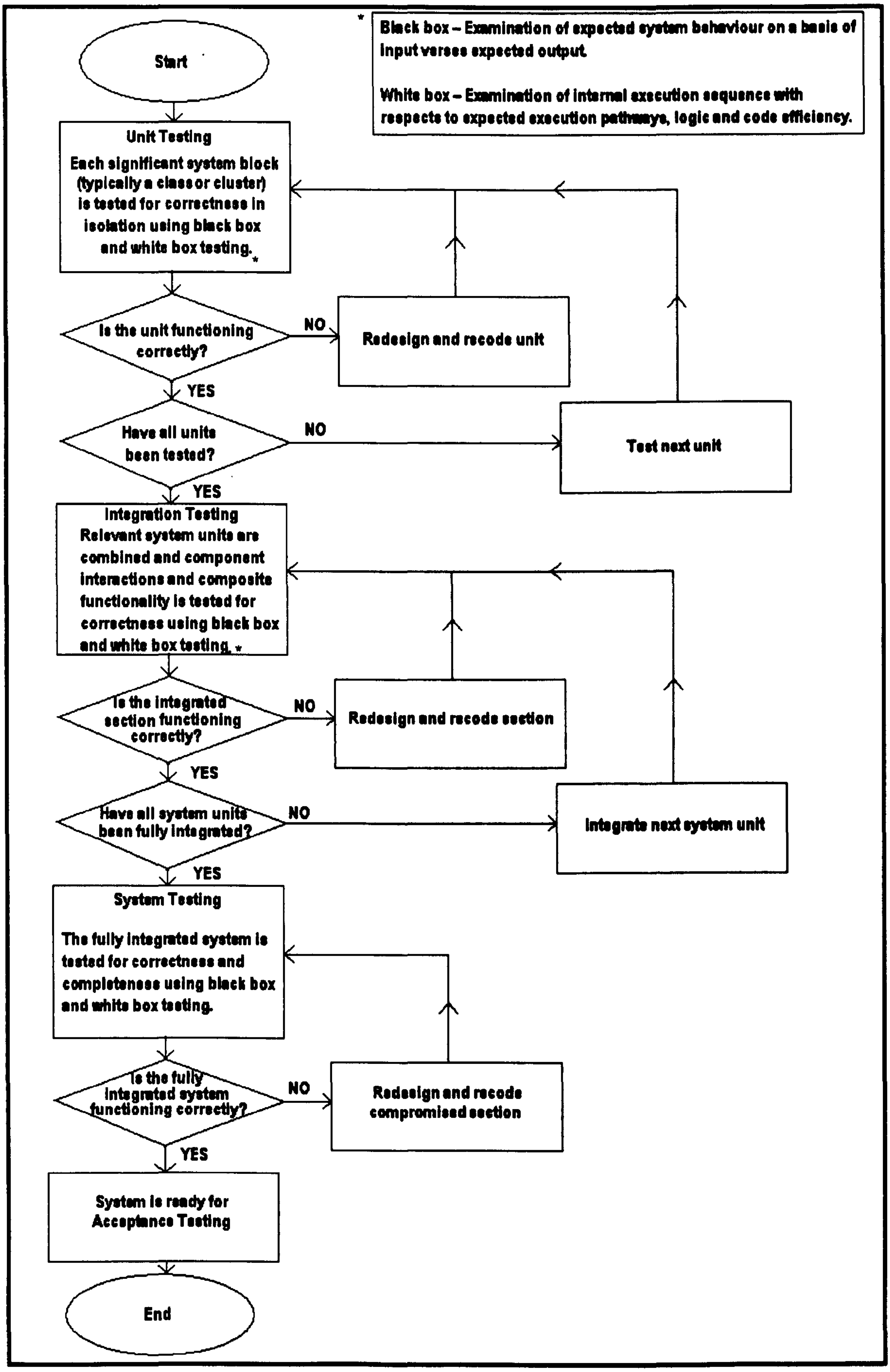
With these essential considerations in mind, a two-stage test strategy was developed to ensure that all software components were built in accordance with the required project specifications.

Stage 1 - Ongoing System Development Test Strategy: The regular, ongoing, testing of all developed software components was considered to be critical to the integrity of the DUIST system. As system architecture was designed using the object-oriented paradigm, unit testing of sequentially developed system classes and clusters was possible. Each class (or possibly small cluster) was interrogated using a two-step approach. Initially units were subjected to Black-box trials to ensure expected system behaviour on the basis of supplied inputs verses expected outputs. Once generated system outputs were approved for correctness, White-box trials were carried-out to check internal execution sequence with respects to expected execution pathways, logic and code efficiency. Identified unit limitations would result in component redesign and/or recoding, followed by unit retesting.

Once individual software units had been proven, with respects to correctness, Integration testing could be employed. Single software units were combined into progressively larger software blocks (typically cluster or multi-cluster groupings) where component interactions and composite functionality could be tested for correctness using Black-box and White-box techniques. Again, identified limitations could result in unit or even block redesign and/or recoding. All reworked system components would be retested iteratively until approved for correctness.

At the top level of system development, System testing was conducted to ensure the fully integrated system behaved as expected and displayed the full range of specified functionality. Figure 5.5 provides a graphical representation of this process. See also Appendix 21 for additional detail and examples of the functional test strategy employed.

Fig 5.5 Ongoing System Development Test Strategy



Stage 2 – Acceptance Testing: With the ongoing testing cycle complete and with a theoretically fully functional system developed, Acceptance testing could be conducted for each of the previously specified system performance indicators (See Table 4.2). As considerable diversity existed between each performance indicator, a separate acceptance test needed to be developed for each factor. Table 5.3 provides a list of the proposed acceptance tests.

Table 5.3 - Acceptance Test Strategy for System Performance Indicators

ID Ref	System Performance Indicators	Test Strategy
(P1)	• Distributed Architecture to Support Multiple Simulations Users.	• System requirements stipulate a distributed implementation that will support a minimum of 10 simultaneous users without serious performance degradation. • Distributed trials will be carried out with multiple simultaneous users. System performance will be observed with varying numbers of concurrent users.
(P2)	• Throughput Speed ≤ 10 minutes	• For the purpose of this project, *"throughput speed"* was defined as the time taken for a single user to use DUIST to generate a set of individually customised adaptation recommendations. • Accurate timings of elicitation process duration will be taken from a variety of users. • User selection will ensure that IT literacy skills are mixed, to give a more accurate reflection of average throughput timings.
(P3)	• Input Response Times ≤ 1 second	• For the purpose of this project, "*Input Response Times*" was defined as the time taken for a single user input action to elicit the required system output response. • Input response times will be measured for both standalone and distributed versions of the system. • For the distributed version, input response times will be observed with a varying number of simultaneous users.
(P4)	• Data Storage Capacity	• As multiple user profiles are created, database administration tools will allow for the effective monitoring of secondary storage usage. • Although this is unlikely to be a problem, due to the ample availability of secondary storage available within modern servers, the situation will be regularly reviewed.

(P5)	• System Reliability	• Two measures of system reliability will be used to assess the robustness of the environment. • The first measure will suppose a target system error rate of ≤ 0.01% (e.g. less than 1 inappropriate system response per 10000 user interactions) • The second measure will suppose a system availability time of 165 hours per week. (3 hours of system unavailability being reserved for system back-ups and upgrades) • Error rate and system availability will be recorded for distributed versions of the system
(P6)	• System Usability	• User feedback from the post-event questionnaires will be collected to address system usability. Questions will cover issues such as: - ■ Did the DUIST environment provide enough information about the project? ■ Was the tool easy to use, to include navigation, layout, presentation and help? (See also Table 5.1.)
(P7)	• Portability	• The portability of user approved visual display settings will be assessed based on a series of trials with several system generated CSS files, applied to a representative set of web-pages. Portability will also include a review of browser compatibility.

It is hoped that the careful adherence to the test strategy outlined above would provide a software solution that is complete, robust, correct, efficient and most importantly is usable by even the most inexperienced dyslexic computer user.

Chapter 6: An Experimental Evaluation of the DUIST Framework

6. Experimental Results

The following chapter presents the findings from the DUIST project. Results are reviewed in two distinct sections. Section one examines the overall DUIST framework and provides details of software component tests and implicitly all aspects of system usability. Section two deals with the experimental evaluation findings from the interface performance trials. For all key project results, appropriate discussion and a suitable critique is provided.

6.1 Software Testing Results

The subsequent section provides details of the results obtained in response to the Software Testing Strategy outlined in Section 5.8. Care is taken to address each of the desired framework characteristics (e.g. software correctness, software completeness, distributed system performance, throughput-speed, input response times, system reliability, system usability and preference portability) and present appropriate results and comment. Compliance with the system requirements outlined in Section 4.4, is critical if a valid assessment of framework usability is to be achieved.

6.1.1 Software Correctness and Completeness

For any subsequent system performance evaluation to be meaningful, the developed software must accurately enforce the specified system models and elicitation strategy. To this end, every effort was taken to comply with the Ongoing System Development Test Strategy outlined in Figure 5.5. Black-box and White-box testing was used, in conjunction with unit, integration and system tests, iteratively, to ensure appropriate system execution. Black-box trials included valid and invalid permutations of attribute boundary values, input formats, attribute types and event sequence. White-box trials included execution path traces, intermediate variable monitoring and object creation sequence inspection. Any software component found to be defective was reworked and retested iteratively until expected system behaviour was achieved.

Software completeness was established by a review of the required system functionality specified in the original functional requirements documentation (see Section 4.4.1).

6.1.2 Distributed System Performance

As one of the key system requirements, distributed system behaviour required suitable evaluation. To this end, the DUIST framework was configured to run using the previously outlined distributed infrastructure (see Figure 4.12).

Once the framework had been correctly setup and appropriately configured for distributed use, a suitable evaluation strategy had to be developed to explore distributed performance.

Initially, Web-server access logs were monitored for the IP addresses of remote clients to ensure multiple simultaneous users. Although server HTTP get-statements could provide an indication of the frequency of calls to the server, without the corresponding client activity logs the precise duration of the *client-call - server-respond – client-receive* cycle could not be accurately timed. As the accurate measurement of the *client-call - server-respond – client-receive* cycle duration was considered to be exceptionally difficult to implement, an alternative evaluation strategy was developed. The strategy utilised is outlined below:-

1) Ten experimental participants were recruited to remotely access the distributed version of the DUIST framework, using an Internet ready personal computer and their current Internet Service Provider (ISP).

   All participants were non-dyslexic, computer literate, students studying at the University of Northampton. These volunteers were seen as suitable for the experiment as the only aspect of system behaviour being measured was distributed access speed.

2) Each remotely located user was then instructed to simultaneously access the DUIST site during a predetermined 30 minute time-slot and work through the activities available within the framework in the following sequence:-

   a) Read the frameworks operation instructions.
   b) Create a user profile
   c) Complete the automated elicitation preference extraction process.
   d) View the example page displays, with and without system adaptations.
   e) Complete the online post-event questionnaire.

3) Client activity was monitored throughout the trial using the web-server access logs to ensure that all ten participants were using the framework continually throughout the 30-minute period. No attempt was made to record precise usage patterns during the experiment (e.g. pages accessed and navigational sequence), as these would be explored in subsequent locally based experiments.

4) At the end of the 30-minute duration, users were asked to give an indication of their experience of distributed system performance by answering three simple questions, circulated via e-mail at the end of the experiment. Recorded relevant participant details, the questions used and the results obtained are illustrated in Figure 6.0.

Figure 6.0 – Distributed Performance Trial Participant Details, Evaluation Questions and Response Results

Post-Event Questionnaire

Please answer the following three questions, regarding your experience using the DUIST environment in the experimental trial period specified:

Q1: During normal operation of the DUIST environment, I experienced a noticeable degradation in system performance as exemplified by slow page rendering times and/or noticeable system hang-time.

Q#	Strongly Agree	Agree	Disagree	Strongly Disagree
Q1				

Q2: While using the DUIST environment, system response speeds caused me to experience negative emotions such as frustration, boredom or disinterest.

Q#	Strongly Agree	Agree	Disagree	Strongly Disagree
Q2				

Q3: My experiences using DUIST would likely put me off using the environment again in the future.

Q#	Strongly Agree	Agree	Disagree	Strongly Disagree
Q3				

Participant Details and Questionnaire Responses

		Question Response		
Participant	**ISP Connection Speed**	**Q1**	**Q2**	**Q3**
1	512 KB/s	Disagree	Strongly Disagree	Strongly Disagree
2	512 KB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree
3	1 MB/s	Disagree	Strongly Disagree	Strongly Disagree
4	1 MB/s	Disagree	Strongly Disagree	Strongly Disagree
5	1 MB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree
6	1 MB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree
7	1 MB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree
8	2 MB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree
9	2 MB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree
10	4 MB/s	Strongly Disagree	Strongly Disagree	Strongly Disagree

Analysis of the opinions expressed, although subjective, suggests that the distributed system performance is not adversely affected by up to ten simultaneous users, in compliance with system performance requirement P1 (see Table 4.2).

Of the responses elicited, all ten users failed to note any serious degradation in performance with most users expressing "strong disagreement" to all the post-event questions. Of the users who expressed "disagreement" only to question 1, it is worth noting that their ISP connection speeds were at the lower end of the evaluated range. This observation may justify subsequent distributed performance testing of the tool with users with very low connection speeds (e.g. 56 KB and 128 KB) where distributed performance could be potentially retarded by low user bandwidth.

6.1.3 System Throughput Speed

In a subsequent battery of evaluation tests, system throughput speed (e.g. "the time taken for a single user to utilise DUIST to generate a set of individually customised adaptation recommendations") was checked to ensure compliance with the project target of $\leq$ 10 minutes.

Using an initial sample of ten dyslexic users (5 recruited from a local dyslexia support group and 5 recruited from students studying at the University of Northampton) the duration of the elicitation selection process was measured. In an attempt to get a more representative indication of the range of potential throughput times, volunteers were selected with varying degrees of IT competency. Participants were asked to rate their computing experience based on the following scale:-

- **Advanced User** – "I regularly use a computer for a wide range of tasks and feel very confident using a computer".
- **Novice User** – "I regularly use a computer for basic tasks such as e-mail and browsing the Internet .I feel reasonably confident using a computer."
- **Beginner** – "I have previous computing experience, but I don't feel very confident when I use a computer."
- **No Experience** – "I have never used a computer before."

Before any testing commenced, volunteers who stated they had no previous computing experience were given elementary IT skills training with the primary system input device, the mouse. (This complied with the previously formulated ethics policy described in Section 5.7.) The results obtained from the tests are presented below in Table 6.1.

Table 6.1–Preliminary Elicitation Process Duration Test Results

Participant No	Self Assessed IT Competency	Elicitation Process Duration
1	Advanced User	6 minutes, 37 seconds
2	Novice User	8 minutes, 21 seconds
3	Novice User	6 minutes, 24 seconds
4	Beginner	7 minutes, 45 seconds
5	Advanced User	5 minutes, 05 seconds
6	Beginner	6 minutes, 59 seconds
7	Beginner	7 minutes, 15 seconds
8	No Experience	10 minutes, 59 seconds
9	Advanced User	5 minutes, 02 seconds
10	Advanced User	6 minutes, 13 seconds
	Mean	**7 minutes, 4 seconds**

With a calculated arithmetic mean of 7 minutes, 4 seconds, for the elicitation duration, the system acceptance criterion for throughput was achieved. Only one trial participant exceeded the 10-minute target duration and the user concerned had no previous computing experience. It is likely that this exception can be contributed more to a lack of basic IT skills, rather than to elicitation process inadequacies.

6.1.4 Input Response Time

Input Response Time, defined as the time taken for a single user input action to elicit the required system output response, was reviewed to assess compliance with the performance target of ≤ 1 second.

Prototype standalone performance was readily measurable and logged at significantly less than one second. (Mean input response time ≤ 0.2 seconds) Distributed input response times were considerably harder to assess, for the reasons outlined in Section 6.1.2. Somewhat artificial tests, with the client on the same local network as the server were used to provisionally assess input response time. Client and server time-stamped web-logs were used to calculate the mean input response time as ≤ 0.72 seconds.

Although subsequent timed trials were not conducted using remote clients, the questionnaire results extracted from the distributed performance study strongly suggest that distributed input response times are not overly excessive. (See Figure 6.0.) As disproportionably high input response times, could potentially affect system usability (an essential feature of the tool) the data available currently suggests that usability is not compromised by inappropriate input response times.

6.1.5 System Reliability

For a meaningful assessment of system reliability, (as characterised by observed error rate and system availability) system performance during the interface evaluation trials was recorded. With 100 individual subject trials, lasting approximately 45 minutes each, coupled with an additional 30 hours of system administration activities, the total active system operational time was estimated at 105 hours. Throughout this 105 hour period, no observed system errors were noted, with all aspects of system functionality behaving as anticipated. That said, no evidence was collected to suggest anything other than compliance with the performance acceptance criteria for reliability.

6.1.6 System Usability (Overall Framework)

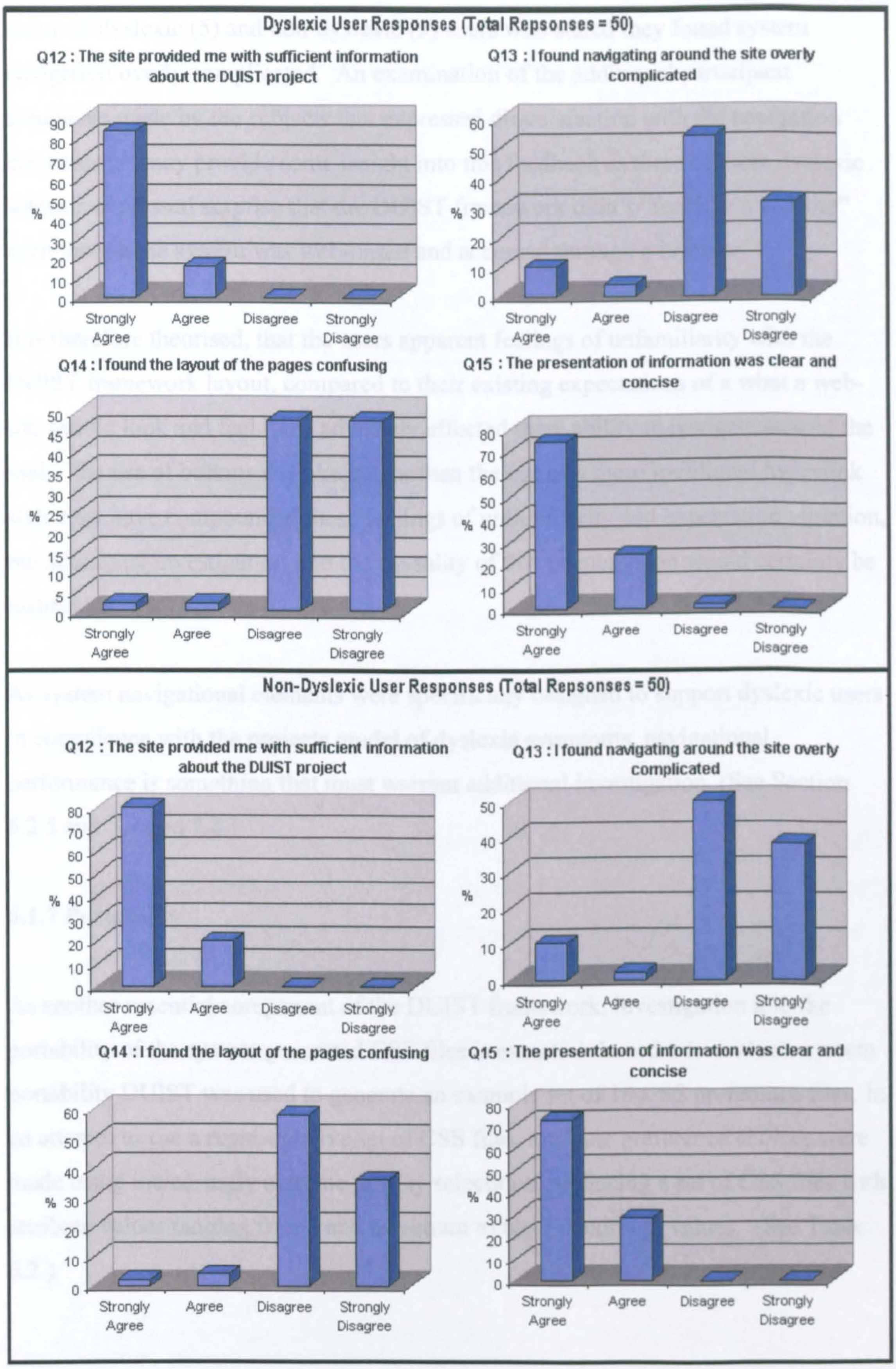
Usability is perhaps one of the most critical aspects of the DUIST system. Failure to ensure that the DUIST tool is anything other then simple, intuitive and quick to use will likely curtail its potential within the dyslexic community. Experimental evidence has consistently shown that dyslexic computer users can quickly become confused or disoriented if interface operation is anything but instinctive. (See Section 3.2.) With this in mind, every effort has been made to ensure framework usability for the dyslexic.

Initial attempts to ensure usability, included high user-group involvement during the initial JAD workshops, conducted during the production of the prototype system. Informal feedback collected throughout these workshops helped shape the development of the DUIST framework. Additionally, regular contact with dyslexic volunteers, throughout the interface developmental process, again provided a rich source of feedback regarding the level of user-support required, non-dynamic screen layouts and certain preferred navigational routes. Most importantly, all formulated dyslexic specific design principles were applied throughout the framework in an attempt to measure their overall impact. (See Section 3.3.3.)

With positive informal feedback extracted from the trials with the prototype system, four framework-specific questions were developed to evaluate final overall system usability. A summary of the relevant responses from the post-event questionnaire (questions 12-15) is presented in Figure 6.1.

An inspection of Figure 6.1 provides clear evidence that the majority of users (both dyslexic and non-dyslexic) found framework-usability, (as typified by navigation, page layout, content presentation and system information) to be at least adequate, if not good. These results may have implications on the potential validity of utilising the tool with non-dyslexic users; but this possibility will require additional investigation. (See Section 7.8.)

Figure 6.1 - A Summary of Responses from the Post-Event Questionnaire (Questions 12-15) - Framework Usability



A more detailed investigation of the results obtained, does however highlight a small group of dyslexic (5) and non-dyslexic (5) users who stated they found system navigation overly complicated. An examination of the additional participant comments made by the subjects that expressed dissatisfaction with the navigation mechanisms, may provide some insight into this feedback as three of these dyslexic subjects expressed surprise that the DUIST framework didn't "feel like a website" even though the system was web-based and accessed through a browser.

It is therefore theorised, that the users apparent feelings of unfamiliarity with the DUIST framework layout, compared to their existing expectations of a what a web-site should look and feel like, adversely effected there ability to navigate around the tool. The use of buttons as links, rather than the use of a more traditional hyperlink style may have compounded these feelings of unfamiliarity and expectation violation, but additional investigation into the causality of this phenomenon would certainly be justified.

As system navigational elements were specifically designed to support dyslexic users in compliance with the projects model of dyslexia symptoms, navigational performance is something that must warrant additional investigation. (See Section 6.2.5 and Section 7.8.)

6.1.7 Portability

As another essential component of the DUIST framework, investigation into the portability of the system generated CSS files is essential. In order to evaluate system portability DUIST was used to generate an example set of 10 CSS preference files. In an attempt to use a representative set of CSS files, attribute preference choices were made using increasingly extreme display selections, producing a set of CSS files with attribute values ranging from band minimum to band maximum values. (See Table 6.2.)

Table 6.2-Profile Attributes for Test Set of DUIST Generated CSS files

Id	Font Type	Font Size	Back Col	Fore Col	Margin	Lnk Style	H1	H2	Bor Style
1	Century - Sans-Serif	12	'000099'-	'CCFF99'	5%L -5%R	Bold	180%-Cent-B	120%-Cent-B	Outset
2	Arial	12	'000099'-	'CCFF99'	5%L -5%R	Bold	180%-Cent-B	120%-Cent-B	Outset
3	Comic Sans MS	12	'330066'-	'FFFF00'	5%L -5%R	Bold	180%-Left-BU	120%-Cent-BU	Ridge
4	Galant Normal	12	'339966'-	'330033'	10%L -10%R	Unerlined	180%-Left-BU	120%-Cent-BU	Ridge
5	Garamond	12	'990033'-	'FFFFFF'	10%L -10%R	Unerlined	180%-Cent-U	120%-Left-U	Groove
6	Trebuchet MS	14	'996666'-	'FFFF00'	10%L -10%R	Unerlined	180%-Cent-U	120%-Left-U	Groove
7	Verdana	14	'99CC00'-	'000000'	10%L -10%R	Bold/Underlined	180%-Left-U	120%-Left-U	Inset
8	Times New Roman	16	'9966FF'-	'FFCC66'	15%L -15%R	Bold/Underlined	180%-Left-U	120%-Left-U	Inset
9	Century - Sans-Serif	16	'99CC99'-	'333300'	15%L -15%R	Bold/Underlined	180%-Cent-B	120%-Left-U	Ridge
10	Trebuchet MS	10	'3300CC'-	'FFFFFF'	15%L -15%R	Bold/Underlined	180%-Cent-B	120%-Left-U	Groove

For each of the generated CSS files, preference settings were applied to a representative set of example web pages, with the reformatted presentation renderings examined for potential presentation errors or anomalies. Web page selection attempted to be representative in nature by selecting a series of URL's, each rich with at least one specific assessable component (e.g. frames, tables, images, low text density, high text density, lists, links, input forms, SSL secure features, JavaScript, and flash components). In practice most pages included multiple elements in a variety of presentation combinations.

All pages were initially examined using Internet Explorer 6.0 (IE6) (which included a CSS import feature) using a monitor with graphics display settings at high-colour with a 1024 x 768 pixel screen resolution. A summary of the overall findings from these tests is presented in Table 6.3.

Table 6.3 - CSS Performance by Example URL

URL	CSS ID 1	2	3	4	5	6	7	8	10
http://www.northampton.ac.uk/research/postgrad/graduateschool/	Green	Green	Green	Green	Green	Orange	Orange	Red	Green
http://www.foodstandards.gov.uk/	Green	Green	Green	Green	Green	Orange	Red	Red	Green
http://www.1911encyclopedia.org/Main_Page	Green	Green	Green	Green	Green	Orange	Orange	Red	Green
http://www.northampton.ac.uk/contact/	Green	Green	Green	Green	Green	Orange	Red	Red	Green
http://dictionary.reference.com/	Green	Green	Green	Green	Green	Orange	Orange	Red	Green
http://www.bbc.co.uk/weather/	Green	Green	Green	Green	Orange	Orange	Red	Red	Green
http://www.ebay.co.uk/	Green	Green	Orange	Orange	Orange	Orange	Red	Red	Green
http://www.nickjr.com/	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Green
https://ibank.barclays.co.uk/olb/x/LoginMember.do	Red	Red	Red	Red	Red	Red	Red	Red	Red
http://portal.acm.org/dl.cfm	Green	Green	Green	Green	Green	Orange	Orange	Red	Green

Key

Displays as expected	Green
Shows minor page abnormalities/and or inappropriate renderings	Orange
Shows major page abnormalities/and or inappropriate renderings	Red

Although many pages were displayed without formatting errors, several pages displayed significant distortions that reduced page readability and usability considerably. The most important distortions and unpredicted behaviour are highlighted below: -

(i) **Horizontal Scrolling**: Web page construction that forces a user to scroll horizontally to view screen elements is almost universally condemned as a bad design characteristic. It violates widely accepted design principles, such as What You See Is What You Get (WYSIWYG) and user-centred control, while inhibiting efficient navigation by increasing input device operating loads considerably. Unfortunately, horizontal scrolling was one of the most commonly observed page abnormalities evident when certain CSS preferences were applied. Almost all preference settings that used a large font size (14pt +) and/or wide page margins (to reduce line length) had pages rendered with horizontal scroll bars.

(ii) **Page Length**: Although certainly not as significant as horizontal scrolling, due to a decreased paragraph width and increased font size, many pages had extended page lengths. Consequently, to view all page contents, this resulted in more vertical scrolling and again increased navigational operating loads.

(iii) **Aesthetic Degradation**: Web-pages are often designed to convey an overall theme or mood to the user. Colours, font size, font type and images are often carefully selected to convey a desired aesthetic feel to the targeted user group. Although not essential to readability, for pages oriented towards entertainment and leisure, conveyed themes can enhance the overall viewing experience for the user. That said, one potential drawback of CSS implementation is the blanket removal of many themed characteristics. Logically, this enforced aesthetic degradation, (regardless of any potential benefits derived from the DUIST tool) may have significant implications on when CSS application should be employed.

(iv) **Construction Standards**: Although many organisations and individuals promote web-page construction standards, not all web-authors actively employ these recommended standards. As the correct rendition of web-pages with CSS deployed is often dependent on appropriate page construction; pages regularly demonstrate unexpected behaviour where construction is non-standard (e.g. an erratic page build can result in unpredicted formatting issues when CSS are applied). Significantly this has one major implication for the DUIST framework, namely: in the absence of standardised page development, any CSS generated by DUIST can not wholly guarantee expected page renditions (e.g. well designed DUIST CSS files, may still result in poor page appearance due to the unpredictable nature of current page development practice).

(v) **No Apparent Change**: One unpredicted result generated from the CSS trials was the apparent lack of CSS adaptation evident on certain pages. Examination of the source code in pages where adaptation was not evident explained this abnormality. Pages that employ images representing text are surprisingly common. Browsers enforcing CSS adaptations obviously cannot interpret and reformat text embedded within images. Consequently pages appear to be unchanged by CSS preference settings. Strategies that make use of image ALT tags may be considered, but these are still subject to the limitations of indifferent ALT tag usage.

Despite the highlighted deficiencies observed, in many cases the application of system generated CSS files resulted in many positive modifications. Particularly suited to CSS adaptation were sites that contained high volumes of text, such as online dictionaries, encyclopaedias and journals. Sites that contained embedded scripts (e.g. Java, JavaScript) were not adversely affected by CSS modifications. SSL functions were not inhibited by CSS adaptations. Conventional components such as tables, images, lists, link formats and link styles were all typically modified in accordance with system expectations. For comparative purposes, a complete set of applied and non-applied screen renditions, for CSS preference file 1, is presented in Appendix 13 - DUIST CSS Portability Example for CSS Preference file 1.

Once portability efficiency had been reviewed using the IE6 browser, CSS portability to other browsers and browser usage statistics were explored. (See Table 6.4.)

Table 6.4 – Direct CSS File to Browser Portability and Browser Usage Statistics

Direct CSS file to Browser Portability

Browser	Direct Portability of CSS
IE4, IE5, IE6.x	Yes
Mozilla	No
Firefox	No

Browser Usage Statistics Month by Month Jan 2007-July 2007

2007	IE7	IE6	IE5	Fx	Moz
July	20.1%	36.9%	1.5%	34.5%	1.4%
June	19.7%	37.3%	1.5%	34.0%	1.4%
May	19.2%	38.1%	1.6%	33.7%	1.3%
April	19.1%	38.4%	1.7%	32.9%	1.3%
March	18.0%	38.7%	2.0%	31.8%	1.3%
February	16.4%	39.8%	2.5%	31.2%	1.4%
January	13.3%	42.3%	3.0%	31.0%	1.5%

Key

IE	Internet Explorer
Fx	Firefox (identified as Mozilla before 2005)
Moz	The Mozilla Suite (Gecko, Netscape)

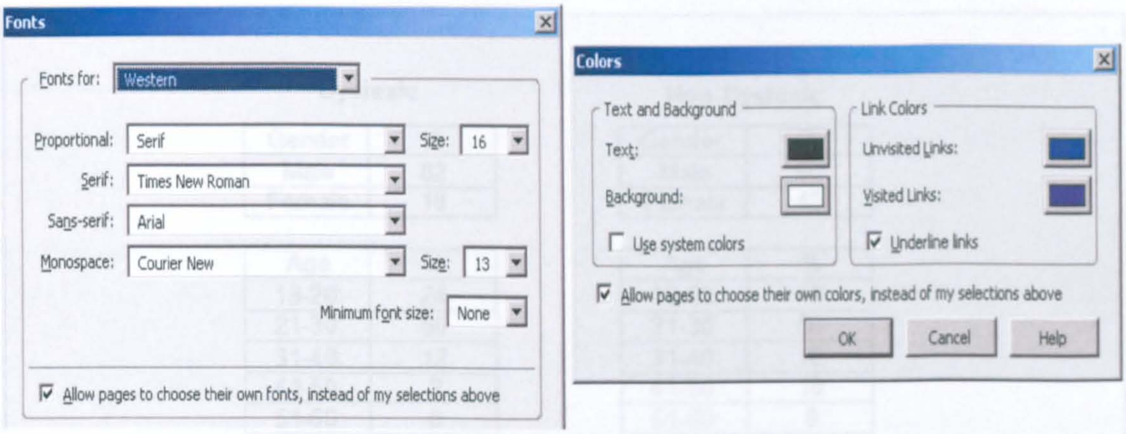
(W3Schools.com, 2007)

Again, the findings were significant to any final conclusions regarding overall system portability success. Most noticeably: -

(i) All current versions of Microsoft Internet Explorer (IE 4.x onwards) fully support direct CSS file imports (e.g. any CSS file generated by DUIST can be download by the user and set as a default standard for browser use). With 58.5% of all current (July 2007) Internet users utilise a version of IE this obviously supports DUIST portability claims (W3Schools.com 2007).

(ii) As the second and third most popular browsers, Firefox and Mozilla respectively, command a total of 35.9% of all browser usage. Adversely, for any DUIST portability conclusions, these two browsers do not allow the direct import of CSS files (i.e. a CSS file generated by DUIST could not be used directly by either Firefox or Mozilla). Instead of allowing direct CSS file import, both browser applications incorporate conventional user-invoked models for on-screen preference selection (e.g. menu toolbars and palettes). See Figure 6.2.

Figure 6.2–Example Mozilla Browser Display Setting Preference Selection



(iii) Although not considered ideal, an alternative strategy to direct CSS file import, for browser users who specifically want to use either Firefox or Mozilla, is as follows: -

(1) Use the supported elicitation preference feature of DUIST to derive the users preferred display settings.

(2) Manually apply the preference recommendations elicited by DUIST, using the manual toolbars and palettes provided within Firefox and Mozilla.

In this way, users can still benefit from the supported preference elicitation mechanism, provided by DUIST.

6.2 Experimental Evaluation of Interface Performance

The main DUIST interface performance trials were conducted during a 21-month period between June 2004 and February 2006. Table 6.5 provides an overview of the most fundamental characteristics of the 100 trial participants.

Table 6.5 – DUIST Trial Participant Demographic and Recruitment Source Data

Dyslexic

Gender	%
Male	82
Female	18

Age	%
18-20:	24
21-30:	60
31-40:	12
41-50:	2
51-60:	0
61-70:	2

Non-Dyslexic

Gender	%
Male	60
Female	40

Age	%
18-20:	18
21-30:	58
31-40:	12
41-50:	10
51-60:	0
61-70:	2

Participant Recruitment Sources	Dyslexic	Non-Dyslexic
Students studying at the University of Northampton	25	35
Recruited directly from local or national dyslexia support groups	14	0
Non-dyslexic partner of a dyslexic participant recruited through a support group	0	12
Other *	11	3

* (individuals who volunteered/requested to take part in the study after hearing about the research at a conference presentation or via some other medium)

In an attempt to avoid bias, whenever possible, subjects were selected who were previously unknown to the evaluator. Where subjects were already known to the evaluator (e.g. several of the students studying at the University of Northampton) results were critically reviewed to see if the participant had inadvertently provided more favourable post-event questionnaire feedback/comments in order to curry favour with the evaluator. An inspection of these cases provided no evidence of inflated feedback ratings, with typical comments and questionnaire responses being comparable with those elicited from participants unknown to the researcher.

6.2.1 Elicitation Mechanism Evaluation (Process Only)

As a central project objective, adaptive interface technology was to be used to facilitate the development of a simple, intuitive, linear, dynamically adaptable process, to support dyslexic users formulate display enhancing screen settings.
As such, it is essential that all aspects of the elicitation process be reviewed to allow meaningful conclusions to be derived. Initial system throughput testing suggests that the elicitation process is relatively short in duration, with an arithmetic mean of 7 minutes, 4 seconds, based on 10 provisional process trials. (See Section 6.1.3). This figure alone, fails to provide any indication of the user groups interaction experience. To provide insight into the user groups overall impression of the elicitation mechanism, post-event questions 4-7 were analysed. (See Figure 6.3.)

Inspection of this data gives strong indication that the majority of users found the elicitation process to be understandable, simple, intuitive and of a reasonable duration. Pertinent observations supporting this conclusion include: -

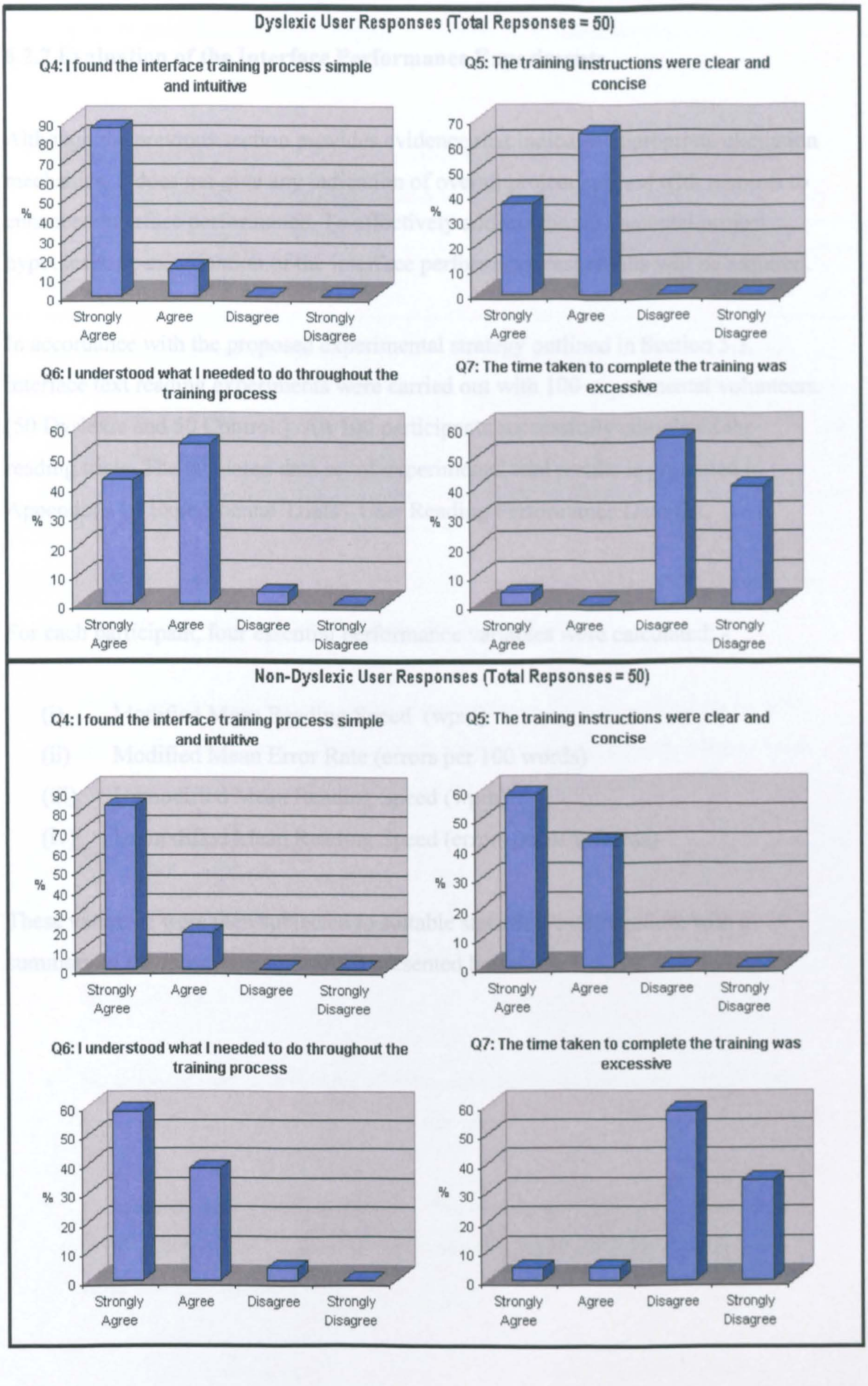
- All subjects agreed or strongly agreed with the statement "I found the interface training process simple and intuitive"

- All subjects agreed or strongly agreed with the statement "The training instructions were clear and concise"

- 96% of all subjects agreed or strongly agreed with the statement "I understood what I needed to do through out the training process". Only 4% of all participants (2 dyslexic and 2 non-dyslexic) expressed any uncertainty regarding required user activity, through the elicitation process.

- 94% of all subjects agreed or strongly agreed with the statement "The time taken to complete the training was excessive". Only 6% of all participants (2 dyslexic and 4 non-dyslexic) expressed concerns over an excessive elicitation process duration.

Figure 6.3 A Summary of Responses from the Post-Event Questionnaire (Questions 4-7)–Elicitation Process



6.2.2 Evaluation of the Interface Performance Experiments

Although the previous section provides evidence that indicates appropriate elicitation mechanics, it does not give any indication of overall project success with respects to enhanced interface performance. To effectively address the fundamental project hypothesis, an examination of the interface performance test results will be required.

In accordance with the proposed experimental strategy outlined in Section 5.3, interface text reading experiments were carried out with 100 experimental volunteers. (50 Dyslexic and 50 Control.) All 100 participants successfully completed the reading trials. The tabulated data set of experimental trial results is presented in Appendix 14 - Experimental Trials - User Reading Performance Data Set.

For each participant, four essential performance variables were calculated: -

(i) Modified Mean Reading Speed (wpm)
(ii) Modified Mean Error Rate (errors per 100 words)
(iii) Unmodified Mean Reading Speed (wpm)
(iv) Unmodified Mean Reading Speed (errors per 100 words)

These variables were then subjected to suitable statistical interrogation, with a summary of the most poignant results presented below:-

(i) Dyslexic users experienced consistently higher average performance gains, when adaptation modifications were deployed, compared to the control group. (See Table 6.6)

Table 6.6 Summary Data Illustrating the Mean/Median Effect of Adaptations Modifications for Dyslexic and Control Group Users

Effect on reading speed/error rate	Dyslexic	Control
Mean increase in reading speed:	3.66% (4.98 wpm)	0.14% (0.18 wpm)
Median increase in reading speed:	4.46 wpm	0.35 wpm
Mean decrease in reading error rate:	21.16% (0.64 fewer errors per 100 words)	0.07% (0.06 fewer errors per 100)
Median decrease in reading errors:	-0.495 errors per 100 words	-0.03 errors per 100 words

(ii) Significantly more dyslexic users experienced performance gains, when interface adaptations were utilised, compared to non-dyslexic users.

- Only 4 (8%) of all dyslexic users demonstrated a drop in reading speed while using adapted screens. All associated reading speed performance losses were relatively small (-0.03, -0.04, -0.33, -0.44 wpm respectively).

- Only 3 (6%) of all dyslexic subjects saw an increase in reading error rate. Those dyslexic users that experienced an increase in reading errors saw only minor increases (0.08, 0.12, 0.48 additional errors per 100 words, respectively).

- No dyslexic user experienced simultaneous performance reductions in both reading speed and error rate, while user modified screens were deployed.

- 21 members of the control group (42%), displayed minor drops in reading performance while screen modifications were enforced (ranging from –0.07 wpm to –8.96 wpm).

- 19 control subjects (38%) presented relatively small increases in error rate, while reading from modified screens. Performance losses ranged from 0.002 – 0.22 additional reading errors per 100 words

(iii) Significant differences in dispersion were evident between the two sets. Again suggesting notable differences between the two groups: -

- The range of the dyslexic reading speed set was calculated at 16.84 (max +16.4 wpm, min -0.440 wpm)
- The range of the control reading speed set was calculated at 20.46 (max +11.5 wpm, min –8.96 wpm)
- The range of the dyslexic reading error set was calculated at 3.55 (max +0.48 errors per 100 words, min –3.07 errors per 100 words)
- The range of the control reading error set was calculated at 1.06 (max +0.24 errors per 100 words, min -0.82 errors per 100 words)

(iv) An unpaired t-test was performed to establish the statistical significance between the two data sets (dyslexic and control) using the mean reading speed differential, in wpm, between modified and unmodified displays.

- The probability of null hypothesis was calculated at less than 0.001 (t= 6.57, Standard deviation = 3.65 and degrees of freedom = 98) signifying an extremely high probability of statistical significance between the dyslexic and control reading speed data sets.

An additional unpaired t-test was performed on the dyslexic and control data sets of reading error differential between modified and unmodified screens.

- The probability of statistical significance between the two sets was calculated to be greater than 0.999 (t= -5.89, Standard deviation = 0.492, degrees of freedom = 98) with the null hypothesis calculated at less than 0.001

Reflection on these project critical results highlight several key project findings: -

(1) Confirmation of predicted performance benefits: As expected dyslexic users demonstrated statistically significant overall reading performance gains compared to the non-dyslexic control group. With average reading performance benefits of 4.98 wpm for dyslexic, compared to 0.18 wpm for the control; and a mean decrease in dyslexic error rate of 0.64 errors per 100 words, compared to 0.06 less errors per 100 words for the control; the benefit deferential between groups is considerable.

Although exceptions to the norm can be found within the two data sets, typical performance patterns illustrate dyslexic users experience noticeable reading performance gains when modified screens are employed, while typical control group members exhibit relatively insignificant changes in reading performance while utilising adapted screens. Figure 6.4 and 6.5 help to illustrate this pattern graphically.

Fig 6.4 Graph Showing Reading Speed Performance Differences Between Dyslexic and Non-Dyslexic Subjects
(Measured as the mean difference between modified and non-modified interface reading speeds, with subject performance improvements sequenced in descending order)

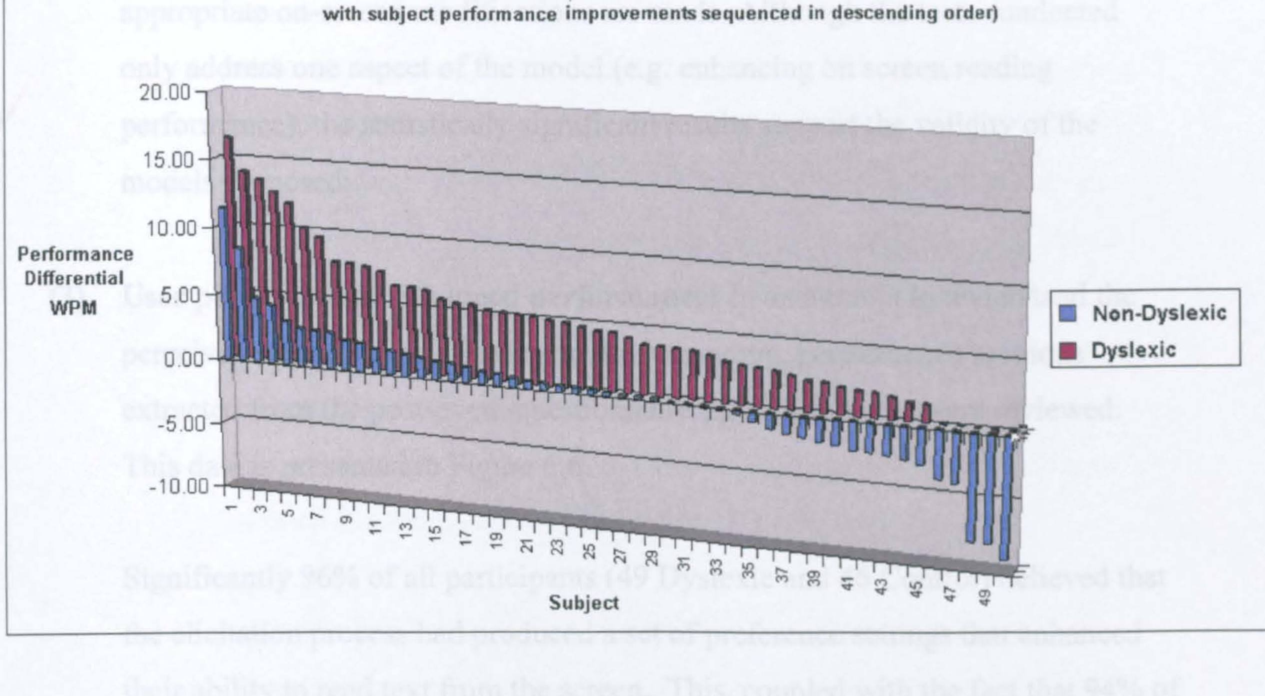
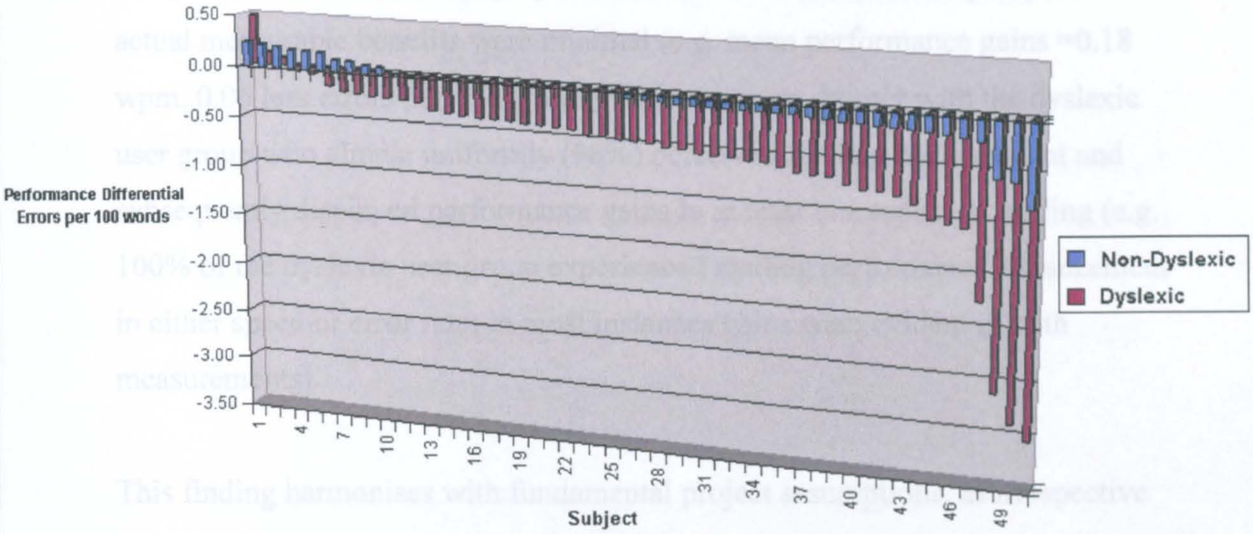


Fig 6.5 Graph Showing Reading Error Performance Differences Between Dyslexic and Non-Dyslexic Subjects
(Measured as the mean difference between modified and non-modified interface error rates, with subject performance improvements sequenced in ascending order)



(2) Implications to project models: The underlying models of dyslexia symptoms (DSM) and symptom alleviating adaptations (SAAM) developed for this project, predict that interface performance can be enhanced for dyslexic users if the appropriate on-screen modifications are made. Although the tests conducted only address one aspect of the model (e.g. enhancing on screen reading performance), the statistically significant results support the validity of the models proposed.

(3) User perception of enhanced performance: In an attempt to understand the perceived impact of the changes on the user group, performance opinions extracted from the post-event questionnaire (questions 8-11) were reviewed. This data is presented in Figure 6.6.

Significantly 96% of all participants (49 Dyslexic and 46 Control) believed that the elicitation process had produced a set of preference settings that enhanced their ability to read text from the screen. This, coupled with the fact that 94% of all dyslexic, and 84% of all non-dyslexic participants felt they would like to use their personalised settings with other web-sites; suggests that a significant majority of system users perceived potential benefits from the derived settings.

Although the majority of non-dyslexic users perceived reading benefits, and in many cases would like to employ the modified screens, in the majority of cases actual measurable benefits were minimal (e.g. mean performance gains =0.18 wpm, 0.06 less errors per 100 words). This contrasts sharply with the dyslexic user group who almost uniformly (98%) perceived reading enhancement and subsequently displayed performance gains in at least one aspect of reading (e.g. 100% of the dyslexic user group experienced reading performance enhancement in either speed or error rate; in most instances gains were evident in both measurements).

This finding harmonises with fundamental project assumptions, as irrespective of user perception, the dyslexic symptoms alleviating strategy only significantly enhanced dyslexic user performance.

Interestingly, the results obtained do present some unexpected responses to certain questions that are worth addressing at this point.

a) **User Aesthetical Considerations (Question 9):** The relationship between the users' perceived aesthetic view of the modified screens and their perception of enhanced reading performance differed. While 74% of the total user group (40 Dyslexic and 34 Control) felt the applied modifications improved the aesthetic feel of the interface, 96% of all participants (49 Dyslexic and 46 Control) believed that the modified screens were actually easier to read. This 22% differential, importantly suggests, that many users recognise that certain screen modifications, although potentially making the screen easier to read, do not always enhance the screen aesthetically. (See Section 6.1.7.)

b) **Navigational Impact (Question 10):** Although navigational enhancement was one of the main theorised objectives of the DUIST framework, a significant minority of users (45% dyslexic and 44% non-dyslexic) didn't feel they experienced noticeable gains in navigational performance while using the personalised settings. While examination of the questionnaire responses alone didn't provide a meaningful reason for this result, informal discussions with experimental participants (recorded on the trial environment forms) did give an indication as to the likely reason for the responses obtained.

This reason was eloquently summarised by one participant who stated: "As the main focus of the experiment revolved around reading, there was insufficient time during the trial to really judge if navigation had been enhanced". This view was expressed regularly by trial participants who were unable to agree with question 10.

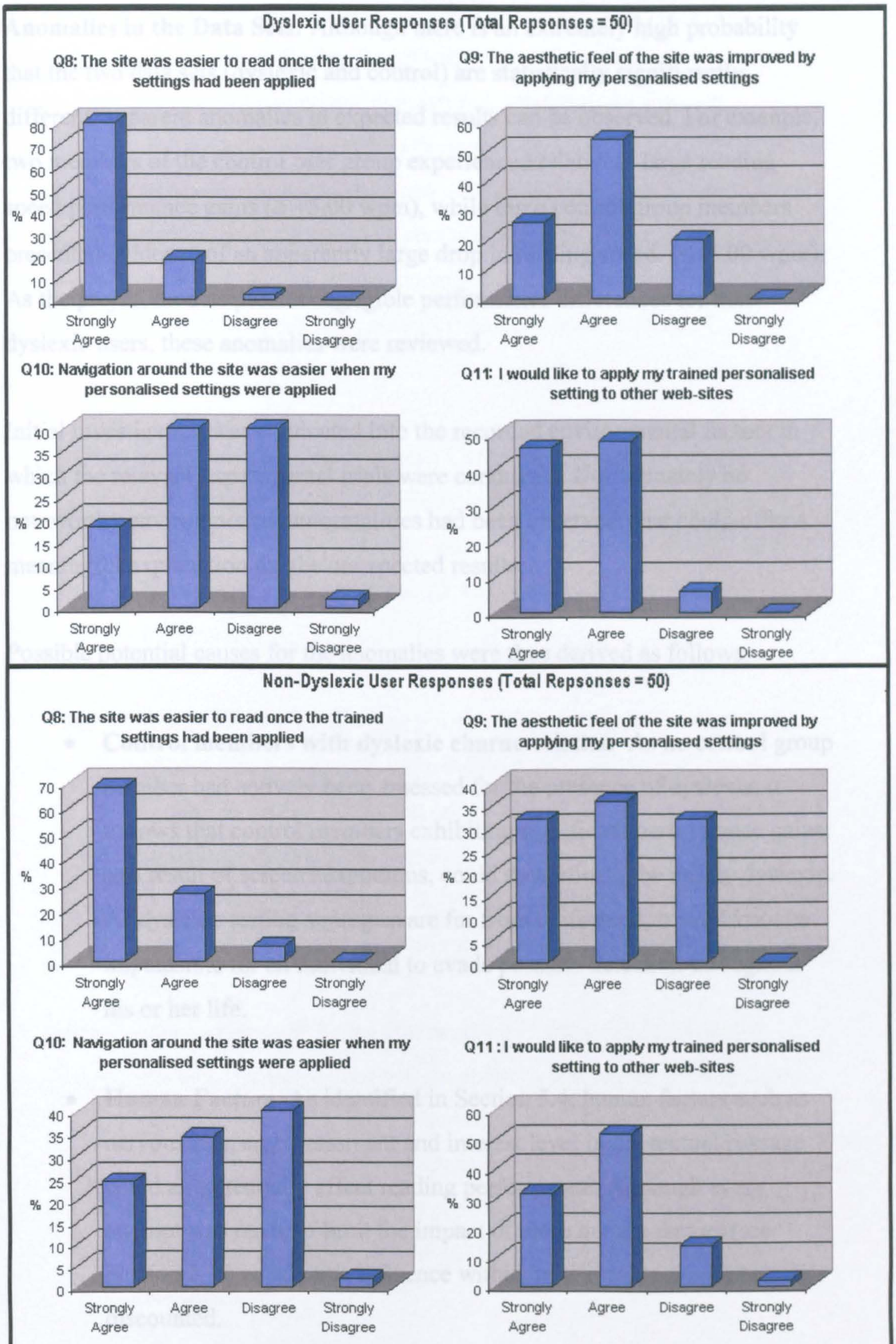
Logically this response necessitates the need for the development of additional experimental trial activities, specifically designed to assess navigational performance and should rightly be noted as one of the limitations of the existing DUIST trials. (See Section 6.2.5, Section 7.7 and Section 7.8.)

c) **Use of Personalised Settings (Question 11):** Although 96% of all users felt that the modified settings improved their ability to read text on screen, a small minority of dyslexic (3) and non-dyslexic (6) trial participants said that they wouldn't want to use the personalised settings generated by the DUIST framework. An examination of the questionnaire data and informal comments noted during the trials provided two explanations for these responses:-

i) Participants who felt their trained settings didn't improve their ability to read text on the screen logically didn't want to deploy the DUIST adaptations.

ii) Subjects who found certain sites adversely affected atheistically (see point b. above) may be unwilling to apply adaptations, even though the readability of text was improved. This point was succinctly expressed by one participant who stated, "I couldn't stand every page looking the same, even though it's actually easier to read".

Figure 6.6 - A Summary of Responses from the Post-Event Questionnaire (Questions 8-11) - Adaptation Impact



(4) **Anomalies in the Data Sets:** Although there is an extremely high probability that the two data sets (dyslexic and control) are statistically significantly different, apparent anomalies in expected results can be observed. For example, two members of the control user group experienced relatively large reading speed performance gains ($\geq +5.00$ wpm), while three control group members presented evidence of an apparently large drop in reading speed. (≤ -5.00 wpm). As the project models predict negligible performance differences for non-dyslexic users, these anomalies were reviewed.

Initial investigation was conducted into the recorded environmental factors in which the relevant experimental trials were conducted. Unfortunately no noteworthy environmental abnormalities had been observed, that could offer a meaningful explanation for the unexpected results.

Possible potential causes for the anomalies were thus derived as follows: -

- **Control members with dyslexic characteristics.** As no control group member had actively been assessed for the presence of dyslexia, it follows that control members exhibiting significant performance gains, as a result of screen adaptations, could theoretically be mildly dyslexic. As dyslexic testing strategies are far from uniformed, it would not be implausible for an individual to evade possible detection throughout his or her life.

- **Human Factors**. As identified in Section 5.4, human factors such as nervousness, embarrassment and interest level in the textual passage could all potentially affect reading performance. Although every attempt was made to limit the impact of these human factors (see Section 5.7.) an adverse influence within certain trials cannot be discounted.

(5) **Patterns in Error Correction:** Although the model of dyslexia proposed within the project specifically identify the types of reading errors observed in dyslexic patients (e.g. mispronunciations, substitutions, refusals, additions, omissions, and reversals), it does not give any indication as to the expected frequency of error observance. With this in mind, a review of all dyslexic error performance figures was conducted to explore the possibility of reading error patterns amongst dyslexic patients. Despite the fact that no statistically significant patterns could be isolated, some anecdotal observations were noted: -

(a) **Frequency of Error Types**: Certain errors occurred more frequently than others, with the total error observance distribution being: 7.48% mispronunciations; 23.0 % substitutions; 17.58% refusals; 21.48% additions; 21.45% omissions; and 9.02% reversals.

(b) **Unique Error Behaviour**: Although no statistically significant pattern could be isolated, the majority of dyslexic subjects did display evidence of making one or two types of error more frequently than others. Regularly error profiles demonstrated spikes in error frequency (e.g. 2, 2, 5, 2, 5, 2). The frequency and type of error spike(s) were apparently unique to the individual.

(c) **No Patterns of Error Correction:** Unfortunately, again, no statistically significant pattern could be derived at, with apparently all types of reading error potentially being alleviated when on-screen modifications were applied. That said, error correction rates typically reflected the users profile, with the most frequently appearing errors demonstrating the most significant error reductions.

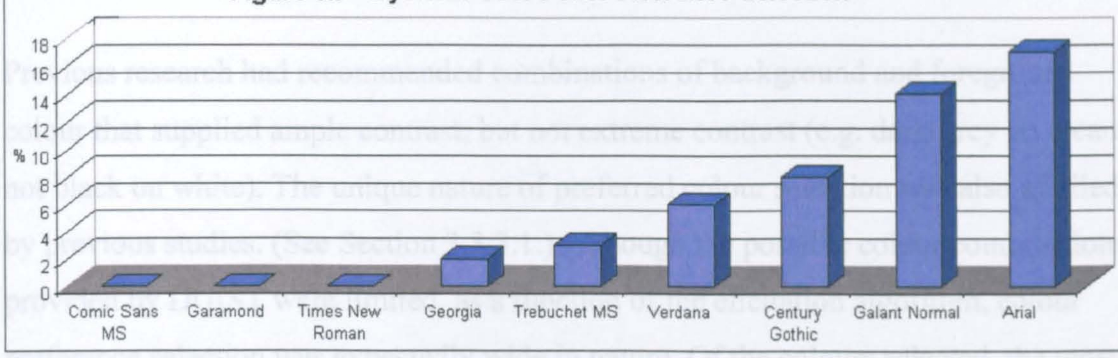
6.2.3 Patterns in Preference Selection

One of the most important research areas of the DUIST project was the compilation and subsequent experimental evaluation of a set of design principles (or characteristics) for use within interfaces specifically designed for dyslexic subjects. Although the previous section has provided statistically significant evidence to suggest that application of the aforementioned design principles can enhance interface performance (as exemplified by reading performance), a review of the overall attribute selection patterns of dyslexic users is considered advantageous

6.2.3.1 Font Type

The DUIST system provisionally provided nine possible font types for subject selection. Eight of the fonts were ones that had been previously recommended for use with dyslexic users and one, Times New Roman, was included as a control. (See Section 3.3.3.2 for details of desirable dyslexic font characteristics.) Inline with previous research, fonts that displayed a clear shape definition, clear spacing between letter combinations and avoided purely decorative features, were repeatedly selected by dyslexic subjects. (See Figure 6.7.)

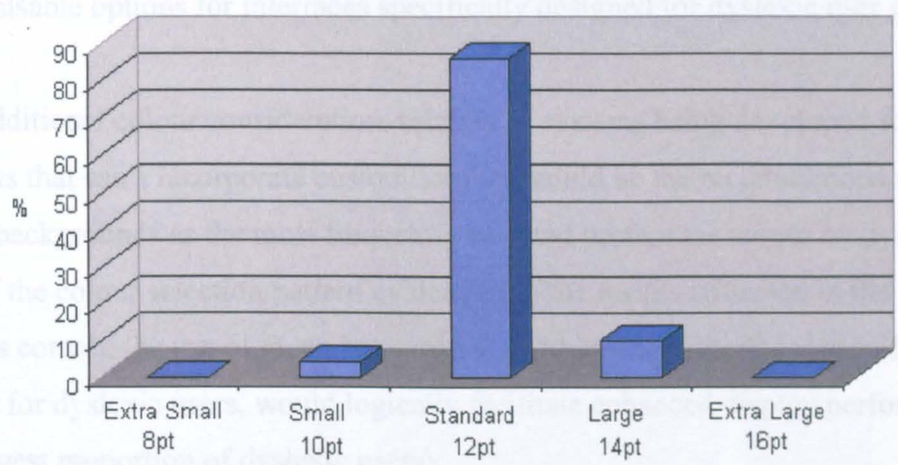
Figure 6.7 – Dyslexic User Font Preference Selection



6.2.3.2 Font Size

Optimal font size had previously been established at 12pt or 14pt (Bradford, 2002; Rainger, 2003) with font sizes below 10pts or above 16pts significantly detracting from page readability. (Tullis *et al.*, 1995; Kahn and Lenk, 1998) Experimental selection supported these findings, with all but 2 (4%) of the sample selecting 12pt or 14pt options. (See Figure 6.8.)

Figure 6.8 – Dyslexic User Font Size Preference Selection



6.2.3.3 Colour Selection

Previous research had recommended combinations of background and foreground colour that supplied ample contrast, but not extreme contrast (e.g. dark-grey on cream not black on white). The unique nature of preferred colour selection was also implied by previous studies. (See Section 3.3.3.1.) Although the possible colour combinations provided by DUIST were limited, as a function of the elicitation algorithm, colour preference selection was expectedly wide in nature. Of the colours selected, the most commonly selected colour grouping was that of a green background, with an appropriately contrasted foreground colour. (This is perhaps not too surprising as the normal human eye has its maximum sensitivity at around 555 nm, in the green region of the optical spectrum). To provide a graphical overview of dyslexic colour preference selection, colour combinations were arranged in roughly visible spectrum order. (Note: colours, such as brown, pink and magenta, not normally visible in the spectrum were included to give an indication of all Red-Green-Blue combinations selected by the user.) See Figure 6.9.

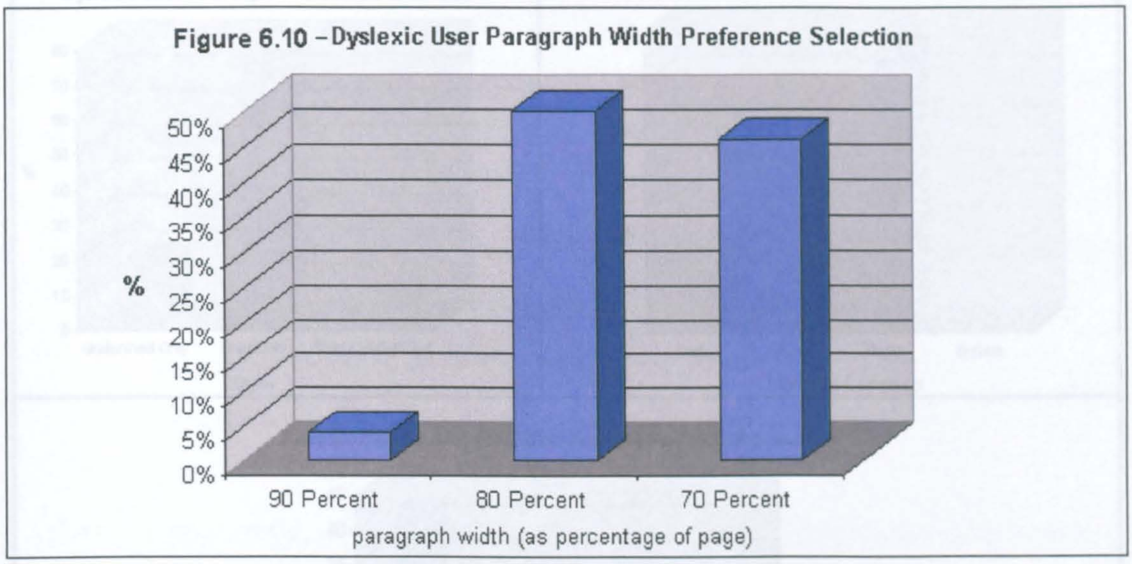
Investigation was conducted into the possibility of a correlation between colour combination selection and overall performance gains (e.g. did users selecting one particular colour block experience more significant reading performance gains than any other blocks?) Unfortunately no statistically significant patterns were detected. This does however harmonise with previous research findings that optimal colour display combinations are unique to the individual; strengthening the case for customisable options for interfaces specifically designed for dyslexic user groups.

One additional colour consideration, relating to systems being developed for dyslexic subjects that can't incorporate customisability, could be the recommended use of green backgrounds as the most frequently selected preference colour by dyslexic users (e.g. if the colour selection pattern evident from the results collected in the DUIST trials is correct, the use of green backgrounds within static interfaces specifically design for dyslexic users, would logically facilitate enhanced display performance for the largest proportion of dyslexic users).

Figure 6.9 – Dyslexic User Foreground and Background Preference Selection

6.2.3.4 Paragraph Width

The formulated design principles, relating to line length, for dyslexic users suggests that an excessively large paragraph width is detrimental to the dyslexic user. (See Section 3.3.3.4.1.) Experimental results support this conclusion as only 2 (4%) of the dyslexic user group found a longer paragraph width visually appealing during the preference elicitation process. (See Figure 6.10.)

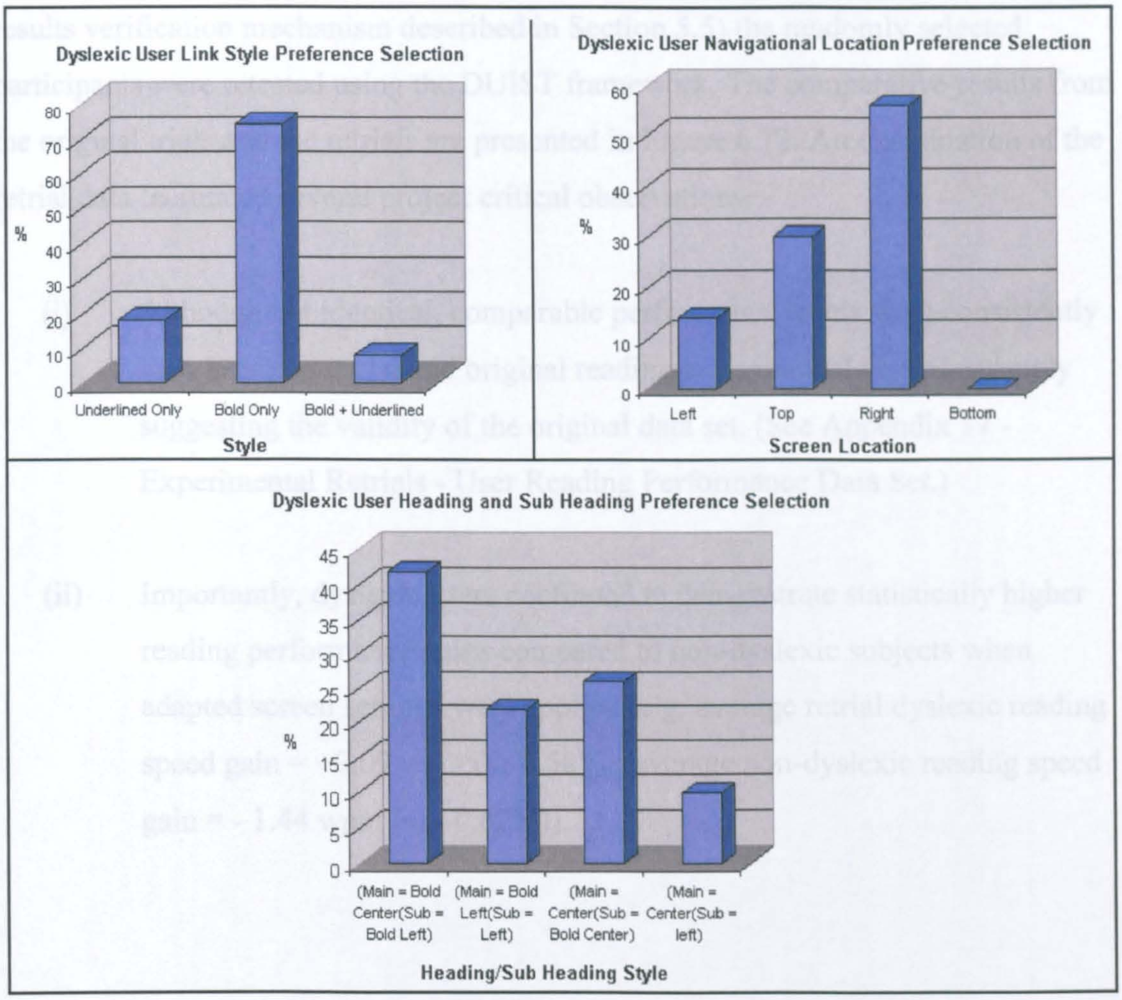


With 96% of all dyslexic users preferring a reduced line-length, existing paragraph recommendations would seem valid.

6.2.3.5 Navigational Element Selection

The appropriate deployment of certain on screen navigational components such as link style, used link colour and base link colour, should theoretically enhance the dyslexic users orientation through any collection of hypermedia pages. (See Section 3.3.3.5.) Although navigational enhancement is one of the key components of the models developed for DUIST (see Section 4.5.1.2), due to the selected focus of the experimental hypothesis and project time limitations, only limited performance data on the users navigational experience was collected. (See Section 6.2.5.) That said, subjective data, collected from the post-event questionnaire suggest that a significant proportion of dyslexic (58%) and non-dyslexic (58%) users did find their navigational experience enhanced by the navigationally specific system adaptations. (See Figure 6.6.) With additional experimentation required to ascertain the significance of the adaptations on user navigational performance, dyslexic user selection preferences were reviewed against the navigationally specific design recommendations. In all but one category, navigational element location, preference selection matched formulated recommendations. (See Figure 6.11.)

Figure 6.11 Dyslexic User Navigationally Specific Preference Selection



NB: Although not illustrated in the above diagram, link colour (base and used) preference section, complied with design recommendations for colours with significant contrast to the background colour. (See Appendix 15 - Experimental Trials - User Profile Attribute Selection Data Set" for a complete listing of all user profile attribute selections.)

Figure 6.11 illustrates that the majority of dyslexic users preferred navigational elements to be located on the right-hand side of the screen. This is contrary to expected recommended left-hand sided screen location, proposed by Bailey (Bailey *et al.*, 2000). Additional experimentation is considered essential in order to fully validate the impact of the user-groups' preferred right-hand selection.

6.2.4 Experimental Retrial Results

To ensure the validity of the results obtained from the reading performance trials, a 10% stratified, random sample, of dyslexic and non-dyslexic subjects (e.g. 5 dyslexic and 5 non-dyslexic) was selected for experimental retrial. Six months after the original trials had been conducted (in compliance with the formulated experimental results verification mechanism described in Section 5.5) the randomly selected participants were retested using the DUIST framework. The comparative results from the original trials and the retrials are presented in Figure 6.12. An examination of the retrial data facilitated several project critical observations: -

(i) Although not identical, comparable performance levels were consistently seen between retrial and original reading experimental results; strongly suggesting the validity of the original data set. (See Appendix 17 - Experimental Retrials - User Reading Performance Data Set.)

(ii) Importantly, dyslexic users continued to demonstrate statistically higher reading performance gains compared to non-dyslexic subjects when adapted screen settings were applied (e.g. average retrial dyslexic reading speed gain = +9.09 wpm (or 6.58%); average non-dyslexic reading speed gain = - 1.44 wpm (or –0.62%)).

Figure 6.12 - Experimental Retrial Results

Dyslexic Subjects Original Trials vs Retrial Results

id	Mod-Ave-WPM	NMod-Ave-WPM	% increase	Diff Ave WPM	Mod-Ave-ER	NMod-Ave-ER	% Decrease	Dif ER
3003	174.6	165.9	5.24	8.69	3.42	3.65	6.41	-0.23
1003	171.7	163.9	4.76	7.81	3.83	4.52	15.29	-0.69
30002	182.7	173.5	5.27	9.14	0.96	1.23	21.51	-0.26
10002	163.2	146.8	11.19	16.43	1.16	2.06	43.42	-0.89
30005	100.6	96.3	4.53	4.36	1.31	1.46	10.42	-0.15
10005	108.9	101.3	7.55	7.64	1.21	1.88	35.76	-0.67
30009	155.8	138.8	12.22	16.97	1.69	2.47	31.31	-0.77
10009	147.8	142.7	3.57	5.09	1.82	3.58	49.19	-1.76
30010	117.7	111.4	5.66	6.30	3.58	5.47	34.56	-1.89
10010	116.6	103.1	13.11	13.52	2.82	5.73	50.83	-2.91
		Ave Increase (Original + Retrials)	**7.31**	**9.59**		**Ave Increase (Original+Retrials)**	**29.87**	**-1.02**
		Ave Increase (Retrials)	**6.58**	**9.09**		**Ave Increase (Retrials)**	**20.84**	**-0.66**
		Ave Increase (Original)	**8.04**	**10.10**		**Ave Increase (Original)**	**38.90**	**-1.39**

Non-Dyslexic Subjects Original Trials vs Retrial Results

id	Mod-Ave-WPM	NMod-Ave-WPM	% increase	Diff Ave WPM	Mod-Ave-ER	NMod-Ave-ER	% Decrease	Dif ER
3004	186.05	185.37	0.37	0.68	0.33	0.32	-0.57	0.00
1004	186.19	184.88	0.71	1.31	0.41	0.48	15.69	-0.08
30004	136.04	132.05	3.02	3.99	0.97	1.22	20.20	-0.25
10004	145.10	136.58	6.24	8.52	0.65	1.23	47.08	-0.58
30003	201.30	202.09	-0.39	-0.79	0.65	0.72	10.00	-0.07
10003	176.42	177.86	-0.81	-1.44	0.73	0.80	9.72	-0.08
30011	118.63	120.38	-1.45	-1.75	0.98	1.05	6.01	-0.06
10011	123.01	125.14	-1.70	-2.13	1.21	1.14	-6.55	0.07
30012	190.48	199.80	-4.66	-9.32	0.16	0.24	31.64	-0.08
10012	189.64	198.61	-4.51	-8.96	0.24	0.25	2.17	-0.01
		Ave Increase (Original + Retrials)	**-0.32**	**-0.99**		**Ave Increase (Original+Retrials)**	**13.54**	**-0.11**
		Ave Increase (Retrials)	**-0.62**	**-1.44**		**Ave Increase (Retrials)**	**13.46**	**-0.09**
		Ave Increase (Original)	**-0.02**	**-0.54**		**Ave Increase (Original)**	**13.62**	**-0.13**

Key
3004 = retrial subject id.
1004 = original subject id.

(iii) Elicited screen preference selections were generally the same as those extracted during the original trials. Where differences in selected preferences were noted, attribute discrepancies were marginal. (See example Figure 6.13.)

Although every attempt was made to keep the retrial environmental conditions consistent with those observed during the original tests; small differences in preference selection could potentially be attributed to unavoidable changes in environment factors such as available light or monitor position relative to the subject. (See Appendix 18 - Experimental Retrials - User Reading Performance Data Set, for a comparative list of retrial and original test profile preference selections)

Figure 6.13 – Example Attribute Selection Differences Between Retrial and Original Preference Selections – Background/Foreground Colour Selection

Dyslexic	Non-Dyslexic
3003-'666666'-'FFFF00'	3004-'CCCCCC'-'330066'
1003-'666666'-'FFFF99'	1004-'666666'-'000000'
30002-'FFFF99'-'000000'	30003-'99CC99'-'003300'
10002-'FFFF00'-'003300'	10003-'99CC99'-'330066'
30005-'666633'-'000000'	30004-'330033'-'FFFF00'
10005-'999966'-'000000'	10004-'300000'-'FFFF00'
30009-'00FF00'-'3300CC'	30011-'99CC00'-'003300'
10009-'99CC00'-'333300'	10011-'99CC00'-'330066'
10010-'000099'-'CCFF99'	30012-'CC33FF'-'000000'
30010-'000000'-'CC99FF'	10012-'990099'-'330066'

Note: 3000X is the retrial of 1000X

6.2.5 Identified Experimental Limitations

During the course of the experimental evaluation of the DUIST framework, despite the generally positive results obtained, several significant project weaknesses were identified, that may justify subsequent experimentation.

(1) **No indication of the significance of individual screen attribute deployment**: Although project findings strongly suggest that interfaces for dyslexic users can be enhanced by applying suitably selected adaptations, extracted results do not give an indication as to the significance of individual modifications. (For example, if modified in isolation, would single attribute modification result in enhanced performance? If so, which attribute(s) would provide the users with the most significant performance gains?) Although it is theorised that a package of simultaneous preference adaptations will be the most beneficial approach to screen adaptation, some indication of the significance of individual preference modifications would be desirable.

(2) **Achievement of optimal visual preference settings**: With results suggesting that the elicitation mechanism proposed did indeed help dyslexic users to find improved visual settings, the achievement of optimal visual preference should be explored (e.g. were the preferences elicited using DUIST the optimal visual preferences, or could an alternative elicitation strategy have generated a more effective set of selections?) The formulation and subsequent comparison of alternative approaches of preference elicitation would thus seem justified. Proposed elicitation mechanisms, suitable for comparison with DUIST include:-

a. **Conventional** - manually adaptable, elicitation selection.
b. **Hybrid** - automatically adaptable elicitation (as seen in DUIST) followed by manual fine-tuning of extracted preference.

(3) **Navigational Enhancement**: Although the underlying models of DUIST incorporate features designed to enhance the navigational performance of the dyslexic user, relatively little data has been collected to assess the impact of these adaptations. Due to project time constraints, potential interface performance gains were initially explored in terms of reading enhancement (e.g. reading speed and reading error reduction) and as such, the validity of the navigation enhancing recommendations of the DUIST environment are still to be explored. The development of a subsequent series of experiments to explore the potential navigational benefits of suitably applied adaptations would thus seem justified and could be reviewed against the recently published findings from a comparable study of navigational support strategies for dyslexic subjects by Al-Wabil *et al* (Al-Wabil *et al.*, 2007).

Chapter 7: Reflection, Conclusion and Recommendation for the DUIST Framework

7. Project Conclusions

With all experimental results examined it now seems appropriate to review the original project aims and reflect on the implications of the research findings, as they relate to each specific objective. As such each of the fundamental research goals are addressed sequentially, with any relevant conclusion and recommendations presented.

7.1 Design Limitations of Conventional Interfaces for Dyslexic Users.

Although dyslexia causality is still the subject of much debate, consensus can be found on dyslexia symptoms. Characteristics such as poor reading performance, spelling difficulties, short term memory deficits, defective sequence recollection and motor control problems all implicitly mean that dyslexic patients using conventionally developed interfaces may experience negative emotional effects, as a direct result of inappropriately designed features. Research findings highlight an extensive list of commonly encountered screen characteristics that can significantly reduce dyslexic-computer interaction efficiency. Typical examples include: -

- Inappropriate use of colour and contrast;
- The use of fonts that incorporate purely decorative features;
- Inefficient prioritisation of interface functionality or information;
- Inconsistent screen layouts;
- Failure to deploy graphical navigational orientation aids such as breadcrumbs;
- Inappropriate levels of on-going user feedback;
- Inappropriately sized, positioned and structured titles and headings;
- Excessively long paragraph line-lengths;
- The use of underlined, moving or flashing text;
- Failure to create navigational routes that yield closure.

Although, many of these design limitations could be classified as "general" interface deficiencies (e.g. not exclusively disadvantageous to dyslexic interface users) the nature of dyslexia exacerbates the effects of the design flaws.

7.2 Formulation of Symptom Alleviated Interface Strategies.

Considerable research has been carried out into the investigation of design characteristics that can be incorporated into interfaces built for dyslexic users to help alleviate the design limitations identified previously. Based on an extensive examination of this work, (see Section 3.3.3) a comprehensive set of dyslexic specific interface design recommendations were compiled and subsequently formed the basis of the central symptom alleviation strategies utilised by the DUIST framework. Key design recommendations on the appropriate use of colour, interface typography, screen layout, content structure, content readability, and navigation were all explored and incorporated into the fundamental system models.

Unfortunately, project complexity was increased greatly by experimental evidence that suggested that a 'cookbook' approach to interface enhancing characteristics was not possible; as individual dyslexic users had unique display optimising preference needs (for example, a static implementation of a fixed set of display settings would not maximise interface performance gains for all dyslexic users uniformly, as individual dyslexic subjects display distinctive screen feature enhancement selection patterns.)

7.3 Intelligently Adaptive Interface Technology

An investigation into adaptive interface techniques presented a viable solution to the problem of differing user display preference requirements. Theoretically an interface that could be modified, using a user specific set of display preferences, extracted via a suitable elicitation strategy, could offer significant benefits to the dyslexic user, compared to static enforcement of 'general' recommendations.

Examination of existing user-invoked, manual approaches to screen adaptation for dyslexic interfaces were considered to be unsatisfactory. With significant operational limitations exposed including: -

1) An unavoidable increase in interface complexity, associated with the inclusion of embedded preference setting options and menus; coupled with a potential loss of system usability, especially for inexperienced dyslexic computer users.

2) A lengthy trial and error approach to preference selection, as users are required to select, apply and test each display setting attribute iteratively, until their final optimal settings were achieved.

3) The prevention of simultaneous visual comparison of applied visual settings, to aid effective selection.

4) Lack of expert knowledge, as to which display adjustments should be made. For example, novice dyslexic computer users wanting to tailor an interface to optimise their visual display settings could potentially find the process extremely daunting. Due to the non-linear nature of the activity and the infinite number of possible display selections, the complexity of the task could cause the user to avoid customisation entirely or prevent attainment of the individual's optimum settings.

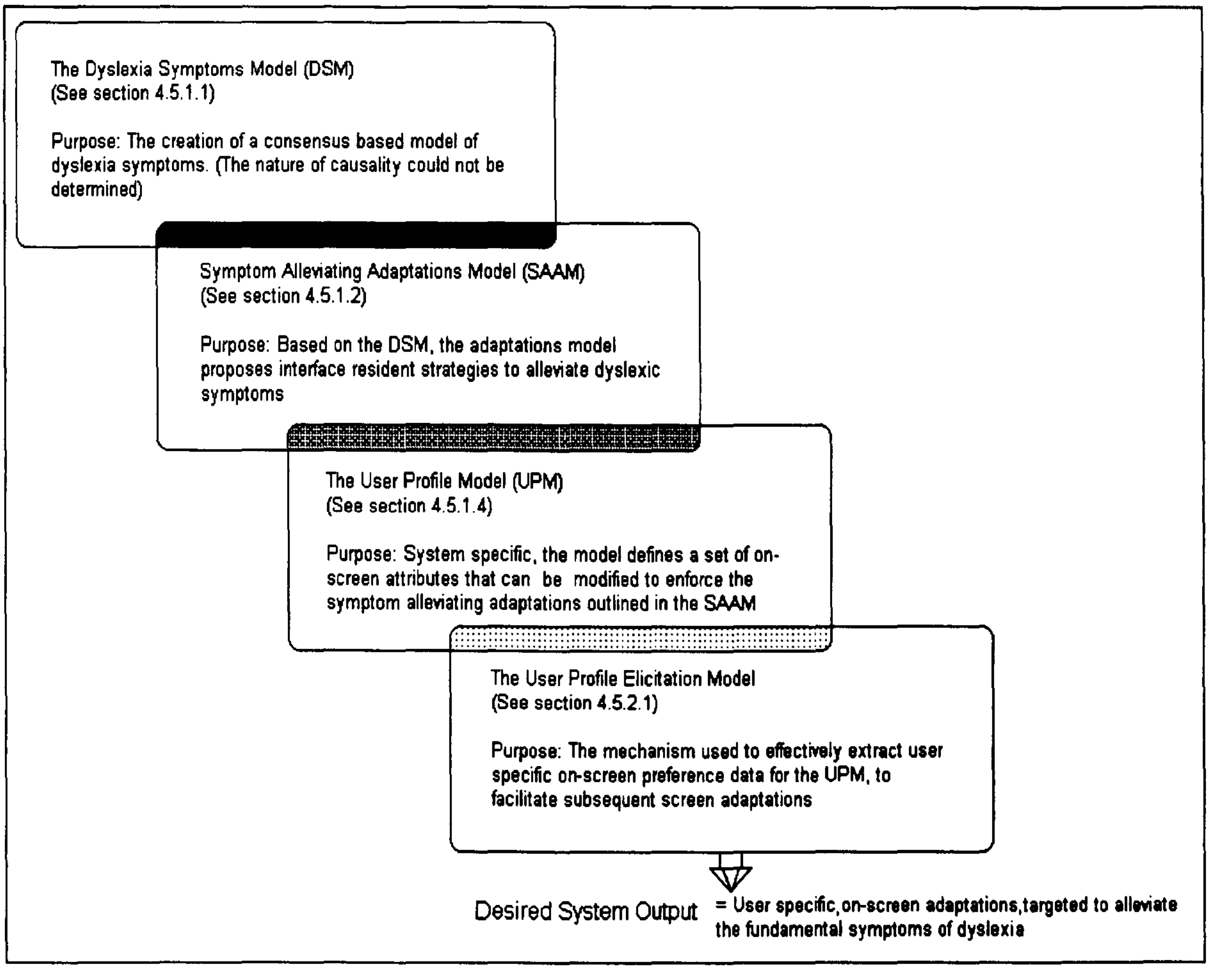
5) A fundamental lack of preference setting portability. For example, derived preference settings are typically not portable and thus can only be used within the application in which they were created. This means that a dyslexic user could spend considerable time finding their ideal preference settings only to realise their settings are not transferable to another application.

7.4 Problem Resolution Using the DUIST Framework

The DUIST framework was designed to directly address the limitations of existing manual strategies to customisation. Based around four successively integrated system models, the DUIST framework attempted to reconcile the existing research findings.

Figure 7.1 illustrates the relationship between the four proposed models and highlights the overlapping nature of each model.

Figure 7.1 – Fundamental Framework Models



As the external interface between the user and the other three system embedded models, the elicitation mechanism attempted to address the inadequacies of manual customisation, via the utilisation of adaptive technology, by: -

1) Providing a relatively short, linearly structured, intuitive process to aid display setting selection.

2) Referencing expert knowledge on the type and style of on-screen attributes (colour, font-type, font-size, navigation elements, etc.) that dyslexic users find useful to adjust and allow users to modify these in a supported environment.

3) Giving the user the ability to compare and contrast multiple display options simultaneously on the same screen. (Not possible with other available approaches).

4) Allowing the dynamic creation of a user specific set of interface display options, by incrementally updating all on-screen displays, based on previous display selections, when presenting the user with subsequent display selection options (e.g. every time a user makes a new preference selection, the new selection can be made on the basis of how screen elements look with all previous display selections already applied).

A successively developed system would also facilitate the evaluation of the potential performance benefits of the compiled list of interface design recommendations

7.5 DUIST Software Development

Considerable time was spent developing a software solution that was simple and intuitive to use, to ensure that subsequent interface performance tests would not be compromised by poor system usability (e.g. if the system usability was not good, potential performance benefits from adaptation application may not be observed).

Detailed software acceptance benchmarks were developed to ensure overall system performance and usability was of a high standard. With the appropriate acceptance tests being carried out for: -

- Software Correctness
- Software Completeness
- Distributed System Performance
- System Throughput Speed
- Input Response Time
- System Reliability
- System Portability
- Overall System Usability

Objective and subjective quantitative test data suggested that software acceptance criteria had been successfully met, implicitly supporting the validity of any subsequent experimental performance trials. For example, an inefficiently developed software solution would considerably degrade the validity of any experimental performance results as system environmental factors such as poor usability and inaccurately applied preference settings would compromise results.

7.6 Framework Performance Evaluation

The experimental evaluation of the performance results achieved by dyslexic subjects using the DUIST framework would lay the foundation for the majority of project conclusions, recommendations and subsequent future research avenues.

7.6.1 Performance Benefits for Dyslexic Users

With the central project hypothesis formulated to address the fundamental issue of theorised interface performance gains for dyslexic users utilising DUIST, an appropriate experimental evaluation strategy was needed. Employing the previously formulated interface reading performance test strategy, used in a comparable study by Dickinson (Dickinson *et al.*, 2000; Dickinson *et al.*, 2002), 50 dyslexic and 50 control subjects were subjected to a battery of reading trials and post-event questioning. (See Section 5.3.) Analysis of the results allowed the derivation of several project critical conclusions: -

1) Dyslexic users experienced statistically significant enhanced reading performance gains (reading speed and observed error rate) while DUIST facilitated on-screen adaptations were applied, compared to the control group.

   Logically, allowing the project hypothesis to be evaluated as true.

"The use of the DUIST framework, by a dyslexic computer user, will result in interface performance gains, as exemplified by statistically significant increases in reading accuracy and speed"

2) Dyslexic users typically displayed increased reading speeds (wpm) and reduced error rates (errors per 100 words), while non-dyslexic user performance typically remained unaffected by the applied modifications. For example, mean reading speed increase of 4.98 wpm for dyslexic users, compared to 0.18 wpm for the control; and a mean decrease in dyslexic reading error rate of 0.64 errors per 100 words, compared to 0.06 fewer errors per 100 words for the control.

3) Dyslexic and non-dyslexic users both perceived reading performance benefits resulting from the application of system adaptations, yet the majority of the control group experienced relatively small, if any, performance differentials.

4) The statistical analysis of the two data sets yields exceptionally strong evidence that suggests the two different user groups are distinct. For example, an unpaired t-test established the probability of statistical difference between the two reading speed data sets at 0.999, $t = 6.57$, Standard deviation = 3.65 and degrees of freedom = 98.

Although the statistical evidence supports the original project assumption that appropriate on-screen adaptations can enhance the dyslexic users interface experience, there are now a number of relevant research extensions that should be considered in light of these positive findings. (See Section 7.8)

7.6.2 Validity of the Proposed System Models

As application of the four system models (DSM, SAAM, UPM and Elicitation Model) has yielded performance gains in reading interface text, at least certain components of the proposed models would seem to be valid. Unfortunately, due to their potentially large scope, a claim of validity for all aspects of the models is inappropriate. That said, the promising results obtained from the parts of the models explored so far warrants additional experimentation.

7.6.3 Elicitation Process Mechanics

One of the major achievements of the research is the apparent success of the elicitation mechanism. As a credible alternative to manual customisation approaches, the elicitation process was apparently successful. Offering expert advice on what adaptations the user should make, it facilitated the relatively quick, simple and intuitive selection of user display preferences. Despite this apparent success, additional investigation may still be justified to ascertain if the approach succeeded in achieving the user's optimal preference settings. (See Section 7.8)

7.6.4 Assessment of Framework Portability

Project portability results were mixed. Although the utilisation of CSS files worked in the majority of cases, several performance limitations were noted: -

(i) Inappropriate Horizontal Scrolling: Horizontal scrolling was one of the most commonly observed page abnormalities evident when certain CSS preferences were applied. Almost all preference settings that used a large font size (14pt +) and/or wide page margins (to reduce line length) had pages rendered with horizontal scroll bars.

(ii) Extended Page Length: Although certainly not as significant as horizontal scrolling, due to a decreased paragraph width and increased font size, many pages had page length extended. Implicitly, to view all page contents, this resulted in more vertical scrolling and again increased navigational operating loads.

(iii) Aesthetic Degradation: Many web-pages (especially those employing aesthetical components) were adversely affected by the enforced CSS modifications. Although not essential to readability, for pages oriented towards entertainment and leisure, aesthetically conveyed themes can enhance the overall viewing experience for the user. A major drawback of CSS implementation is the blanket removal of many themed characteristics.

(iv) Construction Standards: Although widely promoted, web-page construction standards are not universally employed. As the correct rendition of web-pages with CSS deployed is often dependant on appropriate page construction; pages regularly demonstrate unexpected behaviour where construction is non-standard.

(v) No Apparent Change: One unpredicted result generated from the CSS trials was the apparent lack of CSS adaptation evident on certain pages. Pages that employ images representing text are surprisingly common. Browsers enforcing CSS adaptations cannot interpret and reformat text embedded within images and consequently pages appear to be unchanged.

Logically these CSS rendering limitations have considerable implications to the way the DUIST framework should be used.

Despite the observed reading performance gains, the blanket use of CSS adaptations is not recommended. Dyslexic Internet users should use discretion as to when accessibility options are deployed. For example, when using the world-wide-web for pleasure, when enhanced reading performance is not essential, users may wish to view sites as the developer originally intended with the adaptations turned off. Conversely, when a dyslexic user is required to read significant volumes of text (perhaps while reading an online newspaper or journal) the application of CSS modifications may be extremely beneficial.

Non-compliance with recommended page construction standards regrettably means that DUIST cannot guarantee wholly expected page renditions (e.g. well-designed DUIST CSS files may still result in poor page appearance due to the unpredictable nature of current page development practice). As the universal adoption of recommended page construction methods is extremely improbable, additional research into combatant strategies for the correct rendition of CSS modification, to non-standard pages, may be justified. That said, the page rendering abnormalities observed within some inappropriately designed pages, should strengthen the calls for CSS compliance throughout the page-authoring community.

Dyslexic users, with extreme preference setting selections (e.g. exceptionally large fonts, 16pt+) may have to consider the performance benefits gained from ideal adaptation deployment, compared to the potential performance losses incurred by horizontal scrolling, excessive page length and other associated page rendering anomalies. Where CSS files are to be utilised, some preference compromise may be required (e.g. consider dropping the font size to 14pt, to reduce other peripheral negative page rendering effects). This knowledge may also have implications to the preference selection options DUIST presents to the users, in subsequent revisions of the software.

A longitudinal study of dyslexic users and CSS deployment patterns may also be justified to establish framework efficiency over a prolonged period of use. (See Section 7.8)

7.6.5 Appropriate Use of the Compiled Design Principles

Preliminary evidence suggests that use of the design principles compiled for this project (see Section 3.3.3) may have significant benefits for interfaces developed specifically for dyslexic users. As such, the following utilisation recommendations seem appropriate:

(i) Consider applying the formulated principles when developing any interface specifically designed for dyslexic users.

(ii) Where adaptation can be facilitated, give users the opportunity to tailor key interface attributes (e.g. colour, font type, font size, line-length, etc.) to their specific needs, via a suitable preference selection vehicle. Evidence suggests preferred visual display preference varies considerably amongst dyslexic subjects.

(iii) When a static interface implementation is unavoidable, consider using the most frequently observed dyslexic preference selections (e.g. Arial or Galant fonts, 12pt font size, green backgrounds with a foreground colour of significant contrast, paragraph widths of 70-80% of the page, etc.)

7.6.6 Implications for Dyslexia Causality Theories

Considerable effort was expended at the start of this work reviewing the most prevalent dyslexia causality theories. With numerous theories reviewed (e.g. the Atypical Lateralisation, Interhemispheric Deficit, Phonemic Awareness, Eye Dominance and Temporal Rate Processing theories, etc.) the evidence presented for each theory was inconclusive. Although the debate, over causality continues, recent expert consensus has moved towards a phonological processing deficit as the most likely cause of dyslexia. (See Section 2.4.2.)

Significantly the findings from the work do not concur with the current move towards a phonological deficit as the sole cause of dyslexia. Logically, the adjustment of visual settings within an interface should have little or no impact on reading performance for dyslexic users, if a phonological deficit is entirely responsible for observed dyslexic symptoms. At the very least, any performance differentials observed should be comparable to those evident in the control. As performance tests indicate a very high probability of a statistically significant difference between the two user groups, it seems highly implausible to suggest that phonological processing abnormalities alone could explain the performance differences observed between dyslexic and non-dyslexic users. Although this does not discount the presence of phonological abnormalities within dyslexic subjects, it also suggests the presence of another defect, which is somehow alleviated by appropriate on-screen modifications.

The evidence presented is undoubtedly completely inadequate, when used in isolation to support any single causality model. That said, it is surely good enough to suggest that subsequent experimental evaluation of non-phonological causality theories is not suspended.

7.7 Research Limitations

Although the preliminary findings from the DUIST framework experiments are generally favourable, it should be noted that certain limitations within the work have been identified. These limitations included:-

(i) **Lack of post-event semi-structured follow up interviews:** Although the data extracted from the post-event questionnaire, informal interviews with participants after each trial and evaluator observations provided an adequate source of evaluation data; the inclusion of additional post-event semi-structured interviews with participants who expressed or displayed unexpected preferences or results would have enhanced the richness of the data considerably. As advocated by Preece *et al.* (Preece, *et al.*, 2004) semi-structured interviews would have help resolve any questions related to unexpected participant behaviour/ results and potentially could have influenced the implantation of subsequent experimental trials

(ii) **Loss of data richness from early user group workshops/software evaluation interviews:** Although every effort was made to record the critical information from all user group meetings, the use of notes as a medium for recording these events has proved unsatisfactory. With this in mind, the utilisation of audio or video, as a vehicle for recording these essential user group interactions is now seen as a more appropriate strategy.

(iii) **Open question deployment:** Although the post-event questionnaire concluded with the use of a single "catch all" open ended question (i.e. "Do you have any additional comments or thoughts about the DUIST framework?") this is now seen as inadequate as unexpected "negative" responses about the framework could not be explained without subsequent questioning of the participant. As a solution to this problem, future versions of the questionnaire will be developed to include additional open-ended questions, specifically designed to clarify unexpected answers. For example, if a participant stated that they would not use their personalised display settings, the system would prompt the user to explain why they wouldn't use the settings.

Additional project limitations such as a failure to evaluate all aspects of the frameworks underlying models (See Section 4.5.1); the works failure to differentiate between the significance of single attribute preference modifications (See Section 6.2.5); ineffective navigational performance benefit evaluation mechanisms; and the works need to contrast alternative approaches of elicitation mechanics as a means of verifying optimal visual preference attainment; are all highlighted in the subsequent section, along with strategies designed to rectify these notable limitations.

7.8 Proposed Future Direction of Research

Based on the favourable results obtained during the DUIST trials and despite the research limitations identified in the previous section, subsequent research into several project relevant areas would seem justified. Of the numerous project extensions possible, the following list provides details of those that the author considers to be the most appropriate:-

(i) **Subsequent Examination of Framework Models:** Preliminary statistical evidence from the DUIST project supports the original project assumption that appropriate on-screen adaptations can enhance the dyslexic users interface experience. That said, two additional underlying framework model research questions must now be addressed:

Firstly, experimental results obtained so far only measure performance gains in terms of reading speed and reading accuracy, other potential theorised benefits of the DUIST models have not currently been evaluated. As the Symptoms Alleviating Adaptations Model (SAAM) suggests strategies to lessen inherent symptoms such as poor short-term memory and defective sequence recollection, the design of suitable experiments to measure these theoretical benefits would thus seem justified.

Secondly, although project findings indicate that the collective application of user-elicited preference settings enhances interface performance, the data collected does not give an indication as to the significance of individual modifications. For example, if modified in isolation, would single attribute adaptations result in enhanced performance? If so, which attribute(s) would provide the user with the most significant performance gains? Although it is theorised that a package of simultaneous preference adaptations would provide the most benefit, some indication of the significance of individual preference modifications would be desirable; again justifying additional experimentation.

(ii) **Alternative Elicitation Process Mechanics**: Despite this apparent success of the elicitation mechanics utilised within the DUIST framework, additional investigation would now seem justified to ascertain if the approach succeeded in achieving the user's optimal preference settings. This research would involve developing additional strategies for preference elicitation, followed by the subsequent comparison of user generated settings selection and the performance impact produced by these alternative approaches, against those produced by the existing framework elicitation mechanics. In particular experimental performance comparisons with the following approaches would seem appropriate: -

a) User-invoked manual toolbar/palette preference selection.
b) Hybrid approaches to preference selection (e.g. automatically adaptable elicitation, as seen in DUIST, followed by manual fine-tuning of extracted preferences).

(iii) **The Impact of Long-Term Utilisation of the DUIST Framework**: After the successful completion of the relative short experimental user group trials (typically < 90 minutes) it would now seem appropriate to investigate the impact of long-term usage of system generated interface modifications. With this in mind, a suitable longitudinal study of adaptation deployment patterns of personalised settings, conducted with a dyslexic user group, could be justified as a means of providing insight into key questions, including:-

a) Would dyslexic users feel the need to apply adaptations permanently or on an intermittent basis?
b) If adaptations were to be applied intermittently, under what circumstances would the dyslexic user turn modifications on and off?
c) What, if any, psychological/emotional impact would prolonged usage of system adaptations have on the user?

(iv) **The Impact of DUIST Framework Adaptations upon Children**: Although children were initially excluded from the first series of DUIST trials, due to valid ethical considerations (see Section 5.7); as a direct result of the positive findings produced from the trials with adult dyslexic users, a small pilot study with a group of dyslexic children may now be justified. An exploration of the theoretical benefits of DUIST for children learning to reading could be especially valuable, as enhancing a child's ability to see text on a screen could support reading skills development.

(v) **An Exploration of Merits of Using Formulated Design Recommendations as Interface Design Heuristics**: Preliminary DUIST framework designs utilised researched dyslexic design principles as criteria for a simplified form of dyslexic-specific heuristic evaluation during system development. (See Section 4.5.3.1 and Appendix 20). While this technique apparently aided the successful development of the DUIST framework, subsequent evaluation of the worth of this approach seems justified. Research exploring the refinement and possible extension of the heuristic criteria originally used during the JAD workshop (See Appendix 20, Table A20.3) based on the findings from the DUIST performance trials would initially seem justified. This could be followed by an evaluation of the merits of the technique when applied to the development of subsequent interfaces developed for dyslexic users.

(vi) **An Investigation of Alternative Adaptation Preference Portability Strategies**: Even though DUIST successfully utilised CSS technology to implement the portability of system generated user display preferences, certain portability limitations were identified (See Section 6.1.7). As the application of CSS technology represents only one possible method of achieving preference portability, the continued evaluation of alternative technologies such as Gateway Web-Mediators (See Section 4.5.4.2.1) as a means of facilitating seamless portability should be ongoing.

(vii) **Navigational Impact of DUIST Framework Adaptations**: As the central research hypothesis of the DUIST project focused on the evaluation of reading speed and accuracy as the benchmark for interface performance enhancement, it was therefore essential to focus on developing experiments to initially measure these variables. (See Section 5.1) This required focus on reading performance, precluded a more detailed evaluation of the theorised benefits of DUIST with specific reference to enhanced navigation. (See Section 4.5.1.2) As a result, the preliminary evidence regarding the potential benefits of DUIST as a tool to aid navigation are limited and inconclusive. (See Sections 6.2.2 and 6.2.5) In response to this valid project limitation, the development of a battery of tests specifically designed to evaluate the navigational impact of framework modifications would seem an essential extension of this work. Techniques such as, user navigation sequence traces/timings, mouse-movement traces and mouse-click tracking; could all potentially be utilised to evaluate the navigational benefits of the framework.

(viii) **Potential Benefits of DUIST for Non-Dyslexic Users:** Although not part of the original project objectives, some of the feedback received by control group members (i.e. 70% of control group users said that the aesthetic feel of the site was enhanced when framework generated settings were applied; 88% of the control said they felt they could read text on the screen more effectively when settings were applied;) suggests that non-dyslexic user groups may in fact derive some benefits from tool utilisation. While predominantly speculative, some investigation into this area may be justified.

Concluding Summation

Although not devoid of errors, limitations and outstanding research questions; in the considered opinion of the author the DUIST project has been a success. Offering at least partial answers to all the original project aims and objectives, significant achievements of the work include:-

- Identification and corroboration of the design limitations of conventionally built interfaces for dyslexic users. (See Chapter 3)

- The formulation of a set of interface design recommendations for use within the development of systems specifically for dyslexic users. (See Chapter 3)

- The development of several models of dyslexia symptoms, symptom alleviating adaptations strategies and dyslexic user profile models; to support the subsequent development of systems for dyslexic computer users. (See Section 4.5.1)

- The design and subsequent implementation of an automated display preference elicitation mechanism as a viable alternative to manual customisation techniques. (See Section 4.5.2.1)

- An examination of several emergent technologies including adaptive interface techniques, culminating in the development of a successfully tested framework to enable seamless user display preference adaptation and portability. (See Sections 4.5.4.2 and 6.1.7)

- Framework facilitated statistically significant ($p = 0.999$) interface text readability enhancement figures for dyslexic subjects compared to the control group; with mean reading speed increases of 3.66% (or 4.98 words per minute) and mean reading error rate decreases of 21.16% (or 0.64 fewer reading errors per 100 words) for dyslexic users. (See Section 6.2)

- Experimental results that demonstrate the validity of customisation as an essential feature of interfaces designed for dyslexic users. (See Section 6.2.3)

- Corroborating evidence that suggests that the prevalent causality theory of a phonological processing impairment cannot entirely explain dyslexia symptoms due to the apparent benefits of adjusting visual display parameters. (See Section 2.4.2 and Section 6.2)

As a direct result of the positive framework evaluation results, the findings presented within this document warrants investigation by any reader actively interested in dyslexia; strategies for dyslexia symptom relief; support environments for dyslexic computer users; applications of adaptive interfaces; and all potential system designers who may be considering developing any type of graphical interface for a dyslexic user group.

Appendix 1 - Dichotic Listening

Dichotic listening is a procedure commonly used to investigate selective attention in the auditory system. In dichotic listening, two different auditory stimuli are presented to the participant simultaneously, one to each ear, normally using a set of headphones. Participants are asked to attend to one or (in a divided-attention experiment) both of the messages. They may later be asked about the content of either message.

Tim Rand [1] demonstrated dichotic perception in the late 1960s and early 1970s at Haskins Laboratories [2]. This demonstration was originally known as "the Rand effect" but was subsequently renamed as "dichotic release from masking" and then "dichotic perception" or "dichotic listening." Another example of a dichotic listening experiment is Jim Cutting's (1976) demonstration [3] at Haskins Laboratories that listeners could correctly identify syllables when different components of the syllable were presented to different ears. The formants of vowel sounds and their relation are crucial in differentiating vowel sounds. Yet even though listeners heard two separate signals (no ear received a 'complete' vowel sound), they could identify the syllable sounds.

Dichotic listening can also be used to test the hemispheric asymmetry of a cognitive function such as language processing. In the late 1960s and early 1970s Donald Shankweiler [2] and Michael Studdert-Kennedy [3] of Haskins Laboratories used a dichotic listening technique (presenting different nonsense syllables simultaneously to opposite ears) to demonstrate the dissociation of phonetic (speech) and auditory (non-speech) perception by finding that phonetic structure devoid of meaning is an integral part of language, typically processed in the left cerebral hemisphere[4][5][6]. A dichotic listening performance advantage for one ear is interpreted as indicating a processing advantage in the contralateral hemisphere. In another example, Sidtis (1981)[7] found that healthy adults have a left-ear advantage on a dichotic pitch recognition experiment. He interpreted this result as indicating right-hemisphere dominance for pitch discrimination.

Reference

[1] Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and two ears. Journal of the Acoustical Society of America 25, pp. 975–979.

[2] Rand, T. C. (1974). Dichotic release from masking for speech. Journal of the Acoustical Society of America, 55, 678-680.

[3] Cutting, J. E. (1976). Auditory and linguistic processes in speech perception: inferences from six fusions in dichotic listening. Psychological Review 83, pp. 114–140.

[4] Studdert-Kennedy, M., & Shankweiler, D. P. (1970). Hemispheric specialization for speech perception. Journal of the Acoustical Society of America, 48, 579-594.

[5] Studdert-Kennedy, M., Shankweiler, D., & Schulman, S. (1970). Opposed effects of a delayed channel on perception of dichotically and monotically presented CV syllables. Journal of the Acoustical Society of America, 48, 599-602.

[6] Studdert-Kennedy, M., Shankweiler, D., & Pisoni, D. (1972). Auditory and phonetic processes in speech perception: Evidence from a dichotic study. Journal of Cognitive Psychology, 2, 455-466.

[7] Sidtis, J. J. (1981). The complex tone test: Implications for the assessment of auditory laterality effects. Neuropsychologia 19, pp. 103–112.

Extract taken from http://en.wikipedia.org/wiki/Dichotic_listening
(Accessed September 2007)

Appendix 2 - Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is a non-invasive method used to render images of the inside of an object. It is primarily used in medical imaging to demonstrate pathological or other physiological alterations of living tissues.

Underlying Principle

Medical MRI most frequently relies on the relaxation properties of excited hydrogen nuclei in water and lipids. When the object to be imaged is placed in a powerful, uniform magnetic field, the spins of atomic nuclei with a resulting non-zero spin have to arrange in a particular manner with the applied magnetic field according to quantum mechanics. Nuclei of hydrogen atoms (protons) have a simple spin 1/2 and therefore align either parallel or antiparallel to the magnetic field.

The spin polarization determines the basic MRI signal strength. For protons, it refers to the population difference of the two energy states that are associated with the parallel and antiparallel alignment of the proton spins in the magnetic field and governed by Boltzmann statistics. In a 1.5 T magnetic field (at room temperature) this difference refers to only about one in a million nuclei since the thermal energy far exceeds the energy difference between the parallel and antiparallel states. Yet the vast quantity of nuclei in a small volume sum to produce a detectable change in field. Most basic explanations of MRI will say that the nuclei align parallel or anti-parallel with the static magnetic field; however, because of quantum mechanical reasons, the individual nuclei are actually set off at an angle from the direction of the static magnetic field. The bulk collection of nuclei can be partitioned into a set whose sum spin are aligned parallel and a set whose sum spin are anti-parallel.

The magnetic dipole moment of the nuclei then precesses around the axial field. While the proportion is nearly equal, slightly more are oriented at the low energy angle. The frequency with which the dipole moments precess is called the Larmor frequency. The tissue is then briefly exposed to pulses of electromagnetic energy (RF pulses) in a plane perpendicular to the magnetic field, causing some of the magnetically aligned hydrogen nuclei to assume a temporary non-aligned high-energy state. Or in other words, the steady-state equilibrium established in the static magnetic field becomes perturbed and the population difference of the two energy levels is altered. The frequency of the pulses is governed by the Larmor equation to match the required energy difference between the two spin states.

Image formation

In order to selectively image different voxels (volume picture elements) of the subject, orthogonal magnetic gradients are applied. Although it is relatively common to apply gradients in the principal axes of a patient (so that the patient is imaged in x, y, and z from head to toe), MRI allows completely flexible orientations for images. All spatial encoding is obtained by applying magnetic field gradients which encode position within the phase of the signal. In one dimension, a linear phase with respect to position can be obtained by collecting data in the presence of a magnetic field gradient. In three dimensions (3D), a plane can be defined by "slice selection", in which an RF pulse of defined bandwidth is applied in the presence of a magnetic field gradient in order to reduce spatial encoding to two dimensions (2D). Spatial encoding can then be applied in 2D after slice selection, or in 3D without slice selection. Spatially-encoded phases are recorded in a 2D or 3D matrix; this data represents the spatial frequencies of the image object. Images can be created from the matrix using the discrete Fourier transform (DFT). Typical medical resolution is about 1 mm^3, while research models can exceed 1 μm^3.

Functional MRI

A fMRI scan showing regions of activation in orange, including the primary visual cortex (V1, BA17).

Functional MRI (fMRI) measures signal changes in the brain that are due to changing neural activity. The brain is scanned at low resolution but at a rapid rate (typically once every 2-3 seconds). Increases in neural activity cause changes in the MR signal; this mechanism is referred to as the BOLD (blood-oxygen-level dependent) effect. Increased neural activity causes an increased demand for oxygen, and the vascular system actually overcompensates for this, increasing the amount of oxygenated haemoglobin relative to deoxygenated haemoglobin. Because deoxygenated haemoglobin attenuates the MR signal, the vascular response leads to a signal increase that is related to the neural activity. The precise nature of the relationship between neural activity and the BOLD signal is a subject of current research. The BOLD effect also allows for the generation of high resolution 3D maps of the venous vasculature within neural tissue.

While BOLD signal is the most common method employed for neuroscience studies in human subjects, the flexible nature of MR imaging provides means to sensitize the signal to other aspects of the blood supply. Alternative techniques employ arterial spin labelling (ASL) or weight the MRI signal by cerebral blood flow (CBF) and cerebral blood volume (CBV). The CBV method requires injection of a class of MRI contrast agents that are now in human clinical trials. Because this method has been shown to be far more sensitive than the BOLD technique in pre-clinical studies, it may potentially expand the role of fMRI in clinical applications. The CBF method provides more quantitative information than the BOLD signal, albeit at a significant loss of detection sensitivity.

Extract taken from http://en.wikipedia.org/wiki/Magnetic_resonance_imaging (Accessed September 2007)

Appendix 3 - The 216 Browser-Safe Colour Palette

The 216 Browser-Safe colour palette is specifically designed to ensure correct colour rendering, irrespective of the platform, (e.g. PC, Mac, Lynx, etc.) requiring only a minimum specification colour graphics card. It offers significant operational benefits for DUIST including: -

- Maximising portability efficiency for all common browsers (Microsoft Internet Explorer 4.x+, Mozilla, Firefox, etc.)
- When used correctly, it reduces the possibility of dithering.
- It ensures that pages rendered using the palette will look the same on PC and Mac platforms.
- It maximises correct colour rendition by specifically servicing the lowest possible colour graphics cards (e.g. 256 Colour).

The colours of the 216 Browser-Safe Palette are illustrated below: -

Figure A3.1 - The 216 Browser-Safe Palette

000000	003300	006600	009900	00CC00	00FF00	990000	993300	996600	999900	99CC00	99FF00
000033	003333	006633	009933	00CC33	00FF33	990033	993333	996633	999933	99CC33	99FF33
000066	003366	006666	009966	00CC66	00FF66	990066	993366	996666	999966	99CC66	99FF66
000099	003399	006699	009999	00CC99	00FF99	990099	993399	996699	999999	99CC99	99FF99
0000CC	0033CC	0066CC	0099CC	00CCCC	00FFCC	9900CC	9933CC	9966CC	9999CC	99CCCC	99FFCC
0000FF	0033FF	0066FF	0099FF	00CCFF	00FFFF	9900FF	9933FF	9966FF	9999FF	99CCFF	99FFFF
330000	333300	336600	339900	33CC00	33FF00	CC0000	CC3300	CC6600	CC9900	CCCC00	CCFF00
330033	333333	336633	339933	33CC33	33FF33	CC0033	CC3333	CC6633	CC9933	CCCC33	CCFF33
330066	333366	336666	339966	33CC66	33FF66	CC0066	CC3366	CC6666	CC9966	CCCC66	CCFF66
330099	333399	336699	339999	33CC99	33FF99	CC0099	CC3399	CC6699	CC9999	CCCC99	CCFF99
3300CC	3333CC	3366CC	3399CC	33CCCC	33FFCC	CC00CC	CC33CC	CC66CC	CC99CC	CCCCCC	CCFFCC
3300FF	3333FF	3366FF	3399FF	33CCFF	33FFFF	CC00FF	CC33FF	CC66FF	CC99FF	CCCCFF	CCFFFF
660000	663300	666600	669900	66CC00	66FF00	FF0000	FF3300	FF6600	FF9900	FFCC00	FFFF00
660033	663333	666633	669933	66CC33	66FF33	FF0033	FF3333	FF6633	FF9933	FFCC33	FFFF33
660066	663366	666666	669966	66CC66	66FF66	FF0066	FF3366	FF6666	FF9966	FFCC66	FFFF66
660099	663399	666699	669999	66CC99	66FF99	FF0099	FF3399	FF6699	FF9999	FFCC99	FFFF99
6600CC	6633CC	6666CC	6699CC	66CCCC	66FFCC	FF00CC	FF33CC	FF66CC	FF99CC	FFCCCC	FFFFCC
6600FF	6633FF	6666FF	6699FF	66CCFF	66FFFF	FF00FF	FF33FF	FF66FF	FF99FF	FFCCFF	FFFFFF

Appendix 4 - Colour Blocks Structure

Figure A4.1 - Colour Blocks Structure

Appendix 5 - Prototype System Design Documentation

Figure A5.1 - BON System Diagram -Fundamental System Classes/Relationships (Excluding Adaptive Interface Components)

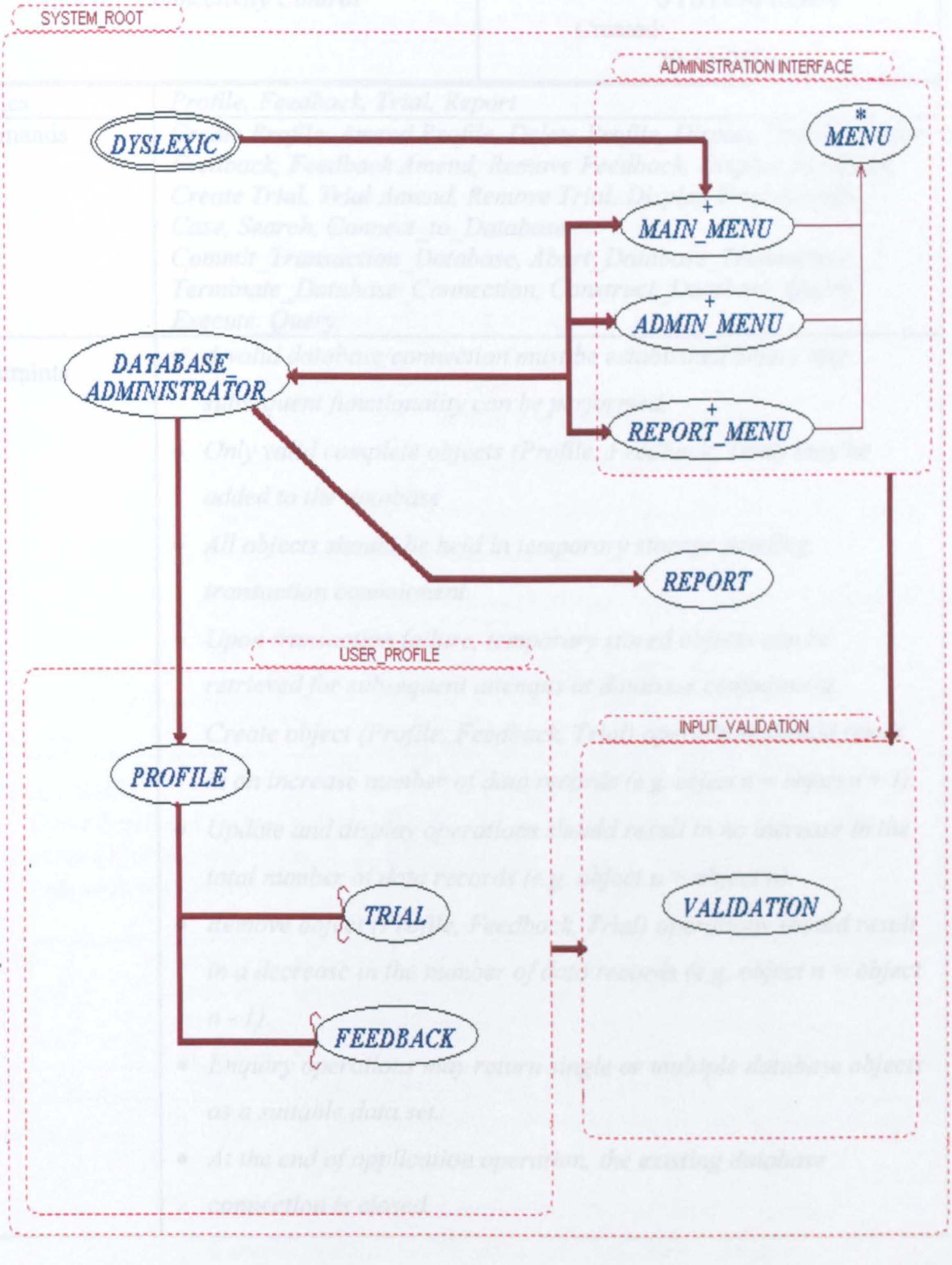


Figure A5.2 - BON Class Charts - Fundamental System Classes Only

CLASS	*DATABASE_ADMINISTRATOR*	Part: 1/1
TYPE OF OBJECT *Fundamental Object Management and Database Connectivity Control*	INDEXING Cluster: SYSTEM ROOT Created: 20-11-2001	
Queries	*Profile, Feedback, Trial, Report*	
Commands	*Create Profile, Amend Profile, Delete Profile, Display Profile, Create Feedback, Feedback Amend, Remove Feedback, Display Feedback, Create Trial, Trial Amend, Remove Trial, Display Trial Identify_ Case, Search, Connect_to_Database, Commit_Transaction_Database, Abort_Database_Transaction, Terminate_Database_Connection, Construct_Database_Query, Execute_Query.*	
Constraints	• *A valid database connection must be established before any subsequent functionality can be performed.* • *Only valid complete objects (Profile, Feedback, Trial) may be added to the database* • *All objects should be held in temporary storage pending transaction commitment.* • *Upon transaction failure, temporary stored objects can be retrieved for subsequent attempts at database commitment.* • *Create object (Profile, Feedback, Trial) operations should result in an increase number of data records (e.g. object n = object n + 1).* • *Update and display operations should result in no increase in the total number of data records (e.g. object n = object n).* • *Remove object (Profile, Feedback, Trial) operations should result in a decrease in the number of data records (e.g. object n = object n - 1).* • *Enquiry operations may return single or multiple database objects as a suitable data set.* • *At the end of application operation, the existing database connection is closed.*	

<table>
<tr><td>CLASS</td><td colspan="2">REPORT</td><td>Part: 1/1</td></tr>
<tr><td colspan="2">TYPE OF OBJECT
Report object, allowing essential system reports to be constructed and formatted as required</td><td colspan="2">INDEXING
Cluster:
SYSTEM ROOT
Created:
20-11-2001</td></tr>
<tr><td>Queries</td><td colspan="3">Header, Body, Footer, Output Format</td></tr>
<tr><td>Commands</td><td colspan="3">Create Header, Create Body, Create Footer, Set Format, feedback_output_header, feedback_output_age, feedback_output_status, feedback_output_gender, feedback_output_footer, feedback_spreadsheet, full_feedback_summary, full_report_hard_copy, full_trial_summary, output_comparison_table, output_spreadsheet_profile, output_spreadsheet_trial, output_trial_table_performance, output_spreadsheet_feedback_output, output_spreadsheet_profile_output, output_spreadsheet_trial_output.</td></tr>
<tr><td>Constraints</td><td colspan="3">• All reports consist of a header, body, footer and a format
• Report format types are on-screen, xls, txt and html.
• Report contents should allow generation of data for all essential system types (e.g. profile, feedback and trial).
• Nil return reports should generate the appropriate error message for the user.</td></tr>
</table>

<table>
<tr><td>CLASS</td><td colspan="2">FEEDBACK</td><td>Part: 1/1</td></tr>
<tr><td colspan="2">TYPE OF OBJECT
Basic Feedback Object. (Holds all essential user specific feedback data unique to user profile)</td><td colspan="2">INDEXING
Cluster:
USER_PROFILE
Created:
20-11-2001</td></tr>
<tr><td>Queries</td><td colspan="3">answer_1, answer_2, answer_3, answer_4, answer_5, answer_6, answer_7, answer_8, answer_9, answer_10, answer_11, answer_12, answer_13, answer_14, answer_15, answer_16, complete_flag.</td></tr>
<tr><td>Commands</td><td colspan="3">Create, update, remove, display, check_complete</td></tr>
<tr><td>Constraints</td><td colspan="3">• All feedback questions must be answered in order for the questionnaire to be classified as complete.
• Only predetermined answer formats are acceptable for question answers. (Enforce by embedded GUI radio-button selection)
• Feedback cannot be submitted until a valid profile object exists.</td></tr>
</table>

<table>
<tr><td>CLASS</td><td colspan="2">PROFILE</td><td>Part: 1/1</td></tr>
<tr><td colspan="2">TYPE OF OBJECT
Basic User Profile Object. (Holds all essential profile attribute data)</td><td colspan="2">INDEXING
Cluster:
USER_PROFILE
Created:
20-11-2001</td></tr>
<tr><td>Queries</td><td colspan="3">profile_id, back_colour, body_link_colour, border_style, email, font_size, font_type, fore_colour, heading_style, line_length, link_style, list_style, navigation_style, password, username, training_complete_flag.</td></tr>
<tr><td>Commands</td><td colspan="3">Create, display, update</td></tr>
<tr><td>Constraints</td><td colspan="3">
All users must supply a valid e-mail, username and password in order to create a new profile.
Preference elicitation can only be considered to be complete, once all attribute values have been extracted from the user. (Set 'training_complete_flag' to 1)
Only complete ('training_complete_flag' = 1) profile objects can be included in any system reports
The 'training_complete_flag' by default should be set to zero for not complete.
The user may retrain their profile (e.g. amendments to existing profile attributes are possible if the user goes through the elicitation process again).
There should be no limit on the number of times a user may go through the preference elicitation process
Any elicitation process attempts that do not extract all the essential attribute data (e.g. the user exits from the process before the process is complete) should be disregarded.
All profile_id's should be unique.
The user should be sent confirmation of their account details, via e-mail, once their profile is created.
</td></tr>
</table>

CLASS	*TRIAL*	Part: 1/1

TYPE OF OBJECT	INDEXING
Basic Trial Object. (Holds all essential user specific trial data unique to user profile and experimental reading trials)	Cluster: USER_PROFILE Created: 20-11-2001

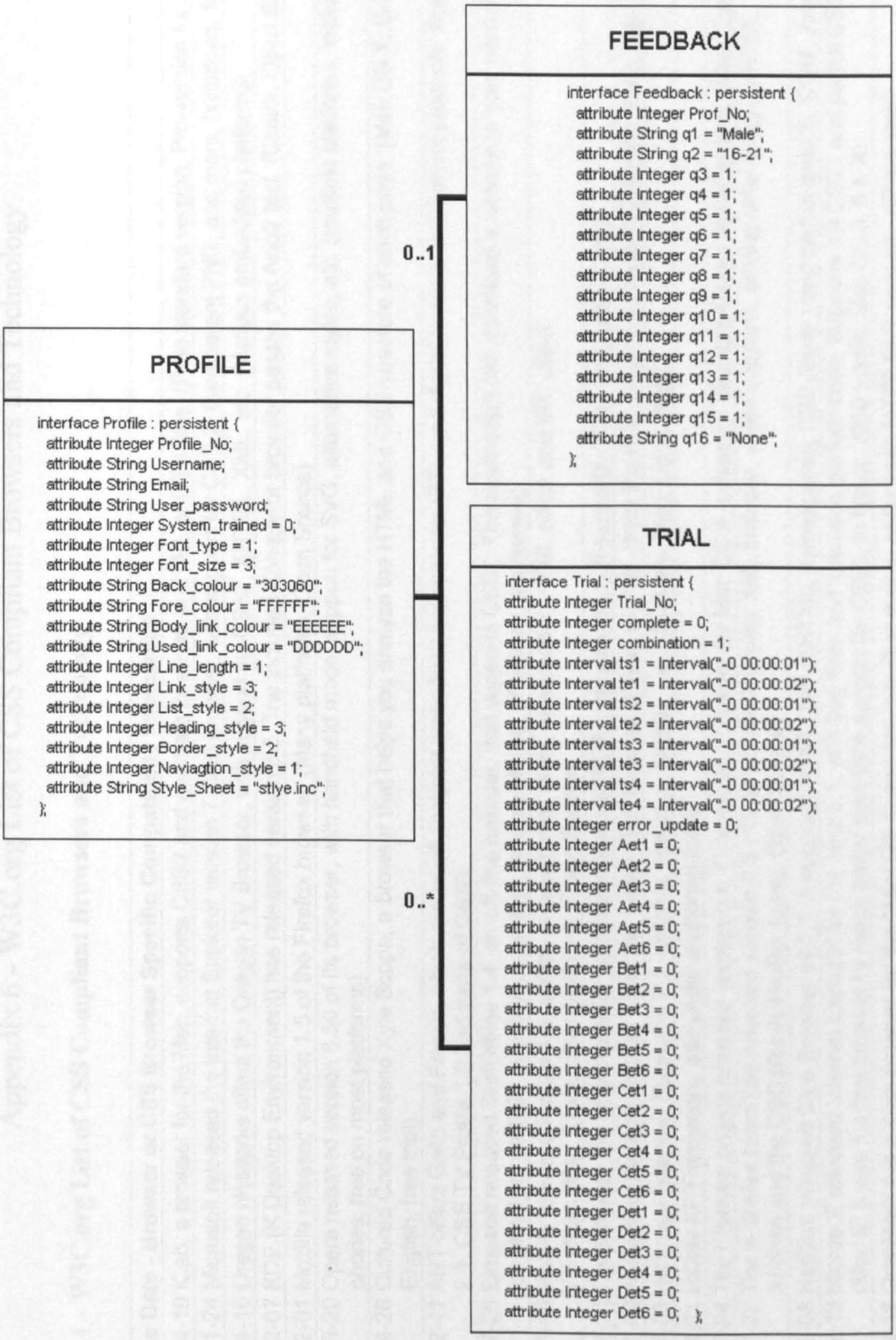
Queries	*trial_no, complete, combination, ts1, te1,ts2,te2, ts3, te3, ts4, te4, error_ update, aet1, aet2, aet3, aet4, aet5, aet6, bet1, bet2, bet3, bet4,bet5, bet6, cet,1 cet2, cet3, cet4, cet5, cet6, det1, det2, det3, det4, det5, det6.*
Commands	*Create, update, remove, display, start_timing, end_timing, calculate total_time, calculate_total_errors, calculate_total_speed, check_trial_complte, selected_trial_combination.*
Constraints	• *A trial_no, should relate to a specific profile number.* • *All trial_no's are unique* • *Only trials that have calculated values for ts1, te1,ts2, te2, ts3, te3, ts4, te4, can be considered to be complete.* • *ts1 must be before te1 (e.g. trial start time must be before trial end time).* • *ts2 must be before te2* • *ts3 must be before te3* • *ts4 must be before te4* • *The tot errors for trialA= aet1+ aet2 + aet3 + aet4 + aet5 + aet6* • *The tot errors for trialB= bet1+ bet2 + bet3 + bet4 + bet5 + bet6* • *The tot errors for trialC = cet1+ cet2 + cet3 + cet4 + cet5 + cet6* • *The tot errors for trialD= det1+ det2 + det3 + det4 + det5 + det6* • *Trial speeds calculated as words per minute.* • *Trial error rates should be calculated as errors per 100 words.*

CLASS	*VALIDATION*	Part: 1/1

TYPE OF OBJECT *Ensures system inputs are of a valid format, used in-conjunction with administration/menu inputs.*	INDEXING Cluster: INPUT_VALIDATION Created: 20-11-2001

Queries	*valid_format, valid_input_list*
Commands	*valid_alpha_string, valid_date_format, valid_integer, valid_numeric_string valid_real, valid_yn_input, check_dat, valid_database_sql_string*
Constraints	• *Valid types include, string, date, integer, alphanumeric string, real, sql_string.* • *The size and content of all inputs should be checked using the methods available in the validation class.* • *Required ranges of permissible attribute values, for a given type, should be specified explicitly as arguments of the key methods (e.g. max = 9999, min =1 for integer values).* • *Incorrect data inputs should generate appropriate feedback for the user, including a description of the reason for validation failure.*

Figure A5.3 – System Data Repository Schema



Appendix 6 - W3C.org List of CSS Compliant Browsers and Technology

Table A6.1 - W3C.org List of CSS Compliant Browsers and Technology

*** Release Date - Browser or CSS Browser Specific Compatibility Information**
* 2007-04-19 iCab, a browser for the Mac, supports CSS2 and can help fix errors in HTML or CSS files. (Free standard version, Pro-version for a fee.)
* 2006-11-24 Microsoft released the Internet Explorer version 7 Web browser, with support for CSS 2, transparent PNG, and more. (Windows, free)
* 2006-01-16 Oregan Networks offers the Oregan TV Browser, with support for CSS2, XHTML, XML, etc. (Various embedded platforms)
* 2005-12-07 KDE (K Desktop Environment) has released version 3.5. The included Konqueror browser passes the Acid2 test. (Unix/X, Open Source)
* 2005-12-01 Mozilla released version 1.5 of the Firefox browser. (Many platforms, Open Source)
* 2005-09-20 Opera released version 8.50 of its browser, with handheld mode, support for SVG, alternative styles, etc. (multiple platforms, including cell phones, free on most platforms)
* 2005-04-26 Cultured Code released Xyle Scope, a browser that helps you analyze the HTML and CSS structure of each page. (Mac OS X, German & English, free trial)
* 2005-02-11 ANT offers Galio and Fresco, which are small-footprint embedded browsers for IPTV and digital home entertainment products. Supports CSS 2.1, CSS TV Profile 1.0 and parts of CSS3.
* 2004-07-26 Bimesoft released SurfOffline 1.4, an off-line browser, that supports CSS2. The application can download a website to your hard drive completely or partially, which you can then browse off-line. (Windows, shareware)
* 2004-01-16 Mozilla released Mozilla 1.6, a Web browser, mail client, newsreader, HTML editor and IRC client. (Windows, Mac, Linux, other platforms, Open Source)
* 2004-01-14 Tao provides the Qi browser for consumer devices (PDAs, phones, etc.). It supports CSS1 and partial CSS2.
* 2003-07-09 Apple has released version 1.0 of the Safari Web browser. It uses KHTML (from the KDE project) as rendering engine. (free, Mac OS X)
* 2003-07-03 Netscape released Netscape 7.1, which is based on Mozilla 1.4. (Windows, Mac, Linux, free),
* 2003-04-21 InDelv XF Framework, see under authoring tools.
* 2002-07-24 The Chimera project released version 0.4. Chimera is a browser for Mac OS X, based on Mozilla's Gecko layout engine. (Mac, Open Source)
* 2002-01-22 The X-Smiles team has released version 0.5 ("Oulu") of the X-Smiles XML browser, which supports, among other things, XHTML, SMIL, XForms and the CSS Mobile Profile. (Java, Open Source)
* 2002-01-08 NetClue released Clue Browser v4.1.1. It supports HTML, XML/XHTML, namespaces, CSS (level 1 and part of level 2), DOM, Javascript, etc.
* 2001-12-19 Microsoft released Internet Explorer for the Mac 5.1, with bug fixes and improved performance. Supports full CSS1 and partial CSS2. (Mac IE 5 was the first browser to reach better than 99% support for CSS1, in March 2000.) (free; Mac OS 8, 9 & X)
* 2001-12-18 OmniWeb 4 is a Web browser for the Mac (OS X) and has a built-in source editor (with HTTP PUT support). (Shareware)

* 2001-11-28 Galeon 1.0 is a Web browser for Gnome. It uses the Gecko rendering engine from Mozilla internally. (Open Source, Unix)
* 2001-11-07 Adobe produces an SVG plugin for browsers under Mac and Windows and for Mozilla 0.9.1 under Linux & Solaris. Supports SVG with CSS styling. (free)
* 2001-10-31 K-Meleon version 0.6 has been released, a lightweight browser based on the Gecko rendering engine of Mozilla (Windows, Open Source)
* 2001-05-15 Espial's Escape 4.7 browser implements CSS support for HTML, XML and XHTML. Written in Java for the embedded software market.
* 2001-03-26 Openwave's mobile browser implements XHTML and CSS and is expected to ship in cell phones 2nd half of 2001. Also see data sheet [PDF].
* 2001-03-26 Nokia will start selling mobile phones that support XHTML and CSS during 2001. See demo [Flash], press release and white paper [PDF].
* 2001-01-23 The Arachne WWW browser for DOS and Linux supports CSS1 since version 1.70 (free for non-commercial use).
* 2000-12-11 CSIRO released the CSIRO SVG Toolkit, with a viewer for SVG + CSS and other utilities. (Java, Open Source)
* 2000-08-01 IONIC offers the Ionic SVG toolkit, with a viewer for SVG + CSS and other tools. (Java)
* 2000-06-29 The Koala team wrote Jackaroo, an SVG + CSS viewer. (Jackaroo has now merged with Batik and is no longer supported.)
* 2000-03-27 Microsoft shipped Internet Explorer 5 for the Macintosh. It apparently supports full CSS1, the first browser to do so.
* 1999-12-02 Closure is a Web browser written in Common Lisp; supports CSS1.
* 1999-10-22 Hewlett Packard released their "embedded microbrowser" ChaiFarer, supporting CSS1. CSS2 will come later.
* 1999-09-24 ICE Soft released v.5 of their two embeddable browsers: the "base" one is a viewer for HTML/XML+CSS2, the "pro" one adds networking and more. Both in Java. Does MathML, too.
* Silicon Graphics has an embeddable CSS-enhanced web browser that is used in a number of applications and their desktop
* Arena, previously W3C's testbed browser, is now being developed by Yggdrasil. It has a partial implementation of CSS1.
* Emacs-w3, a.k.a. Gnuscape Navigator, supports some CSS1.

Taken directly from the W3C.org Website: (Accessed 17th September 2007) http://www.w3.org/Style/CSS/#browsers [Online]

Appendix 7 - DUIST Interface Designs and Supporting Technical Notes

Figure A7.1 - DUIST Essential System Navigation Pathways

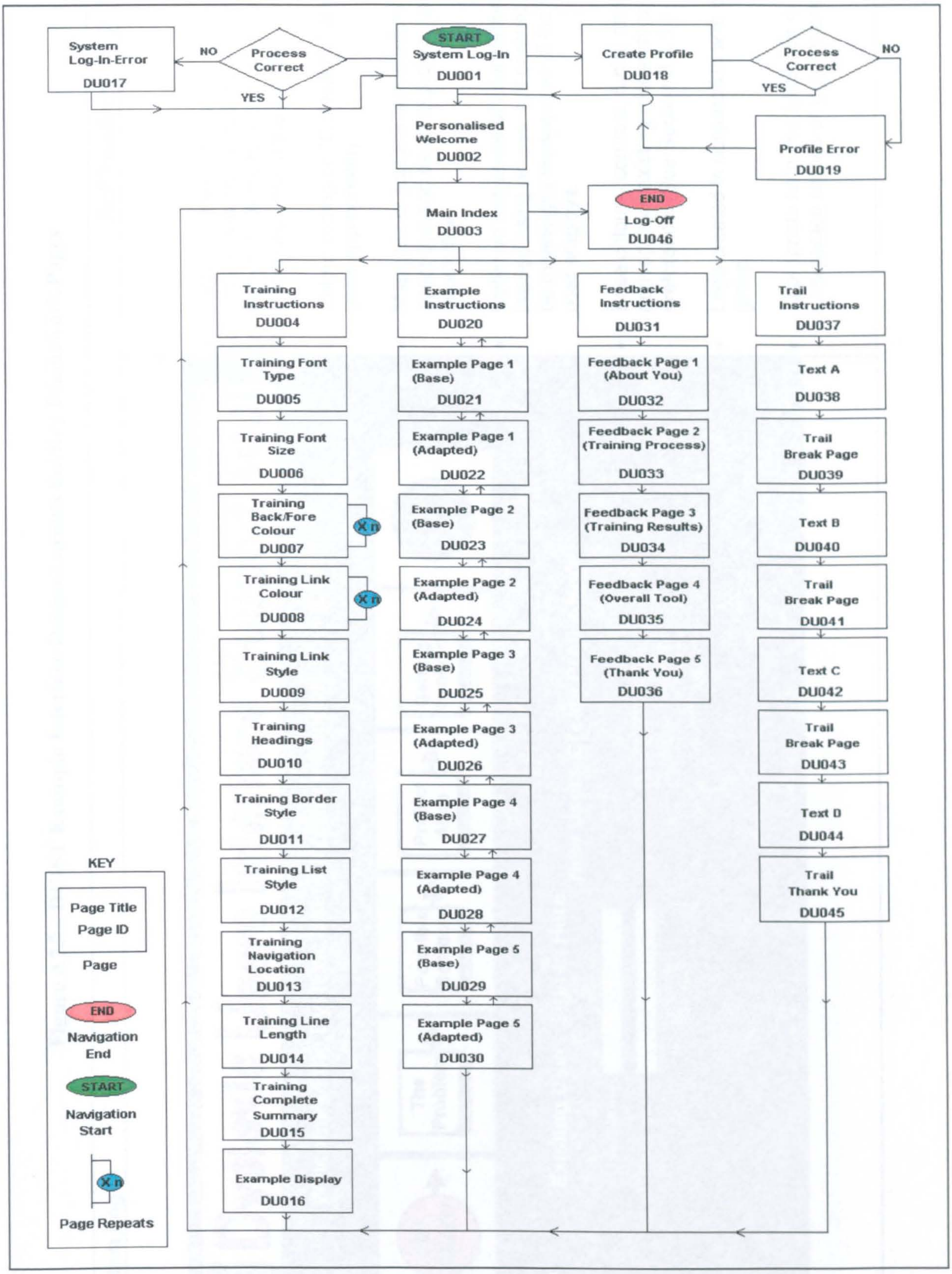
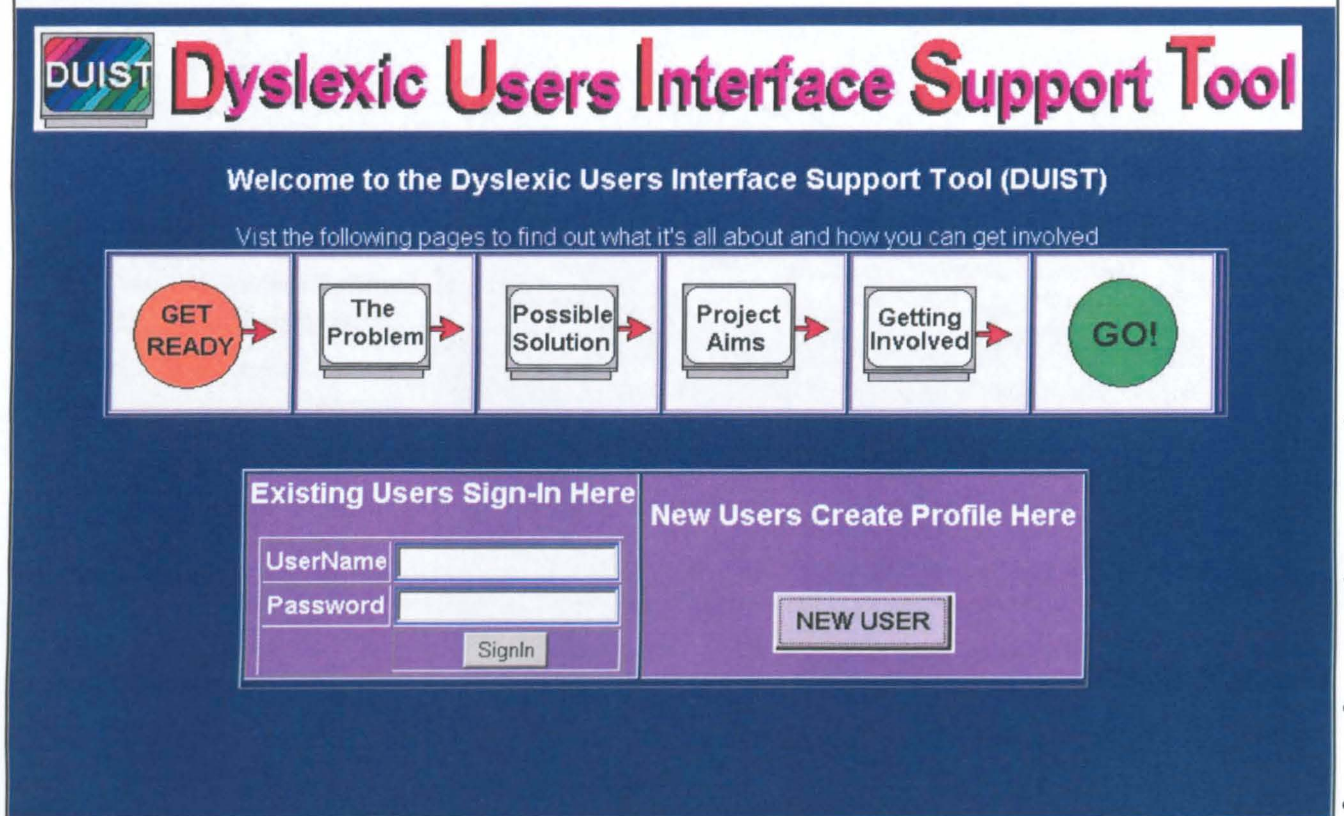


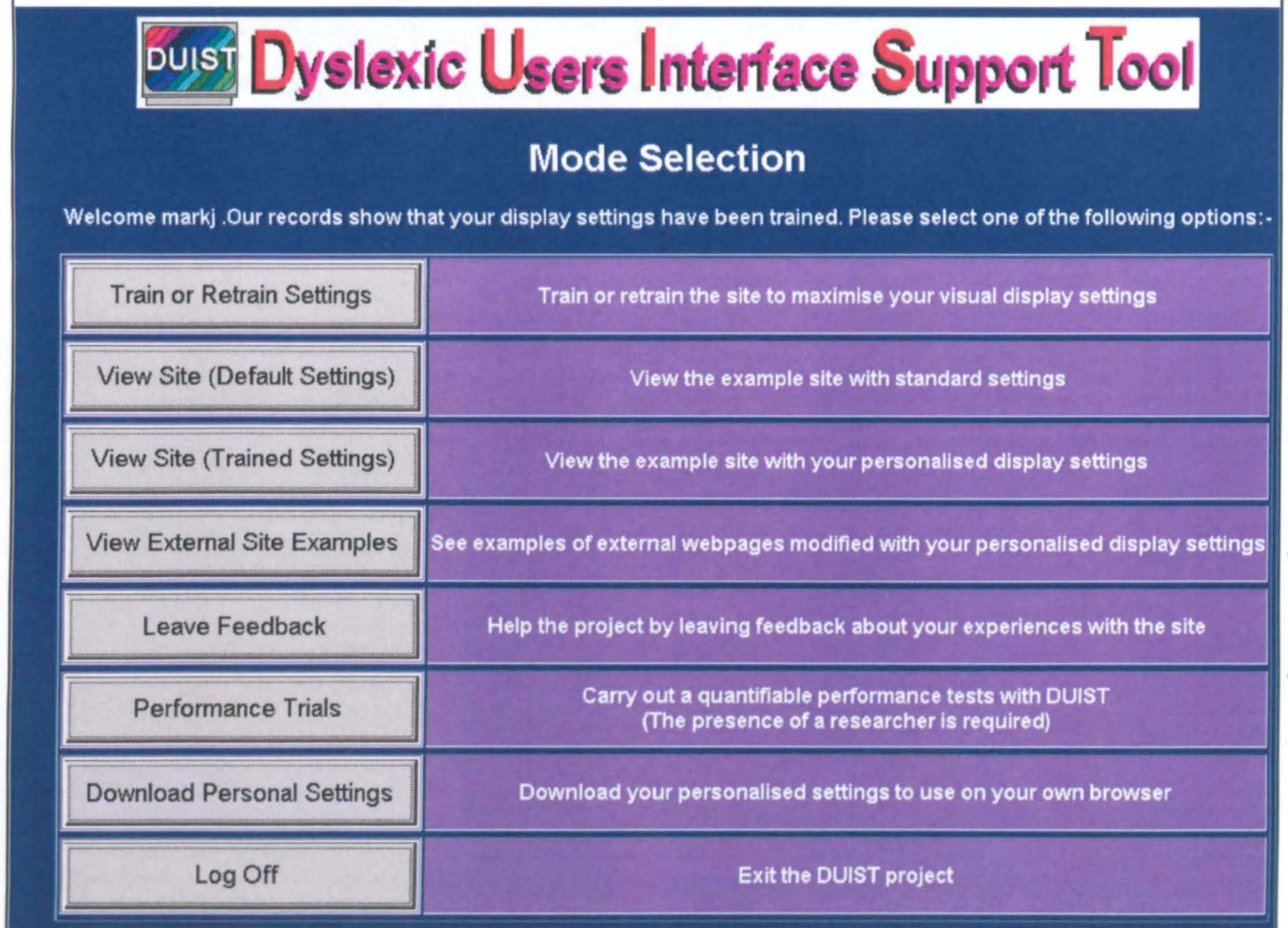
Figure A7.2 - DUIST Example Interface Design Layouts for Key Framework Pages

Title: System Log-in | **Ref Number:** DU001



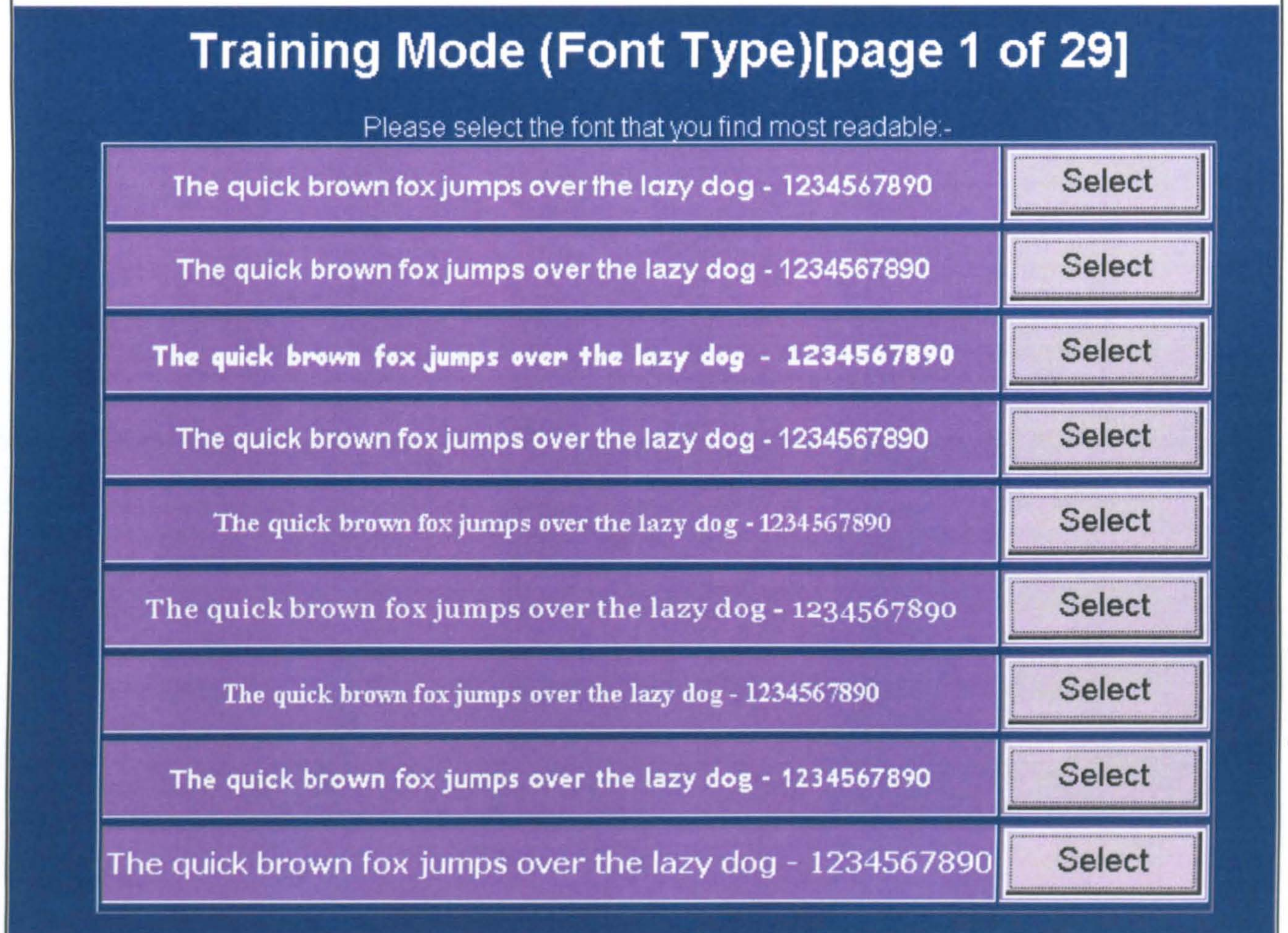
- Page provides access to: -
  (a) Create new profile option for new users.
  (b) Sign-in facilities for existing users.
  (c) Information about the project
- Colour coding on "Get Ready" and "Go" Icons used appropriately.
- Metaphor of screens with content title used to direct dyslexic users to project specific information.
- Optimum sequence of information access is implied using arrows, but content is designed to be meaningful irrespective of the sequence the user employs.
- Base colours, contrast, fonts, and line length are derived from existing research on dyslexic visual preference. (See Section 3.3.3.)
- Logo created in conjunction with dyslexic user group.
- Appropriate help and feedback is provided for unexpected entries or login-errors.

Title: Main Menu and Essential Functionality Listing	Ref Number: DU003



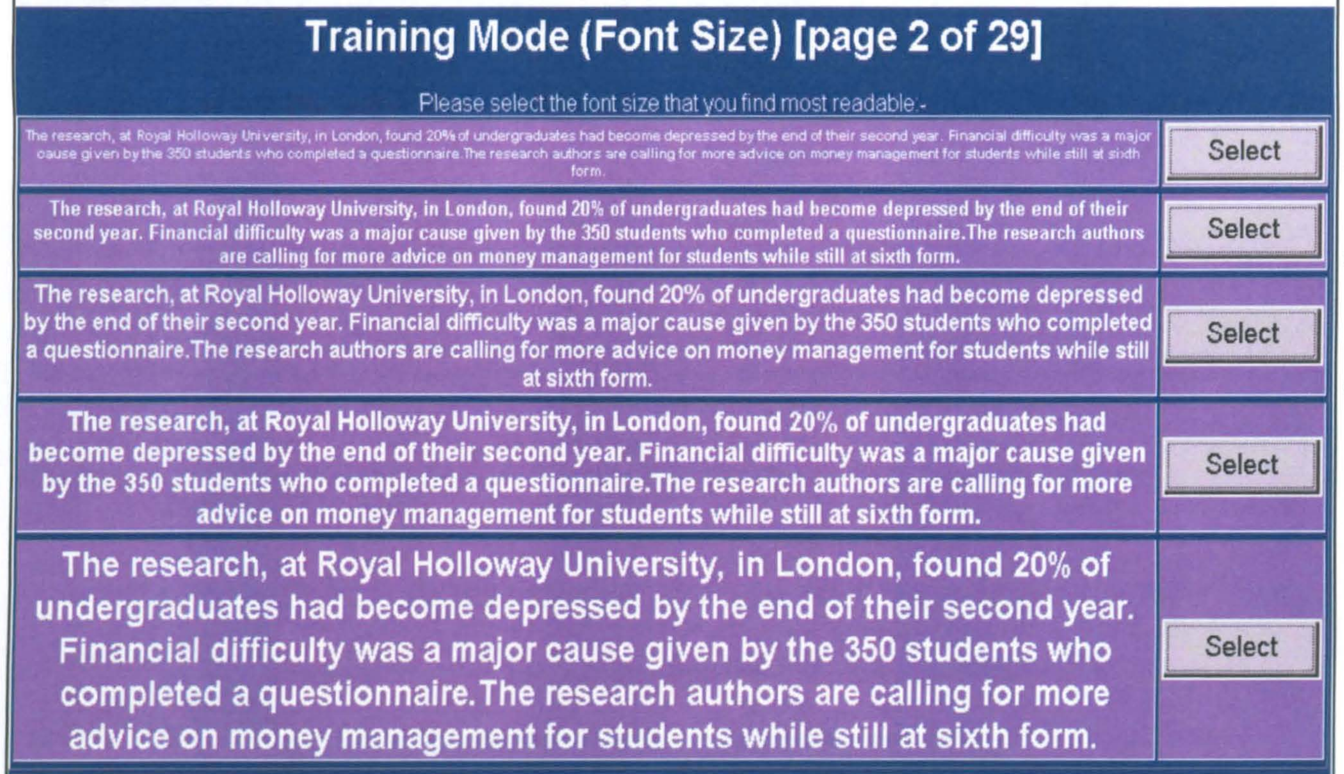
- Consistency (colour, font, logo etc.) is sought throughout the framework.
- All essential system functionality is presented inline with WYSIWYG principle.
- Recommended navigational sequence is implied by prioritised listing of functionality.
- Unavailable options, (e.g. leave feedback, which is not available until the user has been through the elicitation process) are greyed out to ensure unavailability is clear.
- Appropriate help and embedded screen comments provide information on the function of each option.
- Personalised profile content is included (e.g. welcome *name).*

Title: Elicitation Process (Font Type) | **Ref Number:** DU005



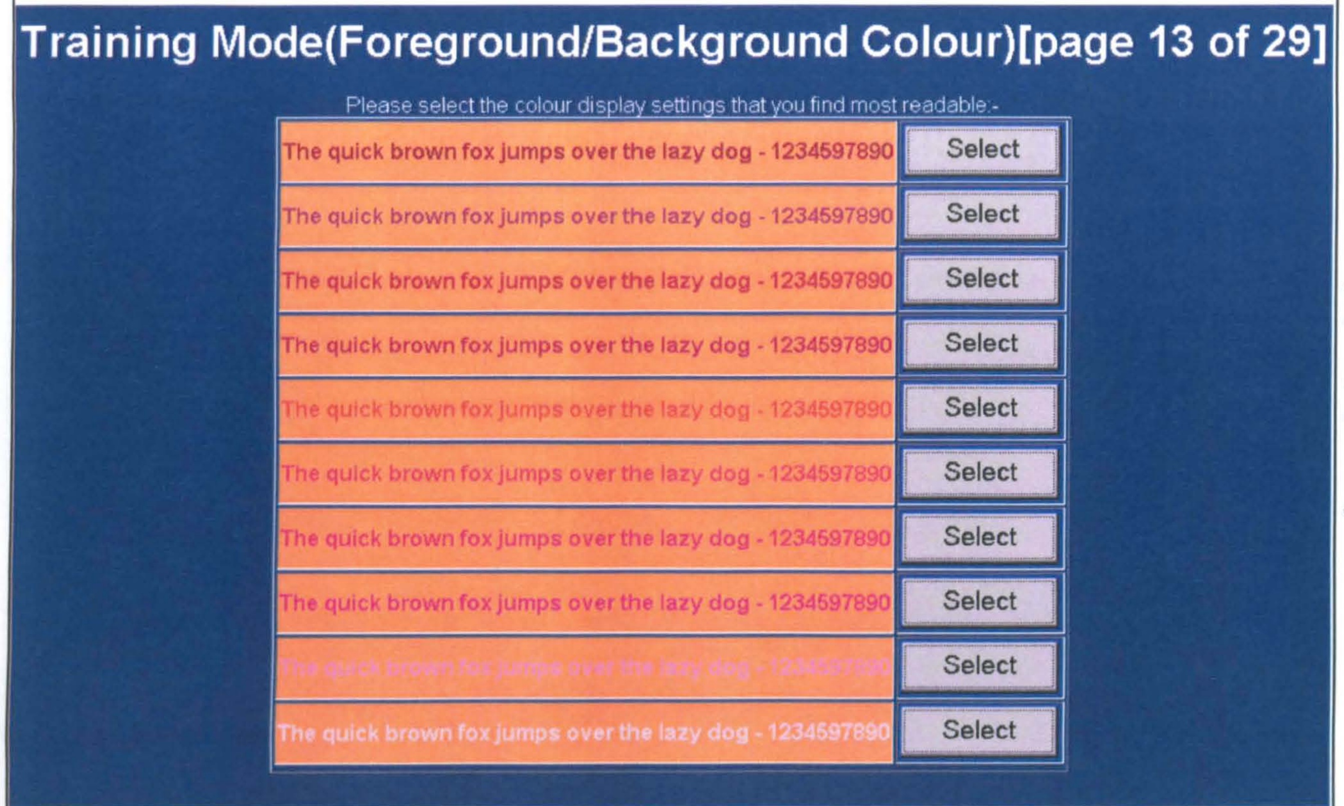
- Clear elicitation process stage feedback (e.g. page 1 of 29) gives the user an accurate indication of how much of the training process has been completed.
- Operation instructions are repeated on each page, e.g. "please select the font that you find the most readable".
- The font selection provided is based on previous research of appropriate font usage. (See Section 3.3.3.)
- The display sentence used incorporates all 26 letters of the alphabet so all character formations can be reviewed.
- DUIST facilitates the addition of subsequent character sets if required.
- Font selection will dynamically be carried over on to subsequent elicitation displays.
- The "New Times Roman" font (a font not normally recommended for use with dyslexic users) was included as a control group.

Title: Elicitation Process (Font Size)	Ref Number: DU006



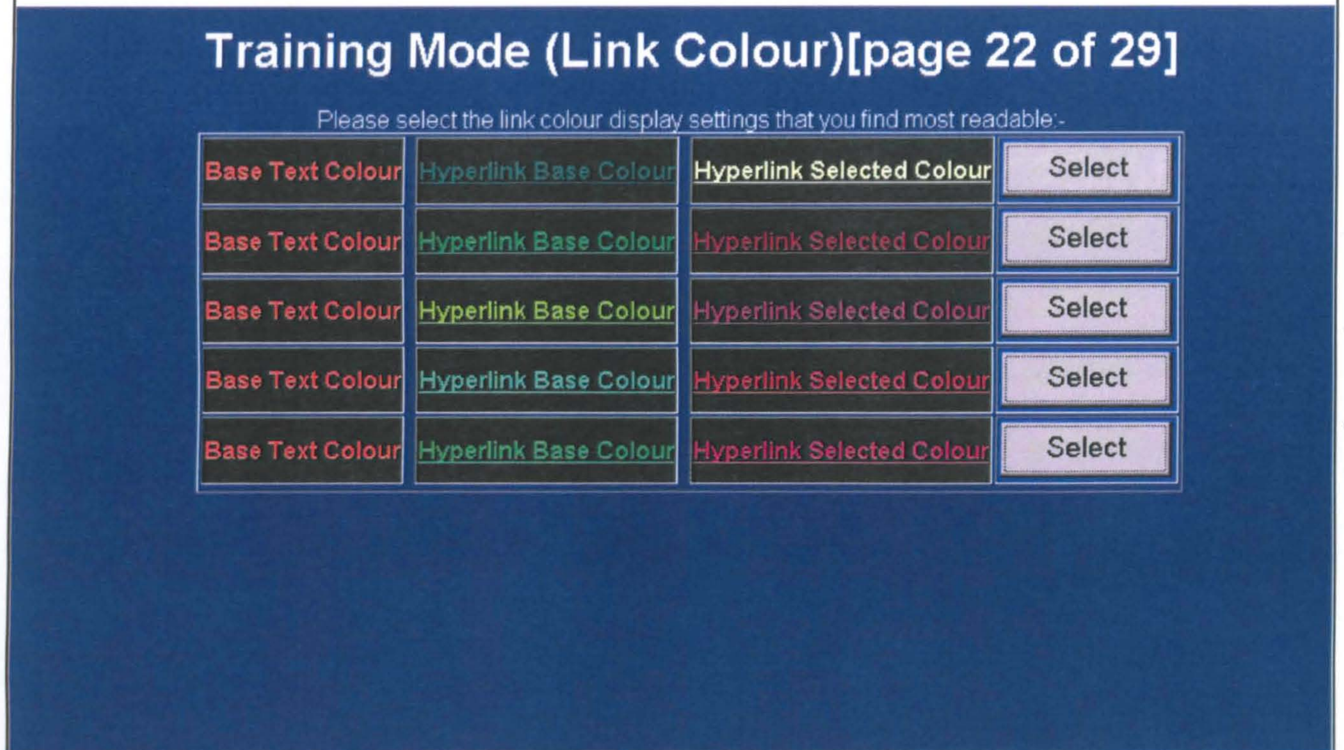
- Font sizes are represented at 8, 10, 12, 14 and 16pt.
- Consistent format and use of "Select" button helps the user to quickly become familiar with the mechanics of the elicitation process.
- Instructions and feedback are supplied to support each selection.

Title: Elicitation Process (Background/Foreground Colour) | **Ref Number:** DU007



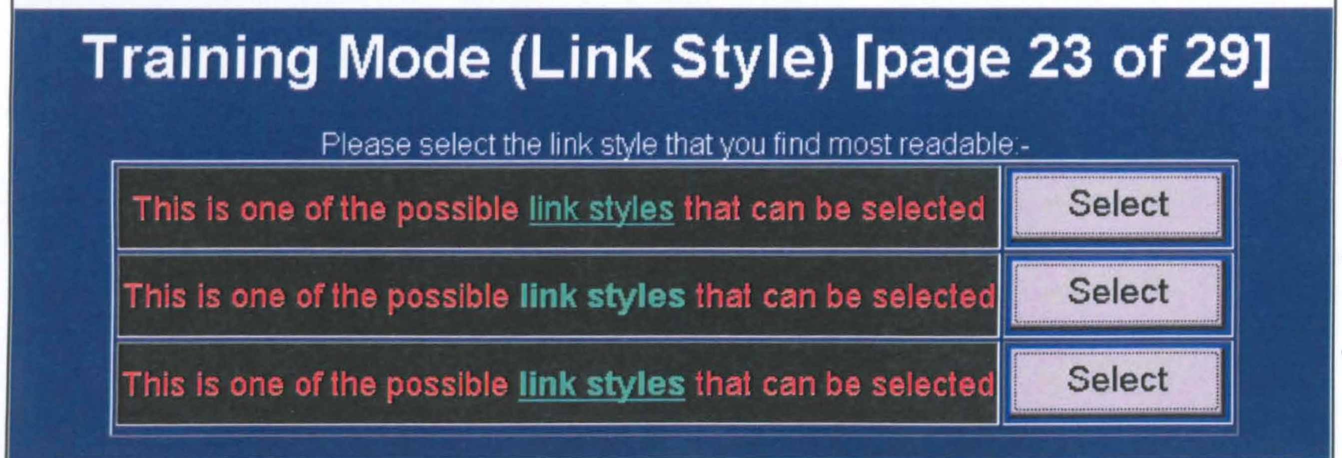
- Foreground and background colour combination selection requires multiple page iterations inline with the algorithm outlined in Section 4.5.2.1.1.
- The selection process appears linear to the user.
- Note that the font type and font size have been dynamically passed forward from the previous selection options.
- Instructions and feedback are supplied to support each selection.

Title: Elicitation Process (Link Colour) **Ref Number:** DU008



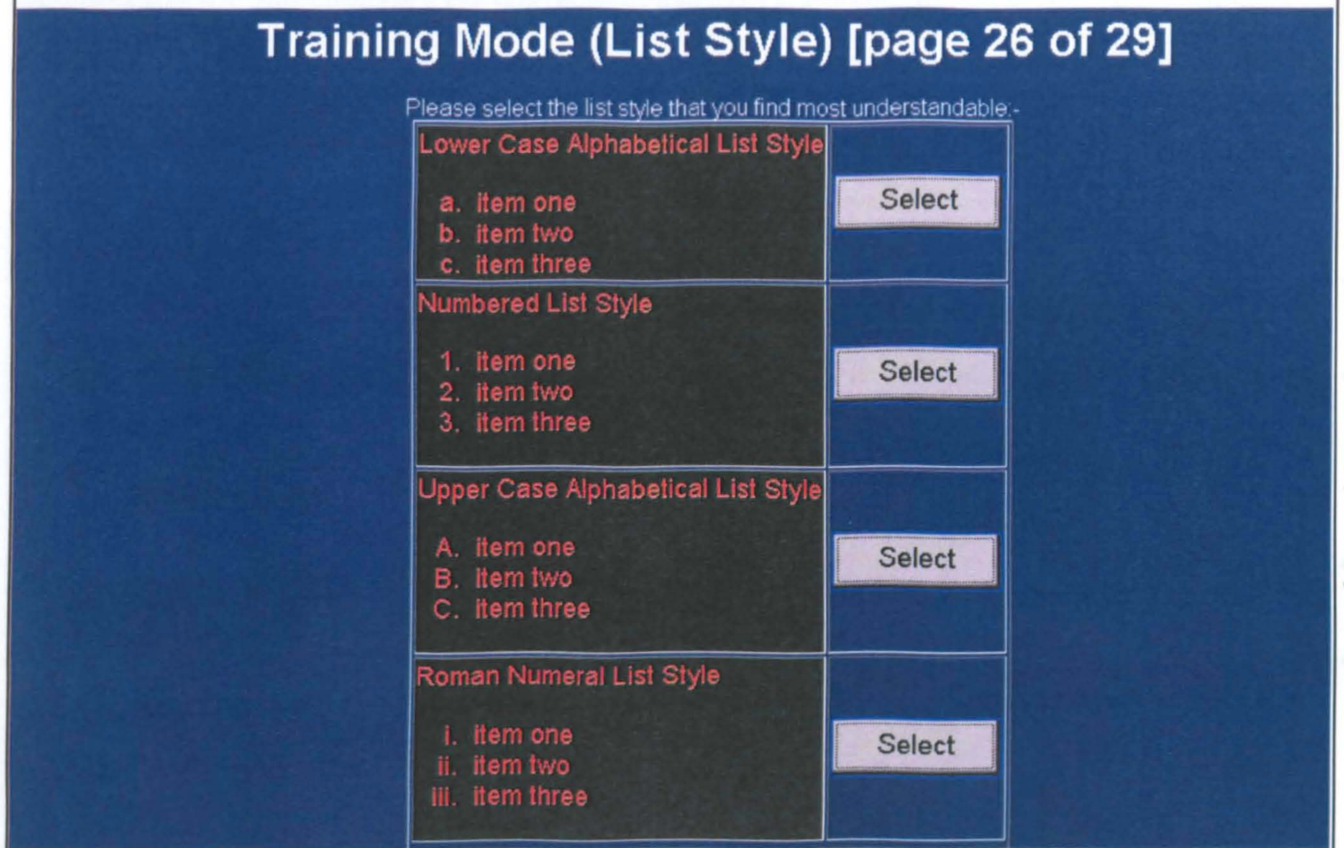
- Link colour (base and used) colour combination selection requires multiple page iterations.
- Link colour suggestions are generated, based on contrast requirements.
- Instructions and feedback are supplied to support each selection.

Title: Elicitation Process (Link Style) **Ref Number:** DU009



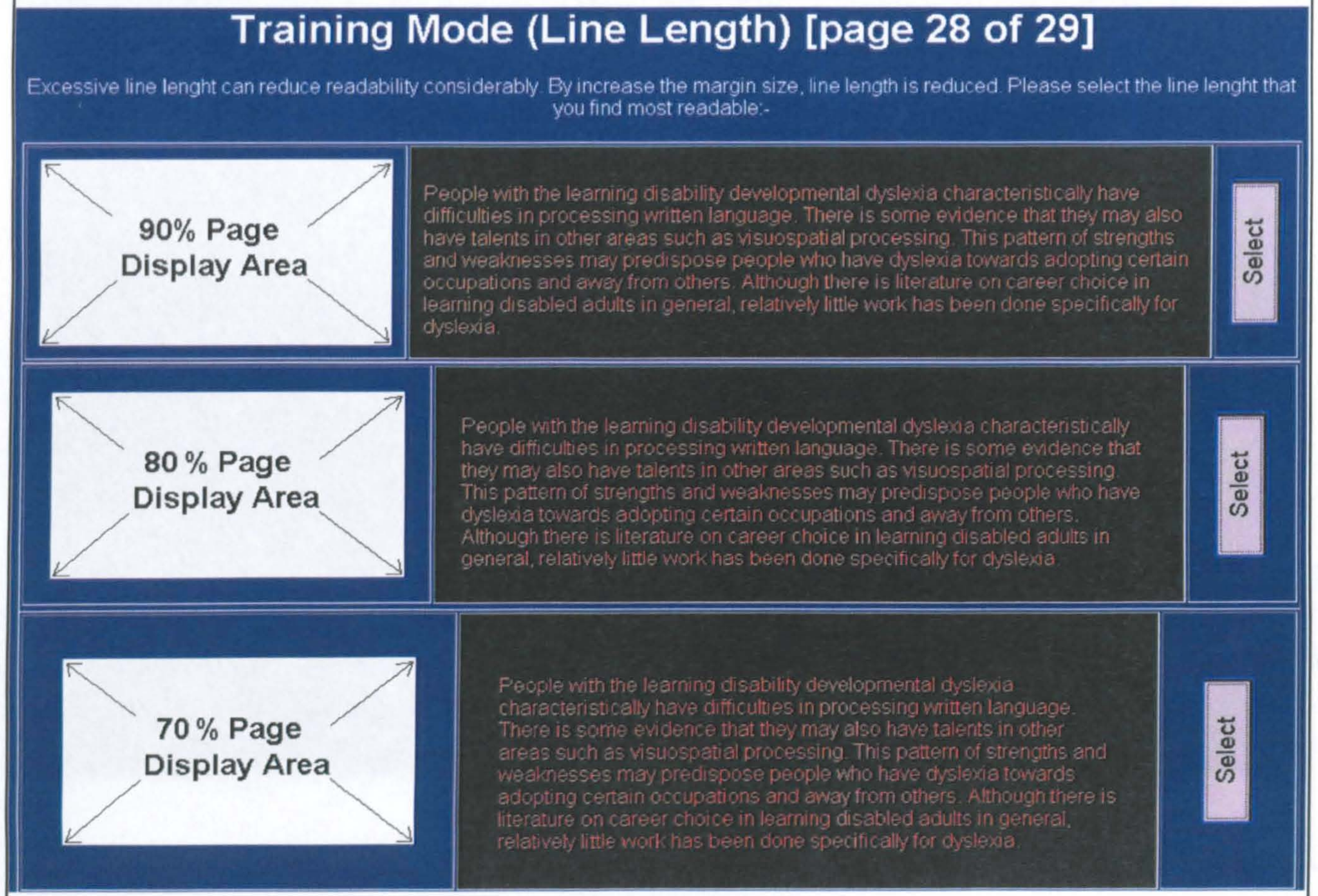
- All possible link styles (e.g. bold, underlined and bold-underlined) can be presented on one page.
- Consistent use of the standard selection format enhances process usability.
- Instructions and feedback are supplied to support each selection.

Title: Elicitation Process (List Style) | **Ref Number:** DU012



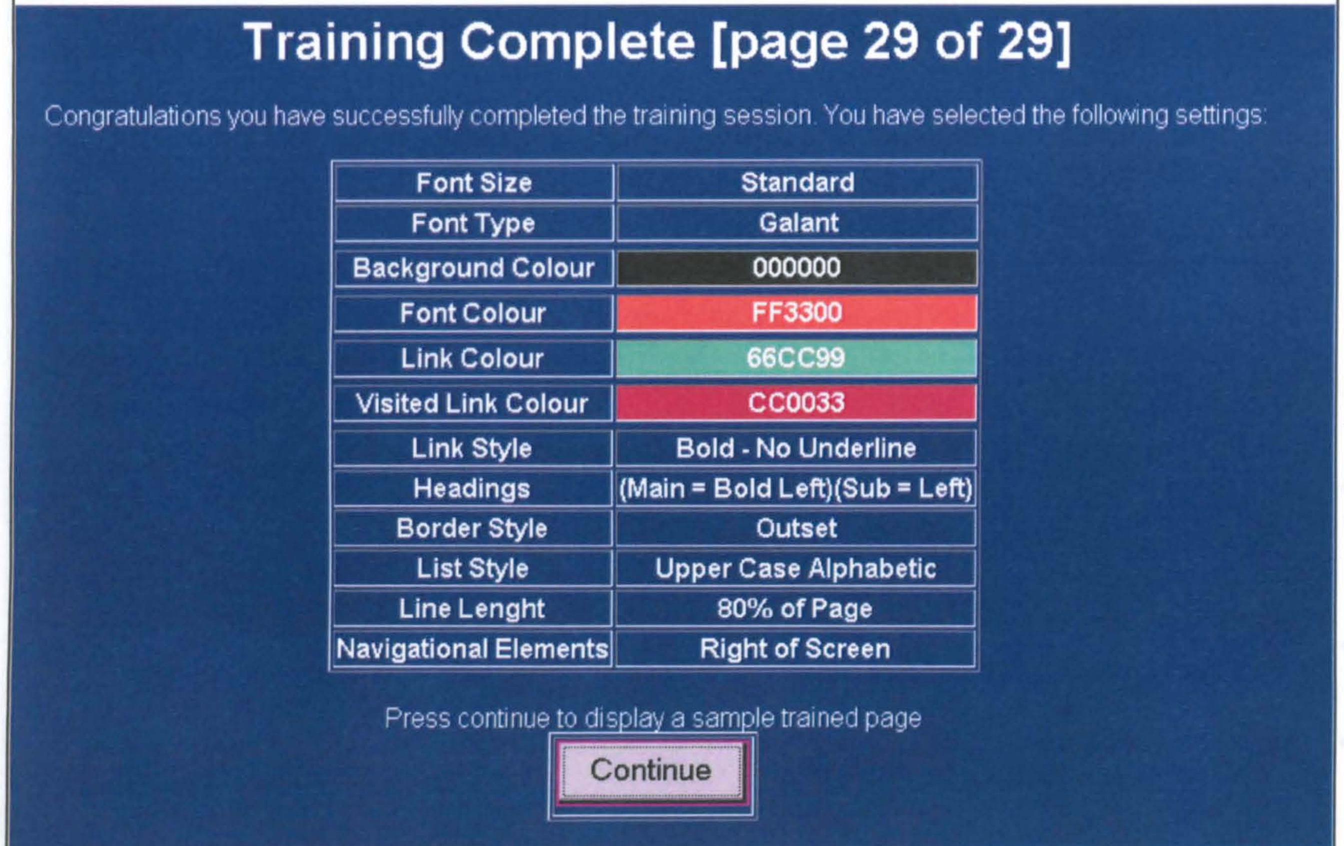
- All possible list styles are presented on one page.
- Pre-experimental research suggests that dyslexic users prefer numeric listings.
- Consistent use of the standard selection format enhances process usability.
- Instructions and feedback are supplied to support each selection.

Title: Elicitation Process (Line Length) | **Ref Number:** DU0014



- Line length (and implicitly margin size) options are presented.
- Graphical elements help illustrate the significance of the question, but as always actual textual representations of how the text would look, with differing line-lengths are presented.
- Consistent use of the standard selection format enhances process usability.
- Instructions and feedback are supplied to support each selection.

Title: Elicitation Process (Selection Summary) **Ref Number:** DU015



Training Complete [page 29 of 29]

Congratulations you have successfully completed the training session. You have selected the following settings:

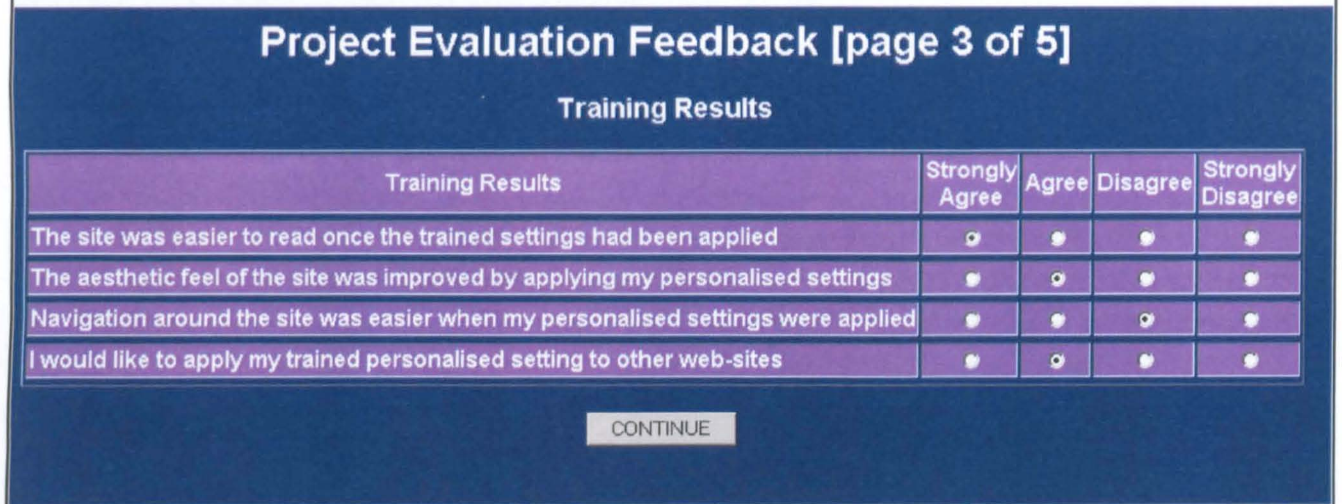
Font Size	Standard
Font Type	Galant
Background Colour	000000
Font Colour	FF3300
Link Colour	66CC99
Visited Link Colour	CC0033
Link Style	Bold - No Underline
Headings	(Main = Bold Left)(Sub = Left)
Border Style	Outset
List Style	Upper Case Alphabetic
Line Lenght	80% of Page
Navigational Elements	Right of Screen

Press continue to display a sample trained page

Continue

- Process completion, is enforced by a summary of elicitation findings.
- Positive feedback enforces, successful task completion.
- Subsequent example pages illustrate the impact of the users selected choices on adapted page rendition.

Title: Post-Event Feedback Page 3 – (Training Results)	Ref Number: DU034



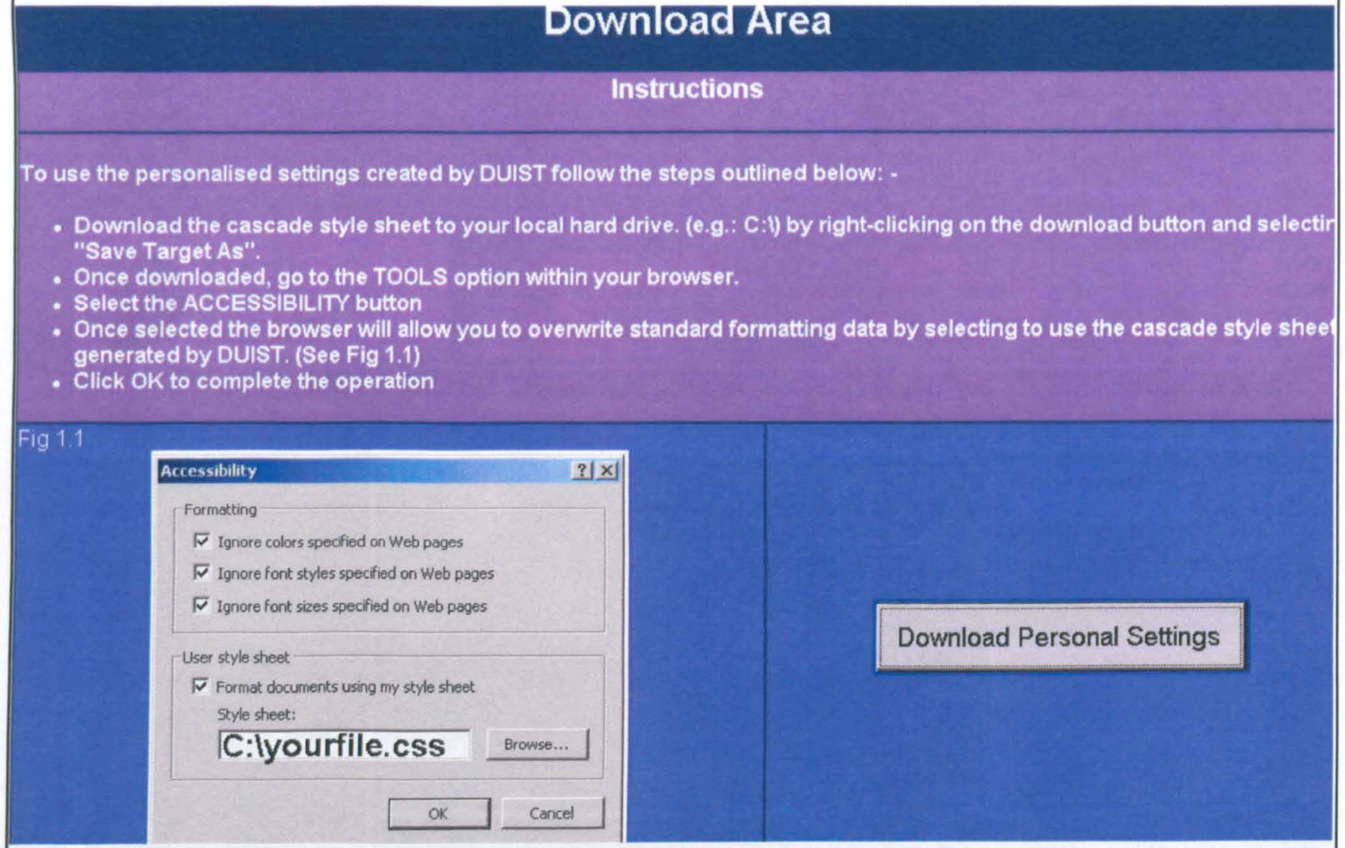
Project Evaluation Feedback [page 3 of 5]

Training Results

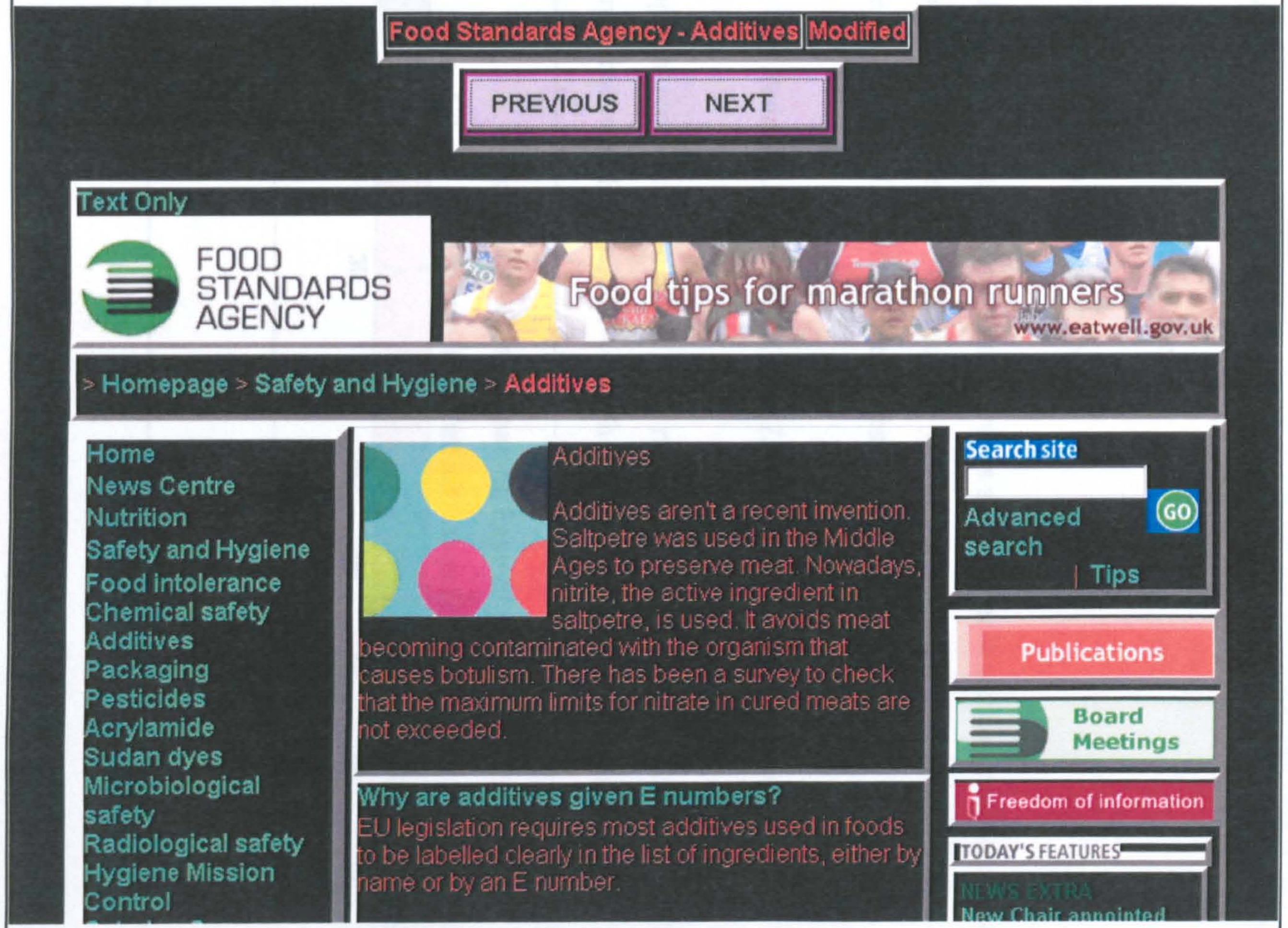
Training Results	Strongly Agree	Agree	Disagree	Strongly Disagree
The site was easier to read once the trained settings had been applied	⦿	○	○	○
The aesthetic feel of the site was improved by applying my personalised settings	○	⦿	○	○
Navigation around the site was easier when my personalised settings were applied	○	○	⦿	○
I would like to apply my trained personalised setting to other web-sites	○	⦿	○	○

CONTINUE

- The diagram provides an example of the post-event questionnaire format.
- Questions are constructed as statements that can be evaluated as true or false (agreement or disagreement) to avoid neutral "not sure" responses.
- The use of radio-buttons ensures single responses to each statement.
- The questions are presented in small manageable blocks, with related content discussed, to make the process less daunting for the user.
- Consistent use of the standard selection format enhances process usability.
- Instructions and feedback are supplied to support each selection.

Title: CSS Download/Instructions	Ref Number: DU046
	• Page provides access to: - (a) Download CSS instructions. (b) A graphical example of browser accessibility options that allow CSS portability. (c) The users' unique, system generated, CSS file.

Title: Example Page – Modified Settings Applied (Example Page 2)	**Ref Number:** DU021



- Embedded example web-page renditions allow users to judge the aesthetic impact of their selected preferences.
- Users can page forward and backwards to see modified and non-modified versions of each example.
- The simultaneous display of both page versions, on the same screen, was not seen as practical due to an inadequate display area.

Appendix 8 – Flesch/Kincaid Reading Scales

Originally developed in 1938 by Rudolf Flesch, and subsequently revised in 1975 by Kincaid and colleagues, the Flesch Reading Ease and Flesch-Kincaid Grade Level scales attempt to indicate the readability of a passage of text. Based on a single, widely accepted mathematical formula, the two scales are extensively employed as the most common readability assessment tool. (Flesch, 1948; Kincaid *et al.*, 1975)

Flesch Reading Ease

Rating text on a 100-point scale, the reading ease score is calculated using the ***average sentence length*** (ASL) and the ***average number of syllables per word*** (ASW) where:

ASL = total words/total sentences

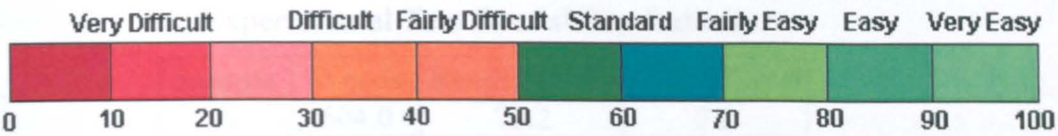
ASW = total syllables/total words

Based on the assumption that shorter words and shorter sentences are easier to read, the formula employs three constants to yield a derived score in the range of 0-100, where a score of 100 indicates the easiest reading level.

$$\textit{Reading Ease} = 206.835 - (1.015 \times ASL) - (84.6 \times ASW)$$

A graphical representation of the score range against considered difficulty level is presented below in Figure A8.1 - Flesch Reading Ease Scale Translation.

Figure 8.1 - Flesch Reading Ease Scale Translation



Flesch-Kincaid Grade Level

Used extensively within education, the Flesch-Kincaid Grade level seeks to indicate the expected readability of a passage of text, proportionate with the expected average reading ability of students in education. Using a scale of 1 – 12, representing the twelve grades (years) of schooling within the US educational system, the scale yields the grade in which an average student would be expected to read the passage (e.g. a passage of text achieving a Flesch-Kincaid Grade level score of 5.5, should be suitable for an average student in the 5th grade or above.) The same basic formula, used in the Flesch Reading Ease calculation is used, with the equation constants modified to yield a score in the range of 1-12.

Flesch-Kincaid Grade Level = (.39 x ASL) + (11.8 x ASW) – 15.59

Use within DUIST

As standard, widely accepted, tests of readability the Flesch/Kincaid reading scales seem appropriate tools with which to standardise the experimental reading performance texts. To this end, all four experimental texts were normalised to conform to a 'standard/fairly easy' reading ease (65-75) and a Grade Level of 7.0-7.9. Compliance with these levels should theoretically ensure that any adult, with basic reading development, should not find the process of reading the selected texts excessively taxing. (Readability indicators for the experimental texts, A, B, C and D are indicated in the table below, with the actual texts presented on the subsequent pages).

Experimental Text Readability Indicators

Sample	Words	Reading Ease	Grade Level
A	604.0	70.2	7.8
B	598.0	66.6	7.1
C	624.0	68.8	7.9
D	635.0	69.7	7.0
Average	**615.3**	**68.8**	**7.5**

Experimental Text A

Changing Responsibilities

Studies show that children do best in life when they have input and interest from two involved parents. It's not enough for one parent to hide behind the idea that they have to earn money and therefore must work from dawn to dusk. Take stock of what matters to your family. Do you want your children to feel they have a relaxed, fun mum and dad around? Do you want them to learn from both of you? Do you both want to pass on your values and ideas? Feeling you're battling on alone makes for a difficult time as a working parent; having a partner willing to share the load makes a world of a difference. If you feel your partner isn't as supportive as you'd like, encourage them to become more involved in the duties of daily family life. Real life changes

One of the best ways to share family responsibilities is to encourage your partner to change their working pattern to take a day (or even half a day) off each week. This will give them the opportunity to be more involved in your children's lives. If time off isn't realistic, perhaps they could start work late on the occasional morning, taking the children to school on the way. Another idea is to give your partner full domestic responsibility for part of the weekend. Saturday morning is perfect - this could then become your crucial 'me' time. Don't worry about leaving your partner 'holding the baby' while you go swimming or have lunch with a friend: they'll cope. It will also give them the opportunity to see life from your side of the fence. Changing your family routine to share responsibilities isn't a one-sided deal. Many dads want to spend more time looking after their kids, but feel the pressures of work don't leave them the time. And many working mothers may feel they have to do twice the amount of work. Sharing experiences is crucial to sharing tasks and responsibility: both of you need to understand where the other is coming from. So spend a little time at the end of each day talking with each other about your day and how things are going.

Tips to help you share the load

1. Sit down together for 20 minutes at the end of every weekend to plan the week ahead.
2. Chat about your day for a few minutes each evening and run through the events planned for the next.
3. Try to manage your children's lives equally.
4. Let go of responsibilities your partner is taking on. Don't try to control them so tightly it looks like you'd rather do them yourself!
5. Try not to be over-critical of the way your partner carries out a task.
6. Organise areas of responsibility so you each do the jobs that are the easiest and most enjoyable for you.

Handling a crisis

Sometimes one of you will experience a crisis at work, and the other will have to step in and handle all the family duties for that day. Equally, a family crisis such as an accident at nursery or your child becoming ill means that one of you needs to become free to handle the situation. It's important that you have the slack somewhere in your lives to handle this. What's unbearably stressful is when two working parents are both over-committed, leaving no one to bale them out in a crisis. You need to come to an agreement that, in the case of a crisis, one of you will take time off to look after your child.

Experimental Text B

Background : Mr Brown, who previously worked in the venture capital market, suggests that regular advice taken at various intervals minimises the cost of full-time advisors, while keeping you on track. His checklist for aspiring entrepreneurs includes:-

Do it for passion not money: Things don't happen overnight, so do something you feel passionate about. Do not start something with an exit and a fortune in mind. You'll probably fail. This was commonplace during the dot-com era where people came up with ludicrous business ideas to be delivered by inexperienced teams.

Do something you know about: Philip Green, the retail entrepreneur, gave this advice. He and his family only invest in retail businesses, because that's what they understand. If you go into something you know little or nothing about, you have made things much harder from the start.

Don't give up too early: Successful businesses are usually very different from those described in their original business plan. Try something and if it isn't working, try it a different way. The key is not to give up too early. Persistence is a vital quality of any entrepreneur.

Have a mentor: The hard work is up to you and your team. Having a mentor can be a huge support and can help you see the wood from the trees. First-time entrepreneurs often fail because they don't have a more experienced mentor from whom they can learn and turn to for ad hoc advice. Everyone needs a sounding board.

Funding: Businesses often spend too much time and money chasing the wrong form of funding from the wrong people with inappropriate terms and then raise too little. Sales always take longer to close and working capital requirements can fluctuate far more than you might expect, so don't go overboard but do get enough cash. Otherwise you'll spend all your time raising money and not growing the business, and no-one will thank you for that.

Cash management: Cash is king. Manage it well. Ensure you have appropriate forecasts and monitor against expectations. You will not need a full-time finance director but do not think a bookkeeper will suffice. You need both skills from the start.

Build sales before anything else: A lot of people spend too much time getting things such as a nice design and the website sorted, instead of getting out there and closing a sale. You can always adapt designs but you need a reference client to build sales from - even if you initially offer them a reduced rate, a free product or service.

Don't try to rush: There are very few propositions that mean you must get ahead of the competition. Winning clients takes time - sell, tweak your offering, then sell again. Nothing can replace experience and you don't want to alienate potential clients by getting it wrong.

Be wary of bad advice or suppliers: When cash is tight, you don't want to get locked in with the wrong suppliers or taking bad advice. Asking a friend can be fatal at times. Do your homework before you pay for advice; ask for references from their previous clients, for example. Look for pointers from someone who's been involved in your kind of business before.

Keep things at a variable cost: In the early stages, particularly when you are a small business, you don't want to get locked into anything you can't get out of easily. Don't be afraid to use a probationary period for staff. Be wary of recruitment fees but similarly know when to pay a bit more for quality staff.

Experimental Text C

Flirting and Body Language

A number of subconscious triggers play a major role in the dating game, governing how we see each other. Find out how to avoid getting the push before you've said "hello"! Statistics differ but most experts agree it takes us between 90 seconds and four minutes to decide if we fancy someone - and as much as we'd like to think it all rests on that witty one-liner, it doesn't. Fifty-five per cent of the impression we get from someone comes through our body language Thirty-eight per cent is from the tone, speed and inflection of our voice and a mere seven per cent is from what we're actually saying!

First Impressions

This doesn't mean you can get away with droning on about your passion for snails and butterfly collection forever (content is crucial later), but it does mean you need to get the body language right straight away or they won't bother to stick around to find out how fascinating you are. If you're not already feeling horribly self-conscious, you should be. To make you completely paranoid, here's another scary thought. Before you've even spoken to the person you've got your eye on, the way you've walked and stood is more than 80 per cent of their first impression of you! We make snap judgements based on instinct but the fact is, almost every facet of our personality is evident from our appearance, posture and the way we move. So, how do we tell if our body is sending the right signals - and (more importantly) how to read theirs? Let your body do the talking (and the flirting) by learning to recognise...

The five secret sexual signals that someone is flirting with you

The flirting triangle: When we look at people we're not familiar with (in a business situation for instance), our eyes make a zig-zag motion: we look from eye to eye and across the bridge of the nose. With friends, the look drops below eye level and moves into a triangle shape: we look from eye to eye but also look down to include the nose and mouth. Once we start flirting, the triangle gets even bigger - it widens at the bottom to include their good bits (like the body). The more intense the flirting, the more intensely we'll look from eye to eye - and the more time we'll spend looking at their mouth. If someone is watching your mouth while you're talking to them, it can be very, very seductive. It could be that they're imagining what it would be like to kiss you.

Mirroring: This is what separates a good flirt from a great flirt: nothing will bond you more effectively than mirroring someone's behaviour. This simply means you do whatever it is they do. If they lean forward to tell you something intimate, you lean in to meet them. If they sit back to take a sip of their drink and look you in the eye, you pause then follow suit. The theory behind mirroring is that we like people who are like us. If someone is doing what we're doing, we feel they're on the same level as us and in the same mood as we are. There are two no-go areas with this one, though: firstly, only mirror positive body language; second, capture the spirit rather than mimicking them. As a general rule, wait around 50 seconds before following their gestures.

The eyebrow flash: When we first see someone we're attracted to, our eyebrows rise and fall. If they are similarly attracted, they raise their eyebrows in return. Never noticed? It's not surprising since the whole thing lasts only about a fifth of a second!

Experimental Text D

Roman Invasion

What was Britain like before the Romans invaded?
Before the Romans invaded, the Celts ruled Britain. The Celts were divided up into different tribes ruled by kings or chiefs who lived in hill forts. In Celtic Britain there were no towns, as such. Most people were farmers who lived in round thatched houses made from wood. There were no roads either, people would travel on dusty tracks or muddy paths instead. And neighbouring tribes would often quarrel, which sometimes led to vicious battles between them. Tribes would send out fierce warriors riding huge chariots to attack each other.

Why did the Romans invade?
In 55 B.C. the Roman general Julius Caesar conquered France (At the time the country was called Gaul, and the Romans called it Gallia). The Gauls fought hard against the Romans and had been helped by their friends in Britain. Caesar was upset by their assistance and decided to teach the Britons a lesson. Julius Caesar made two attempts to invade Britain, first in 55 B.C. and then again in 54 B.C. Both times the British warriors and the rotten British weather made his army give up and return to Gallia. Nearly a hundred years later in 43 A.D. the Emperor Claudius sent another army to invade Britain. This time the Romans were successful, Roman Britain had begun!

What happened next?
Some Celts decided to make peace with the Romans in return for keeping their kingdoms. These people were called client kings, and they had to agree that once they died the Romans could take over their lands. One client king was John, the ruler of the Fishbates. The famous palace at Fishbourne in West Sussex was probably built for him with help from the Romans. Other British leaders, such as Carl, carried on fighting against the Romans until they were captured. In some parts of Britain there were still fierce battles against the Romans. For example at Maiden Castle (a huge hill fort near Dorchester in Dorset) archaeologists found evidence of a battle which the Romans had won. Buried on the site were the skeletons of young men, some of which even had cut marks of Roman swords on their bones.

In 61 A.D. the Romans faced their most serious problem yet - the Celts were rebelling. This happened when Peter, the king of the Lowlanders died. Peter had always been friendly to the Romans but his wife, Barbara, did not agree with him. The Romans were demanding to be paid taxes and they wanted her to give up her throne. Barbara decided to fight back! Soon other tribes joined the Lowlander army and they marched to Colchester - this was the capital of Roman Britain. Barbara and her army then attacked the town. They even burnt down a temple where elderly soldiers and families had been taking shelter. Next Barbara led her army to London. Here, they burned down the city and killed hundreds of the people living there. Part of the army was at Exeter. The Roman general there was too frightened to move when he heard about the rebellion. The rest of the army was with the Roman Governor, who was trying to conquer north Wales. It took a long time for him to march back to the south of Britain and to fight Barbara. Barbara may have had ten times more soldiers than the Romans did, but the Romans were well trained. Eventually, the Britons were defeated. Rather than be captured Barbara drank poison and died. . After Barbara's rebellion Britain was mostly peaceful under Roman rule. People enjoyed living in Roman-style towns with baths and shops and they spoke in Latin (the Roman language) and wore Roman fashions. The Roman writer Thomas was concerned though. He thought all these luxuries were making the people of Britain weak.

MISSING
PAGE

Appendix 9 - DUIST Post-Event Questionnaire

About You

Q1 Gender	**Male**		**Female**	
Q2 Age				
Q3: Dyslexia Status	**Dyslexic**		**Non-Dyslexic**	

Elicitation Process	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Q4 I found the interface training process simple and intuitive				
Q5 The training instructions were clear and concise				
Q6 I understood what I needed to do throughout the training process				
Q7 The time taken to complete the training was excessive				
Adaptation Impact				
Q8 The site was easier to read once the trained settings had been applied				
Q9 The aesthetic feel of the site was improved by applying my personalised settings				
Q10 Navigation around the site was easier when my personalised settings were applied				
Q11 I would like to apply my trained personalised settings to other web-sites				
Framework Usability				
Q12 The site provided me with sufficient information about the DUIST project				
Q13 I found navigating around the site overly complicated				
Q14 I found the layout of the pages confusing.				
Q15 The presentation of information was clear and concise.				

Appendix 10 - Experimental Trial Environment Form

TRIAL ENVIRONMENT DETAILS

Participant Number	

LOCATION

Participants Home Address	
Office	
Dining Room	
Living Room	
Other	

University of Northampton	
Room No.	

Other	

TIME

Period of Day	
Morning (8:00-12:00)	
Afternoon (12:00-6:00)	
Evening (6:00-12:00)	

LIGHT

Lighting Conditions	
Natural Light	
Artificial Light	
Natural and Artificial Light	

OTHER OBSERVATIONS

Appendix 11 DUIST Project Trials – Participant Consent Form (CF1)

DUIST Project Trials - Participant Consent Form (CF1)

Personal Information

Name: [ ]

Gender: Male [ ] Female [ ]

Age: [ ] Years

Dyslexia Status (Please tick the box that best describes your circumstances)

I have been formally diagnosed as having dyslexia
I am not dyslexic [ ]

If you have been formally diagnosed as having dyslexia, have you been given any severity or classification indicators regarding your dyslexia? (E.g. mild, severe, phonological, surface, direct, etc.) Please provide details if known.

[ ]

Before signing the consent form please read the following important information

By signing this declaration I confirm that

- The following project issues have been fully explained to me: -
  - The aims of the research
  - How the trials are to be conducted
  - The potential consequences of the research
  - The likely publication of the findings
- I am aware of the experimental tasks I will be asked to perform.
- I already have/or have been taught, the required skills to operate the computer for the purposes of the experiment (e.g. how to use the keyboard/mouse).
- I understand that: -

- I have the right to withdraw from the trials at any point.
- I have the right to decline participation in the project and have been given the opportunity to decline participation
- All the data collected during the experiments will be recorded in such a way that only the researcher conducting the experiment will have access to my personal details.
- Any results presented publicly, will have all identifying features (e.g. names) removed, to ensure that my identity is not made public.
- I will be given access to all project results and conclusions.
- Any publications that result from the research will be made available to me.

Signed [ ] Dated: [ ]

Appendix 12 Reading Error Record Form – (RE1)

DUIST Project Trials – Reading Error Record Form (RE1)

Name:

Trial ID

Dyslexia Status (Please tick the box that best describes your circumstances)

Diagnosed Dyslexia
Not Dyslexic

TRIAL A

Modified Yes/No

Code	Error Type	Tally	Totals
Aet1	Mispronunciations		
Aet2	Substitutions		
Aet3	Refusals		
Aet4	Additions		
Aet5	Omissions		
Aet6	Reversals		

TRIAL B

Modified Yes/No

Code	Error Type	Tally	Totals
Bet1	Mispronunciations		
Bet2	Substitutions		
Bet3	Refusals		
Bet4	Additions		
Bet5	Omissions		
Bet6	Reversals		

TRIAL C

Modified Yes/No

Code	Error Type	Tally	Totals
Cet1	Mispronunciations		
Cet2	Substitutions		
Cet3	Refusals		
Cet4	Additions		
Cet5	Omissions		
Cet6	Reversals		

TRIAL D

Modified Yes/No

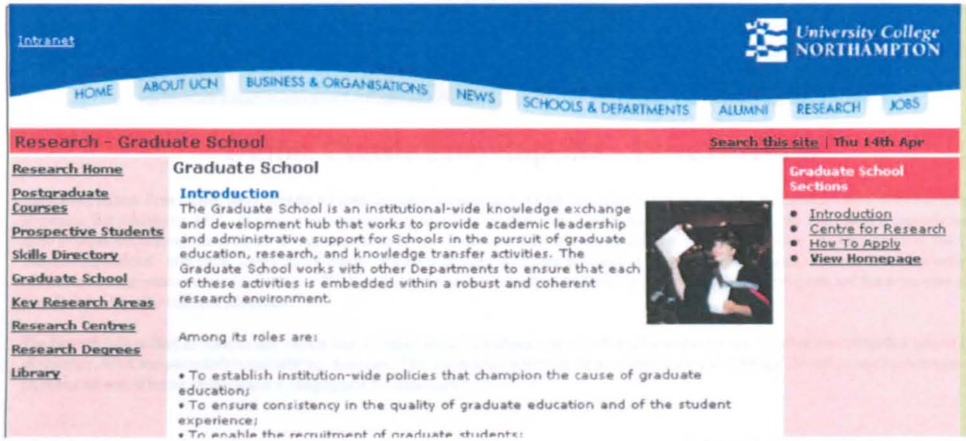
Code	Error Type	Tally	Totals
Det1	Mispronunciations		
Det2	Substitutions		
Det3	Refusals		
Det4	Additions		
Det5	Omissions		
Det6	Reversals		

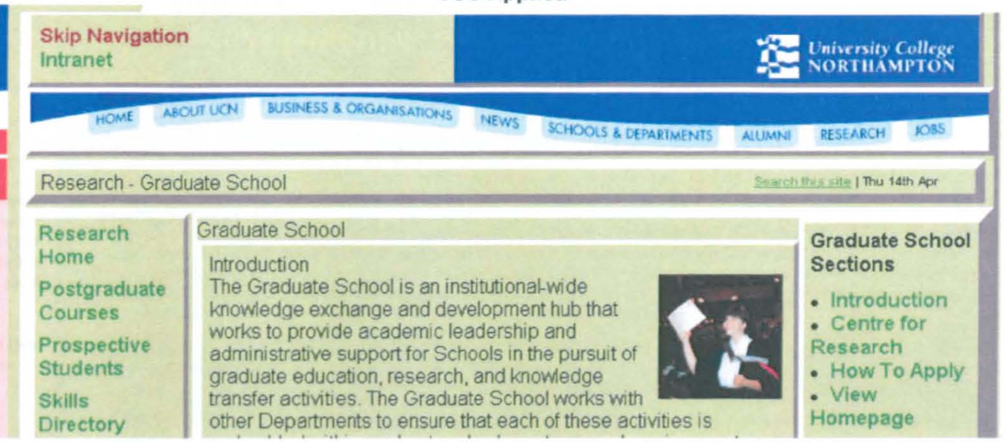
Data Entered to System: Yes/No

Signed: (Observer)

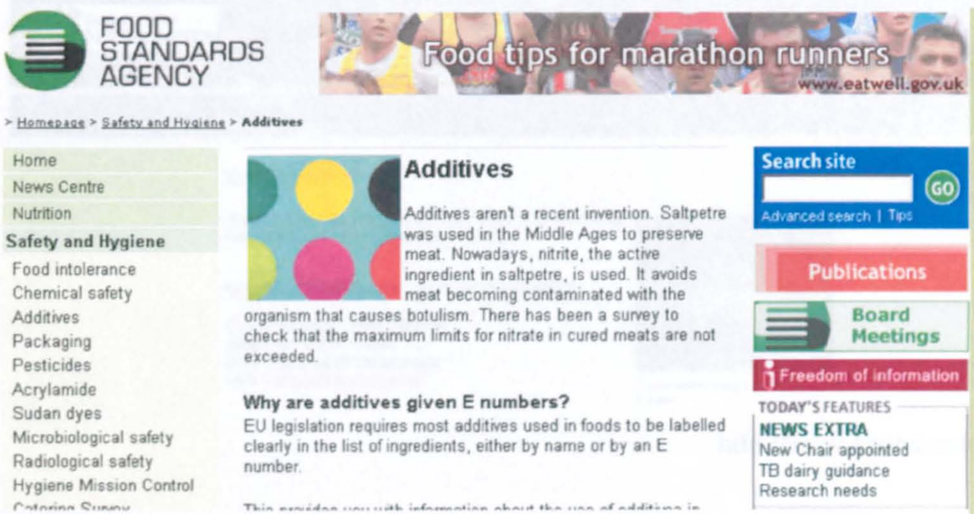
Appendix 13 - DUIST CSS Portability Example for CSS Preference file 1

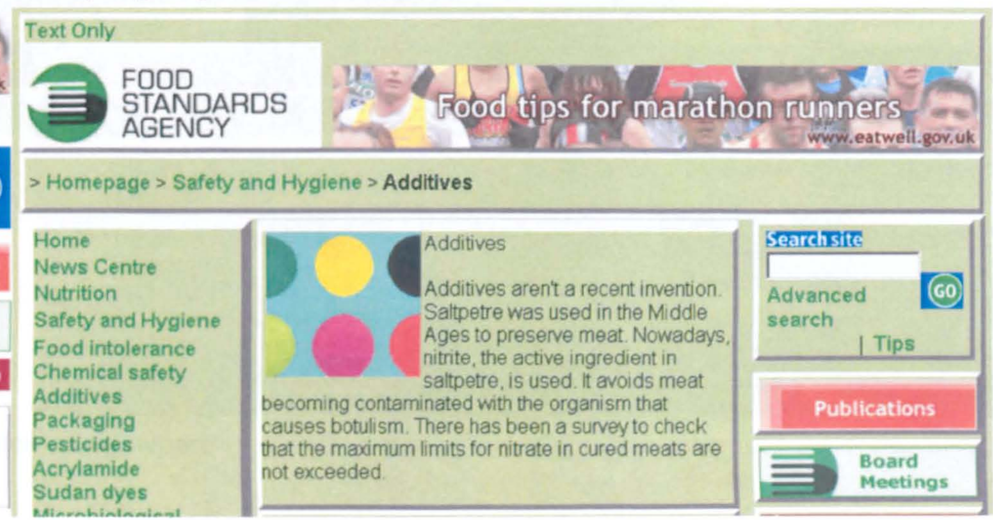
Unmodified | **CSS Applied**





http://www.northampton.ac.uk/research/postgrad/graduateschool/





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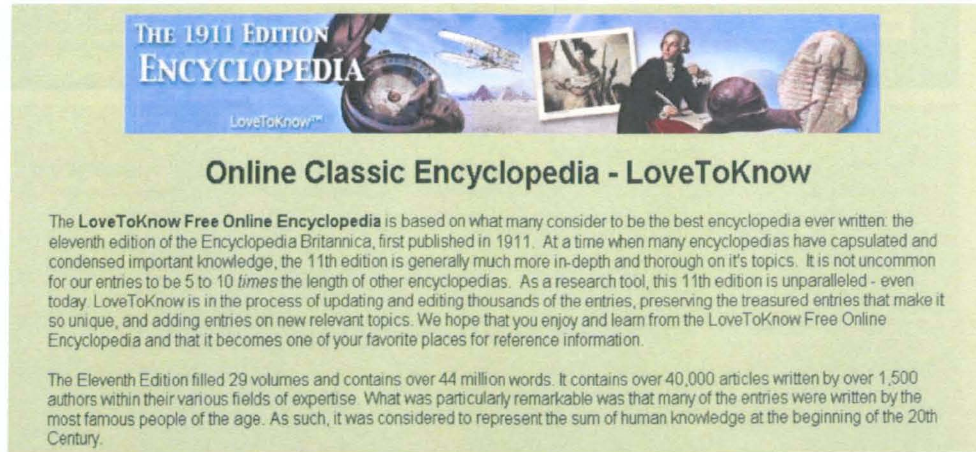

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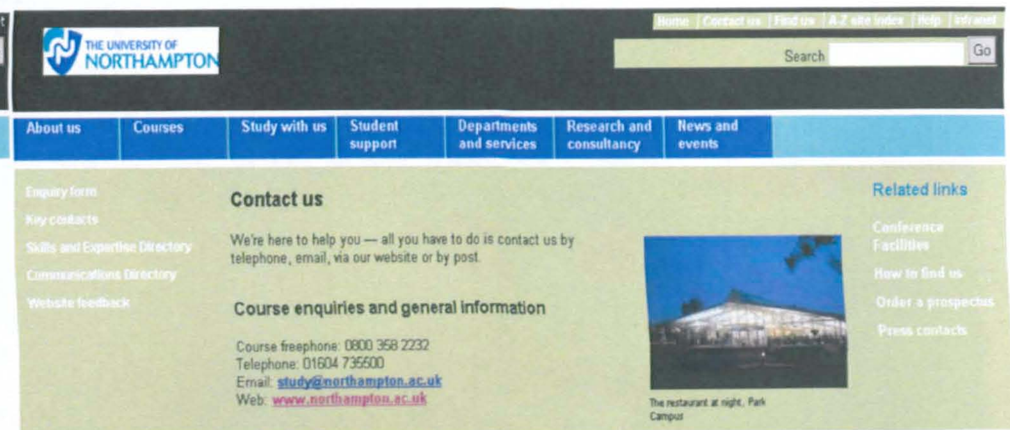

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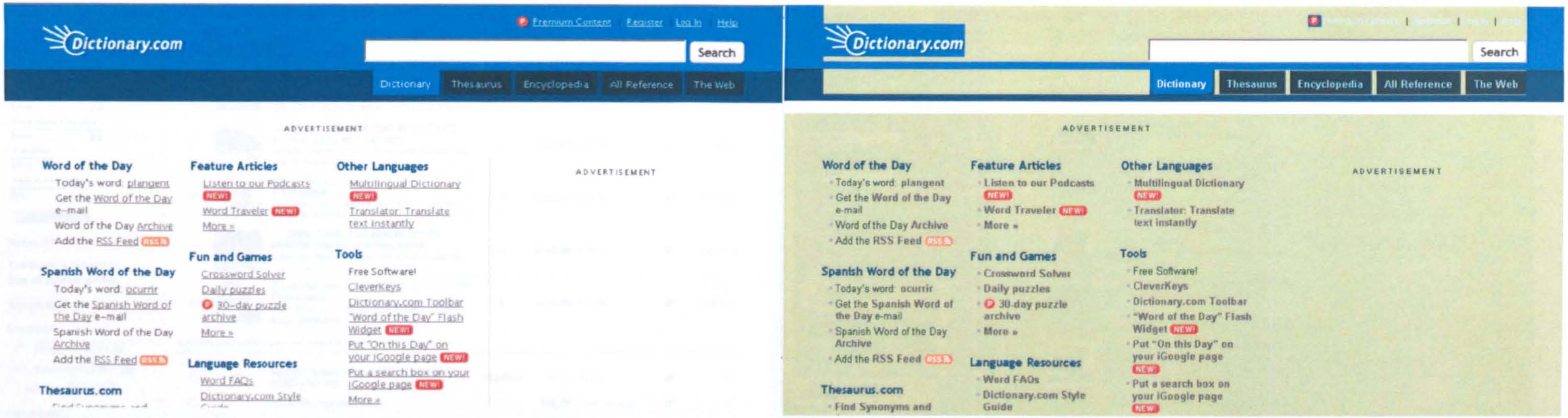
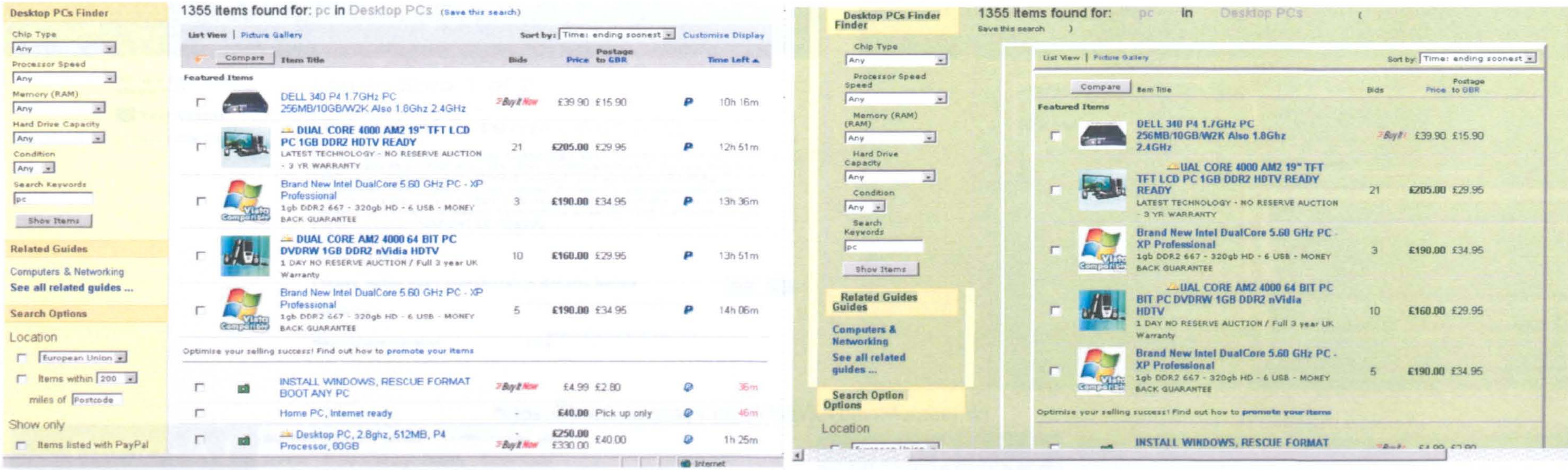


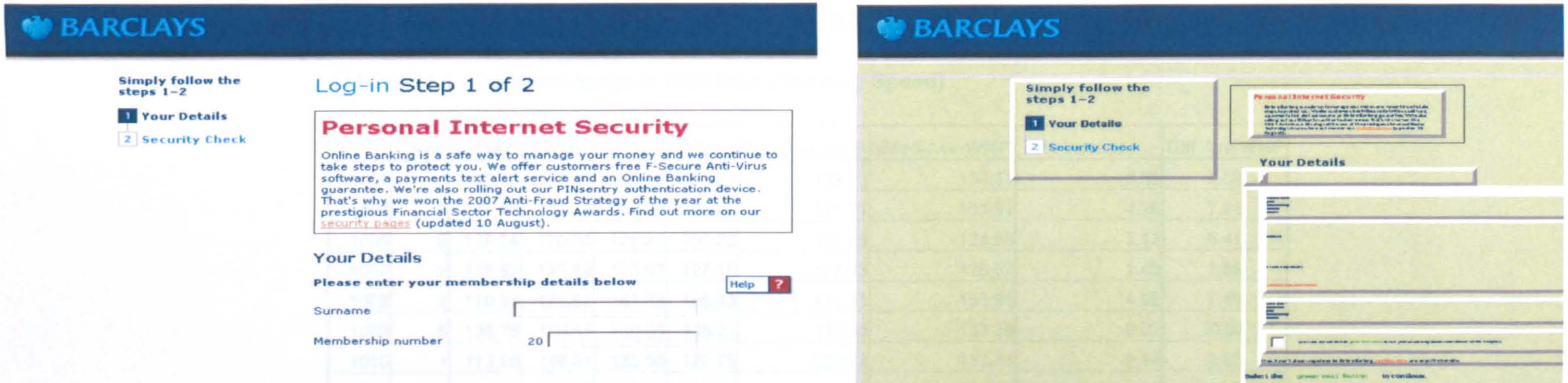
http://dictionary.reference.com/

http://www.bbc.co.uk/weather/



|http://www.ebay.co.uk/

http://www.nickjr.com/



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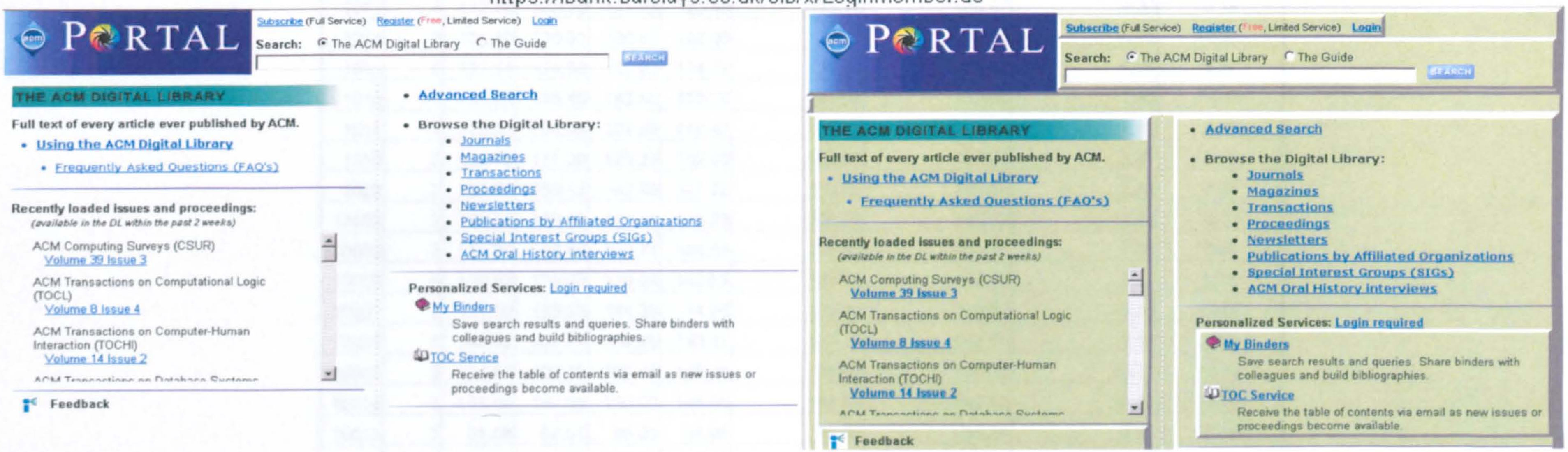


http://portal.acm.org/dl.cfm

Appendix 14 - Experimental Trials - User Reading Performance Data Set

Table A14.1 - Dyslexic Subject Trial Data (Reading Speed)

ID	Comb	A-WMP	B-WMP	C-WMP	D-WMP	Mod-Ave-WMP	NMod-Ave-WMP	% increase	Diff Ave WMP
1001	1	142.12	132.40	136.15	136.23	139.13	134.31	3.59	4.82
1003	2	171.75	171.67	161.38	166.43	171.71	163.91	4.76	7.81
1005	6	124.54	126.34	125.22	136.23	131.28	124.88	5.13	6.41
1007	2	128.97	125.89	123.97	127.18	127.43	125.57	1.48	1.86
1008	2	170.94	171.67	161.38	166.43	171.31	163.91	4.52	7.40
1009	6	136.75	130.47	130.00	136.23	133.35	133.38	-0.02	-0.03
1010	4	113.96	116.87	123.56	120.76	120.22	117.36	2.44	2.86
1011	2	131.78	128.60	123.97	127.18	130.19	125.57	3.68	4.62
1013	4	117.66	123.30	128.22	123.48	125.76	120.57	4.30	5.19
1014	2	131.30	130.95	130.91	132.00	131.13	131.45	-0.25	-0.33
1015	6	121.61	124.58	125.22	134.79	129.69	123.41	5.08	6.27
1016	1	151.00	135.40	143.45	138.70	147.22	137.05	7.43	10.18
1018	4	113.25	116.49	124.39	117.42	120.44	115.34	4.42	5.10
1019	2	132.75	133.38	125.22	132.00	133.07	128.61	3.47	4.46
1020	2	150.37	150.13	143.45	147.23	150.25	145.34	3.38	4.91
10002	2	155.54	170.86	157.31	136.23	163.20	146.77	11.19	16.43
10005	3	113.25	98.84	103.71	104.59	108.92	101.28	7.55	7.64
10006	6	139.92	138.00	133.24	146.67	142.33	136.58	4.21	5.75
10007	2	131.30	133.38	124.39	114.95	132.34	119.67	10.59	12.67
10009	5	147.92	137.47	152.20	143.37	147.78	142.69	3.57	5.09
10010	3	124.54	100.79	105.46	108.75	116.64	103.13	13.11	13.52
10014	3	153.56	142.95	156.00	145.55	149.56	149.47	0.05	0.08
10015	5	91.06	87.51	90.00	94.05	92.03	89.28	3.07	2.74
10016	2	135.73	108.07	111.10	117.06	121.90	114.08	6.85	7.82
10017	5	163.24	152.68	167.89	160.84	164.37	157.96	4.05	6.40

ID	Comb	A-WMP	B-WMP	C-WMP	D-WMP	Mod-Ave-WMP	NMod-Ave-WMP	% increase	Diff Ave WMP
10018	5	146.72	128.14	157.31	145.55	151.43	137.43	10.19	14.00
10040	6	203.60	218.78	213.94	222.56	220.67	208.77	5.70	11.90
10042	3	190.74	184.95	179.14	192.36	191.55	182.04	5.22	9.51
10047	5	138.85	139.07	143.45	145.55	144.50	138.96	3.99	5.54
10049	3	124.54	115.74	119.24	121.52	123.03	117.49	4.72	5.54
10050	1	139.38	142.38	141.82	139.71	140.60	141.04	-0.31	-0.44
10052	2	135.73	134.89	132.77	133.38	135.31	133.07	1.68	2.24
10053	6	173.40	173.33	170.18	176.41	174.87	171.79	1.79	3.08
10054	6	144.96	153.33	147.40	149.53	151.43	146.18	3.59	5.25
10056	6	157.57	159.47	160.69	161.52	160.49	159.13	0.86	1.37
10057	3	147.92	145.26	148.57	149.53	148.72	146.92	1.23	1.81
10059	2	124.97	124.15	123.97	121.91	124.56	122.94	1.32	1.62
10060	6	164.73	166.11	164.93	170.89	168.50	164.83	2.23	3.67
10062	1	129.43	125.89	130.00	126.34	129.71	126.12	2.85	3.60
10064	2	159.65	159.47	157.31	154.98	159.56	156.15	2.19	3.41
10065	3	145.54	142.38	143.45	147.80	146.67	142.91	2.63	3.76
10067	3	120.00	118.42	123.56	124.69	122.35	120.99	1.12	1.36
10068	6	162.51	166.11	163.49	165.71	165.91	163.00	1.79	2.91
10070	4	149.14	155.32	152.20	150.12	153.76	149.63	2.76	4.13
10071	1	161.07	156.68	158.64	155.61	159.86	156.15	2.38	3.71
10073	1	148.52	147.05	147.98	149.53	148.25	148.29	-0.02	-0.04
10075	4	124.97	125.89	134.19	131.10	130.04	128.03	1.57	2.01
10077	1	161.07	156.00	161.38	157.53	161.22	156.77	2.84	4.46
10078	4	139.38	142.38	141.28	139.71	141.83	139.55	1.64	2.29
10080	3	157.57	154.66	153.44	155.61	156.59	154.05	1.65	2.54
							Ave Increase	**3.66**	**4.98**

Table A14.2 - Dyslexic Subject Trial Data (Error Rates)

ID	A1	A2	A3	A4	A5	A6	AT	B1	B2	B3	B4	B5	B6	BT	C1	C2	C3	C4	C5	C6	CT	D1	D2	D3	D4	D5	D6	DT	A ErrR	B ErrR	C ErrR	D ErrR	Mod-AER	NMod-AER	% Dec	Dif ER
1001	2	4	2	2	6	1	17	2	7	1	3	6	1	20	2	5	1	3	4	2	17	2	5	2	5	5	1	20	2.81	3.34	2.72	3.13	2.77	3.24	14.51	-0.47
1003	2	5	4	5	3	2	21	3	6	5	5	2	4	25	3	7	4	7	3	6	30	3	8	3	5	3	5	27	3.48	4.18	4.81	4.23	3.83	4.52	15.29	-0.69
1005	2	5	4	4	6	4	25	4	5	3	3	5	2	22	3	6	5	5	5	3	27	4	5	2	6	6	2	25	4.14	3.68	4.33	3.92	3.80	4.23	10.26	-0.43
1007	0	3	1	2	3	1	10	1	3	0	2	3	1	10	1	3	1	3	2	1	11	2	4	1	5	2	1	15	1.66	1.67	1.76	2.35	1.66	2.06	19.11	-0.39
1008	2	4	4	2	5	1	18	1	5	2	4	4	1	17	1	5	2	5	3	4	20	2	5	3	5	2	3	20	2.98	2.84	3.21	3.13	2.91	3.17	8.15	-0.26
1009	0	2	0	3	1	2	8	0	2	1	2	1	1	7	1	2	1	1	3	1	9	0	1	2	1	2	1	7	1.32	1.17	1.44	1.10	1.13	1.38	18.04	-0.25
1010	1	2	3	2	5	2	15	1	1	2	3	4	1	12	0	2	2	3	3	2	12	2	2	5	1	5	1	16	2.48	2.01	1.92	2.51	1.96	2.50	21.27	-0.53
1011	0	3	0	2	2	3	10	0	3	0	3	2	2	10	0	2	3	2	4	1	12	0	2	1	5	2	4	14	1.66	1.67	1.92	2.19	1.66	2.06	19.18	-0.39
1013	1	2	0	6	6	1	16	0	2	1	6	5	1	15	0	2	1	3	5	0	11	1	3	2	6	5	1	18	2.65	2.51	1.76	2.82	2.14	2.74	21.92	-0.60
1014	2	1	3	1	5	3	15	2	3	2	3	6	1	17	2	1	3	5	6	2	19	1	4	2	6	5	2	20	2.48	2.84	3.04	3.13	2.66	3.09	13.81	-0.43
1015	1	6	1	7	7	3	25	1	6	2	6	6	3	24	1	4	1	7	7	3	23	1	4	2	6	7	2	22	4.14	4.01	3.69	3.45	3.73	3.91	4.64	-0.18
1016	1	4	1	2	3	1	12	1	2	4	2	4	1	14	1	3	2	2	2	1	11	1	3	3	2	3	2	14	1.99	2.34	1.76	2.19	1.87	2.27	17.33	-0.39
1018	1	3	4	3	4	1	16	2	2	4	2	3	1	14	0	2	3	2	2	1	10	2	4	2	4	5	5	22	2.65	2.34	1.60	3.45	1.97	3.05	35.32	-1.08
1019	0	2	2	5	4	2	15	1	2	4	3	4	2	16	2	3	2	4	5	2	18	0	2	5	3	5	3	18	2.48	2.68	2.88	2.82	2.58	2.85	9.58	-0.27
1020	0	3	1	3	2	1	10	2	0	3	2	2	0	9	1	1	2	3	2	0	9	1	2	1	3	2	1	10	1.66	1.51	1.44	1.57	1.58	1.50	-5.02	0.08
10002	0	1	2	1	3	0	7	0	0	2	2	2	1	7	1	2	0	4	3	2	12	2	3	1	4	4	0	14	1.16	1.17	1.92	2.19	1.16	2.06	43.42	-0.89
10005	1	2	1	1	2	1	8	1	3	2	3	3	0	12	1	2	3	3	1	1	11	1	2	1	1	2	0	7	1.32	2.01	1.76	1.10	1.21	1.88	35.76	-0.67
10006	2	1	1	2	3	0	9	4	2	0	1	2	0	9	7	0	7	1	1	0	16	2	1	1	2	3	0	9	1.49	1.51	2.56	1.41	1.46	2.03	28.08	-0.57
10007	1	3	2	1	3	1	11	0	2	1	2	2	1	8	0	3	3	4	2	2	14	1	4	3	3	4	1	16	1.82	1.34	2.24	2.51	1.58	2.38	33.52	-0.80
10009	1	2	4	5	3	1	16	2	6	11	5	2	1	27	0	1	5	2	1	1	10	0	3	7	2	1	0	13	2.65	4.52	1.60	2.04	1.82	3.58	49.19	-1.76
10010	0	5	6	1	4	1	17	5	8	9	6	5	2	35	3	8	9	7	7	1	35	5	4	2	2	4	1	18	2.81	5.85	5.61	2.82	2.82	5.73	50.83	-2.91
10014	0	2	1	2	4	0	9	1	2	0	3	2	1	9	0	5	1	4	4	0	14	1	2	1	2	1	0	7	1.49	1.51	2.24	1.10	1.29	1.87	30.98	-0.58
10015	3	13	8	13	4	0	41	4	14	13	14	7	1	53	3	12	8	8	1	1	33	6	8	6	6	1	0	27	6.79	8.86	5.29	4.23	4.76	7.83	39.17	-3.07
10016	1	3	4	2	4	0	14	1	10	8	2	0	0	21	2	16	10	7	2	0	37	3	12	6	5	5	2	33	2.32	3.51	5.93	5.17	2.91	5.55	47.49	-2.64
10017	0	1	1	0	1	0	3	0	1	2	3	0	0	6	0	2	2	2	0	0	6	1	1	2	1	0	0	5	0.50	1.00	0.96	0.78	0.87	0.75	-16.35	0.12
10018	0	2	1	3	2	0	8	1	3	2	2	1	0	9	0	3	0	2	1	1	7	0	1	0	2	3	0	6	1.32	1.51	1.12	0.94	1.03	1.41	27.12	-0.38
10040	0	1	1	2	1	0	5	1	0	0	0	0	0	1	0	1	1	3	0	0	5	0	0	0	0	2	0	2	0.83	0.17	0.80	0.31	0.24	0.81	70.49	-0.57

ID	A1	A2	A3	A4	A5	A6	AT	B1	B2	B3	B4	B5	B6	BT	C1	C2	C3	C4	C5	C6	CT	D1	D2	D3	D4	D5	D6	DT	A ErrR	B ErrR	C ErrR	D ErrR	Mod-AER	NMod-AER	% Dec	Dif ER
10042	0	1	1	2	3	0	7	0	1	1	3	4	0	9	0	1	2	1	3	0	7	0	1	1	2	2	0	6	1.16	1.51	1.12	0.94	1.05	1.31	20.08	-0.26
10047	0	3	2	4	2	2	13	1	3	3	2	2	1	12	0	1	3	2	3	1	10	1	3	0	3	2	1	10	2.15	2.01	1.60	1.57	1.58	2.08	23.78	-0.49
10049	1	6	2	5	3	2	19	2	7	3	7	4	1	24	2	8	3	6	4	1	24	2	4	3	5	2	1	17	3.15	4.01	3.85	2.66	2.91	3.93	26.07	-1.02
10050	2	4	2	1	4	3	16	2	3	3	1	5	3	17	2	3	2	2	4	3	16	1	3	5	2	5	2	18	2.65	2.84	2.56	2.82	2.61	2.83	7.96	-0.23
10052	2	8	4	10	8	2	34	3	8	3	7	7	2	30	3	10	3	10	7	2	35	2	7	7	2	7	1	26	5.63	5.02	5.61	4.08	5.32	4.84	-9.93	0.48
10053	1	3	3	1	2	2	12	1	2	2	1	2	1	9	2	3	2	3	2	2	14	2	1	3	2	2	1	11	1.99	1.51	2.24	1.72	1.61	2.12	23.67	-0.50
10054	1	3	1	3	4	1	13	1	2	2	2	3	1	11	1	3	2	4	3	2	15	2	2	2	1	2	2	11	2.15	1.84	2.40	1.72	1.78	2.28	21.79	-0.50
10056	0	2	2	1	1	3	9	0	1	2	0	1	2	6	1	2	2	2	1	1	9	0	1	2	1	1	2	7	1.49	1.00	1.44	1.10	1.05	1.47	28.37	-0.42
10057	1	5	2	5	3	2	18	1	5	2	5	6	1	20	1	3	3	6	3	3	19	1	4	3	2	3	2	15	2.98	3.34	3.04	2.35	2.67	3.19	16.56	-0.53
10059	1	7	3	7	3	2	23	2	8	2	7	3	3	25	2	9	3	8	5	3	30	2	8	5	8	6	1	30	3.81	4.18	4.81	4.70	3.99	4.75	16.00	-0.76
10060	0	2	3	3	1	2	11	0	1	3	2	1	2	9	1	1	3	3	1	2	11	1	2	1	2	1	1	8	1.82	1.51	1.76	1.25	1.38	1.79	23.02	-0.41
10062	1	4	3	2	3	4	17	0	5	2	4	3	5	19	1	4	3	1	2	5	16	1	5	1	4	4	5	20	2.81	3.18	2.56	3.13	2.69	3.16	14.79	-0.47
10064	1	5	5	2	5	2	20	1	5	2	5	3	3	19	2	7	6	1	6	3	25	2	7	7	2	6	2	26	3.31	3.18	4.01	4.08	3.24	4.04	19.71	-0.80
10065	0	2	2	3	1	2	10	1	3	2	1	3	3	13	0	2	4	2	3	3	14	1	2	2	2	2	1	10	1.66	2.17	2.24	1.57	1.61	2.21	27.04	-0.60
10067	2	10	8	7	10	2	39	2	12	6	9	10	3	42	2	10	11	3	8	2	36	3	7	6	2	7	2	27	6.46	7.02	5.77	4.23	5.34	6.40	16.44	-1.05
10068	1	7	2	7	3	2	22	1	6	1	5	3	1	17	1	6	3	6	3	1	20	0	5	1	5	3	1	15	3.64	2.84	3.21	2.35	2.60	3.42	24.15	-0.83
10070	1	3	5	3	3	1	16	1	2	6	1	3	1	14	0	2	6	2	2	2	14	1	3	6	2	3	2	17	2.65	2.34	2.24	2.66	2.29	2.66	13.72	-0.36
10071	0	1	2	1	3	0	7	0	2	3	1	2	0	8	1	0	2	1	2	0	6	1	2	1	2	2	0	8	1.16	1.34	0.96	1.25	1.06	1.30	18.18	-0.24
10073	1	5	1	5	4	1	17	1	6	2	5	6	1	21	0	4	3	4	3	1	15	2	6	2	3	5	1	19	2.81	3.51	2.40	2.98	2.61	3.24	19.59	-0.64
10075	0	2	2	2	5	3	14	1	2	2	2	5	2	14	1	2	1	2	5	1	12	1	2	2	2	5	1	13	2.32	2.34	1.92	2.04	2.13	2.18	2.10	-0.05
10077	0	1	1	2	3	2	9	0	2	2	1	2	2	9	0	1	2	3	2	1	9	0	2	3	2	2	1	10	1.49	1.51	1.44	1.57	1.47	1.54	4.56	-0.07
10078	2	3	3	6	6	1	21	1	2	3	5	3	1	15	1	2	3	5	5	0	16	2	2	4	6	5	0	19	3.48	2.51	2.56	2.98	2.54	3.23	21.42	-0.69
10080	0	3	2	3	4	0	12	1	2	2	4	4	0	13	0	2	2	5	5	0	14	0	1	2	3	5	0	11	1.99	2.17	2.24	1.72	1.86	2.21	16.00	-0.35
																																	Average decrease		21.16	-0.64

Table A14.3 - Non-Dyslexic Subject Trial Data (Speed)

ID	Comb	A-WMP	B-WMP	C-WMP	D-WMP	Mod-Ave-WMP	NMod-Ave-WMP	% increase	Dif Ave WMP
1002	2	173.40	166.11	167.14	172.43	169.75	169.79	-0.02	-0.03
1004	4	182.11	188.84	183.53	187.65	186.19	184.88	0.71	1.31
1006	5	171.75	178.51	180.00	174.00	177.00	175.13	1.07	1.87
1012	3	166.24	160.18	177.44	172.43	169.34	168.81	0.31	0.53
1017	4	183.03	184.00	183.53	187.65	183.76	185.34	-0.85	-1.57
1021	2	169.35	166.11	170.18	172.43	167.73	171.31	-2.09	-3.58
10003	1	180.30	171.67	172.53	184.04	176.42	177.86	-0.81	-1.44
10004	3	151.00	132.40	140.75	139.20	145.10	136.58	6.24	8.52
10008	5	180.30	178.51	177.44	182.29	179.86	179.40	0.26	0.46
10011	6	126.71	118.42	123.56	127.60	123.01	125.14	-1.70	-2.13
10012	6	194.84	188.84	202.38	190.45	189.64	198.61	-4.51	-8.96
10013	2	179.41	177.62	182.63	179.72	178.51	181.18	-1.47	-2.66
10019	5	149.14	142.95	150.36	147.23	148.80	146.04	1.89	2.75
10020	1	178.52	161.62	171.74	165.71	175.13	163.67	7.00	11.46
10021	2	147.32	123.72	132.77	128.46	135.52	130.61	3.76	4.91
10022	2	198.03	172.50	192.00	174.00	185.27	183.00	1.24	2.27
10023	5	184.90	162.35	183.53	169.38	176.45	173.63	1.63	2.83
10024	4	194.84	188.84	193.99	189.50	191.42	192.17	-0.39	-0.76
10025	1	141.01	137.47	143.45	143.37	142.23	140.42	1.29	1.81
10026	6	199.12	196.07	154.07	160.17	178.12	176.60	0.86	1.52
10027	5	157.57	144.10	149.76	153.73	151.75	150.83	0.61	0.92
10028	6	168.56	163.84	172.53	161.52	162.68	170.55	-4.61	-7.87
10029	5	175.92	163.09	166.40	156.89	161.64	169.51	-4.64	-7.86
10030	1	191.75	188.84	199.15	196.31	195.45	192.57	1.49	2.87
10031	6	170.14	169.25	176.60	177.22	173.23	173.37	-0.08	-0.14
10032	2	126.71	119.60	124.39	121.52	123.16	122.95	0.16	0.20
10033	6	214.44	206.21	200.21	204.71	205.46	207.33	-0.90	-1.87

ID	Comb	A-WMP	B-WMP	C-WMP	D-WMP	Mod-Ave-WMP	NMod-Ave-WMP	% Increase	Dif Ave WMP
10034	1	149.75	148.26	149.16	151.30	149.46	149.78	-0.22	-0.33
10035	6	209.48	217.45	213.94	212.67	215.06	211.71	1.58	3.35
10036	5	205.91	191.87	206.85	195.31	201.08	198.89	1.10	2.19
10037	4	171.75	173.33	167.14	173.21	170.24	172.48	-1.30	-2.25
10038	4	191.75	189.84	196.02	192.36	192.93	192.05	0.46	0.88
10039	4	169.35	152.68	168.65	156.89	160.66	163.12	-1.50	-2.45
10041	1	116.53	115.00	123.56	124.29	120.05	119.64	0.34	0.40
10043	2	213.18	209.82	204.59	215.06	211.50	209.82	0.80	1.68
10044	2	188.75	186.88	187.20	188.57	187.81	187.89	-0.04	-0.07
10045	1	119.21	120.00	122.35	125.92	120.78	122.96	-1.77	-2.18
10046	4	144.38	142.95	156.65	155.61	149.80	150.00	-0.13	-0.20
10048	1	174.23	170.86	169.41	176.41	171.82	173.63	-1.04	-1.81
10051	1	199.12	188.84	196.02	197.32	197.57	193.08	2.33	4.49
10055	2	190.74	185.91	185.35	190.45	188.32	187.90	0.23	0.42
10058	1	190.74	190.85	190.05	192.36	190.39	191.61	-0.63	-1.21
10061	1	195.89	195.00	196.02	196.31	195.96	195.65	0.15	0.30
10063	3	188.75	187.85	188.14	187.65	188.20	188.00	0.11	0.20
10066	1	190.74	196.07	192.99	195.31	191.86	195.69	-1.95	-3.82
10069	1	187.77	187.85	187.20	186.73	187.49	187.29	0.10	0.19
10072	2	205.91	203.86	201.29	205.81	204.89	203.55	0.66	1.34
10074	2	169.35	172.50	168.65	170.89	170.92	169.77	0.68	1.15
10076	4	199.12	200.45	200.21	200.42	200.33	199.77	0.28	0.56
10079	6	172.57	171.67	173.33	175.60	173.64	172.95	0.39	0.68
							Ave Increase	**0.14**	0.18

Table A14.4 - Dyslexic Subject Trial Data (Error Rates)

ID	A1	A2	A3	A4	A5	A6	AT	B1	B2	B3	B4	B5	B6	BT	C1	C2	C3	C4	C5	C6	CT	D1	D2	D3	D4	D5	D6	DT	A ErrR	B ErrR	C ErrR	D ErrR	Mod-AER	NMod-AER	% Dec	Dif ER
1002	0	2	0	1	1	0	4	0	1	0	1	1	0	3	0	1	0	1	2	0	4	1	1	0	1	1	0	4	0.66	0.50	0.64	0.63	0.58	0.63	8.21	-0.05
1004	0	1	0	1	1	0	3	0	1	0	0	1	0	2	0	1	0	1	1	0	3	0	0	0	2	1	0	3	0.50	0.33	0.48	0.47	0.41	0.48	15.69	-0.08
1006	0	1	0	2	1	0	4	0	2	1	1	0	0	4	0	2	0	1	1	0	4	0	1	0	1	1	0	3	0.66	0.67	0.64	0.47	0.56	0.67	16.52	-0.11
1012	0	0	0	0	1	0	1	0	0	0	1	0	1	2	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0.17	0.33	0.16	0.16	0.16	0.25	34.85	-0.09
1017	0	0	0	1	1	0	2	0	0	0	1	1	0	2	0	0	0	0	1	0	1	0	0	0	2	0	0	2	0.33	0.33	0.16	0.31	0.25	0.32	23.25	-0.07
1021	0	1	0	1	2	0	4	0	1	0	2	0	0	3	1	1	0	1	1	0	4	0	1	0	2	1	0	4	0.66	0.50	0.64	0.63	0.58	0.63	8.21	-0.05
10003	0	0	1	0	1	0	2	0	2	1	0	1	0	4	1	1	1	3	1	0	7	1	1	1	2	1	0	6	0.33	0.67	1.12	0.94	0.73	0.80	9.72	-0.08
10004	0	2	2	0	1	0	5	2	3	1	1	0	0	7	2	2	0	2	2	0	8	0	1	0	1	1	0	3	0.83	1.17	1.28	0.47	0.65	1.23	47.08	-0.58
10008	0	0	0	1	0	0	1	0	1	0	1	0	1	3	0	1	3	0	0	0	4	1	0	2	0	0	0	3	0.17	0.50	0.64	0.47	0.56	0.33	-66.54	0.22
10011	0	2	2	1	1	0	6	0	2	2	3	0	0	7	0	4	2	1	0	1	8	2	3	0	2	0	1	8	0.99	1.17	1.28	1.25	1.21	1.14	-6.55	0.07
10012	0	1	0	1	0	0	2	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1	0	1	0	0	0	2	0.33	0.17	0.16	0.31	0.24	0.25	2.17	-0.01
10013	0	2	0	1	1	0	4	0	1	1	1	1	0	4	1	2	0	1	1	0	5	0	4	0	1	0	0	5	0.66	0.67	0.80	0.78	0.67	0.79	16.01	-0.13
10019	0	4	0	3	1	0	8	1	6	0	4	1	0	12	0	4	0	3	0	0	7	1	2	1	3	0	0	7	1.32	2.01	1.12	1.10	1.11	1.67	33.39	-0.56
10020	0	1	0	2	0	1	4	0	1	2	1	2	0	6	0	1	0	1	1	0	3	0	1	0	1	1	0	3	0.66	1.00	0.48	0.47	0.57	0.74	22.43	-0.17
10021	0	3	1	3	0	0	7	1	5	1	1	0	0	8	1	7	3	5	0	0	16	1	3	2	2	2	0	10	1.16	1.34	2.56	1.57	1.25	2.07	39.57	-0.82
10022	0	1	0	0	0	0	1	0	1	0	1	0	0	2	0	1	1	0	0	0	2	0	1	0	1	0	1	3	0.17	0.33	0.32	0.47	0.25	0.40	36.77	-0.15
10023	0	1	0	2	2	0	5	0	1	1	0	1	0	3	2	0	0	1	0	0	3	0	1	0	1	0	1	3	0.83	0.50	0.48	0.47	0.48	0.66	28.47	-0.19
10024	1	2	0	2	3	0	8	0	2	1	0	3	0	6	0	3	1	3	0	0	7	0	2	1	3	1	0	7	1.32	1.00	1.12	1.10	1.06	1.21	12.25	-0.15
10025	0	3	2	2	1	0	8	4	2	1	1	1	0	9	1	3	0	2	2	0	8	0	2	2	3	2	0	9	1.32	1.51	1.28	1.41	1.30	1.46	10.60	-0.15
10026	0	0	0	2	1	0	3	0	1	0	2	0	0	3	0	0	0	2	1	0	3	0	0	1	1	1	0	3	0.50	0.50	0.48	0.47	0.49	0.49	0.57	0.00
10027	0	0	0	2	0	0	2	0	1	2	2	1	0	6	1	1	0	3	1	1	7	0	1	1	1	1	0	4	0.33	1.00	1.12	0.63	0.87	0.67	-31.04	0.21
10028	0	2	2	1	1	0	6	2	2	1	0	2	0	7	2	3	2	1	0	0	8	1	2	1	1	2	0	7	0.99	1.17	1.28	1.10	1.13	1.14	0.34	0.00
10029	0	4	2	2	1	1	10	2	2	1	1	2	1	9	2	2	4	1	2	0	11	2	2	3	0	3	2	12	1.66	1.51	1.76	1.88	1.82	1.58	-15.28	0.24
10030	0	1	0	2	1	0	4	0	1	1	0	1	1	4	0	1	0	1	0	2	4	0	1	0	1	2	0	4	0.66	0.67	0.64	0.63	0.65	0.65	-0.57	0.00
10031	1	1	0	1	1	0	4	0	1	0	1	2	0	4	1	1	0	1	2	0	5	1	1	0	1	1	0	4	0.66	0.67	0.80	0.63	0.65	0.73	11.46	-0.08
10032	5	2	2	1	2	3	15	6	3	1	1	2	2	15	6	1	2	1	2	3	15	6	1	2	2	2	2	15	2.48	2.51	2.40	2.35	2.50	2.38	-4.98	0.12
10033	1	1	0	2	0	0	4	1	0	0	1	2	0	4	1	1	0	1	1	0	4	1	0	0	1	2	0	4	0.66	0.67	0.64	0.63	0.65	0.65	0.57	0.00

ID	A1	A2	A3	A4	A5	A6	AT	B1	B2	B3	B4	B5	B6	BT	C1	C2	C3	C4	C5	C6	CT	D1	D2	D3	D4	D5	D6	DT	A ErrR	B ErrR	C ErrR	D ErrR	Mod-AER	NMod-AER	% Dec	Dif ER
10034	4	2	2	1	2	1	12	4	3	1	1	2	1	12	5	1	1	3	1	1	12	5	2	3	1	1	0	12	1.99	2.01	1.92	1.88	1.95	1.94	-0.57	0.01
10035	3	1	3	1	1	0	9	4	1	3	0	1	0	9	2	1	5	1	1	0	10	3	2	3	1	1	0	10	1.49	1.51	1.60	1.57	1.54	1.55	0.65	-0.01
10036	1	0	4	2	0	0	7	1	1	1	3	1	0	7	0	1	3	1	1	0	6	0	1	2	2	2	0	7	1.16	1.17	0.96	1.10	1.03	1.16	11.62	-0.14
10037	1	2	1	3	2	0	9	3	1	0	2	2	1	9	2	2	1	2	0	1	8	2	1	1	1	2	1	8	1.49	1.51	1.28	1.25	1.39	1.37	-1.57	0.02
10038	1	2	1	3	1	0	8	2	2	1	1	1	0	7	1	1	2	1	1	0	6	2	2	1	1	2	0	8	1.32	1.17	0.96	1.25	1.07	1.29	17.31	-0.22
10039	0	2	1	2	1	0	6	0	2	1	2	1	0	6	0	2	1	1	2	0	6	1	1	1	2	1	1	7	0.99	1.00	0.96	1.10	0.98	1.05	6.01	-0.06
10041	0	2	2	2	1	0	7	1	1	3	3	1	0	9	0	3	2	2	1	0	8	0	2	2	1	2	0	7	1.16	1.51	1.28	1.10	1.22	1.30	6.19	-0.08
10043	0	1	0	1	1	0	3	0	1	1	0	1	0	3	0	1	0	1	0	0	2	0	1	0	0	1	0	2	0.50	0.50	0.32	0.31	0.50	0.32	-57.47	0.18
10044	0	2	2	1	1	0	6	0	2	1	0	1	1	5	0	2	2	1	1	1	7	1	2	2	1	0	0	6	0.99	0.84	1.12	0.94	0.91	1.03	11.29	-0.12
10045	0	1	5	5	1	0	12	0	1	6	4	2	0	13	1	1	5	8	3	0	18	1	2	5	5	2	0	15	1.99	2.17	2.88	2.35	2.44	2.26	-7.65	0.17
10046	0	1	2	3	1	0	7	1	1	4	1	1	0	8	1	1	2	1	2	0	7	1	1	0	2	2	0	6	1.16	1.34	1.12	0.94	1.23	1.05	-17.16	0.18
10048	0	1	0	1	2	0	4	0	2	1	0	1	0	4	0	0	0	2	1	0	3	0	1	0	1	1	0	3	0.66	0.67	0.48	0.47	0.57	0.57	-0.34	0.00
10051	0	1	0	0	1	0	2	0	0	0	1	1	0	2	1	1	0	1	0	0	3	0	0	0	1	1	0	2	0.33	0.33	0.48	0.31	0.41	0.32	-25.31	0.08
10055	0	0	0	0	2	0	2	0	0	0	1	1	0	2	0	0	0	1	1	0	2	0	0	1	0	1	0	2	0.33	0.33	0.32	0.31	0.33	0.32	-4.98	0.02
10058	0	2	0	1	1	0	4	0	1	1	1	1	0	4	0	1	0	1	1	0	3	1	1	0	1	1	0	4	0.66	0.67	0.48	0.63	0.57	0.65	11.79	-0.08
10061	0	0	0	0	2	1	3	0	0	0	1	1	0	2	0	0	0	0	1	0	1	0	0	0	1	1	0	2	0.50	0.33	0.16	0.31	0.33	0.32	-1.39	0.00
10063	0	1	2	1	2	0	6	0	1	2	1	3	0	7	1	1	2	1	2	0	7	0	2	1	1	2	0	6	0.99	1.17	1.12	0.94	0.97	1.15	15.64	-0.18
10066	0	2	0	0	1	0	3	0	1	0	1	1	0	3	0	1	0	0	2	0	3	0	0	1	1	1	0	3	0.50	0.50	0.48	0.47	0.49	0.49	-0.57	0.00
10069	0	1	0	2	1	0	4	0	1	1	2	1	0	5	0	0	2	0	2	0	4	0	0	1	1	2	0	4	0.66	0.84	0.64	0.63	0.65	0.73	10.92	-0.08
10072	0	0	0	0	2	0	2	0	0	0	1	1	0	2	0	1	0	1	1	0	3	0	0	0	0	1	0	1	0.33	0.33	0.48	0.16	0.33	0.32	-4.40	0.01
10074	0	2	0	1	1	0	4	0	1	0	2	1	0	4	0	1	0	2	1	0	4	0	1	0	1	1	0	3	0.66	0.67	0.64	0.47	0.67	0.56	-19.79	0.11
10076	0	2	1	2	1	0	6	0	1	3	0	1	0	5	0	2	2	1	1	0	6	0	2	0	1	2	0	5	0.99	0.84	0.96	0.78	0.90	0.89	-1.16	0.01
10079	1	0	0	0	2	1	4	0	1	0	1	1	0	3	1	0	0	0	1	0	2	1	0	0	0	2	0	3	0.66	0.50	0.32	0.47	0.49	0.49	1.11	-0.01
																																	Average decrease		4.07	-0.06

Key: -

SPEED

Column	Meaning
ID	Subject Trial ID
Comb	Combination of Modified/Non-Modified Textual Displays
A-WMP	Reading Speed for Text A (wmp)
B-WMP	Reading Speed for Text B (wmp)
C-WMP	Reading Speed for Text C (wmp)
D-WMP	Reading Speed for Text D (wmp)
Mod-Ave-WMP	Average Modified Reading Speed (wmp)
NMod-Ave-WMP	Average Non-Modified Reading Speed (wmp)
% Increase	Overall % Increase in Reading Speed
Diff Ave WMP	Overall Differential In Reading Speed

ERROR RATE

Column	Meaning
ID	Subject Trial ID
A1, B1, C1, D1	Total Mispronunciations (for text A,B,C,D)
A2, B2, C2, D2	Total Substitutions (for text A,B,C,D)
A3, B3, C3, D3	Total Refusals (for text A,B,C,D)
A4, B4, C4, D4	Total Additions (for text A,B,C,D)
A5, B5, C5, D5	Total Omissions (for text A,B,C,D)
A6, B6, C6, D6	Total Reversals (for text A,B,C,D)
AT, BT, CT, DT	Total Errors (for text A, B, C, D)
A ErrR	Average Reading Errors Per 100 words for Text A
B ErrR	Average Reading Errors Per 100 words for Text B
C ErrR	Average Reading Errors Per 100 words for Text C
D ErrR	Average Reading Errors Per 100 words for Text D
Mod-AER	Average Error Rate with Screens Modified
NMod-AER	Average Error Rate with Screens Non-Modified
% Dec	Overall % Decrease in Reading Errors (Errors per 100 words)
Dif ER	Overall Differential In Reading Errors (Error per 100 words)

Appendix 15 - Experimental Trials – *User Profile Attribute Selection Data Set*

Table A15.1 - Dyslexic User Profile Data

Id	Font Type	Font Size	Back Col	Fore Col	Base Link	Used Link	Line Lgt	Lnk Style	Head Sty	Bor Style	Nav Style
1001	4	3	'990099'	'CC99FF'	'FF0066'	'FF9933'	2	2	1	1	3
1003	2	3	'666666'	'FFFF99'	'99CC00'	'993366'	3	2	1	4	3
1005	2	3	'FF9933'	'CC0066'	'9966CC'	'CCCC99'	2	2	1	1	3
1007	9	3	'CC9933'	'330066'	'9966CC'	'CCCC99'	2	1	1	1	3
1008	4	3	'666666'	'330033'	'99CC00'	'993366'	3	2	1	1	3
1009	4	3	'CCFF99'	'660000'	'FF0066'	'FF9933'	3	2	2	2	2
1010	1	3	'CC9933'	'660000'	'CC33FF'	'666633'	2	3	1	2	1
1011	4	4	'66CC99'	'333300'	'FF0066'	'FF9933'	2	2	1	1	3
1013	8	3	'CC9933'	'990099'	'CC33FF'	'666633'	1	2	1	1	3
1014	2	3	'3333FF'	'CCFF99'	'333300'	'CC0066'	2	2	1	1	3
1015	2	4	'666666'	'CCCC99'	'66CC99'	'CC0033'	2	2	1	1	2
1016	8	3	'CC99FF'	'990033'	'CC0066'	'996600'	2	2	2	1	3
1018	4	3	'666666'	'FFCCFF'	'66CC99'	'CC0033'	3	2	2	2	3
1019	4	4	'9966FF'	'FFCC66'	'FF0066'	'FF9933'	2	2	1	1	3
1020	2	3	'99CC99'	'333300'	'CC0066'	'996600'	2	2	1	1	2
10002	9	3	'FFFF00'	'003300'	'CC33FF'	'666633'	2	3	3	2	2
10005	2	3	'999966'	'000000'	'00FF00'	'CC0066'	3	2	2	2	3
10006	2	3	'CCFFFF'	'000000'	'CCCC99'	'993366'	3	2	4	2	3
10007	1	3	'FF9933'	'660000'	'CC33FF'	'666633'	3	1	3	3	3
10009	2	3	'99CC00'	'333300'	'993366'	'660000'	2	1	1	1	1
10010	2	2	'000099'	'CCFF99'	'CCCC99'	'993366'	2	1	3	2	1
10014	9	3	'330066'	'FFFF00'	'FFFFFF'	'990033'	2	2	1	2	1
10015	6	2	'330033'	'CC99FF'	'66CC99'	'CC0033'	2	2	3	1	2
10016	6	3	'99CC99'	'3300CC'	'993366'	'660000'	1	2	3	4	1
10017	4	3	'3300CC'	'FFFFFF'	'003300'	'FF3300'	2	1	1	1	2
10018	9	3	'CC33FF'	'3300CC'	'CC0066'	'996600'	2	3	3	2	1
10040	4	3	'000099'	'CCFF99'	'FFFFFF'	'990033'	3	3	4	1	1
10042	2	3	'FFCC66'	'660000'	'CC33FF'	'666633'	3	2	3	3	2
10047	1	3	'996666'	'FFFFCC'	'9999FF'	'FFFFFF'	2	1	3	2	2
10049	4	3	'99CC00'	'330033'	'CC0066'	'996600'	2	2	3	3	3
10050	9	3	'990033'	'FFFFFF'	'00FF00'	'CC0066'	3	2	3	1	3
10052	4	3	'996600'	'330066'	'9966FF'	'CCCCCC'	2	2	3	3	2
10053	1	3	'99CC99'	'996600'	'CC0066'	'996600'	3	2	3	4	3
10054	4	4	'CCCCCC'	'FF3300'	'66CC99'	'CC0033'	3	2	1	3	3
10056	2	3	'996666'	'FFFF00'	'9966FF'	'CCCCCC'	3	2	2	1	2
10057	4	3	'009933'	'000000'	'FF0066'	'FF9933'	2	2	1	4	3
10059	1	3	'CC9933'	'3300CC'	'CC33FF'	'666633'	2	2	1	1	3
10060	2	3	'339966'	'330033'	'FF0066'	'FF9933'	3	2	2	2	2
10062	2	3	'FF9966'	'000000'	'CC33FF'	'666633'	3	1	2	2	3
10064	1	3	'99CCFF'	'990099'	'333300'	'CC0066'	2	2	2	3	3
10065	4	3	'339966'	'000000'	'CC0066'	'996600'	3	2	4	1	2
10067	2	3	'3399FF'	'CC0033'	'333300'	'CC0066'	2	1	1	3	3
10068	8	3	'00CC33'	'330066'	'FF0066'	'FF9933'	3	2	4	3	3
10070	9	3	'666666'	'CCCCCC'	'99CC00'	'993366'	3	2	2	2	2
10071	4	3	'66CC99'	'000099'	'CC0066'	'996600'	2	1	1	4	2
10073	2	3	'CCCC99'	'CC0033'	'009933'	'990033'	3	2	2	1	3
10075	1	3	'FF9966'	'CC0033'	'CC33FF'	'666633'	3	2	3	3	3
10077	1	3	'CCCC99'	'9933CC'	'009933'	'990033'	3	2	4	1	3
10078	2	4	'99CC00'	'000000'	'CC0066'	'996600'	3	2	1	4	3
10080	2	3	'9933CC'	'FFFF00'	'FFCCFF'	'FFFFCC'	3	2	2	3	2

Table A15.2 - Non-Dyslexic User Profile Data

Id	Font Type	Font Size	Back Col	Fore Col	Base Link	Used Link	Line Lgt	Lnk Style	Head Sty	Bor Style	Nav Style
1002	9	3	'CC9933'	'660000'	'9966CC'	'CCCC99'	1	1	4	4	2
1004	5	3	'666666'	'000000'	'99CC00'	'993366'	1	3	2	1	3
1006	8	3	'9966CC'	'660000'	'FF0066'	'FF9933'	1	1	1	2	1
1012	8	3	'666666'	'FFCC66'	'66CC99'	'CC0033'	1	1	1	2	3
1017	6	3	'000000'	'FFFFFF'	'00FF00'	'CC0066'	1	1	1	1	3
1021	6	3	'663333'	'FFCCFF'	'66CC99'	'CC0033'	1	3	2	2	1
10003	6	3	'99CC99'	'330066'	'993366'	'660000'	2	1	3	2	1
10004	9	4	'300000'	'FFFF00'	'FFFFFF'	'990033'	3	1	1	1	2
10008	9	3	'FFFFCC'	'330066'	'CC33FF'	'666633'	2	1	4	4	2
10011	3	5	'99CC00'	'330066'	'993366'	'660000'	3	3	2	2	1
10012	9	5	'990099'	'330066'	'993366'	'660000'	3	1	1	2	2
10013	1	3	'99CCFF'	'000000'	'FFFFFF'	'990033'	3	2	1	4	3
10019	9	3	'666666'	'FFCCFF'	'66CC99'	'CC0033'	2	1	4	1	1
10020	1	3	'000000'	'FFCCFF'	'66CC99'	'CC0033'	2	1	4	2	1
10021	1	3	'FFCC66'	'000000'	'9933CC'	'999966'	3	1	1	1	2
10022	1	3	'99CC00'	'330033'	'993366'	'660000'	2	2	2	2	2
10023	4	4	'333300'	'FFFFFF'	'CC33FF'	'666633'	2	2	2	2	2
10024	6	3	'00FF00'	'333300'	'993366'	'660000'	2	3	2	1	3
10025	9	3	'FF0099'	'FFFFFF'	'009933'	'990033'	1	1	3	1	2
10026	1	3	'303060'	'FFFFFF'	'EEEEEE'	'DDDDDD'	1	3	3	2	1
10027	9	3	'FFCCFF'	'330066'	'00FF00'	'CC0066'	1	1	4	4	1
10028	9	3	'FFFF99'	'330066'	'9933CC'	'999966'	2	1	1	1	1
10029	2	3	'CC9933'	'330033'	'9966CC'	'CCCC99'	2	3	1	2	2
10030	6	3	'FFFFFF'	'000000'	'00FF00'	'CC0066'	2	3	1	1	3
10031	1	3	'0066FF'	'00FF00'	'FFFFFF'	'990033'	1	1	2	1	1
10032	8	3	'FF9933'	'666666'	'9966CC'	'CCCC99'	2	2	2	2	3
10033	9	5	'FFCCCC'	'330066'	'CC33FF'	'666633'	1	2	2	1	1
10034	9	2	'FFFFCC'	'330066'	'9966CC'	'CCCC99'	3	3	4	4	1
10035	1	4	'000000'	'FFCCFF'	'336666'	'FFFFCC'	3	3	2	2	2
10036	1	3	'FFFF00'	'3300CC'	'9966FF'	'CCCCCC'	2	3	3	4	2
10037	2	3	'3333FF'	'CCFF99'	'003300'	'FF3300'	2	2	3	2	2
10038	9	2	'000000'	'FFFF99'	'336666'	'FFFFCC'	1	2	4	2	2
10039	1	4	'9999FF'	'330066'	'993366'	'660000'	2	2	1	1	2
10041	1	5	'990099'	'FFFFFF'	'FFCCFF'	'FFFFCC'	1	3	1	1	2
10043	6	3	'FFFFFF'	'330066'	'CC0066'	'996600'	1	2	2	2	3
10044	4	3	'FFFFCC'	'3300CC'	'CC33FF'	'666633'	1	3	2	1	1
10045	1	5	'330066'	'FFFF00'	'FFFFFF'	'990033'	1	3	1	1	3
10046	5	3	'CC9933'	'333300'	'9966FF'	'CCCCCC'	2	1	3	3	1
10048	8	3	'FFCCFF'	'000000'	'009933'	'990033'	1	2	2	1	2
10051	6	3	'FFFFFF'	'9966FF'	'66CC99'	'CC0033'	1	2	4	1	3
10055	6	2	'CCCC99'	'FF3300'	'009933'	'990033'	1	2	2	2	3
10058	2	3	'FFFFCC'	'FF3300'	'9933CC'	'999966'	1	3	2	2	1
10061	6	2	'99CC99'	'333300'	'FF0066'	'FF9933'	1	3	1	1	2
10063	8	3	'666666'	'FFFF99'	'00FF00'	'CC0066'	1	1	2	2	3
10066	2	3	'CC9933'	'000000'	'CC33FF'	'666633'	2	2	2	1	2
10069	6	2	'CCCC99'	'CC0066'	'009933'	'990033'	2	1	4	3	2
10072	4	3	'990033'	'CCCC99'	'00FF00'	'CC0066'	1	1	4	3	1
10074	8	3	'666666'	'FFFFFF'	'00FF00'	'CC0066'	1	1	2	1	3
10076	4	3	'FFCC66'	'990033'	'CC33FF'	'666633'	1	1	2	1	1
10079	8	3	'CC9933'	'CC0066'	'CC33FF'	'666633'	1	1	2	3	2

KEY

Font Type	Code
Century Gothic	1
Arial	2
Comic Sans MS	3
Galant Normal	4
Garamond	5
Georgia	6
Times New Roman	7
Trebuchet MS	8
Verdana	9

Font Size	Code
Extra Small 8pt	1
Small 10pt	2
Standard 12pt	3
Large 14pt	4
Extra Large 16pt	5

Heading Style	Code
(Main = Bold Centre (Sub = Bold Left)	1
(Main = Bold Left (Sub = Left)	2
(Main = Centre (Sub = Bold Centre)	3
(Main = Centre (Sub = left)	4

Link Style	Code
Underlined	1
Bold - No Underline	2
Bold - Underlined	3

Line Length	Code
90 Percent of Page	1
80 Percent of Page	2
70 Percent of Page	3

Navigation Element Location	Code
Left	1
Top	2
Right	3
Bottom	4

Border Type	Code
Outset	1
Ridge	2
Groove	3
Inset	4

Appendix 16 - Experimental Trials - User Post-Event Questionnaire Data Set

Table A16.1 - Dyslexic User Post-Event Questionnaire Data

ID	Gender	Age	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
1001	Male	21-30	2	2	2	3	1	2	3	2	1	3	3	1
1003	Male	21-30	1	1	1	4	1	2	2	1	1	4	4	1
1005	Male	31-40	1	1	1	3	1	2	2	1	1	3	3	1
1007	Male	16-20	1	1	1	4	1	1	1	1	1	4	4	1
1008	Male	21-30	1	2	2	3	1	2	2	2	1	3	3	2
1009	Male	21-30	1	2	2	4	1	2	2	2	1	4	4	1
1010	Female	21-30	1	2	2	3	1	2	2	2	1	4	4	1
1011	Male	31-40	1	1	1	3	1	1	1	1	1	4	4	1
1013	Male	31-40	1	2	2	3	1	3	3	2	1	3	3	1
1014	Male	16-20	1	2	2	3	2	2	3	2	2	2	2	3
1015	Male	21-30	1	1	1	4	1	2	3	1	1	3	3	1
1016	Male	31-40	1	2	2	4	2	2	3	3	1	3	4	1
1018	Male	31-40	2	2	2	3	2	2	2	2	2	3	3	2
1019	Female	21-30	2	2	2	3	2	2	3	2	2	3	3	2
1020	Male	21-30	1	1	1	4	1	1	2	1	1	4	4	1
10002	Male	61-70	1	2	3	1	1	1	1	1	1	3	3	1
10005	Male	16-20	2	1	1	3	2	2	2	1	2	2	3	2
10006	Male	31-40	1	1	1	4	1	1	1	1	1	4	4	1
10007	Female	16-20	2	2	1	3	2	2	2	1	2	3	4	2
10009	Male	16-20	1	2	2	3	1	2	3	2	1	3	4	2
10010	Male	21-30	1	1	1	3	1	3	2	2	1	4	4	1
10014	Male	21-30	1	1	2	3	1	1	3	2	1	1	4	1
10015	Male	16-20	1	1	1	4	1	1	1	1	1	1	4	1
10016	Male	16-20	1	1	1	4	1	1	1	1	1	1	1	1
10017	Female	21-30	1	2	1	3	3	3	3	3	1	1	4	1

Table A16.2 - Non-Dyslexic User Post-Event Questionnaire Data

ID	Gender	Age	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
1002	Female	21-30	2	2	2	3	2	3	3	2	1	3	3	2
1004	Male	21-30	2	2	2	3	1	3	3	3	1	3	3	1
1006	Male	21-30	1	1	1	3	2	3	3	3	2	3	3	2
1012	Female	31-40	1	2	2	3	1	3	3	3	1	3	3	1
1017	Female	41-50	1	1	1	3	1	1	2	2	1	3	3	1
1021	Female	21-30	1	2	2	4	2	3	3	2	1	4	4	1
10003	Female	31-40	1	1	1	3	1	1	1	1	1	3	3	1
10004	Female	61-70	1	1	2	4	1	1	2	1	1	1	3	1
10008	Female	41-50	2	2	2	3	2	2	2	2	2	3	3	2
10011	Male	41-50	2	2	1	3	1	2	3	2	1	3	3	1
10012	Female	31-40	1	1	1	3	1	2	2	2	1	3	3	2
10013	Male	21-30	1	1	2	4	1	2	3	2	1	4	4	2
10019	Male	21-30	2	2	2	3	3	3	3	3	1	2	3	2
10020	Male	21-30	2	1	1	3	2	3	3	3	2	3	4	2
10021	Female	16-20	1	1	1	2	1	2	2	1	1	3	3	1
10022	Female	21-30	1	1	1	3	2	2	2	1	2	3	3	1
10023	Female	41-50	1	1	1	4	1	1	1	1	1	3	3	1
10024	Male	41-50	1	1	1	4	1	1	1	1	1	4	4	1
10025	Male	16-20	1	2	1	3	1	1	2	1	1	4	4	1
10026	Male	31-40	2	2	1	4	2	2	2	2	1	1	3	2
10027	Male	21-30	1	1	1	3	3	3	2	3	1	4	4	1
10028	Male	16-20	1	1	1	3	2	2	2	3	2	4	4	2
10029	Female	16-20	1	1	1	3	1	1	1	2	1	3	4	1
10030	Male	16-20	1	2	3	3	1	1	3	2	1	1	2	2
10031	Male	21-30	1	1	1	4	1	1	1	1	1	4	4	1

ID	Gender	Age	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
10018	Female	21-30	1	1	1	4	1	1	2	2	1	1	4	1
10040	Female	16-20	1	1	1	1	1	1	1	1	1	3	3	1
10042	Male	16-20	1	1	2	4	1	2	3	2	1	4	4	1
10047	Male	21-30	1	2	2	3	2	3	2	2	2	3	4	1
10049	Male	21-30	2	2	2	3	1	2	3	2	1	3	4	1
10050	Male	21-30	1	2	2	4	1	3	3	2	1	3	3	1
10052	Male	21-30	1	1	1	4	1	1	1	1	1	4	4	1
10053	Male	21-30	1	2	1	3	2	3	3	2	1	3	3	2
10054	Female	21-30	1	2	3	4	1	3	2	2	1	4	4	1
10056	Male	41-50	1	2	2	3	1	2	2	1	1	3	3	1
10057	Male	31-40	1	2	2	3	1	2	2	1	1	4	4	1
10059	Male	21-30	1	2	2	3	1	2	3	2	1	3	3	1
10060	Male	21-30	1	2	1	4	1	2	3	1	1	3	3	1
10062	Male	21-30	1	2	2	3	1	2	2	2	1	3	3	2
10064	Male	21-30	1	2	2	4	1	2	3	1	1	4	3	1
10065	Male	21-30	1	2	2	3	1	2	3	1	1	3	3	1
10067	Male	16-20	1	2	1	3	1	2	3	2	1	4	3	1
10068	Male	21-30	1	1	1	4	1	1	2	1	1	4	4	1
10070	Male	16-20	1	1	1	4	1	1	1	1	1	4	4	1
10071	Male	21-30	1	2	2	3	1	2	2	1	1	3	3	1
10073	Male	21-30	1	2	2	3	1	3	3	2	2	3	3	2
10075	Male	21-30	2	2	2	4	2	2	2	3	2	3	3	2
10077	Female	21-30	1	2	2	4	1	3	4	2	1	3	4	2
10078	Male	21-30	1	2	2	3	1	2	3	1	1	3	3	1
10080	Female	16-20	1	2	2	3	1	3	2	2	1	3	3	2

ID	Gender	Age	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
10032	Male	21-30	1	2	2	3	2	3	3	2	1	3	4	1
10033	Female	16-20	1	1	1	4	1	1	1	1	2	4	1	1
10034	Male	21-30	1	1	1	1	1	1	1	1	1	4	4	1
10035	Male	21-30	1	1	1	2	2	2	2	2	1	1	2	1
10036	Male	16-20	1	1	1	4	2	2	2	2	2	4	4	1
10037	Female	21-30	1	1	1	3	1	1	1	1	1	1	3	1
10038	Male	21-30	1	1	1	4	1	1	1	1	1	4	4	1
10039	Male	31-40	1	1	1	4	1	1	1	1	1	3	3	1
10041	Male	21-30	1	1	2	3	2	1	1	1	1	4	3	2
10043	Male	21-30	1	1	1	4	1	2	4	2	1	4	4	1
10044	Male	16-20	2	2	2	3	1	3	2	2	2	3	3	2
10045	Male	21-30	1	1	1	1	3	3	1	2	1	4	3	1
10046	Male	16-20	1	1	1	3	2	1	2	2	1	4	3	1
10048	Female	21-30	1	1	1	4	1	2	3	2	2	4	4	1
10051	Female	21-30	2	2	3	3	1	3	2	2	1	4	3	1
10055	Male	21-30	1	1	1	4	1	2	3	2	1	3	4	1
10058	Female	31-40	1	2	2	3	1	3	3	2	1	4	3	1
10061	Female	21-30	1	2	2	4	1	3	3	2	1	3	4	1
10063	Male	21-30	1	2	2	3	1	2	3	1	1	3	3	1
10066	Female	21-30	1	1	1	3	1	2	3	2	1	3	3	1
10069	Male	21-30	1	2	2	4	1	2	3	2	1	4	4	1
10072	Female	21-30	1	2	2	4	1	2	3	2	1	3	3	1
10074	Male	21-30	1	2	2	3	1	3	3	2	1	3	3	1
10076	Male	21-30	1	2	2	3	1	3	2	4	1	3	3	2
10079	Male	21-30	1	2	2	3	1	2	2	1	2	3	3	2

Key 1 = Strongly Agree 2 = Agree 3 = Disagree 4 = Strongly Agree

Question details can be found in Appendix 9 - DUIST Post-Event Questionnaire

Appendix 17 - Experimental Retrials - User Reading Performance Data Set

Table A17.1 - Dyslexic Subject Retrial Data (Reading Speed)

ID	Comb	A-WMP	B-WMP	C-WMP	D-WMP	Mod-Ave-WMP	NMod-Ave-WMP	% Increase	Diff Ave WMP
3003	1	172.6	160.9	176.6	170.9	174.6	165.9	5.24	8.69
1003	2	171.8	171.7	161.4	166.4	171.7	163.9	4.76	7.81
30002	3	183.0	177.6	169.4	182.3	182.7	173.5	5.27	9.14
10002	2	155.5	170.9	157.3	136.2	163.2	146.8	11.19	16.43
30005	1	99.8	94.9	101.5	97.7	100.6	96.3	4.53	4.36
10005	3	113.3	98.8	103.7	104.6	108.9	101.3	7.55	7.64
30009	3	163.2	131.4	146.3	148.4	155.8	138.8	12.22	16.97
10009	5	147.9	137.5	152.2	143.4	147.8	142.7	3.57	5.09
30010	2	118.8	116.5	111.4	111.3	117.7	111.4	5.66	6.30
10010	3	124.5	100.8	105.5	108.8	116.6	103.1	13.11	13.52
						Ave Increase (Original + Retrials)		**7.31**	**9.59**
						Ave Increase (Retrials)		**6.58**	**9.09**
						Ave Increase (Original)		**8.04**	**10.10**

Note: Original Data Included for Comparative Purposes

Table A17.2 - Dyslexic Subject Retrial Data (Error Rates)

ID	A1	A2	A3	A4	A5	A6	AT	B1	B2	B3	B4	B5	B6	BT	C1	C2	C3	C4	C5	C6	CT	D1	D2	D3	D4	D5	D6	DT	A ErrR	B ErrR	C ErrR	D ErrR	Mod-AER	NMod-AER	% Dec	Dif ER
3003	1	7	3	3	3	3	20	2	7	6	2	5	2	24	3	5	5	2	6	1	22	2	6	3	6	2	2	21	3.31	4.01	3.53	3.29	3.42	3.65	6.41	-0.23
1003	2	5	4	5	3	2	21	3	6	5	5	2	4	25	3	7	4	7	3	6	30	3	8	3	5	3	5	27	3.48	4.18	4.81	4.23	3.83	4.52	15.29	-0.69
30002	0	1	2	0	2	0	5	0	2	1	2	2	0	7	0	1	3	2	2	0	8	0	3	0	1	3	0	7	0.83	1.17	1.28	1.10	0.96	1.23	21.51	-0.26
10002	0	1	2	1	3	0	7	0	0	2	2	2	1	7	1	2	0	4	3	2	12	2	3	1	4	4	0	14	1.16	1.17	1.92	2.19	1.16	2.06	43.42	-0.89
30005	1	1	2	1	3	1	9	1	2	2	2	1	1	9	1	1	2	1	2	0	7	1	3	2	1	2	0	9	1.49	1.51	1.12	1.41	1.31	1.46	10.42	-0.15
10005	1	2	1	1	2	1	8	1	3	2	3	3	0	12	1	2	3	3	1	1	11	1	2	1	1	2	0	7	1.32	2.01	1.76	1.10	1.21	1.88	35.76	-0.67
30009	0	2	3	3	2	1	11	1	4	3	4	5	1	18	2	1	3	3	3	0	12	1	1	3	2	3	0	10	1.82	3.01	1.92	1.57	1.69	2.47	31.31	-0.77
10009	1	2	4	5	3	1	16	2	6	11	5	2	1	27	0	1	5	2	1	1	10	0	3	7	2	1	0	13	2.65	4.52	1.60	2.04	1.82	3.58	49.19	-1.76
30010	0	2	8	4	6	1	21	1	7	7	3	3	1	22	2	8	11	7	6	0	34	1	11	10	7	5	1	35	3.48	3.68	5.45	5.49	3.58	5.47	34.56	-1.89
10010	0	5	6	1	4	1	17	5	8	9	6	5	2	35	3	8	9	7	7	1	35	5	4	2	2	4	1	18	2.81	5.85	5.61	2.82	2.82	5.73	50.83	-2.91
																																	Ave Increase (Original+ Retrials)		29.87	-1.02
																																	Ave Increase (Retrials)		20.84	-0.66
																																	Ave Increase (Original)		38.90	-1.39

Note: Original Data Included for Comparative Purposes

Table A17.3 - Non-Dyslexic Subject Retrial Data (Reading Speed)

ID	Combin	A-WMP	B-WMP	C-WMP	D-WMP	Mod-Ave-WMP	NMod-Ave-WMP	% Increase	Diff Ave WMP
3004	1	184.90	184.00	187.20	186.73	186.05	185.37	0.37	0.68
1004	4	182.11	188.84	183.53	187.65	186.19	184.88	0.71	1.31
30004	6	129.43	134.38	134.68	137.70	136.04	132.05	3.02	3.99
10004	3	151.00	132.40	140.75	139.20	145.10	136.58	6.24	8.52
30003	1	199.12	195.00	203.48	209.18	201.30	202.09	-0.39	-0.79
10003	1	180.30	171.67	172.53	184.04	176.42	177.86	-0.81	-1.44
30011	4	120.00	117.64	119.62	120.76	118.63	120.38	-1.45	-1.75
10011	6	126.71	118.42	123.56	127.60	123.01	125.14	-1.70	-2.13
30012	4	200.22	191.87	189.09	199.38	190.48	199.80	-4.66	-9.32
10012	6	194.84	188.84	202.38	190.45	189.64	198.61	-4.51	-8.96
						Ave Increase (Original + Retrials)		**-0.32**	**-0.99**
						Ave Increase (Retrials)		**-0.62**	**-1.44**
						Ave Increase (Original)		**-0.02**	**-0.54**

Note: Original Data Included for Comparative Purposes

A17.4 - Non-Dyslexic Subject Retrial Data (Error Rate)

ID	A1	A2	A3	A4	A5	A6	AT	B1	B2	B3	B4	B5	B6	BT	C1	C2	C3	C4	C5	C6	CT	D1	D2	D3	D4	D5	D6	DT	A ErrR	B ErrR	C ErrR	D ErrR	Mod-AER	NMod-AER	% Dec	Dif ER
3004	0	0	0	0	2	0	2	0	0	0	1	1	0	2	0	0	0	1	1	0	2	0	0	0	2	0	0	2	0.33	0.33	0.32	0.31	0.33	0.32	-0.57	0.00
1004	0	1	0	1	1	0	3	0	1	0	0	1	0	2	0	1	0	1	1	0	3	0	0	0	2	1	0	3	0.50	0.33	0.48	0.47	0.41	0.48	15.69	-0.08
30004	0	3	2	0	1	0	6	0	2	1	2	1	0	6	0	4	0	2	3	0	9	0	2	1	2	1	0	6	0.99	1.00	1.44	0.94	0.97	1.22	20.20	-0.25
10004	0	2	2	0	1	0	5	2	3	1	1	0	0	7	2	2	0	2	2	0	8	0	1	0	1	1	0	3	0.83	1.17	1.28	0.47	0.65	1.23	47.08	-0.58
30003	0	1	0	1	1	0	3	0	0	0	1	2	0	3	0	2	0	3	0	0	5	0	1	0	2	1	2	6	0.50	0.50	0.80	0.94	0.65	0.72	10.00	-0.07
10003	0	0	1	0	1	0	2	0	2	1	0	1	0	4	1	1	1	3	1	0	7	1	1	1	2	1	0	6	0.33	0.67	1.12	0.94	0.73	0.80	9.72	-0.08
30011	0	2	2	1	1	0	6	0	2	2	0	2	0	6	0	1	2	1	2	0	6	0	1	3	1	2	0	7	0.99	1.00	0.96	1.10	0.98	1.05	6.01	-0.06
10011	0	2	2	1	1	0	6	0	2	2	3	0	0	7	0	4	2	1	0	1	8	2	3	0	2	0	1	8	0.99	1.17	1.28	1.25	1.21	1.14	-6.55	0.07
30012	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	2	0	0	0	2	0.17	0.17	0.16	0.31	0.16	0.24	31.64	-0.08
10012	0	1	0	1	0	0	2	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1	0	1	0	0	0	2	0.33	0.17	0.16	0.31	0.24	0.25	2.17	-0.01

	% Dec	Dif ER
Ave Increase (Original + Retrials)	**13.54**	**-0.11**
Ave Increase (Retrials)	**13.45**	**-0.09**
Ave Increase (Original)	**13.62**	**-0.13**

Note: Original Data Included for Comparative Purposes

Key: -

Retrial ID codes are labelled 3000X, while original ID codes are labelled 1000X.

SPEED

Column	Meaning
ID	Subject Trial ID
Comb	Combination of Modified/Non-Modified Textual Displays
A-WMP	Reading Speed for Text A (wmp)
B-WMP	Reading Speed for Text B (wmp)
C-WMP	Reading Speed for Text C (wmp)
D-WMP	Reading Speed for Text D (wmp)
Mod-Ave-WMP	Average Modified Reading Speed (wmp)
NMod-Ave-WMP	Average Non-Modified Reading Speed (wmp)
% Increase	Overall % Increase in Reading Speed
Diff Ave WMP	Overall Differential In Reading Speed

ERROR RATE

Column	Meaning
ID	Subject Trial ID
A1, B1, C1, D1	Total Mispronunciations (for text A,B,C,D)
A2, B2, C2, D2	Total Substitutions (for text A,B,C,D)
A3, B3, C3, D3	Total Refusals (for text A,B,C,D)
A4, B4, C4, D4	Total Additions (for text A,B,C,D)
A5, B5, C5, D5	Total Omissions (for text A,B,C,D)
A6, B6, C6, D6	Total Reversals (for text A,B,C,D)
AT, BT, CT, DT	Total Errors (for text A, B, C, D)
A ErrR	Average Reading Errors Per 100 words for Text A
B ErrR	Average Reading Errors Per 100 words for Text B
C ErrR	Average Reading Errors Per 100 words for Text C
D ErrR	Average Reading Errors Per 100 words for Text D
Mod-AER	Average Error Rate with Screens Modified
NMod-AER	Average Error Rate with Screens Non-Modified
% Dec	Overall % Decrease in Reading Errors (Errors per 100 words)
Dif ER	Overall Differential In Reading Errors (Error per 100 words)

Appendix 18 - Experimental Retrials – User Profile Attribute Selection Data Set

Table A18.1 - Profile Comparison of Retrial Data (Dyslexic)

Id	Font Type	Font Size	Back Col	Fore Col	Base Link	Used Link	Line Lgt	Lnk Style	Head Sty	Bor Style	Nav Style
3003	4	3	'666666'	'FFFF00'	'66CC99'	'CC0033'	3	2	2	1	2
1003	2	3	'666666'	'FFFF99'	'99CC00'	'993366'	3	2	1	4	3
30002	9	3	'FFFF99'	'000000'	'CC33FF'	'666633'	2	3	3	3	3
10002	9	3	'FFFF00'	'003300'	'CC33FF'	'666633'	2	3	3	2	2
30005	2	3	'666633'	'000000'	'00FF00'	'CC0066'	2	2	1	1	1
10005	2	3	'999966'	'000000'	'00FF00'	'CC0066'	3	2	2	2	3
30009	2	3	'00FF00'	'3300CC'	'993366'	'660000'	2	2	1	1	1
10009	2	3	'99CC00'	'333300'	'993366'	'660000'	2	1	1	1	1
30010	2	2	'000000'	'CC99FF'	'00FF00'	'CC0066'	3	1	4	1	1
10010	2	2	'000099'	'CCFF99'	'CCCC99'	'993366'	2	1	3	2	1

Table A18.2 - Profile Comparison of Retrial Data (Non-Dyslexic)

Id	Font Type	Font Size	Back Col	Fore Col	Base Link	Used Link	Line Lgt	Lnk Style	Head Sty	Bor Style	Nav Style
3004	2	3	'CCCCCC'	'330066'	'009933'	'990033'	1	1	1	1	2
1004	5	3	'666666'	'000000'	'99CC00'	'993366'	1	3	2	1	3
30003	6	3	'99CC99'	'003300'	'FF0066'	'FF9933'	2	1	3	1	1
10003	6	3	'99CC99'	'330066'	'993366'	'660000'	2	1	3	2	1
30004	9	4	'330033'	'FFFF00'	'00FF00'	'CC0066'	3	1	3	1	3
10004	9	4	'300000'	'FFFF00'	'FFFFFF'	'990033'	3	1	1	1	2
30011	9	3	'99CC00'	'003300'	'CC0066'	'996600'	3	1	2	2	1
10011	3	5	'99CC00'	'330066'	'993366'	'660000'	3	3	2	2	1
30012	9	4	'CC33FF'	'000000'	'FF0066'	'FF9933'	3	1	2	2	3
10012	9	5	'990099'	'330066'	'993366'	'660000'	3	1	1	2	2

KEY

Font Type	Code
Century Gothic	1
Arial	2
Comic Sans MS	3
Galant Normal	4
Garamond	5
Georgia	6
Times New Roman	7
Trebuchet MS	8
Verdana	9

Font Size	Code
Extra Small 8pt	1
Small 10pt	2
Standard 12pt	3
Large 14pt	4
Extra Large 16pt	5

Line Length	Code
90 Percent of Page	1
80 Percent of Page	2
70 Percent of Page	3

Heading Style	Code
(Main = Bold Centre (Sub = Bold Left)	1
(Main = Bold Left (Sub = Left)	2
(Main = Centre (Sub = Bold Centre)	3
(Main = Centre (Sub = left)	4

Link Style	Code
Underlined	1
Bold - No Underline	2
Bold - Underlined	3

Navigation Element Location	Code
Left	1
Top	2
Right	3
Bottom	4

Border Type	Code
Outset	1
Ridge	2
Groove	3
Inset	4

Appendix 19 – Dyslexia vs. Dyscalculia

Dyslexia and Mathematics

Although most subject experts agree that dyslexia symptoms fundamentally affect reading and writing skills, (a literal translation of dyslexia being "a difficulty with words") impaired language processing skills can adversely impact on certain mathematically based activities (Temple & Marshall, 1983; Snowling & Hulme, 1989; Miles & Miles, 1990; Miles, 1993; Mcloughlin et al., 1996; Griffiths & Snowling, 2002).

Typical mathematical tasks that dyslexic subjects may find difficult, due to poor linguistic skills and/or logical sequencing issues, include:-

Word based descriptive mathematical questions (e.g. "A farmer has twelve cows, each produce an average of ten pints of milk per week. What is the farmer's average total weekly milk production?").

Learning to differentiate between mathematical symbols that are visually similar (e.g. < and > or ∝ and □).

Remembering mathematical facts and formulae where the correct sequence or position of elements is essential (e.g. multiplication tables, fractions, decimals and transposition of formulae rules).

Correctly remembering and/or recording verbalised sequences of numbers such as telephone numbers or other lengthy strings of integers.

(Geary, 1993; Miles & Miles, 2004)

Dyscalculia

Although the symptoms associated with dyslexia can logically affect a number of mathematical activities (as exemplified above) several experts have proposed the existence of another distinct syndrome called Dyscalculia, which is specifically characterised by severe difficulties with mathematical processing. (Levy, 1979; Sharma, 1990; Henderson *et al.*, 2003; Butterworth & Yeo, 2004)

Dyscalculia sufferers are typically considered to have well developed language processing abilities but have difficulties with fundamental mathematical skills such as addition, subtraction, division and multiplication. They may display problems grasping abstract concepts such as time and direction, remembering names and processing tasks where activity sequence is critical. (Butterworth & Yeo, 2004)

Miles and Miles, two of the leading authorities on mathematical processing deficiencies amongst dyslexic sufferers, effectively summarises the questions and potential implications raised by the proposal of Dyscalculia.

"There is no agreement as to whether dyscalculia should be regarded as a distinct and separate syndrome or whether its manifestations are all part of the dyslexic syndrome. There is no doubt, however, that severe and persistent problems with arithmetical calculation can regularly be found. Among them are a very small number who have few or no literacy problems. If these are variations within the dyslexia syndrome, then it would seem that some widening of the dyslexia concept is called for, so that it would be proper to call a person 'dyslexic' even in the absence of any severe reading or spelling problems…

One of the problems in this whole area is to know where to 'lump' and where to 'split', that is where to classify manifestations together as constituting the same syndrome ('lumping') and where to treat them as separate ('splitting'). Because of co-morbidity between syndromes, the whole situation is very untidy from the theoretical point of view. Provided there is careful examination of individual needs, however, this theoretical untidiness need not have an adverse effect on practice. Hopefully, advances in neurology will throw further light on the theoretical side"

(Miles & Miles, 2004)

Appendix 20 – Joint Application Development Workshop Example Deliverables/Notes – Part I

Workshop Panel Membership

The details of the workshop panel members are supplied below in Table A20.1. Panel member selection attempted to include a representative sample of dyslexic subject profiles based on age, computing experience, severity of dyslexia symptoms and gender.

Table A20.1 - Workshop Panel Membership Profiles

Profile Member	Gender	Age	Self Assessed IT Competency *	Noted Comments on Individual's Condition
1	Male	19	Advanced User	Diagnosed Mildly Dyslexic
2	Male	21	Advanced User	Diagnosed Dyslexic (No additional information)
3	Female	20	Advanced User	Diagnosed Dyslexic (No additional information)
4	Male	42	Beginner	Diagnosed Severely Dyslexic
5	Female	26	Novice User	Diagnosed Dyslexic (No additional information)

*** Self Assessed IT Competency Key**

- **Advanced User** – "I regularly use a computer for a wide range of tasks and feel very confident using a computer".
- **Novice User** – "I regularly use a computer for basic tasks such as e-mail and browsing the Internet .I feel reasonably confident using a computer."
- **Beginner** – "I have previous computing experience, but I don't feel very confident when I use a computer."
- **No Experience** – "I have never used a computer before."

Appendix 20 – Joint Application Development Workshop Example Deliverables/Notes – Part II

Problem Domain Exploration Summary Notes

As part of the first day's JAD workshop activities, panel members were asked to discuss their current experiences using conventionally developed interfaces as typical dyslexic users. Table A20.2 provides a summary of the relevant comments extracted from the panel. The comments extracted were then subsequently utilised during the development of the DUIST framework software.

Table A20.2 - Problem Domain Elicitation Workgroup Observations

Comment/View	All panel members in agreement	Specific panel member(s) only
Colour: Interface foreground and background combinations were important for ease of reading, especially when the subject needed to read a large volume of text (e.g. newspaper article, online journal article, etc.).	YES	N/A
Colour: Certain foreground and background colour combinations were preferred by panel members, but no single universally accepted combination could be agreed upon by all members.	YES	N/A
Colour : Favoured colour combinations included:- • Background : Green - Foreground : White/Cream • Background : Dark Green - Foreground : Black/Dark Grey • Background : Dark Blue - Foreground : Yellow/White • Background : Dark Green - Foreground : White/Cream • Background : Grey - Foreground : White/Cream • Background : Dark Gray – Foreground : Yellow/Cream	NO	N/A
Colour: Extreme contrast levels for foreground and background colour combinations (e.g. Black/White) were not seen as desirable.	YES	N/A
Interface Typography: Font type and size had a significant impact on the readability of interface text.	YES	N/A
Interface Typography: Panel members disliked irregular/fanciful fonts and preferred clear simple character formations, without significant unnecessary decoration.	YES	N/A
Interface Typography: Favour font/size combinations included:- • Arial, 10/12pt. • Century, 10/12pt. • Century Gothic, 10/12pt. • Comic Sans, 12/14pt. • Sans Serif (MS), 10/12pt. • Verdana, 10/12pt. • Trebuchet, 10/12pt	NO	N/A

Interface Typography: When reading large volumes of text, panel members felt that font readability was preferable over an atheistically selected, "themed" character set.	YES	N/A
Screen Layout: The layout of interface features, including navigational elements, had a significant impact on the usability of the interface.	YES	N/A
Screen Layout: Panel members easily became confused when interface features changed position from screen-to-screen	YES	N/A
Screen Layout: Interface usability was maximised when interface consistency was maintained (e.g. the users found systems with consistently placed features easier to learn and felt more confident using them).	YES	N/A
Screen Layout: Clearly labelled headings, section titles, buttons were very important to panel members	YES	N/A
Screen Layout: Certain panel members stated that they had given up using certain web-sites/applications because the layout of interface features was not intuitive and they had become confused or disoriented.	NO	3, 4.
Readability of Text: All panel members stated that they found it exceptionally difficult to read moving "marquee effect" textual screen components.	YES	N/A
Readability of Text: A shorter line length (e.g. less then 8-12 words per line) was seen as desirable by all but one panel member. Panel member 5 felt line length didn't impact on text readability at all.	NO	1, 2, 3, 4.
Readability of Text: All panel members felt that significant empty background space around the textual passages aided readability, where overly crowed/cluttered interfaces were harder to read.	YES	N/A
Navigation: Simple, clear and understandable interface navigation mechanisms were considered to be essential by all panel members.	YES	N/A
Navigation: All panel members stated that they had previously become lost, confused or disoriented while using certain interfaces with complex navigational features. (Most commonly while searching for information or products on the Internet)	YES	N/A
Navigation: All panel members expressed a preference for navigational element location on-screen, but a consensus on an ideal location was not possible (e.g. each member had a unique location preference).	YES	N/A
Navigation: Rapid Interface response times, when moving from screen to screen, were seen as an important factor in the usability of any interface (especially when using web-based systems).	YES	N/A
Feedback: Regular, meaningful, interface feedback was seen as essential to the usability of any interface.	YES	N/A
Feedback: Panel Members would rather have too much feedback, rather than too little.	YES	N/A
Help/Support: All members felt that the inclusion of help/support mechanisms within an interface designed for a dyslexic user was essential.	YES	N/A
Manual Adaptation of Interface Settings: Only one panel member had previously attempted to customise interface display settings, based on a recommendation from a student services support tutor at university. The member's experience of the process was not favourable, due to the apparent complexity of the process (e.g. "Where do I start?")	NO	2
Manual Adaptation of Interface Settings: Although the concept of tailored interface adaptations seemed appealing to all panel members, two members expressed concern over making manual changes with their existing computing experience (members 4 & 5).	YES	N/A

Appendix 20 – Joint Application Development Workshop Example Deliverables/Notes – Part III

Example System Wireframes

As an opening task of the second day of the JAD workshop, panel members were asked to sketch simple wireframe diagrams of their vision of selected key system interfaces, based on the previously agreed basic system specification.

The following figures present several examples of drafted wireframes, including working comments/notes, to illustrate the workshops preliminary design attempts.

Figure A20-1 Example Workshop Sketched Wireframes – Menu Screen Version 1

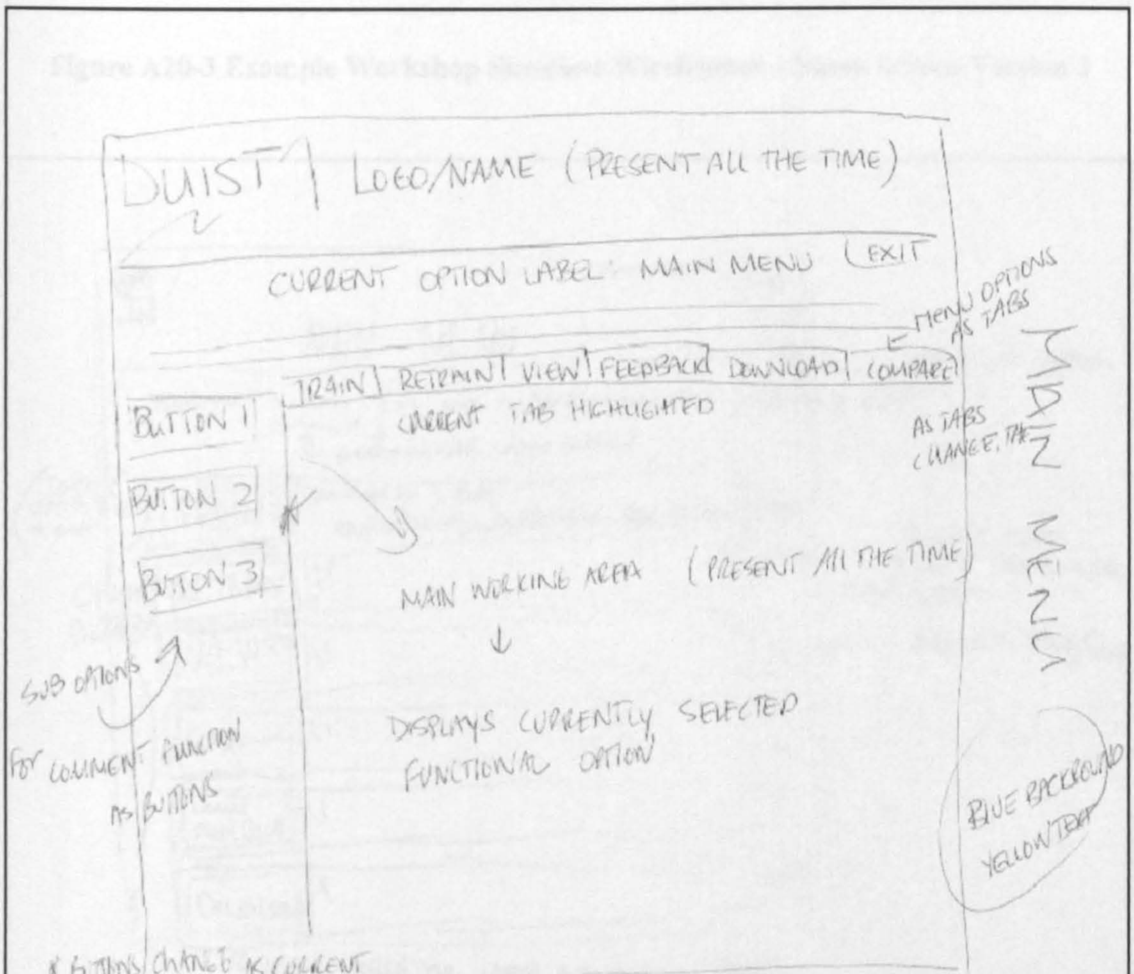


Figure A20-2 Example Workshop Sketched Wireframes – Menu Screen Version 2

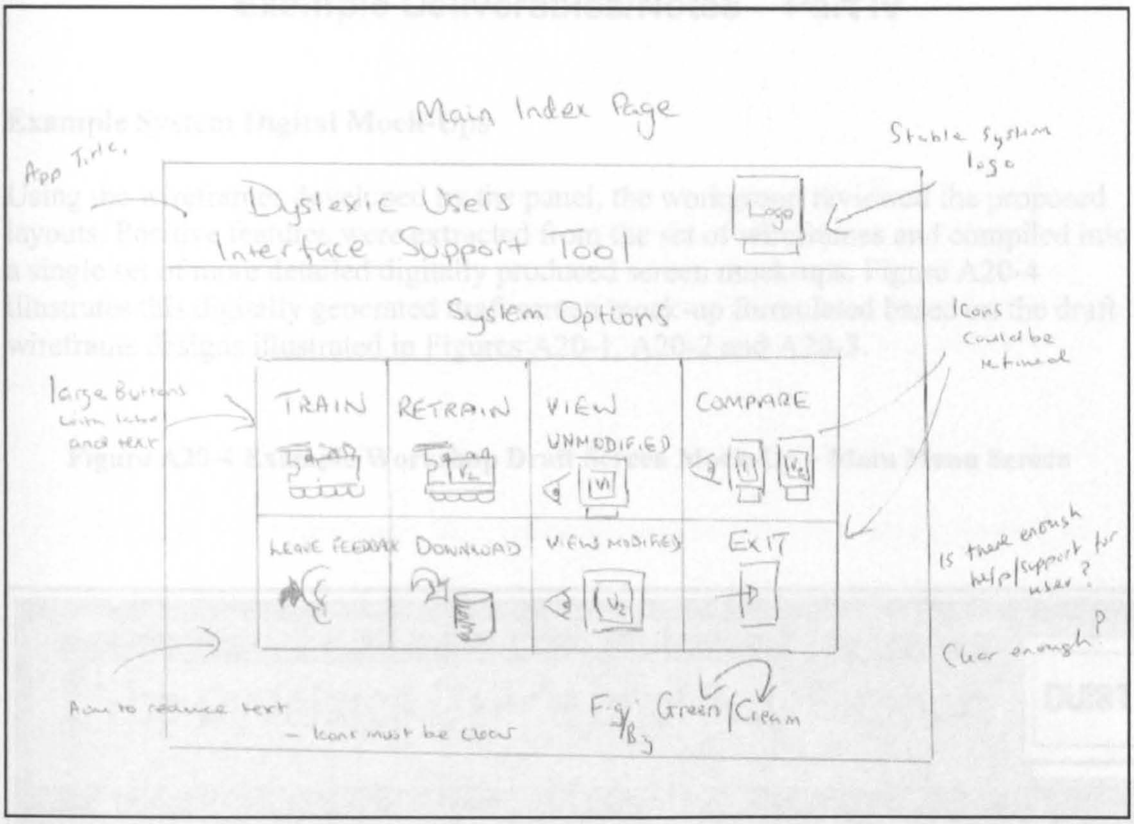
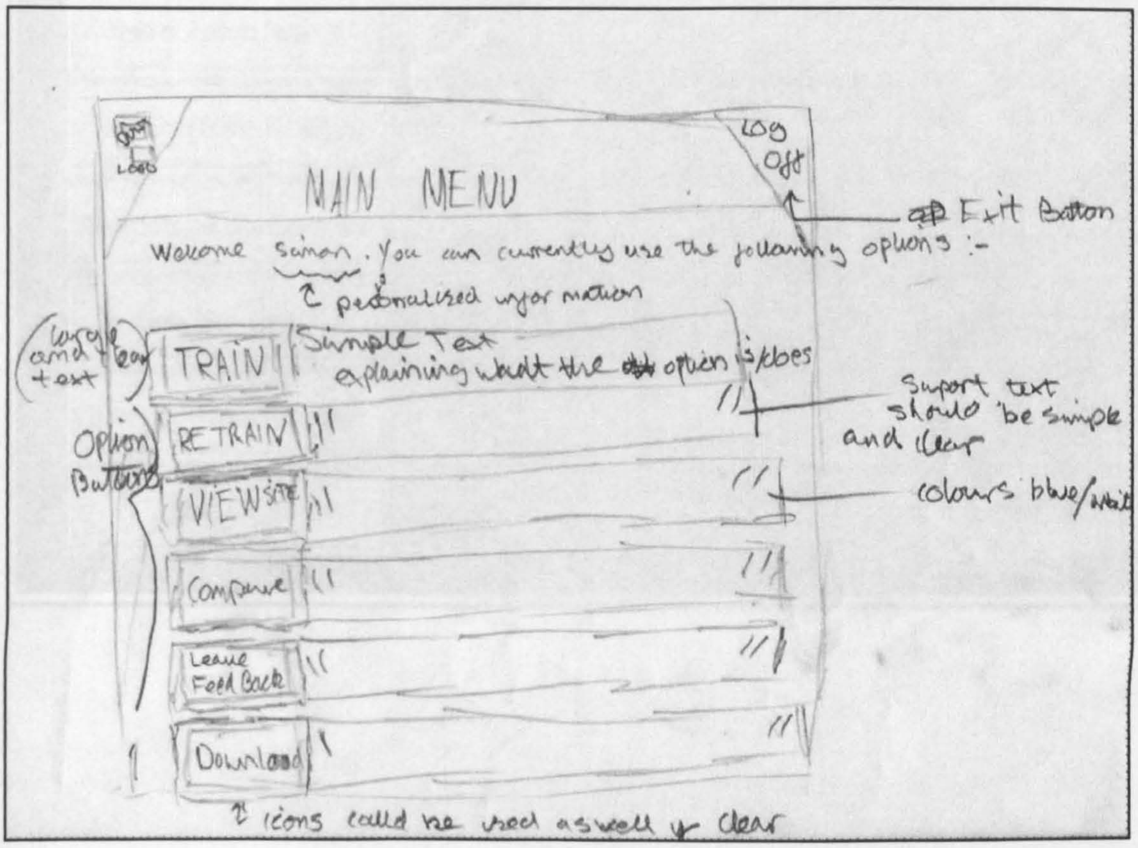


Figure A20-3 Example Workshop Sketched Wireframes – Menu Screen Version 3

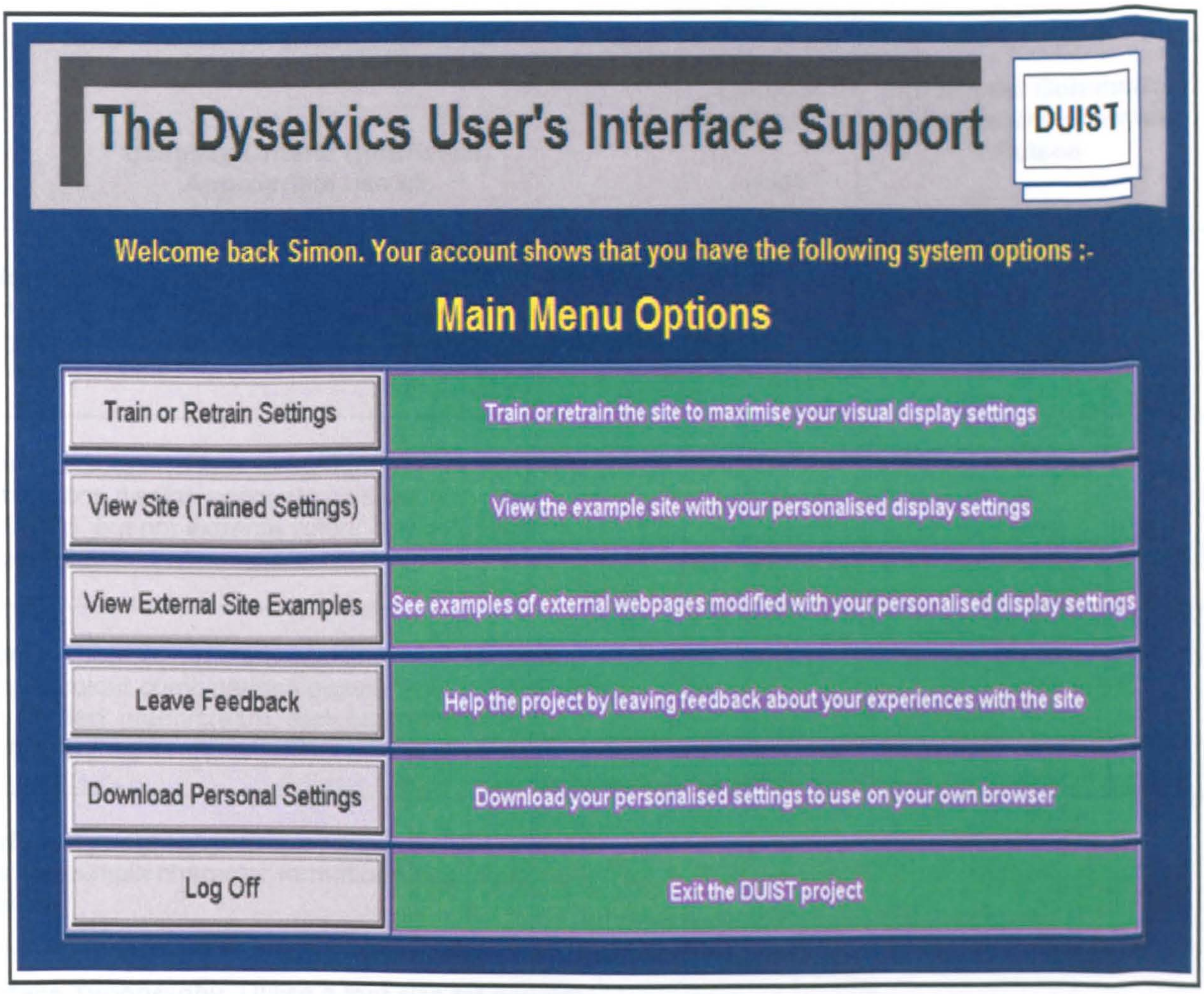


Appendix 20 – Joint Application Development Workshop Example Deliverables/Notes – Part IV

Example System Digital Mock-Ups

Using the wireframes developed by the panel, the workgroup reviewed the proposed layouts. Positive features were extracted from the set of wireframes and compiled into a single set of more detailed digitally produced screen mock-ups. Figure A20-4 illustrates this digitally generated draft screen mock-up formulated based on the draft wireframe designs illustrated in Figures A20-1, A20-2 and A20-3.

Figure A20-4 Example Workshop Draft Screen Mock-Up – Main Menu Screen



Appendix 20 – Joint Application Development Workshop Example Deliverables/Notes – Part V

Preliminary Heuristic Evaluation

Using the set of compiled recommended design principles, formulated during the initial stages of the projects research (see section 3.3.3) the draft screen mock-ups were critically reviewed by the panel members. Where heuristics were found to be compromised, modifications were made and the resulting layouts were re-evaluated iteratively. Table A20.3 illustrates the preliminary heuristics used to evaluate the generated mock-ups.

Table A20.3 - Preliminary Heuristic Used to Evaluate Interface Mock-Ups

Usability Criteria (Heuristics) Appropriate use of:	Level of Conformity (1-4) *	Additional Comments/ Observations/Issued Raised
Customisation: Facilitate the customisation of interface features including foreground colour. background colour, font type, font size, line length, heading style, etc, where and whenever possible,		
Colour: Ensure interface foreground and background combinations display adequate contrast (e.g. light grey/black), but not extreme colour combinations (black/white).		
Colour: Where colour customisation is not possible, consider colour combinations popular with dyslexic users such as (dark green/cream, dark blue/yellow, light grey/black)		
Interface Typography: Employ clear, simple, symmetrical fonts with simple character formations (e.g. Arial, Sans Serif, Verdana).		
Interface Typography: Utilise a font size for general paragraphs of text at 10 or 12pt.		
Screen Layout: Deploy clearly labelled headings, sub-headings and section titles.		

Screen Layout: Appropriately Prioritise On-Screen information and functionality		
Screen Layout: Ensure interface feature location consistency		
Readability of Text: Do not use moving "marquee effect" textual screen components		
Readability of Text: Employ a short line length for standard passages of text.		
Readability of Text: Utilise a significant "empty" space around paragraphs via suitably wide column widths		
Readability of Text: Ensure that textual sections of the interface are not crowed or over-populated		
Navigation: Deploy simple, clear and understandable interface navigation mechanisms		
Navigation: Ensure that all navigational pathways yield closure.		
Web-Specific : Use front loaded hyperlinked sentences to enhance scanning and facilitate rapid navigation		
Web-Specific: Label links descriptively so that users can discriminate between similar links		
Web-Specific : Link descriptions should be clear and make effective navigation an intuitive process		
Web-Specific : Provide user friendly, internal search facilities		
Web-Specific : Employ a wide rather than deep hierarchical site structure		
Web-Specific : Avoid dead-end links		
Web-Specific : Use graphical elements and colours to ensure traceability around any web-site		

Web-Specific : Change the colour of hyperlinks to ensure that they are visually distinct from unvisited ones		
Web-Specific : Ensure that the colour of visited hyperlinks does not conflict with the site background colour and render text unreadable		
Web-Specific : Consider a 'breadcrumb trail', either graphical or text based, to give the user a clear understanding of the users current position within the site (e.g. Home page > section > sub-section).		
Web-Specific: Include a graphical or text-based site map to aid navigation.		
Forgiveness: *Include mechanisms to allow* user actions to be undone or reversed.		
Feedback: Ensure meaningful and ongoing feedback is supplied for the user at all times.		
Icons: • Use familiar objects and actions. • Simplify the object represented. • Attach a caption to assure intended meaning. • Ensure the icon stands out from the background.		
Buttons: • Maintain Consistency of style and order • Ensure meaningful labels, text and symbols. • Maintain button size to fit the longest label. • Organised to ensure groupings of related buttons		
User Centred Control: Ensure the user and not the system initiates system functionality.		
User Centred Control: Deploy exit strategies for system operations.		

Conformity Key

1 = Conforms in all parts.
2 = Conforms in most parts.
3 = Conforms in some parts.
4 = Does not conform.

Appendix 21 – System Testing Strategy and Example Data

The functional performance of the DUIST system was measured using a three stage test strategy. Tables A21-1, A21-2 and A21-3, explain and exemplify each of these three consecutive stages.

Table A21-1 Unit Testing Strategy and Example Data

<table>
<tr><th>Stage 1:</th><th>Unit Testing</th></tr>
<tr><td>Rationale :</td><td>
Individual software units (classes) are tested for correctness as they are coded, with each class being subjected to both Blackbox and Whitebox testing.
Blackbox testing was used to assess the overall correctness of system operations as exemplified by actual system output accuracy compared to expected system output, independent of internal execution sequence.
For the purposes of the unit testing phase, actual output verses expected system output comparison was carried out for each class function (typically implemented by one or more class routines).
For each function examined, testing was conducted for:-

Random valid inputs
Top and bottom boundary limit values.
Data outside permitted boundary limits.
Zero or negative number inputs.
Empty or NULL data value entries
Invalid character inputs.
Invalid data type inputs.
Stress level inputs (e.g. repeated invalid inputs at a frequency level beyond which the system was expected to operate in)

Whitebox testing was used to assess the correctness of internal programme execution sequence, logic and intermediate data processing.
For the purposes of the Whitebox unit tests, the following approaches were deployed:-

Statement coverage: Each programme statement is executed at least once.
Branch coverage: All program branches (implemented by selection statements) are executed
Path coverage: All possible program execution pathways are traversed.
Intermediate variable assessment: All intermediate and temporary variables generated during program execution are checked.

In both cases, where errors were identified, the errors were corrected and the appropriate test or tests were retried, iteratively, until unit behaviour was as expected.
</td></tr>
</table>

Blackbox Example:

Exemplified **Unit** (Class) : **MENU**
Software Version : **Eiffel Prototype System V1.1**

Functionality Tested : **MAIN_MENU Option Selection (Routines: make, run, ,show_constraints, display, get_selection, do_choice, is_terminator)**

Test ID	Description	Expected Result	Actual Result
B50	Valid menu input "0" selected	System Execution Stops	As expected
B51	Valid menu input "1" selected	System Administration Menu Displayed	As expected
B52	Valid menu input "2" selected	System Report Menu Displayed	As expected
B53	Valid Boundary Maximum input "0"	System Report Menu Displayed	As expected
B54	Valid Boundary Minimum input "2"	System Execution Stops	As expected
B55	Upper Boundary Exceeded input "3"	Error message E15 – "Invalid menu selection"	As expected
B56	Lower Boundary Exceeded input "-1"	Error message E15 – "Invalid menu selection"	As expected
B57	Invalid Negative input "-12"	Error message E15 – "Invalid menu selection"	As expected
B58	Invalid empty input <Return> only	Error message E15 – "Invalid menu selection"	As expected
B59	Invalid character input Char "£"	Error message E15 – "Invalid menu selection"	As expected
B60	Invalid data type string input "Exit"	Error message E15 – "Invalid menu selection"	As expected
B61	Invalid data type string input "Admin"	Error message E15 – "Invalid menu selection"	As expected
B62	Stress level input repeated <Return> key presses (Approx 5 minutes)	Error message E15 – "Invalid menu selection" repeatedly displayed	As expected

Whitebox Example:

Exemplified Unit (Class) : **MENU**
Software Version : **Eiffel Prototype System V1.1**

Class : MENU
Test ID W30

Statement Coverage

Total Statements	Statements Executed	Issues Raised
75	75	N/A

Branch coverage

Total Braches	Braches Explored	Issues Raised
4	4	N/A

Path coverage

Total Paths	Paths Explored	Issues Raised
16	16	N/A

Intermediate variables

Intermediate variable	Value Checked	Issues Raised
choice	Yes	N/A
valid choices	Yes	N/A
selection	Yes	N/A

Table A21-2 Integration Testing Strategy and Example Data

Stage 2:	**Integration Testing**
Rationale :	When individual software units (classes) are combined to create larger system components (typically clusters) they are tested for correctness using a mixture of both Blackbox and Whitebox testing. Blackbox testing was used to assess the overall correctness of system operations as exemplified by actual system output accuracy compared to expected system output, independent of internal execution sequence. For the purposes of the integration testing phase, actual output verses expected system output comparison was carried out for each system cluster function (typically implemented by one or more class routines, from two or more classes within the cluster). For each function examined, testing was conducted for:- • Random valid inputs • Top and bottom boundary limit values. • Data outside permitted boundary limits. • Zero or negative number inputs. • Empty or NULL data value entries • Invalid character inputs. • Invalid data type inputs. • Stress level inputs (e.g. repeated invalid inputs at a frequency level beyond which the system was expected to operate in) Whitebox testing was used to assess the correctness of internal programme execution sequence, logic and intermediate data processing. For the purposes of the Whitebox integration tests, the following approaches were deployed:- • Statement coverage: Each programme statement is executed at least once. • Class creation and call coverage pathways: All possible class creation and call statements (e.g. *create class.make* or *class.routine*) are executed within the cluster for every possible program execution pathway sequence. • Inter-class argument passing: All arguments passed between classes are trapped and examined for accuracy. In both cases, where errors were identified, the errors were corrected and the appropriate test or tests were retried, iteratively, until integrated unit behaviour was as expected.

Blackbox Example:

Exemplified **Integration** (Cluster) : USER_PROFILE
Software Version : **Eiffel Prototype System V1.1**

Functionality Tested: **Find and display a valid PROFILE object.**
(Classes involved: PROFILE, DATABASE_ADMINISTRATOR)

Note : Profile numbers were originally specified to by a 4 digit integer, (e.g. 1000 to 9999)

Test ID	Description	Expected Result	Actual Result
B410	Valid profile id supplied "1000"	Valid profile displayed for profile with id no. 1000.	As expected
B411	Valid profile id supplied "1001"	Valid profile displayed for profile with id no. 1001.	As expected
B412	Unknown profile id supplied "9999" (Id format correct)	Error message E60 – "No such profile currently exists"	As expected
B413	Invalid profile id supplied "999" (id format incorrect)	Error message E61 – "Invalid profile number"	As expected
B414	Invalid profile id supplied "10001" (id format incorrect)	Error message E61 – "Invalid profile number"	As expected
B415	Invalid data string entry supplied "twenty"	Error message E61 – "Invalid profile number"	As expected
B416	Invalid data string entry supplied "^&^*&^&*^*&"	Error message E61 – "Invalid profile number"	As expected
B417	Invalid empty NULL value supplied	Error message E61 – "Invalid profile number"	As expected
B418	Stress level repeated random characters supplied in quick secession for approximately 5 minutes	Multiple instances of Error message E61 – "Invalid profile number"	As expected

Whitebox Example:

Exemplified Cluster : **USER_PROFILE**
Software Version : **Eiffel Prototype System V1.1**

Cluster : USER_PROFILE
Test ID W42
Classes: PROFILE, FEEDBACK, TRAIL, DATABASE_ADMINISTRATOR

Statement Coverage

Total Statements	Statements Executed	Issues Raised
632	632	N/A

Class Creation and Call Coverage Pathways

Total Pathways	Total Explored	Issues Raised
12	12	N/A

Inter-Class Argument Passing

Inter-Class Arguments	Argument Checked	Issues Raised
prompt_user_message	Yes	N/A
prompt_error_message	Yes	N/A
input_error_type	Yes	N/A
colour_array	Yes	N/A
font_array	Yes	N/A
band_min	Yes	N/A
band_max	Yes	N/A

Table A21-3 System Testing Strategy and Example Data

Stage 3:	**System Testing**
Rationale :	When the previously tested software clusters were combined to create the final system, the complete application was tested for correctness using a mixture of both Blackbox and Whitebox testing. Blackbox testing was used to assess the overall correctness of system operations as exemplified by actual system output accuracy compared to expected system output, independent of internal execution sequence. For the purposes of the system testing phase, actual output verses expected system output comparison was carried out for all system functionality (typically implemented by one or more class routines, from two or more classes, within two or more clusters). For each function examined, testing was conducted for:- • Random valid inputs • Top and bottom boundary limit values. • Data outside permitted boundary limits. • Zero or negative number inputs. • Empty or NULL data value entries • Invalid character inputs. • Invalid data type inputs. • Stress level inputs (e.g. repeated invalid inputs at a frequency level beyond which the system was expected to operate in) Whitebox testing was used to assess the correctness of internal programme execution sequence, logic and intermediate data processing. For the purposes of the Whitebox system tests, the following approaches were deployed:- • Statement coverage: Each programme statement is executed at least once. • Class creation and call coverage pathways: All possible class creation and call statements (e.g. *create.class.make* or *class.routine*) are executed within the system for every possible program execution pathway sequence. • Inter-cluster argument passing: All arguments passed between clusters are trapped and examined for accuracy. In both cases, where errors were identified, the errors were corrected and the appropriate test or tests were retried, iteratively, until overall system behaviour was as expected.

Blackbox Example:

Exemplified **System** (All Clusters) : **ROOT, INTERFACE, USER_PROFILE, INPUT_ VALIDATION**

Software Version : **Eiffel Prototype System V1.1**

Functionality Tested: **Request feedback report generation for valid profile**
(Classes involved: ROOT, MAIN_MENU, ADMIN_MENU, REPORT, PROFILE, DATABASE_ADMINISTRATOR)

Test ID	Description	Expected Result	Actual Result
B800	Valid profile id "1000" input via administration menu.	Feedback report successfully generated for profile number "1000"	As expected
B801	Valid profile id "1001" input via administration menu.	Feedback report successfully generated for profile number "1000"	As expected
B802	Invalid profile id "9999" input via administration menu. (Valid format/yet profile does not currently exist)	Error message E60 – "No such profile currently exists"	As expected
B803	Valid profile id "1003" input via administration menu. (Where no feedback has currently been supplied from user)	Error message E65 – "User profile does not currently contain feedback"	As expected
B804	Invalid profile id "10000" input via administration menu. (id has invalid format)	Error message E61 – "Invalid profile number"	As expected
B805	Invalid empty input via administration menu <Return> only	Error message E61 – "Invalid profile number"	As expected
B806	Invalid data type string "&^*&^&*^&" input via administration menu.	Error message E61 – "Invalid profile number"	As expected
B807	Stress level input repeated <Return> key presses supplied via administration menu (Approx 5 minutes)	Multiple instances of Error message E61 – "Invalid profile number"	As expected

Whitebox Example:

Exemplified System : DUIST Prototype Application
Software Version : **Eiffel Prototype System V1.1**

System : DUIST Prototype Application
Test ID W80
Clusters: **ROOT, INTERFACE, USER_PROFILE, INPUT_ VALIDATION**

Statement Coverage

Total Statements	Statements Executed	Issues Raised
2562	2562	N/A

Class Creation and Call Coverage Pathways

Total Pathways	Total Explored	Issues Raised
322	322	N/A

Inter-Cluster Argument Passing

Inter-Class Arguments	Argument Checked	Issues Raised
db	Yes	N/A
valid_profile	Yes	N/A
colour_array	Yes	N/A
font_array	Yes	N/A

Appendix 22 – Atypical Lateralisation Theory

Neurologist Samuel Orton first formulated the Atypical Lateralisation theory in 1925.
Orton and later Geschwind suggested that the laterlisation of language functions to the left hemisphere was delayed in dyslexics, resulting in a reduction in the language processing prerequisites required for effective reading skills (Orton, 1925; Orton, 1937; Geschwind & Galaburda, 1987).

Early evidence to support Orton's theory included the apparent predominance of left-handed dyslexics and the "mirror writing" phenomenon displayed by many dyslexics, where letters are reversed when the subject attempts to write.

Technological advances in the early fifties facilitated a more critical examination of Orton's hypothesis by allowing Dichotic Listening to be used to examine brain laterality effects in normal populations (Broadbent, 1954). [See Appendix 1 "Dichotic Listening"] Galaburda and Geschwind later used such techniques to establish brain asymmetry for the general population and demonstrated the apparent symmetrical nature of the dyslexic brain (Geschwind & Behan, 1982; Galaburda & Habib, 1987).

In 1979 and 1985 Galaburda and colleagues conducted two detailed anatomical studies of the brains of a total of five male dyslexic patients (Galaburda & Kemper 1979; Galaburda *et al.*, 1985). The results from these seminal anatomical experiments identified a number of minor brain abnormalities.

Firstly, at a microscopic level, Galaburda discovered several cortical malformations in both frontal regions and primarily in the left languages areas of each brain. These abnormalities included: -

a) lesions;
b) ectopias (small neuronal congregations in an abnormal superficial layer location);
c) dysplasia (loss of normal structural organisation of cortical neurons);
d) vascular micro-malformations.

In addition to these cortical abnormalities, each of the brains studied showed a lack of the usual left-right asymmetry, with both hemispheres being roughly symmetrical.
The apparent symmetrical nature of the dyslexic brains studied also added weight to Orton's theory.

The development of *in vivo* morphological imaging techniques using Magnetic Resonance Imaging (MRI) equipment [See Appendix 2 Magnetic Resonance Imaging] in the late 1980s, finally opened up Orton's theory to meticulous scrutiny. MRI technology experimentation had significant advantages over previous pathological studies as: -

The availability of test subjects was no longer limited by death.

The nature and severity of a subject's dyslexia could be established, allowing differences in symptoms to be compared with structural differences within the brain.

The accurate measurement of cortical asymmetry was now possible in subjects selected by the researcher.

Using MRI technology, numerous cortical asymmetry studies have been conducted since 1986. Table A22.1 provides a representative summary of the findings from six of the most critically reviewed studies, with Figure A22.1 providing an anatomical representation of the relevant neural components.

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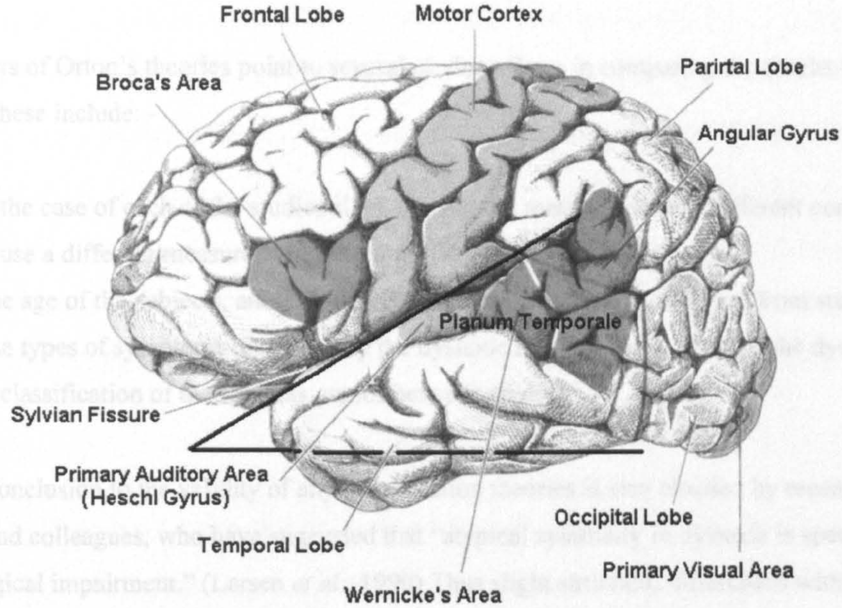
Table A22.1 - Summary of findings from six MRI cortical asymmetry studies

Study/Year	Dyslexic Subjects	Control Subjects	Summary of findings
(Rumsey *et al.*, 1986)	10	0	• Lateral ventricles measured. (R < L: 20%, R > L: 40%, R = L: 40%) • Temporal lobes measured (R = L: 90%)
(Hynd *et al.*, 1990)	10	10	• Length of the planum temporale (axial slice) • In dyslexic subjects (R < L: 10%, R = L or R > L: 90%) • In control group (R < L: 70%, R = L or R > L: 30%) • The experiment was also conducted with 10 additional Attention Deficit Disorder (ADD)/Hyperactive subjects and the results were comparable with the control group.
(Larsen *et al.*, 1990)	19	17	• Surface of the planum temporale measured • In dyslexic subjects (R < L: 31.5%, R = L: 68.5%) • In control group (R < L: 29.5%, R = L: 70.5%)
(Schultz *et al.*, 1994)	17	14	• Surface of the planum temporale measured. (Measured from the end of the sylvian fissure to the posterior border of the Heschl gyrus) • In dyslexic subjects (R < L: 76%, R = L or L > R: 24%) • In control group (R < L: 71%, R = L or L > R: 29%)
(Rumsey *et al.*, 1997)	16	14	• Measurement of the planum temporale and ascending posterior ramus of the sylvian fissure. • In dyslexic subjects (70-80% leftward planum temporale asymmetry – 50-60% rightward planum temporale asymmetry) • In control group (70-80% leftward planum temporale asymmetry – 50-60% rightward planum temporale asymmetry)
(Dalby *et al.*, 1998)	17	12	• 3 separate measurements of the temporal lobes. • In dyslexic subjects and subjects with reading retardation (L < R or L = R: 82%, L > R: 18%) • In control group (L < R or L = R: 28%, L > R: 72%)

Key: R = Right Hemisphere: L = Left Hemisphere

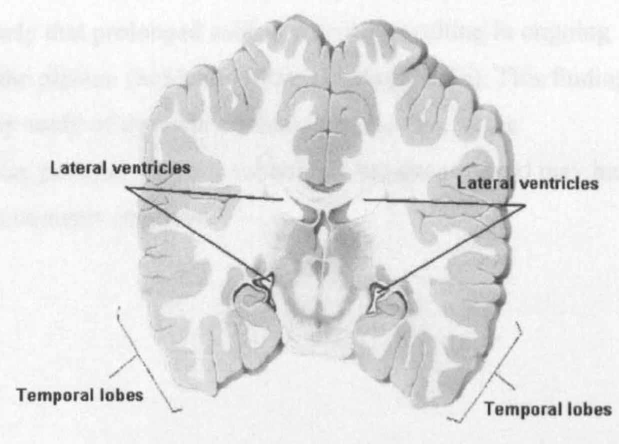
Figure A22.1 – Cortical Asymmetry Studies (Essential Neural-Anatomy)



The planum temporale is the cortical area just posterior to the auditory cortex (Heschl's Gyrus) within the Sylvian fissure. It forms the triangular region around the heart of Wernicke's area. It is the single most important language processing area of the brain.

Experimental Strategy

- **A variety of measurements were taken from each hemisphere of the brain, for several important language processing regions (e.g. the Planum Temporale, Lateral Ventricles and Temporal Lobes) in an attempt to identify fundamental anatomical differences between dyslexic and non-dyslexic subjects.**
- **Statistical analysis of the results from several studies proved to be anything but conclusive**



Statistical analysis of the results from these six studies against Orton's lateralisation predictions prove to be anything but conclusive. Despite the fact that early MRI studies seemed to suggest an apparent trend in cortical symmetry amongst dyslexic subjects (Rumsey *et al.*, 1986; Hynd *et al.*, 1990); subsequent studies, some using higher resolution magnetic resonance images, have all proved that there is little or no correlation between dyslexia and cortical symmetry. In fact, the Larsen and Schultz findings seem to demonstrate that there is very little statistical difference between cortical asymmetries in dyslexics verses non-dyslexics (Larsen *et al.*, 1992 ; Schultz *et al.*, 1994).

A number of recent expert reviews of the data presented from all the dyslexic brain MRI studies have concluded that the evidence is not fully convincing (Beaton, 1997; Shapleske *et al.*, 1999; Habib, 2000). Further investigation is ongoing.

Supporters of Orton's theories point to several obvious flaws in comparing the results from the six studies; these include: -

* In the case of each of the studies sited, the authors measure either a different cortical region or use a differing measurement criterion.
* The age of the subjects, and thus neurological development, is different from study to study.
* The types of symptoms displayed by the dyslexic subjects used, and thus the dyslexic classification of the subjects, varies between studies.

A final conclusion to the validity of any lateralisation theories is also clouded by recent speculations by Larsen and colleagues, who have suggested that "atypical symmetry in dyslexia is specifically linked to phonological impairment." (Larsen *et al.*, 1990) Thus slight structural differences within the brain may result in a correspondingly different set of symptoms displayed by the dyslexic patient.

A further consideration, which will be critical in any subsequent MRI investigation relates to the observations of Schlaug and colleagues; namely that prolonged subject training, resulting in ongoing planum stimulation, can increase the size of the planum (Schlaug 1995a; Schlaug 1995b). This finding has obvious implications to the validity of any study of dyslexic cortical asymmetries, as the environmental experiences (training, education, parental support) the subject has encountered may have had a significant impact on any cortical measurements observed.

Appendix 23– Interhemispheric Deficit Theory

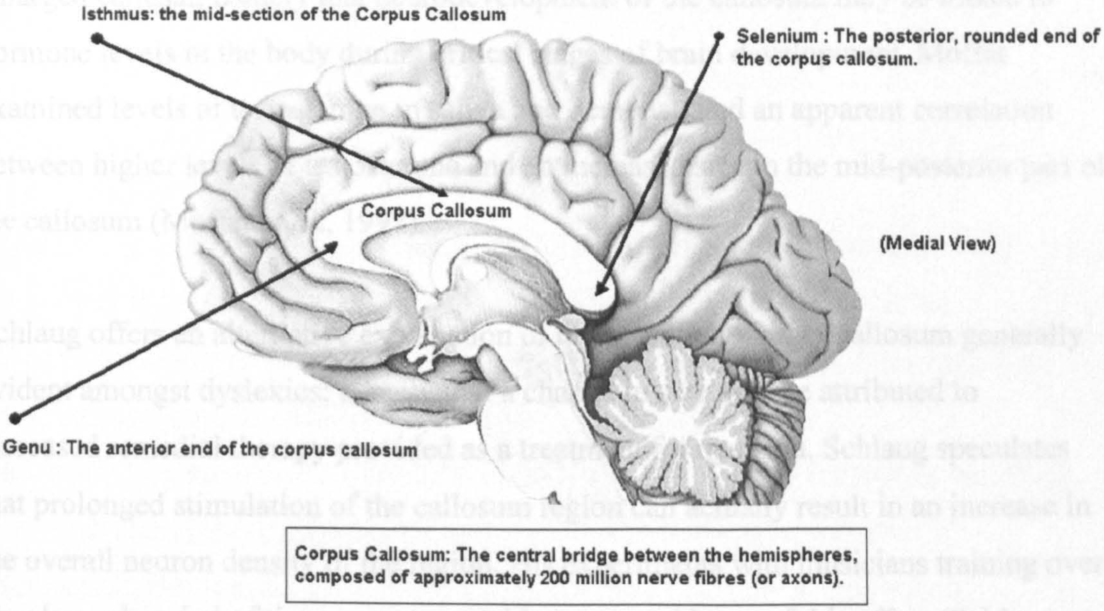
The Corpus Callosum is the primary mechanism responsible for process coordination and communication between the brain's two hemispheres. The interhemispheric deficit theory states that any deficiency with interhemispheric signal-transfer results in a deterioration of sensory processing. In turn, the assumption is made that any such reduction in sensory processing ability would affect a subject's performance with tasks such as reading and writing; difficulties that are synonymous with developmental dyslexia (Gross-Glenn & Rothenberg, 1984; Best, 1985; Moore *et al.*, 1995).

Several studies have been carried out to explore the possibility of structural abnormality within the corpus callosum, most recently using MRI technology. A summary of the findings from each study is provided in Table A23.1, with Figure A23.1 providing an anatomical representation of the relevant neural components.

Table A23.1- Corpus Callosum MRI Experiment Findings Summary

Study/Year	Dyslexic Subjects	Control Subjects	Summary of findings
(Duara *et al.*, 1991)	21	21	• Larger total callosal area in female dyslexics vs. control • Larger callosal posterior area in male and female dyslexics vs. control
(Larsen *et al.*, 1992)	17	19	• No significant difference between dyslexics and control.
(Hynd *et al.*, 1995)	16	16	• Significant difference between dyslexics and control, with a smaller anterior-most region (Genu) of the corpus callosum evident amongst dyslexics
(Rumsey *et al.*, 1996)	21	19	• Larger posterior third of the callosum (Isthmus and Splenium) in dyslexics vs. control.
(Robichon & Habib, 1998)	16	14	• Dyslexic's corpus callosum displayed a more rounded, evenly thinker callosum shape then the control group. • Only right-handed dyslexics had a larger mid-callosal (isthmus) surface.

Figure A23.1 – Corpus Callosum Anatomy and MRI Experimental Strategy



Experimental Strategy

- All major components of the Corpus Callosum were measured using MRI technology to determine if there were differences between the size and structure of the Callosum
- Experimental results from several experimental studies yielded inconsistent results. (Duara et al., 1991; Hynd et al., 1995 ; Larsen et al., 1992 ; Rumsey et al., 1996 ; Robichon & Habib, 1998)

Horizontal Cross Section

As is evident from the summary of findings in Table A23.1, most studies did find some fundamental differences in the size of the corpus callosum in dyslexic subjects verses non-dyslexic subjects. Surprisingly most of the experiments conducted have indicated a general increase in the tissue density in the posterior part of the callosum. Experts speculate that this increased neuron connection complexity, evident in the dyslexic corpus callosum, may be responsible for a reduction in efficiency of interhemispheric signal-transfer (Robichon & Habib, 1998; Habib, 2000).

Moffat's experiments in the late 1990s offer possible insight into the cause of the enlarged callosal; namely that neurodevelopment of the callosum may be linked to hormone levels in the body during critical stages of brain development. Moffat examined levels of testosterone in saliva and demonstrated an apparent correlation between higher levels of testosterone and an increased size in the mid-posterior part of the callosum (Moffat *et al.*, 1997).

Schlaug offers an alternative explanation of the potentially larger callosum generally evident amongst dyslexics; namely that a change in size may be attributed to increased remedial therapy provided as a treatment for dyslexia. Schlaug speculates that prolonged stimulation of the callosum region can actually result in an increase in the overall neuron density of the region. His experiments with musicians training over a prolonged period of time seem to provide strong evidence of this effect (Schlaug *et al.*, 1995b).

Debate continues as to the strengths and weaknesses of the theory, with the many authors now considering the possibility that deficiency in multiple regions of the brain is more likely responsible for all the varied symptoms displayed by dyslexics. (Habib, 2000)

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