Letter Reversals in Adults When Learning Braille Visually or Tactually

Begum Atay

Kingston University

Author Note

This dissertation is being submitted in partial fulfilment of the requirements for the degree of MSc Clinical Applications of Psychology. The research work reported herein was conducted under the supervision of Dr. Fiona Barlow-Brown. Word count excluding references and appendices: 11,623.

Abstract

Most children between the ages of three and seven tend to reverse letters when they learn how to read and write. The main aim of the study was to investigate this letter reversal phenomenon in adults and whether it is a natural stage of learning process. It was hypothesized that adults would make reversal errors when learning a new braille script either visually or tactually, as well as there would be more reversal errors made in the visual condition than in the tactile condition. Moreover, the number of reversal errors would decrease, and the number of correct responses would increase over time, and there would be more vertical errors made than horizontal errors. It was further hypothesized that poor readers and left handers would produce more reversal errors. A mixed design was conducted and 60 participants were recruited. The reading abilities of the participants were assessed by using a fluency test and the NART. The participants were then taught ten braille letters either visually or tactually, and completed the naming, drawing and matching tasks over two separate sessions. The results were significant for the hypotheses that assumed adults would make reversal errors when learning the braille script, and the number of correct responses would increase over time. However, non-significant results were found for other hypotheses. The present study has provided valuable evidence and strong support for the natural stage of learning theory as a plausible explanation for the causes of letter reversals.

1. Introduction

It is common that children between the ages of three and seven reverse letters, which is known as letter reversal phenomenon, at the early stages of learning to read and write. Subsequently, after the age of eight these reversals tend to decline rapidly (Cornell, 1985; Sidman & Kirk, 1974). Mirror writing is a more general form of letter reversals. Buchwald (as cited in Schott, 2007) defined mirror writing first in 1878, as a variety of script that is written in an opposite direction to the normal, as well as the individual letters may also be reversed. In other words, mirror writing is basically writing a letter or a word in the reverse direction, however, if they are held in a mirror, then they can be read as normal (see Figure 1).

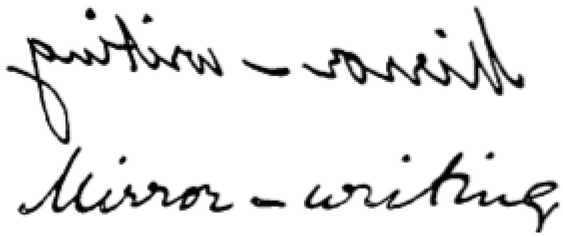


Figure 1. An example of mirror writing. Adapted from "Mirror Writing," by P.J. Allen, 1896, *Brain, 19*, p.387.

Mirror writing can be produced deliberately or involuntarily. In deliberate mirror writing, individuals may mirror write in experimental conditions, for curiosity, or habitually like Leonardo Da Vinci. In fact, his notebooks revealed that he wrote 5000 notebooks in reverse (Cubelli & Della Sala, 2009; Schott, 2007; Gottfried, Sancar, & Chatterjee, 2003). Involuntary mirror writing may occur in pathological situations such as in mentally retarded children, dyslexic children, individuals with focal brain diseases that particularly involves the left hemisphere like a focal trauma or a stroke, in diffuse brain diseases (e.g., head injuries, degenerative brain diseases such as Parkinson's disease, etc.), and in dementia patients.

Moreover, involuntary mirror writing can be observed in individuals who are forced to write with the left hand due to a damage in the preferred right hand (e.g., amputation), as well as in individuals who use a language that is written leftwards, or more commonly, in children at the early stages of learning to read and write (Schott, 2007; Cubelli & Della Sala, 2009).

For decades, letter reversals and mirror writing have been considered as an automatic indication of a reading disability such as dyslexia, and commonly assumed as a characteristic of left-handedness or a symptom of mental deficiency (Orton, 1925; Schott, 2007; Gordon, 1921). However, as more recent studies have been conducted in order to enlighten this field, these assumptions have been dispelled.

1.2. Theories of Letter Reversals and Mirror Writing

There have been several explanatory theories proposed in the past to investigate the underlying causes of the letter reversal phenomenon and mirror writing. The perceptual, motor and natural stage of learning theories are the ones that are most prominent in the literature, however, a unitary explanation could not be achieved to enlighten why reversal errors occur.

1.2.1. Perceptual theory.

The perceptual theory, also known as the visual-dominance hypothesis, was first proposed by Orton (1928). Orton suggested that engrams (visual representations) of the every letter and word that an individual learns, are stored in the dominant (left) hemisphere of the brain and their corresponding engrams (mirrored) are stored in the non-dominant (right) hemisphere. To illustrate, the letter “d” is stored in the left hemisphere, while its mirrored form “b” is stored in the right hemisphere. In children, these images in both hemispheres compete to gain dominance for controlling the lexical processing. This causes the occurrence of reversal errors and mirror writing, however, when the hemispheric dominance is established, the dominant hemisphere guides the lexical routine, while the non-dominant hemisphere is suppressed. Therefore, reversal errors fade away. In brain damaged patients, due to a damage in the dominant hemisphere, the suppressed mirror images are released, leading to mirror writing and letter reversals (Gottfried et al., 2003; Della Sala & Cubelli, 2007).

In order to test Orton's theory, Noble (1968) used monkeys in his research and transected the optic chiasm of them. In this way, each eye conveyed information only to the ipsilateral hemisphere. One eye of the monkeys was closed, whilst the other eye was trained to respond to a pair of mirror imaged stimuli. After that, the same procedure was performed for the untrained eye. The results indicated that monkeys favoured the unconditioned image when one of the eyes was uncovered. Noble's findings confirmed with Orton's theory by addressing that mirror engrams exist in the brain. However, animal studies cannot be directly applicable to human beings, since human brain as well as human behaviour are more complex than animals'.

Conversely, the researchers Corballis and Beale (as cited in Schott, 2007) did not support Orton's theory, suggesting that if the events were recorded in the correct orientation by the dominant hemisphere, and recorded in the reverse orientation by the non-dominant hemisphere, then whenever the dominant hemisphere is not activated, the result would be necessarily mirror writing, which actually does not occur. Furthermore, the researchers claimed that since the information is conveyed to the brain via both eyes, the view that suggests mirror images are stored separately in the brain is irrational (Gottfried et al., 2003).

The perceptual theory explains the causes of reversal errors as a neurological deficit rather than a natural stage of learning process. Considering that most children reverse letters or mirror write at some point, they are being labelled as slow developers or developmentally immature by this theory. Even though Orton was one of the first scholars that stressed the importance of the letter reversal occurrences, the theory has been still considered as having lack of credibility and valid evidence (Moyer & Newcomer, 1977).

1.2.2. Motor theory.

The motor theory has stemmed from the works of Erlenmeyer in 1879 (Gottfried et al., 2003). This hypothesis postulates that motor-writing programs (reversed and bilateral) are present in the opposite hemispheres. The left (dominant) motor program is responsible for guiding the right hand, whilst the right (non-dominant) program is suppressed, however, in case of a damage to dominant motor-writing program, reversed program is released, resulting in mirror writing or letter reversals with the left hand.

An alternative motor theory of Critchley (as cited in Heilman, Howell, Valenstein, & Rothi, 1980) suggests that while learning a skilled movement, an individual learns how to sequentially or simultaneously contract and relax muscles. Using the same motor program as the preferred hand has used, would cause the opposite spatial orientation of that movement in the case of using non-preferred hand. According to Heilman et al. (1980), writing the letter "C" with the right hand, which was first relaxed and then contracted, would cause mirror writing of the "C", if the individual uses the left hand, which is also first relaxed and then contracted. The theory gives a plausible explanation for why some of the right handed patients suffering from right hemiplegia mirror write when they use their left hand.

According to another motor hypothesis (Brown, Knauft, & Rosenbaum, 1948), the centrifugal or abductive movements (away from the body) are easier, smoother, less exhaustive and more controllable than adductive movements (towards to body). Left handed individuals make abductive movements, therefore, they have a tendency to start writing from the opposite direction, which is from right to left. When right handed individuals start writing with the left hand, then they may have a tendency to start from the midline and proceed to the opposite writing direction.

Supporting evidence for the motor theory comes from the research of Balfour, Borthwick, Cubelli, and Della Sala (2007). The scholars investigated mirror writing in several stroke patients and healthy elderly individuals. The results revealed that both left and right hemisphere damaged patients made letter reversals when they used their left hand. Similarly, healthy elderly produced mirror writing only when they wrote with their left hand, indicating that mirror writing occurs only when the non-dominant hand is used.

Della Sala and Cubelli (2007) restructured the motor theory and proposed the "directional apraxia" hypothesis to explain mirror writing phenomenon. The researchers investigated a case of a left hemisphere stroke patient, who had been mirror writing, and a group of healthy children. The tasks involved writing their own name, copying letters, digits, and words. They found that both healthy developing children and the brain stroke patient displayed letter reversals in tasks. Della Sala and Cubelli criticised other theories like the perceptual theory and proposed their own theory; directional apraxia, which presumes that motor programmes do not contain information about the direction of letters, but only contain information about the shape of them. Even though children know the letters, they are not sure about the direction of letters such as whether a letter should be facing right or left because they are inexperienced with writing. Therefore, children need to attain this information. On the other hand, this information may be lost in brain damaged patients due to an injury. In the light of these, Della Sala and Cubelli defined mirror writing as a symptom of a widespread deficit that shows itself on tasks requiring a specific learned motor direction. To illustrate, mirror writers may have a difficulty in rolling up spaghetti on a fork or dealing cards. The researchers concluded that mirror writing should be considered as a specific form of apraxia that affects the direction of over-learned actions. The directional apraxia hypothesis provides an alternative explanation for the cause of mirror writing phenomenon, however, it should be recognized that writing is a process that requires both visual and motor elements. However, the hypothesis emphasizes only the motor elements of writing.

1.2.3. Natural stage of learning theory.

The natural stage of learning theory is a more recent theory that explains the occurrence of mirror writing and letter reversals as a natural stage of learning a new script. The reversals are expected to fade away with adequate training and practice over time. Therefore, the research in this area particularly focuses on age, writing acquisition, and familiarity with script.

The study of Gibson, Gibson, Pick, and Osser (1962) was one of the studies that supported the natural stage of learning theory. The study required the participation of 167 children. The researchers found that four years old children made more reversal errors (45% error rate) compared to older age group. At the age of five, 45% dropped to nearly 31%, six years old children’s error rate was approximately 19% and finally, eight years olds made almost zero reversal errors. The reason for this decline in the letter reversals was considered as the development of increased sensitivity in children. As children grow up and be more exposed to letters, they begin to attend to distinctive features of letters, which help them to distinguish each letter from the other.

The study of Della Sala and Cubelli (2007) also supported the natural stage of learning theory. In the study, 33 nursery and 76 primary school children were tested. Children were required to complete four writing tasks. The results indicated that mirror writing was more frequent among nursery children (M = 82%) compared to primary school children (M = 62%). The researchers agreed with the aforementioned literature, which suggested that younger children tend to mirror write more frequently. However, according to the researchers, age was not the critical variable within the study, instead writing acquisition should be recognized, highlighting the association between illiterate individuals and the high frequency of letter reversals.

A more recent study of Cubelli and Della Sala (2009) was also based on investigating the relationship between mirror writing and age. In the study, 108 preschool children were recruited and asked to complete four writing tasks including writing their own name, as well as an orientation and a perceptual task. The results indicated that mirror writing is age-related. In addition to this, it was found that most of the mirror writers could only managed to copy their own name instead of writing spontaneously (M = 63%), whereas most of the non-mirror writers could write their name spontaneously (M = 77%). This study also revealed the significance of writing acquisition at mirror writing.

The relationship between reversal errors and writing acquisition or familiarity with script has been addressed by other research as well. Krise (1952) conducted an experiment to highlight the importance of familiarity with stimuli. In the experiment, 20 normal adults were tested. The results indicated that all participants reversed unfamiliar symbols, and none of them reversed familiar symbols when reading. Therefore, Krise concluded that tendency to reverse letters exists in all individuals at all ages. Further evidence that supported the natural stage of learning theory was gathered by Sidman and Kirk (1974). In the study, 15 children were required to complete naming, writing, and simultaneous and delayed matching to sample tasks. The results showed that reversal errors rapidly decreased with continued testing in all children. In fact, no reversal errors made in naming and writing tasks as a result of continued testing. The decrease in reversal errors with elevated familiarity with script was pointed out by Lavine (1977) as well. He suggested that more exposure to new stimuli would increase differentiation, and this differentiation would cause decrease in reversal errors. According to Schubenz and Buchwald (as cited in Frith, 1971), letter reversal errors depend on the frequency of occurring letters in a language, because those frequently occurring letters are practiced more and they are remembered better. Therefore, it becomes less likely to make reversal errors.

Further evidence that supported the natural stage of learning theory was obtained from the research of Fischer (2011). Fischer developed "the implicit right writing rule" to explain the reversal error phenomenon. According to the implicit right writing rule, children tend to reverse digits and capital letters that do not have distinctive features on the right or face right (J, Z, S, 1, 2, 3, 7, 9). Therefore, these characters are more likely to be mirror written. The global hypothesis postulates that the implicit right writing rule guides the correct writing direction, thus those digits and capital letters that face right such as B, C, D, E, F, G, K, L, N, P, R, Q and digits 4, 5, 6 are expected to be mirror written less frequently. Fischer tested this theoretical approach by recruiting 300 children and asking them to write 11 digits or series of letters inside 11 squares. As expected, a significant difference was found between two groups of characters (conforming vs. contradicting implicit right writing rule). The mean frequency of reversals for the characters that conform implicit right writing rule (B, C, D, E, F, G, K, L, N, P, R, Q, 4, 5, 6) was M = 8.4 %, on the other hand the mean frequency of reversals for the characters that contradict the rule was M = 45.1%. However, the study had some significant flaws such as examining small number of characters, as well as examining only the capital letters. Children at those ages use lower case letters more frequently than capital letters; hence the results should be interpreted with caution.

In general, the natural stage of learning theory supports the view that everybody has a tendency to reverse letters when confronting with new stimuli, however, with age or with practice, reversal errors are expected to decline. Compared to other theories, this theory has been supported by a growing body of research, and it offers a more plausible explanation for the causes of mirror writing and letter reversals.

1.3. Reading Ability and Reversal Errors

The relationship between reading ability and the occurrence of letter reversals has been investigated by many researchers. Orton (1925) was one of the first scholars that put forward the link between reversal errors and reading disability. He claimed that a neurological impairment or a delay in the development of cerebral dominance are the causes of reversals in reading. In fact, he proposed a term "strephosymbolia", which means twisted symbols, in order to describe a specific reading disability that relates to persistent tendency to reverse letters in writing and reading. He suggested that poor readers such as dyslexics are likely to have more difficulty in differentiating letters especially if they are vertically or horizontally symmetrical to each other (Lachmann & Geyer, 2003). Subsequently, several researchers have conducted studies based on Orton's views. For example, the study of Liberman, Schankweiler, Orlando, Harris, and Berti (1971) investigated the relationship between reading ability and the incidence of reversal errors by recruiting 59 second graders and showing them a list of printed words or letters. Children were assessed by their reading abilities (poor and normal readers) and the total number of errors made. Liberman and his colleagues' findings demonstrated that nearly all errors were made by poor readers. However, reversal errors constituted only a small portion (25%). Other errors were made mostly due to vowel substitutions, additions or omissions. Yet, their study was a direct evidence for Orton's views.

Further evidence that pointed out this relationship was gathered by Terepocki, Kruk and Willows (2002). The researchers compared ten normal readers and ten poor readers by using paper-and-pencil and computer-based tasks. They measured the subjects' abilities to remember, detect, and reproduce the orientation of stimuli, which were unfamiliar to the subjects. The results indicated that poor readers confused the orientation of stimuli more than normal readers. A more recent study of Brooks, Berninger, and Abbott (2011) also investigated letter writing and letter naming reversals in dyslexic children. Their findings demonstrated that dyslexic children made more reversal errors both in letter writing and letter naming tasks compared to non-dyslexic children. On the other hand, there were some dyslexic children, who made no reversal errors at all.

Conversely, there are also alternative findings that are against Orton's (1925) views. To illustrate, Black (1973) compared 100 normal and 100 retarded readers based on the frequency of rotation and reversal errors. The results revealed that the incidence of letter reversals was 22% in retarded readers, and 20% in normal readers. There was no significant difference between two groups. Moreover, in the study of Grosser and Trzeciak (1981), 29 disabled and 15 normal readers were recruited and the exposure time for naming reversible (p, d, q, b) and the non-reversible letters (x, o, u, w) were examined. The researchers concluded that all subjects needed more time to name reversible letters. The proportion of non-reversible and reversible letters was nearly the same for both normal and disabled readers. Likewise, Patton, Yarbrough, and Thursby (2000) investigated the rate of reversal errors among 201 children by dividing them as normal readers and poor readers in a four year of longitudinal study. The findings revealed a non-significant difference between normal readers and poor readers in terms of the number of reversal errors made.

The inconsistent findings for the link between reading ability and reversal errors result in lack of clarity. Even though the majority of studies hold strong evidence for the view that poor readers tend to make significantly more reversal errors compared to normal readers, further research is needed to re-address this issue in order to increase clarification within this particular area.

1.4. Handedness and Reversal errors

The relationship between handedness and reversal errors has been pointed out by numerous research as well, focusing on determining the left hand superiority to the right hand at mirror writing. In order to explain the left hand superiority, three hypotheses become prominent; the motor hypothesis, mirror-engram hypothesis, and spatial bias hypothesis.

According to the motor hypothesis, as discussed above, abductive movements are considered as more comfortable than adductive movements, thus left handers become more superior to right handers (Brown et al., 1948). The mirror-engram hypothesis proposes that normal engrams are stored in the left hemisphere, while the mirror engrams of them are stored in the right hemisphere. While writing, left handers have direct access to mirror engrams because the writing hand is contralateral to the hemispheres. Therefore, they are better at mirror writing (Yang, 1997). In addition to these hypotheses, the spatial bias hypothesis postulates that the reason for left handers' superiority at mirror writing is that their ability to overcome the common left-to right direction bias and switch it to the opposite direction at mirror writing, which is right-to-left (Tankle & Heilman, 1983).

Tankle and Heilman (1983) investigated the left hand superiority at mirror writing by comparing left handed and right handed individuals according to their ability to mirror write. The subjects were asked to mirror write sentences by using both non-dominant and dominant hands. The results revealed that left-handers wrote faster and they made fewer errors compared to right-handers. Tucha, Arschenbrenner, and Lange (2000) tested the findings of Tankle and Heilman by recruiting 49 students and dividing them according to their handedness. The students were asked to write and mirror-write a sentence three times and under four separate conditions. Handwriting movements were recorded by using a digitizing tablet. The experimenters examined the writing time and error rates. Tucha et al. agreed with

Tankle and Heilman, who stated that left handed individuals are superior to right handed individuals at mirror writing because of their ability to reverse common writing direction better.

Contrariwise, Vaid and Stiles-Davis (1989) challenged the assumption of left handers are better at mirror writing than right handers, by comparing the right handers and the left handers' mirror writing abilities. As a result, they found that right handed participants are actually as good as left handed participants at mirror writing. In fact, individuals who started the task with their right hand first, wrote faster while mirror writing. Yang (1997) found similar results with Vaid and Stiles-Davis in his study. He tested writing condition (normal and mirror writing), writing hand, and stimuli types (Chinese characters and pseudocharacters) as variables. The results indicated that the right hand was superior to the left hand at both mirror writing and normal writing. A more recent study of Fisher (2013), involving participation of 367 children, also revealed that handedness has little effect on the frequency of reversals, stating that previous research that supported left handers superiority were poorly established. Even though many studies have favoured the assumption of left handers tend to make more reversal errors, mixed evidence hinders reaching a definite conclusion on this issue.

1.5. Types of Reversal Errors

Types of errors made in letter reversals have been investigated only by a limited number of studies. Orton (as cited in Brendler & Lachmann, 2001) identified three symptoms of "strephosymbolia" and described the common types of reversal errors. According to this identification, poor readers tend to confuse rotated, horizontally or vertically symmetrical letters (e.g., "b" and "d"), which is called as static reversals. Kinetic reversals refer to confusing palindromes such as “was” -“saw”, and lastly poor readers demonstrate a remarkable ability to mirror write and read even better than normal writing and reading.

The researchers, Bornstein, Ferdinandsen, and Gross (1981) investigated the static reversals by observing the preference of horizontally symmetrical, vertically symmetrical, and asymmetrical patterns in infants. They found that four months old infants processed vertically symmetrical patterns better than horizontally symmetrical and asymmetrical patterns without showing preference, however, 12 months old infants preferred vertically symmetrical patterns to others. The researchers suggested that vertical symmetry is treated as mirror images by adults and children. The reason for preferring vertical symmetry is because of its existence in nature such as human face. Likewise, Chapman’s (as cited in Kaufman, 1980) study involving preschool children also found that mirror errors on vertical axis were made more often than mirror errors on horizontal axis.

Fabian (1945) also provided empirical evidence for the tendency to verticalize in his study by recruiting 586 school children and asking them to copy the Bender’s gestalt figures. It was found that over 50% of children rotated the horizontal figures, and among these rotations 80% of them were the rotations from horizontal to vertical direction. Further research of Fabian (1945) also revealed the preference of vertical errors to horizontal errors. Similarly to his previous research, a group of children were recruited and asked to draw straight lines, however, majority of children drew vertical lines.

Contrariwise, Liberman et al. (1971) found conflicting evidence. The researchers recruited 59 elementary school children to investigate sequence, orientation, consonant and vowel errors. The findings of the study revealed that vertical errors were made as frequently as horizontal errors by children, thus contradicted the aforementioned literature, leaving the topic unclear.

1.6. Braille and Reversal Errors

In the current study, braille letters were used to investigate the letter reversal phenomenon. Braille is a system that was invented by Louis Braille in the 19th century (Millar, 1997). It is a tactual script, which can be read with fingertips, and it is mostly used by blind individuals or individuals with low visions. Braille is represented by a certain dot configuration based on the absence or presence of six raised dots (see Figure 2). The dots are over one millimetre in diameter and placed in a matrix of two columns and three rows, which is called as a "braille cell" (Toussaint & Tiger, 2010).

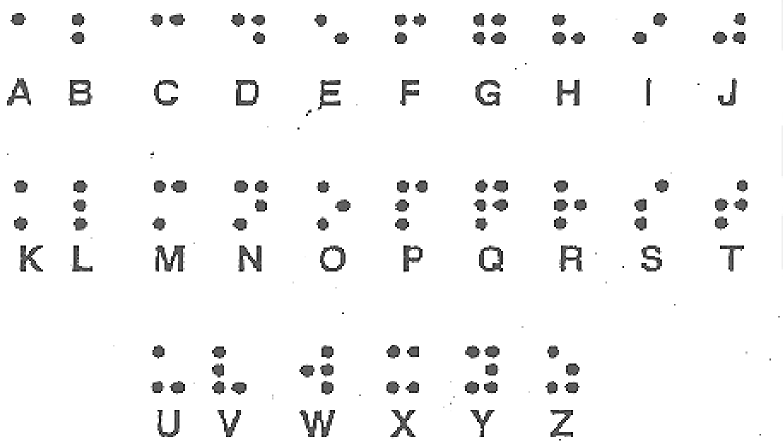


Figure 2. English braille letters.

Many researchers, who investigated the learning process of braille letters, compared print reading and braille reading. The process of learning print and braille letters is considered to be similar. Therefore, braille would give an opportunity to transfer the findings of the current study to print reading and writing. Both blinded and sighted individuals use semantic information and cognitive skills such as verbal short-term memory and phonological awareness when reading (Veispak, Boets, & Ghesquiere, 2013). However, braille reading and print reading differ from each other at some point. Print reading is a simultaneous process, whereas braille reading is sequential, which indicates that braille readers should pass over each letter on a line while reading. Thus, vision might be seen as more advantageous since just by one glance, more information can be obtained than touch (Millar, 1997). Moreover, shape perception by touch is considered to be less accurate and less efficient compared to vision by many researchers (Pring, 1994). Yet, the scholars as Bishop Berkeley and Katz (as cited in Millar, 1997) supported the view that “touch teaches vision” (p.15) and touch is the basis of perception. Therefore, it was suggested that hand should be considered as a unitary organ just as the eye (Millar, 1997). In fact, people prefer to touch, shake, lift and explore an object when they need to attain information about an object’s function, hardness, size, weight, etc. Thus, touch has been considered as a rich source for information.

There has been little research carried out to investigate braille reversals. Millar (1977a) conducted an experiment by recruiting blindfolded sighted children, who had never seen braille before. Children were asked to touch and identify the pairs of braille letters whether they had different or same shape. In the first test, accuracy was unexpectedly high (less than 11% error rate) and in the final test, accuracy test was over 90%. The findings supported the natural stage of learning theory, because more exposure to stimuli reduced the error rates. Braille mirror errors were also found in the study of Nolan and Kederis (as cited in Millar, 1997). Congenitally blind braille readers were asked to draw braille letters. The results indicated that mirror errors consisted only a small proportion; just two mirror errors out of 55 characters were found. Most of the errors were due to dot confusions such as missing dots. More mirror errors were expected to be found if patterns were coded in vertical axis (Millar, 1997). Likewise, Millar (1985c) found that congenitally blind readers, who were in the process of learning braille, made most errors again due to confusing spatial positions of dots, few mirror reversals were found. Although these studies provide a better understanding of braille reversals, recruiting congenitally blind participants for the tasks that involve drawing could affect participants' performances, considering that drawing is a more visual process, thus the findings should be interpreted with caution.

The reason for making braille reversal errors can be explained by the nature of braille characters. Braille characters differ from print letters in numerous ways. To illustrate, print letters have distinctive features; they involve curves and continuous lines, whereas braille letters are lack of these distinctive features, and all characters derive from the same matrix. Differentiation of the characters depends on the absence or presence of small raised dots, which makes it difficult to locate the gaps between them. Two millimetre difference in the location of a dot may even lead a mirror image pattern of the correct letter such as the braille letters "f" and "d", "h", and "j" (Millar, 1997). Therefore, the nature of braille characters in terms of the similarities between the shapes of them, small sizes of the gaps between dots, as well as small sizes of dots play crucial role in the occurrence of reversal errors in braille.

The present study has used braille because it would be like a new language for adults, just as children at the early stages of learning to read and write. Being unfamiliar with braille and having no prior experience with learning braille would give an opportunity to observe learning process more accurately, because braille would be introduced as a new script to adults. As Millar (1997) stated, beginning braille readers also make reversal errors, but in time they learn how to read and write in braille accurately, supporting the view that reversal errors are a natural stage of learning process. Therefore, it has been expected that adults would also make reversal errors when learning braille. Furthermore, braille contains reversible letters just as the print letters. To illustrate, the letters "b" and "d" are the ones that are most confused in print reading and writing, similarly braille letters of "e" and "i" are likely to be confused (Liberman et al, 1971; Moyer & Newcomer, 1977). Additionally, braille serves as a basis to make a comparison between visual and tactile conditions, thus using braille may be beneficial to determine whether reversal errors occur due to a problem in visual processing.

1.7. Aims and Hypotheses

The main aim of the study was to expand the knowledge of letter reversal phenomenon and clarify the previous conflicting body of research that has addressed the possible reasons for why reversal errors occur. Thereby, the current study aimed to investigate whether adults would produce reversal errors when learning a new braille script, similarly to children at the early stages of learning to read and write. If adults make reversal errors when learning an unfamiliar script, it would support the natural stage of learning theory. A further aim was to determine whether reversal occurrences are confined to visual processing or whether the phenomenon is irrespective of modality. If reversal errors are produced in both visual and tactile conditions, then the views based on explaining mirror writing and letter reversals as a consequence of a problem in visual processing would be dispelled. Moreover, the study aimed to explore whether handedness, reading ability and time would influence the occurrence of reversal errors, as well as it was aimed to identify the common types of reversal errors.

In the light of these, the study investigated the following hypotheses considering the past research and evidence. The first hypothesis stated that adults would make reversal errors when learning braille either visually or tactually. Secondly, it was predicted that there would be more reversal errors made in the visual condition than in the tactile condition. The third and fourth hypotheses stated that the number of reversal errors would decrease, and the number of correct responses would increase over time, respectively. It was further hypothesized that there would be more vertical errors made than horizontal errors, as well as poor readers would make more reversal errors compared to normal readers. Lastly, it was hypothesized that left handers would make more reversal errors compared to right handers.

2. Method

2.1. Participants

Sixty participants were recruited from Kingston University London through opportunity sampling method. The criteria in order to be eligible to participate in the study was being 18-30 years old, being able to speak fluent English and not reading braille as well as not suffering from any significant visual and sensory deficits. There were 25 male (41.7%) and 35 female (58.3%) participants. The age range was 18-30 years old, the mean age of the participants was 23.25 (M = 23.25, SD = 2.78). Among the 60 participants, 54 (90%) of them were right handed and six (10%) of them were left handed. Thirty participants were in the visual condition of the experiment and 30 of them were in the tactile condition.

2.2. Materials

An information sheet (see Appendix A), a consent form (see Appendix B) and a demographic questionnaire (see Appendix C), which consisted of questions regarding to age, gender, handedness, whether participants had been familiar with braille characters, and whether they had been diagnosed with a reading disability such as dyslexia, were used.

The National Adult Reading Test (NART) (see Appendix D) was administered in order to assess the participants' reading abilities. The NART was considered as one of the most reliable tests and having a high construct validity to measure reading ability and verbal intelligence (Crawford, Parker, Stewart, Besson, & De Lacey, 1989; Crawford, Moore, & Cameron, 1992). The NART consists of 50 words, which are in an order of increasing level of difficulty (Nelson, 1982). The words were presented on A4 papers separately, held in a ring-binder folder. The correct pronunciation of the words were checked from the Cambridge and Oxford online dictionaries before the experiment.

A fluency test, titled “Every little part” was also administered in addition to the NART to assess participants’ reading abilities (see Appendix E). “Every little part” is an English text, which consists of 250 words. The research of Crawford et al. (1992) revealed a significant correlation between verbal fluency tests and the NART, thus using not only one but two reading tests could be more reliable to assess reading ability.

For the visual condition, ten braille letters (L, I, D, M, C, E, B, H, F, U) (see Figure 3) printed on a white paper and then glued to individual pieces of cardboard cards with the dimensions of 5 cm x 5 cm, and for the tactile condition, the same letters typed on a braille typing machine and then glued to individual pieces of cardboard cards with the dimensions of 5 cm x 5 cm, were used. On the back side of the each card, the identities of the letters were noted, and again on the top back side “top” was written in order to avoid confusion of the upright directions of the letters by the researchers.

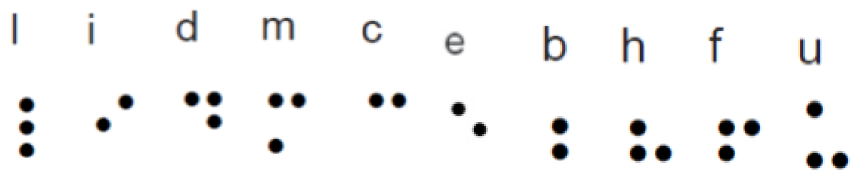


Figure 3. The order of ten braille letters presented.

In the matching task of both conditions, 15 braille letters in line (teaching session: G, C, D, M, I, L, H, A, Y, E, V, B, U, F, P (see Figure 4); testing session: L, A, G, F, B, P, D, C, Y, I, H, M, V, E, U (see Figure 5)) were used. In the visual condition, the letters were printed on a white paper and in the tactile condition, the same letters were typed on a braille typing machine.

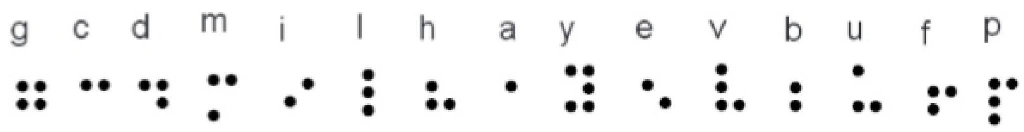


Figure 4. Braille letters presented in the teaching session for the matching task.

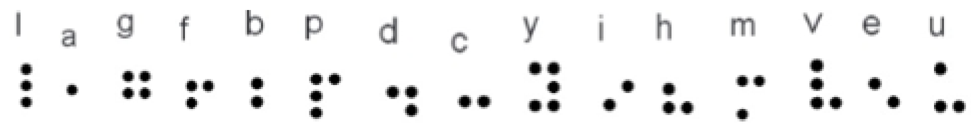


Figure 5. Braille letters presented in the testing session for the matching task.

In order to assess participants' tactile sensitivities for those who were in the tactile condition, the braille letters "A" and "Y" (see Figure 6), which were also typed on a braille typing machine and then glued to individual pieces of cardboard cards with the same dimensions with the other cards, were used.

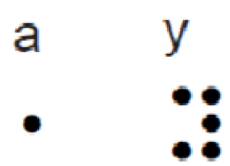


Figure 6. Braille letters "A" and "Y".

Furthermore, in the tactile condition, in order to prevent participants from seeing the letters during the experiment, a cardboard box was used. The cardboard box was cut off from the two opposing long sides. In this way, it was ensured that participants could reach and touch the letters underneath the box without seeing them, and the researcher from the opposing side could monitor the participants' movements and hold the letters to prevent them slipping aside.

2.3. Design

A mixed design was conducted in the current study. An independent measures design was used, in which the independent variable was the conditions of the experiment (visual vs. tactile). A repeated measures design was used, in which the independent variable was the tasks (naming, drawing and matching) over two sessions (teaching vs. testing sessions). Furthermore, a correlational design was used to assess the relationship between reading ability and the number of reversal errors. The dependent variables of the designs were the number of reversal errors, the number of correct responses, and the types of reversal errors (vertical vs. horizontal errors) as well as handedness was the independent variable of the designs.

2.4. Procedure

The experiment had two parts; the first part was the teaching session and the second part was the testing session. These two sessions were conducted two to three days apart depending on the availability of participants. There were two experimenters following the same procedure, however, the experimenters tested the participants independently from each other. The participants were tested individually in several settings. Furthermore, the study had two conditions; visual and tactile, in which the participants were randomly allocated to either the visual or the tactile condition of the experiment. The same number of participants were participated in each condition.

At the beginning of the experiment, participants read an information sheet, signed a consent form and completed a demographic questionnaire. It was ensured that participants could not read braille, those who were familiar with braille and were able to read braille excluded from the experiment because it could have affected the main aim of the study, since braille was introduced as a new script to participants.

The participants in the tactile condition of the experiment were asked to identify embossed letters “A” and “Y” to test whether they had a significant sensory impairment. The letters differ significantly from each other; “A” has one dot, whereas “Y” has five dots. Participants, who could not distinguish these letters were also excluded from the study either.

The NART and the fluency test were administered respectively to assess the participants’ reading abilities. In the NART, participants were required to pronounce each of the 50 words out loud, one by one, and in an order. They were also instructed that if they had no familiarity with the word, then they could make a guess about the pronunciation of them. The number of errors made in the pronunciation of the words were noted by the experimenter on a sheet of paper, which also indicated the NART score of the participant. The experimenter gave no feedback.

In the fluency test titled “Every little part”, the participants were asked to read the text out loud as fast and as accurately as they could, and they were informed that the experimenter would stop them after one minute passed. While the participants were reading the text, the experimenter was timing them for one minute by using a timer. The words that were paused at for more than five seconds, the words that were mispronounced, skipped, substituted or read in a wrong order were counted as errors and noted on a sheet of paper. After one minute passed, the last word that the participant read was circled. No feedback was given either. The fluency test score was obtained by subtracting the number of errors from the total number of words read and then dividing that number by the total words read and then multiplying the result by 100.

After these reading tests, participants were told that they would be taught ten braille letters. Thus, they were asked to pay attention to learn and remember the letters as much as they could. The letters were presented in the same order (L, I, D, M, C, E, B, H, F, U) to each participant. Each letter was presented for ten seconds. After teaching ten braille letters either visually or tactually, the naming, drawing and matching tasks were completed respectively. A similar methodology was used with the research of Sidman and Kirk (1974) in terms of the kinds of tasks, sessions, and stimuli. Using three kinds of tasks (naming, drawing, matching) to assess letter reversals would provide a better understanding of the phenomenon rather than focusing on only one aspect (e.g., only writing).

In the naming task, the cards were shuffled, and then presented one by one. This time, the participants were required to name the letter verbally. They were given feedback each time they named the letter by indicating whether they named the letter correct or incorrect, and the experimenter named the correct letter for each incorrect answer. The letter that was presented and the responses of the participants were noted on a sheet of paper.

In the drawing task, the subjects were asked to draw the same ten letters in braille formation. Thus, they were provided an A4 lined paper and a pen. The feedback was given after they completed the drawing task by stating only whether they drew the letters correct or incorrect.

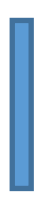
In the matching task, 15 braille letters (G, C, D, M, I, L, H, A, Y, E, V, B, U, F, P) in line were presented, and the participants were required to discriminate the letters that had been taught out of 15 letters. Five distractor letters were used this time (G, A, Y, V, P) to reduce the possibility of guessing the right answer. Participants were asked to name each letter verbally in the same order as letters lined. Each answer was noted on a sheet of paper and the feedback was given after they completed the matching task. Participants were told not to study any braille letters during the break between two sessions.

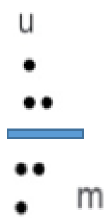
Two to three days later, the testing session took place, in which the participants undertook the same procedure as the teaching session. First, they were reminded the same ten braille letters to reduce the possibility of forgetting the letters. Participants again completed all of the three tasks (naming, drawing, and matching). This time no feedback was given for any of the tasks. Furthermore, the order of the letters in the matching task was altered (L, A, G, F, B, P, D, C, Y, I, H, M, V, E, U) to minimize the practice effect. At the end of the experiment, the participants were debriefed and given a debriefing form (see Appendix F).

3. Results

3.1. Coding of Reversal Errors

In order to code the types of reversal errors as horizontal errors, vertical errors, and “other” errors, an imaginary mirror was placed. For horizontal errors, it was placed above or below the letter (see Figure 7), for vertical errors, an imaginary mirror was placed right or left side of the letter (see Figure 8), and finally if the answer of the participant did not fit either vertical error or horizontal error, then it was coded as “other” error.


= An imaginary mirror



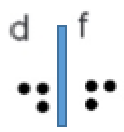


Figure 8. Vertical error example.

Figure 7. Horizontal error example.

In the current study, three tasks (naming, drawing, and matching) were administered to each participant over two sessions (teaching and testing sessions) in two different experimental conditions (visual and tactile conditions). Thus, the data was collapsed to conduct the analysis, in this way the total correct responses, total reversal errors, which include total vertical and total horizontal errors were generated.

3.2. Hypothesis 1

To investigate the first hypothesis, which stated that adults would make reversal errors when learning braille letters either visually or tactually, one sample *t*-test was performed. The results were statistically significant, ($M = 1.07$, $SD = .79$), $t(59) = 10.48$, $p < .001$, thus the hypothesis was supported by the data. It should also be noted that there was only one participant out of 60, who did not make any reversal errors at all.

3.3. Hypothesis 2, Hypothesis 3, and Hypothesis 5

A three way 2 (condition: visual vs. tactile) x 2 (time: teaching session vs. testing session) x 2 (types of reversal errors: vertical error vs. horizontal errors) mixed ANOVA with repeated measures on the second and the third variables was conducted to measure whether there was a statistically significant difference between two conditions in terms of the number of reversal errors made, a statistically significant difference between two sessions again in terms of the number of reversal errors made, and lastly a statistically significant difference between the number of vertical and horizontal errors made.

The Levene's test was non-significant for vertical errors in both sessions, therefore, the assumption of homogeneity of variance was met. However, the test was significant for horizontal errors in both sessions, and thus the assumption of homogeneity of variance has been violated.

The results demonstrated that there was no significant main effect of condition, $F(1,58) = 1.95$, $p = .168$, $\eta_p^2 = .03$. Thus, the second hypothesis, which stated that there would be more reversal errors made in the visual condition than in the tactile condition, could not be supported by the data.

Subsequently, the results showed that there was no significant main effect of time, $F(1,58) = .78$, $p = .382$, $\eta_p^2 = .01$, and there was no significant time and condition interaction, $F(1,58) = .05$, $p = .832$, $\eta_p^2 = .00$, indicating that the number of reversal errors made over time was not influenced by the condition. Therefore, the third hypothesis stated that the number of reversal errors would decrease over time was not supported by the data either.

Additionally, the results demonstrated a non-significant main effect of types of reversal errors, $F(1,58) = 1.55$, $p = .219$, $\eta_p^2 = .03$, a non-significant interaction between time and types of reversal errors, $F(1,58) = .01$, $p = .940$, $\eta_p^2 = .00$, a non-significant interaction between condition and types of reversal errors, $F(1,58) = 1.23$, $p = .272$, $\eta_p^2 = .02$, and finally a non-significant interaction between time, condition, and types of reversal errors, $F(1,58) = 0.91$, $p = .345$, $\eta_p^2 = .02$, indicating that the types of reversal errors made over time were not influenced by either condition or time. Therefore, the fifth hypothesis, which stated that there would be more vertical errors made than horizontal errors, was not supported by the data.

As the descriptive statistics (see Table 1) and the plot graphs, (see Figure 9 and Figure 10) which illustrates the interaction between types of reversal errors, time, and condition, demonstrated, horizontal errors slightly increased over time in both conditions, whereas vertical errors slightly decreased in the visual condition, and slightly increased in the tactile condition over time. Overall, participants in the visual condition made slightly more reversal errors than those in the tactile condition, reversal errors slightly increased over time, and the vertical errors were made slightly more than horizontal errors.

Table 1

Descriptive Statistics of the Avarage Reversal Errors over Time for Visual and Tactile Conditions

	Condition												Total					
	Visual						Tactile											
	Vertical			Horizontal			Vertical			Horizontal			Vertical			Horizontal		
Session	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
teaching	30	.32	.32	30	.26	.39	30	.25	.28	30	.16	.25	60	.28	.30	60	.21	.33
testing	30	.29	.55	30	.34	.62	30	.35	.37	30	.17	.25	60	.32	.46	60	.25	.48

Note. N = number of participants; SD = standard deviation

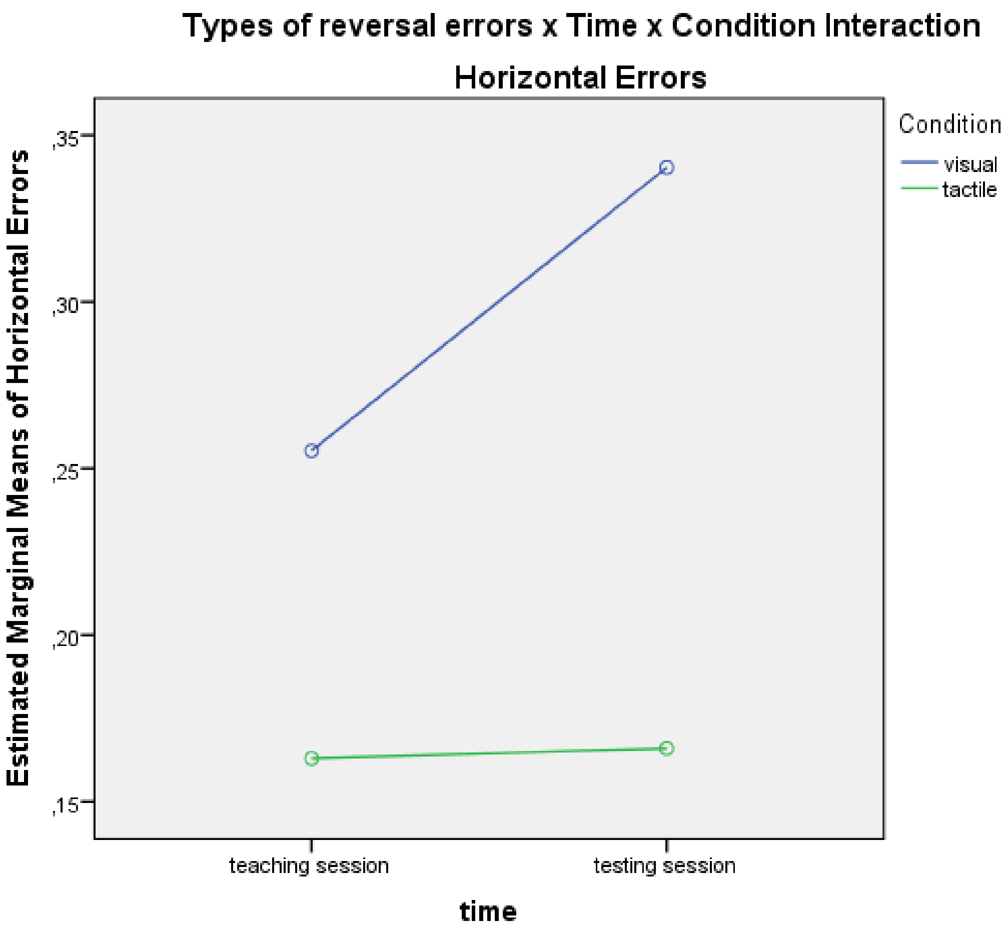


Figure 9. Estimated marginal means of horizontal errors for the interaction between time and condition.

Figure 10. Estimated marginal means of vertical errors for the interaction between time and condition.

3.4. Hypothesis 4

A two way 2 (condition: visual vs. tactile) x 2 (time: teaching session vs. testing session) mixed ANOVA with repeated measure on the second variable was conducted to test whether the number of correct responses significantly increased over time in both conditions. The Levene's test was non-significant at each level, therefore, the assumption of homogeneity of variance was met. The statistical analysis revealed that there was a significant main effect of time, $F(1,58) = 98.64$, $p < .001$, $\eta_p^2 = .63$, as well as a significant main effect of condition, *F*(1,58) = 45.47, *p* < .001, η_p^2 = .44, however, a non-significant interaction between time and condition, *F*(1,58) = 2.78, *p* = .101, η_p^2 =.05, indicating that the number of correct responses given over time was not influenced by the condition.

In the teaching session, participants in the visual condition (*M* = 22.30, *SD* = 5.96) gave a higher number of correct responses than those in the tactile condition (*M* = 13.73, *SD* = 5.54). In the testing session, participants in the visual condition (*M* = 29.27, *SD* = 5.28) also gave a higher number of correct responses than those in the tactile condition (*M* = 18.70, *SD* = 6.95). Overall, in the teaching session participants gave a mean of *M* = 18.02 (*SD* = 7.16) correct responses, and in the testing session participants gave a mean of *M* = 23.99 (*SD* = 8.11) correct responses. The results showed that the number of correct responses significantly increased over time, and the participants in the visual condition gave significantly a higher number of correct responses than those in the tactile condition as it can be also seen from the plot graph (see Figure 11). Therefore, the fourth hypothesis was supported by the data, since a significant increase in the number of correct responses over time was found.

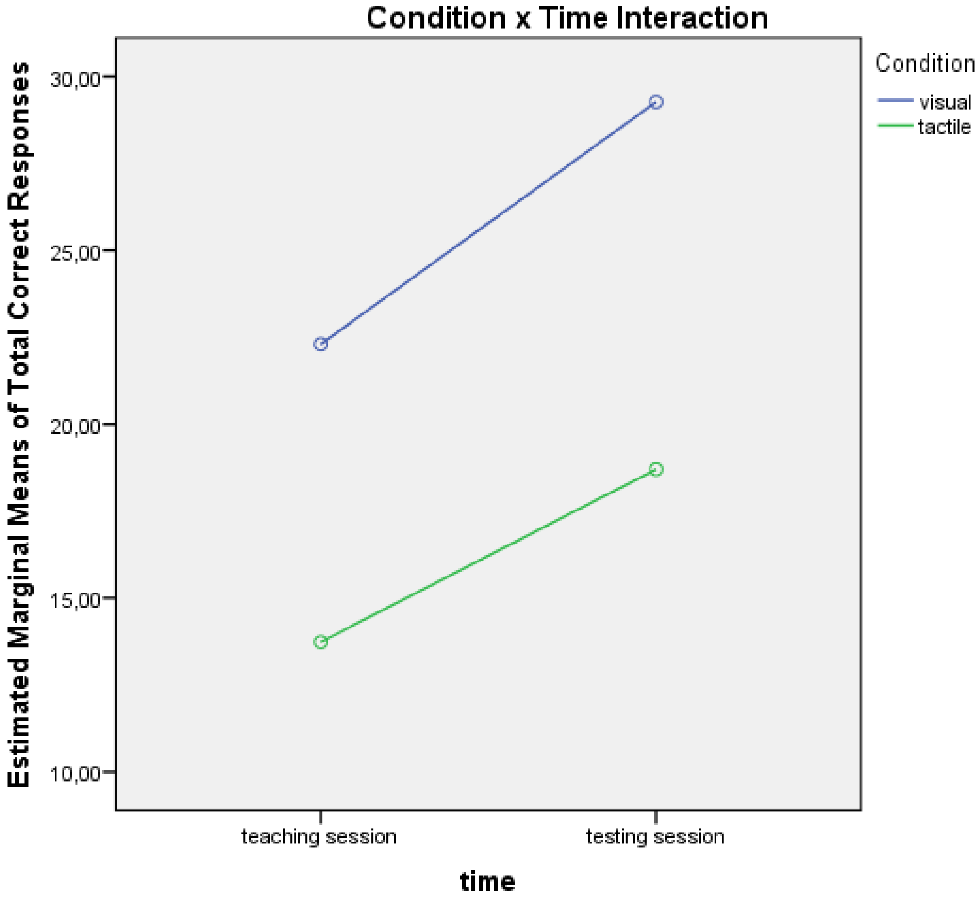


Figure 11. Estimated marginal means of total correct responses for the interaction between condition and time.

3.5. Hypothesis 6

To test the sixth hypothesis, which stated that poor readers would make more reversal errors than normal readers, a Pearson's correlation analysis was conducted. The results demonstrated that there was a non-significant correlation between the NART scores (*M* = 20.57, *SD* = 3.27) and the fluency test (*M* = 99.5 %, *SD* = .79), *r*(58) = -.11, *p* = .406. Considering that the fluency test scores were only varied between three points (100%, 99%, 98% of accuracy), only the NART scores were used in the statistical analysis. The Pearson's correlation analysis revealed that there was no significant relationship between the NART scores and the number of reversal errors, $r(58) = -.12$, $p = .344$, therefore, the hypothesis could not be supported by the data.

3.6. Hypothesis 7

Among the 60 participants, 54 of them were right handed (90%) and six of them were left handed (10%). Due to a low number of left handed participants, statistical analysis could not be conducted. Therefore, the hypothesis stated that the left handers would make more reversal errors than right handers could not be tested.

3.7. Exploratory Qualitative Analysis

A further exploratory qualitative analysis for the drawing task was conducted to explore in more detail of the common types of errors made by the participants in both conditions. It was found that many participants made similar types of errors especially for the certain letters. Braille letters “E” and “I” (see Figure 12), “F” and “D” (see Figure 13 and Figure 14) were the most frequently made vertical errors irrespective of modality. Braille letters “B” and “C” (see Figure 15 and 16) were also confused frequently as well, and they were coded as “other” error.

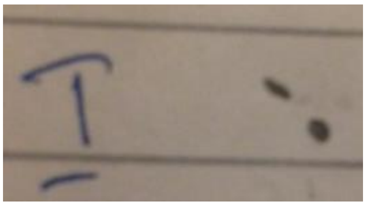


Figure 12. “E” and “I” confusion as a vertical error.

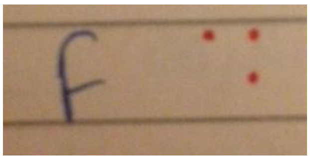


Figure 13. An example of vertical error made by participant 1.

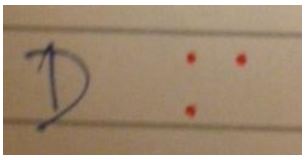


Figure 14. An example of vertical error made by participant 1.

Figure 15. “B” and “C” confusion.

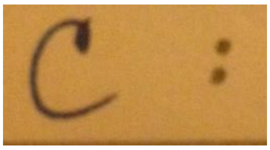


Figure 16. “B” and “C” confusion.

“Other” errors were encountered a lot especially in the tactile condition. An independent samples t-test was performed to compare the “other” errors in the tactile condition with the visual condition. There was a statistically significant difference between two conditions; the participants in the tactile condition (M = 4.99, SD = .84) made more “other” errors compared to those in the visual condition (M = 3.61, SD = .1.5), $t(45.55) = -4.44$, $p < .001$. “Other” errors were made frequently due to confusing the spatial positions of dots (see Figure 17) or adding more number of dots within a braille cell (see Figure 18).

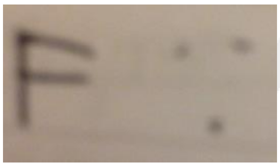


Figure 17. Confusion due to spatial location of dots.

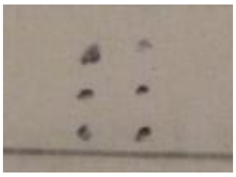


Figure 18. Increased number of dots for the letter “B”.

“L” was drawn most correctly among the other letters for both conditions. Most of the participants drew “L” correctly and indicated that it was the easiest letter to remember and draw. The reason for the accuracy in drawing “L” can be explained by its resemblance with the print letter “L”. Yet, some participants in the tactile condition drew “L” in an oblique direction (see Figure 19).

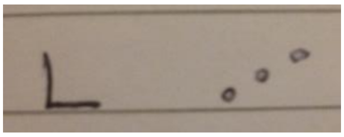


Figure 19. An oblique drawing of “L”.

4. General Discussion

The first hypothesis stated that adults would make reversal errors when learning braille either visually or tactually was found to be statistically significant, therefore, the hypothesis was supported by the data. Secondly, it was hypothesized that the participants in the visual condition would make more reversal errors compared to those in the tactile condition. The results indicated a non-significant difference between two conditions. Additionally, the third and the fourth hypotheses stated that the number of reversal errors would decrease, and the number of correct responses would increase over time, respectively. The results were found to be non-significant for the third hypothesis, and statistically significant for the fourth hypothesis. The fifth hypothesis stated that there would be more vertical errors made than horizontal errors, however, it was also found to be non-significant. It was further hypothesized that poor readers would make more reversal errors compared to normal readers. The results were also non-significant, indicating that there was no significant relationship between reading ability and the occurrence of reversal errors. Lastly, it was hypothesized that the left handed participants would make more reversal errors compared to the right handed participants, however, due to a low number of left handed participants, this hypothesis could not be tested.

The first hypothesis suggested that adults would make reversal errors when learning a new braille script was found to be statistically significant, supporting that reversal errors occur due to a natural stage of learning process. Participants were chosen among adults to investigate whether reversal error occurrences are confined to children. The findings were in line with the research of Krise (1952), who found that adults also have a tendency to make reversal errors when learning unfamiliar symbols. Thus, the findings of the current study have concurred with the previous literature that supported the natural stage of learning theory (Della Sala & Cubelli, 2007; Fischer, 2011, Sidman & Kirk, 1974) and disputed other theories such as the perceptual theory (Orton, 1925), which postulates that reversal errors occur in children because they do not establish a hemispheric dominance, resulting in making reversal errors. In fact, adults have already established a hemispheric dominance, however, they still produce reversal errors as it was observed in the present study. Therefore, it has provided evidence for the view that reversal errors are not just a matter of age. Moreover, the findings of the current study have disputed the views that associate the incidence of reversal errors with motor deficits (Critchley as cited in Gottfried et al., 2003) or views that assume reversal errors as a symptom of mental deficiency or dyslexia (Gordon, 1921; Kaufman, 1980), because adults that participated in the current study were healthy individuals without having a specific reading disability or a mental deficiency.

It was further hypothesized that the participants in the visual condition would produce more reversal errors compared to those in the tactile condition, based on the past literature that has associated the occurrence of reversal errors with visual processing (Orton, 1925). The statistical analysis demonstrated a non-significant difference between two conditions. Therefore, the findings of the current study have contradicted the assumptions that view reversal errors as a result of a problem in visual processing. Furthermore, the participants in the visual condition could have been more advantageous due to being accustomed to learn visually, whereas the participants in the tactile condition could have been more disadvantageous because of the less accuracy and efficacy of tactile acuity compared to visual acuity (Millar, 1977; Pring, 1994). However, as the results demonstrated, similar number of reversal errors made in both conditions, which indicated that reversal errors occur irrespective of modality.

The third and the fourth hypotheses focused on the effect of time on the number of reversal errors. Thus, the third hypothesis stated that the number of reversal errors would decrease, and the fourth hypothesis stated the number of correct responses would increase over time. The results were non-significant for the third hypothesis, however, they were statistically significant for the fourth hypothesis. It was suggested that increased familiarity with script, practice, and adequate training would cause decrease in the number of reversal errors (Cubelli & Della Sala, 2009; Kaufman, 1980; Sidman & Kirk, 1974), which could not be fully supported by the data, however, it did not contradict the data either considering the significant increase in the number of correct responses. In the current study, the participants were reminded of the same ten braille characters in the beginning of the testing session considering the possibility of forgetting the braille letters after two to three days break between sessions. This training may have had a positive effect on performances especially for the participants in the visual condition because they gave a significantly higher number of correct responses than participants in the tactile condition. As the familiarity elevated, the participants may have learnt the correct orientation of some braille letters, however, they may have still confused some certain braille letters such as “E” and “I”, or “D” and “F”, which have a higher possibility to be confused as reversal errors compared to other braille letters, because of the similar shapes and the number of dots they have. Therefore, two findings can be inconsistent with each other, remaining lack of clarity for the effect of time on the number of letter reversal errors.

Subsequently, it was expected that there would be more vertical errors made than horizontal errors, however, due to a non-significant difference between the number of vertical and horizontal errors, the fifth hypothesis could not be supported by the data. As convincing body of literature favoured the view that individuals have a higher tendency to produce vertical errors than horizontal errors (Bornstein et al., 1981; Chapman as cited in Kaufman, 1980; Fabian, 1945), the current study failed to support this view. Future research may replicate the study to gain a better understanding of the common error types and may conduct a statistical analysis of the frequently made errors as well as focusing on the most confused letters (e.g., “E” and “I”, “D” and F”, “B” and “C”).

The sixth hypothesis stated that poor readers would make more reversal errors compared to normal readers could not be supported by the data either. The Pearson’s correlation analysis revealed that there was no statistically significant relationship between reading ability and the number of reversal errors made. The hypothesis of the current study was established based on Orton’s (1925) views that reversal errors are symptom of developmental dyslexia or a reading disability. Considering the evidence from the previous research that has found significant difference between poor readers and normal readers in terms of the number of reversal errors made (Liberman et al., 1971; Brooks et al., 2011; Terepocki et al., 2002), it was predicted that on average, poor readers would produce more reversal errors. However, the findings of the current study were not in line with the aforementioned literature. It is important to note that the NART is not specifically designed to assess reading ability, but also to assess verbal intelligence, which was found to be irrelevant with reversal error occurrences (Crawford et al. 1992; Della Sala & Cubelli, 2007; Fabian, 1945).

Lastly, it was hypothesized that left handed participants would make more reversal errors. Due to a small sample size of left handed participants, the last hypothesis could not be tested. Based on the previous convincing body of literature, the current study predicted that left handers have a higher tendency to reverse letters (Tankle & Heilman, 1983; Tucha et al., 2000). The present study could not confirm the aforementioned literature, however, it has disputed the views that suggest reversal errors are characteristics of left handers (Schott, 2007), because in the current study right handed individuals also made reversal errors.

4.1. Limitations

The exploratory nature of the study has brought several limitations, which may have affected some crucial outcomes obtained from the study. One of the major drawbacks was using unrepresentative and small sample size. Sixty participants were recruited for the study. Among the 60 participants, there were 25 male and 35 female participants, this difference between the number of female and male participants may lead to a gender bias. Furthermore, among the 60 participants, there were only six left handed participants. Handedness was one of the key variables in the study, due to a low number of left handed participants, this variable could not be tested. Therefore, the relationship between handedness and the occurrence of letter reversals remained unclear. Future research may recruit equal left and right handed participants as well as equal number of female and male participants.

Assessment of reading ability was also flawed in the current study. All of the participants were chosen from Kingston University London. Therefore, they had already had a certain level of reading acquisitions and reading skills, which made it difficult to identify poor readers. Moreover, even though the previous literature has found a significant correlation between the NART and verbal fluency tests (Crawford et al. 1992), the present study has failed to support the aforementioned literature. Since the fluency test differed within only three points (100%, 99%, and 98%) in the present study, it was not taken into evaluation. In the NART, participants were required to pronounce each word correctly. Even though the participants were selected among fluent English speakers, the dialect may differ from one country to another. The pronunciation of some words may differ in the United States of America, Canada, Australia, the United Kingdom, etc. or they may differ even within the same country in different regions. The differences in dialect may have caused inaccurate scoring of the NART. Future research may use less culturally biased reading tests to assess reading ability.

Another limitation was the time constraint for learning braille letters and the limited number of sessions. Each of the ten braille letters was presented only ten seconds to each participant, as the same time length for learning unfamiliar symbols in Krise's (1952) research. However, it may have been an insufficient time length for learning and remembering a new script. Ten seconds may have been even more problematic for the participants in the tactile condition, because they were unaccustomed to learn by touch, so comparing to the participants in the visual condition, they may have needed more time to learn and remember the braille letters. The insufficient time length may have been also more challenging in the drawing task, since the participants in the tactile condition were required to draw the letters that they had not seen before. Thus, they may have made more effort to make a mental representation of the letters to be able to draw them accurately. Moreover, there was one teaching session and one testing session in the whole study, which may not be sufficient to investigate the natural stage of learning process. Future research may provide sufficient exposure time to learn braille letters and increase the number of testing sessions.

In addition to these limitations, there was a high possibility of misinterpreting participants' braille drawings. In some drawings of the participants, there were large gaps between the braille dots, and in some of them there were little gaps between them, which may cause a change in its coding. Since braille letters differ only by two millimetres from each other, reversal errors can be easily made by misplacing a single dot or leaving too little or too large gaps between the dots (Millar, 1997). In the current study, it was difficult to estimate the participants' intended positioning of gaps because of the different writing styles. Future research may ask participants to draw the letters as clearly as they could in order to prevent misinterpretation of the drawing task analysis.

A further limitation was the effect of anxiety on the performances of participants. It has been usually considered that anxiety has an adverse effect on cognitive performance especially for the complex and attention demanding tasks as the study conducted (Eysenck, Derakshan, Santos, & Calvo, 2007). Furthermore, anxiety has been seen as an emotion that limits the working memory capacity and attentional resources required for completing the task (Hayes, Hirsch, & Mathews, 2008). In the present study, participants had been sometimes distressed during the tasks. Some participants reflected their anxiety verbally, which may have stemmed from the incorrect answers given in the teaching session, in which they were given feedback for each task. Participants were reassured that they were not expected to give all the answers correct and learning braille in a short period of time is difficult. Yet, it may have not been sufficient reassuring for some participants. Considering the trait and state anxiety differences of the participants, future research may assess the state and trait anxiety levels as well.

4.2. Final Conclusion

To conclude, the current study has challenged the theories that explain reversal errors as a symptom of dyslexia, mental deficiency, characteristic of left-handedness or a problem in visual processing (Kaufman, 1980; Gordon, 1921; Schott, 2007; Orton, 1925). The study has enabled a solid ground for future research, which may wish to replicate the current study considering the aforementioned limitations. Future research may provide a stronger support and further reinforcement for the natural stage of learning theory when they re-address handedness, reading ability, the common error types, the effect of time and the difference between visual and tactile conditions in terms of the number of reversal errors made, since the current study has failed to provide empirical evidence and reach a definite conclusion on these issues. Additionally, future research may also employ a longitudinal design to assess when adults would become a master when confronting with a new script and stop producing reversal errors entirely.

The findings of the current study may be beneficial to highlight the importance of preventing misdiagnosis of learning disabled or dyslexia in children. As previous research stated, mirror writing does not imply neurological malfunctioning but rather it is a normal development of children and should be considered as a transient phase (Fischer & Tazouti, 2012, Moyer & Newcomer, 1977, Cornell, 1985). Therefore, parents and teachers should be aware of it and avoid labelling children as dyslexic or learning disabled. Instead, they may help reducing reversal errors by favouring correct writing. To illustrate, Fischer and Tazouti (2012) suggested that posters, which show how letters should be written, can be hanged on classroom walls, so when children are not sure about the correct writing of a letter, then they can look at the posters. Moreover, a dot can be placed on the top left of a page to show the starting position of writing, which may help children to reduce mirror writing. Deno and Chiang (1979) also did not give credit to explain reversal errors as in neurological terms, but in educational terms by addressing the recent evidence based on the effectiveness of direct training on reducing reversal errors. Lahey and McNees (1975) provided empirical evidence for the efficacy of using token reinforcement combined with a match-to-sample procedure to eliminate reversal errors. Similarly, as the research of Tawney (1972) revealed, letter discrimination can be increased by using reinforcement when children respond to distinctive features of letter-like stimuli.

To summarize, the current study with its exploratory nature stressed the importance of the letter reversal phenomenon and has fulfilled its main object by presenting valuable evidence for the natural stage of learning theory. Yet, more research is needed to be conducted in order to gain a better understanding of the underlying causes of letter reversal errors as well as to aid academia, society, and the educational bodies in developing effective strategies to overcome difficulties that stem from reversal errors in the process of learning letters.

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Appendices

Appendix A

Participant Information Sheet

INFORMATION SHEET

Dear participant,

This is a study of "Learning to read with braille".

You are being invited to take part in a research project. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part. If you decide to take part you will be given this information sheet to keep and will also be asked to sign a consent form. You can change your mind at any time and withdraw from the study without giving a reason. You have the right to omit or refuse to answer or respond to any question that is asked of you.On these occasions you will be taught some letters in braille and then asked to recall them. Each session should last no more than 15 minutes, possibly less. While in the study we respectfully ask that you do not familiarize yourself with braille in any way as this may influence the results.

There are no known benefits or risks for you in this study. You do not need to take part in this study, and you can leave it at any time without affecting your education/relationship with the Faculty or University in any way.

All information we gain from you will be maintained in a strictly confidential manner. The only people who will have access to the information will be the two researchers Victoria Georgieva and Begum Atay and also the supervisor of the project Dr Fiona Barlow-Brown. After the project all raw data that can identify individuals will be destroyed. In the reporting of the project, no information will be released which will enable to reader to identify who the respondent was. We would not reimburse your travel expenses. If you have any questions or problems, please contact us.

If you have any questions as a result of reading this information sheet, you should ask the researcher before the study begins. Also, you are allowed to withdraw your data by one week after your participation.

Yours sincerely,

Victoria and Begum

Contact details:

1. Researchers - Victoria Georgieva k1440317@kingston.ac.uk

Begum Atay - k1448409@kingston.ac.uk

2. Supervisor - Dr Fiona Barlow-Brown - dr.f.barlow-brown@kingston.ac.uk

Appendix B

Consent form

WRITTEN CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Statement by participant

- I confirm that I have read and understood the information sheet/letter of invitation for this study. I have been informed of the purpose, risks, and benefits of taking part.

"Learning to read with braille"

- I understand what my involvement will entail and any questions have been answered to my satisfaction.
- I understand that my participation is entirely voluntary, and that I can withdraw at any time without prejudice. Including withdrawing my data until 30/06/15.
- I understand that all information obtained will be confidential.
- I agree that research data gathered for the study may be published provided that I cannot be identified as a subject.
- Contact information has been provided should I (a) wish to seek further information from the investigator at any time for purposes of clarification (b) wish to make a complaint.

Participant's Signature--

Date --

Statement by investigator

- I have explained this project and the implications of participation in it to this participant without bias and I believe that the consent is informed and that he/she understands the implications of participation.

Name of investigator ---

Signature of investigator ---

Date ---

Appendix C

Demographic Questionnaire

DEMOGRAPHIC QUESTIONNAIRE

Participant number:……..

Please indicate your age:…….

Please indicate your gender: Female ◻ Male ◻

Please indicate your handedness: Right-handed ◻ Left-handed ◻

Are you familiar with the braille alphabet or any letters in braille? Yes ☐ No ☐

Have you ever been diagnosed with a reading disability, such as dyslexia? Yes ☐ No ☐

Appendix D

The National Adult Reading Test (NART)

CHORD
ACHE
DEPOT
AISLE
BOUQUET
PSALM
CAPON
DENY
NAUSEA
DEBT
COURTEOUS
RAREFY
EQUIVOCAL
NAIVE
CATACOMB
GAOLED
THYME
HEIR
RADIX
ASSIGNATE
HIATUS
SUBTLE
PROCREATE
GIST
GOUGE
SUPERFLUOUS
SIMILE
BANAL
QUADRUPED
CELLIST
FACADE
ZEALOT
DRACHM
AEON
PLACEBO
ABSTEMIOUS
DETENTE
IDYLL
PUERPERAL
AVER
GAUCHE
TOPIARY
LEVIATHAN
BEATIFY
PRELATE
SIDEREAL
DEMESNE
SYNCOPE
LABILE
CAMPANILE

Appendix E

The Fluency Test

Reading A-Z LEVEL Z

Fluency Passage–Fiction **Every Little Part**

Name ______________________________ Word Count: 250

Every Little Part

Amanda lay on her back in the driveway, staring into 10
the gears of Chris's motorcycle. Chris was mostly silent, 19
nodding at the toolbox and muttering the size of the 29
wrench or screwdriver he wanted. He would wait patiently 38
for Amanda to read the stamp on each tool until she found 50
the right one. Every once in a while, he would burst out 62
with what seemed like an enormous speech. 69

"Gears control how fast and how powerful it goes. Low 79
gear is slow and strong. High gear is fast, but not powerful." 91

Amanda's mom sometimes complained that Chris spent 98
more time with his motorcycle than he did with Amanda, 108
his new stepdaughter. But Amanda didn't mind. She also 117
didn't mind that Chris's hands had grease on them or that 128
there were always parts lying around. In fact, she loved 138
watching the way every little piece fit together just so. Each 149
part did its own job. Each worked with all the others. Each 161
one was important, and without it, the bike wouldn't run. 171

She especially loved when Chris put everything together, 179
cleaned up, and then started the bike with a tremendous 189
roar. 190

Years later, when Amanda was a surgeon, she often 199
thought about Chris and his bike. He had taught her to be 211
patient and careful with moving parts, whether they were 220
the parts of a motorcycle or a human body. And when 231
she saw her patients sitting up and feeling well again, she 242
couldn't help imagining the roar of a motorcycle. 250

Appendix F

Debriefing Form

Debriefing form

Learning to read with braille.

Thank you for taking part in the study “Learning to read with braille”.

The purpose of this study is to improve our understanding as to the causality of common errors when learning a new script, particularly the occurence of letter reversals. It is hypothesised that letter reversals will occur in adults and through both touch and vision and is therefore not just a visual or developmental problem. It has been thought in the past that letter reversal is a visual or a developmental problem. However, this does not explain why blind children or indeed adults learning a new language letter reverse. This study therefore investigated whether letter reversals can occur in adults and by touch as well as vision. It is hoped that by better understanding the causes of letter reversals it may be possible to develop effective strategies to help prevent these errors and aid reading and learning.

Should you need more information regarding the study itself or anything else please contact me or my supervisor.

Yours sincerely,

Victoria and Begum

Contact details:

1. Researchers –Viktoriya Georgieva k1440317@kingston.ac.uk and Begum Atay k1448409@kingston.ac.uk.

2. Supervisor – Dr. Fiona Barlow-Brown dr.f.barlow-brown@kingston.ac.uk

Appendix G

SPSS Outputs

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
TotalMiErrors	60	1,0657	,78766	,10169

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
TotalMiErrors	10,480	59	,000	1,06567	,8622	1,2691

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
day1totalver	,008	1	58	,930
day1totalhor	7,395	1	58	,009
day2totalver	1,509	1	58	,224
day2totalhor	9,505	1	58	,003

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Condition

Within Subjects Design: time + orientation + time * orientation

Tests of Between-Subjects Effects

Measure: mirrorerror

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	17,035	1	17,035	111,606	,000	,658
Condition	,298	1	,298	1,954	,168	,033
Error	8,853	58	,153			

Descriptive Statistics

	Condition	Mean	Std. Deviation	N
day1totalver	visual	,3177	,32341	30
	tactual	,2497	,28236	30
	Total	,2837	,30294	60
day1totalhor	visual	,2553	,38701	30
	tactual	,1630	,24917	30
	Total	,2092	,32604	60
day2totalver	visual	,2933	,54518	30
	tactual	,3460	,36691	30
	Total	,3197	,46149	60
day2totalhor	visual	,3403	,62335	30
	tactual	,1660	,24766	30
	Total	,2532	,47840	60

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
day1totalcorrect	,322	1	58	,573
day2totalcorrect	1,544	1	58	,219

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Condition

Within Subjects Design: time

Tests of Between-Subjects Effects

Measure: correctness

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	52920,000	1	52920,000	876,367	,000	,938
Condition	2745,633	1	2745,633	45,468	,000	,439
Error	3502,367	58	60,386			

Tests of Within-Subjects Effects

Measure: correctness

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Sphericity Assumed	1068,033	1	1068,033	98,645	,000	,630
	Greenhouse-Geisser	1068,033	1,000	1068,033	98,645	,000	,630
	Huynh-Feldt	1068,033	1,000	1068,033	98,645	,000	,630
	Lower-bound	1068,033	1,000	1068,033	98,645	,000	,630
time * Condition	Sphericity Assumed	30,000	1	30,000	2,771	,101	,046
	Greenhouse-Geisser	30,000	1,000	30,000	2,771	,101	,046
	Huynh-Feldt	30,000	1,000	30,000	2,771	,101	,046
	Lower-bound	30,000	1,000	30,000	2,771	,101	,046
Error(time)	Sphericity Assumed	627,967	58	10,827			
	Greenhouse-Geisser	627,967	58,000	10,827			
	Huynh-Feldt	627,967	58,000	10,827			
	Lower-bound	627,967	58,000	10,827			

Descriptive Statistics

	Condition	Mean	Std. Deviation	N
day1totalcorrect	visual	22,3000	5,96050	30
	tactual	13,7333	5,53941	30
	Total	18,0167	7,15563	60
day2totalcorrect	visual	29,2667	5,28455	30
	tactual	18,7000	6,94883	30
	Total	23,9833	8,11463	60

Correlations

		NART	Fluency
NART	Pearson Correlation	1	-,109
	Sig. (2-tailed)		,406
	N	60	60
Fluency	Pearson Correlation	-,109	1
	Sig. (2-tailed)	,406	
	N	60	60

Correlations

		NART	TotalMiErrors
NART	Pearson Correlation	1	-,124
	Sig. (2-tailed)		,344
	N	60	60
TotalMiErrors	Pearson Correlation	-,124	1
	Sig. (2-tailed)	,344	
	N	60	60

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Fluency	60	97,00	100,00	99,5500	,79030
NART	60	13,00	28,00	20,5667	3,27480
Valid N (listwise)	60				

Group Statistics

	Condition	N	Mean	Std. Deviation	Std. Error Mean
TotalOtherErrors	visual	30	3,6050	1,49654	,27323
	tactual	30	4,9937	,83770	,15294

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
TotalOtherErrors	Equal variances assumed	18,913	,000	-4,435	58	,000	-1,38867	,31312	-2,01545	-,76188
	Equal variances not assumed			-4,435	45,548	,000	-1,38867	,31312	-2,01912	-,75821

Appendix H

PS7000: Supervisory Meeting Log **Name: BEGUM ATAY**

KU ID: K1448409

Date	**Comments/Actions**	**Supervisors signature**
1 08/12/2014	General discussion about the study.	
2 14/01/2015	Ethics review.	
3 23/01/2015	Ethics review.	
4 23/02/2015	General discussion about the oral presentation.	

5 11/03/2015	Discussion about the procedure.	
6 25/04/2015	Discussion about the data collection and administration of materials.	
7 05/06/2015	General discussion about the statistical analysis	
8		
9		

10		

Any additional comments: