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The effect of handedness on interhemispheric interaction in a simple reaction time task

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Abstract

An individual's handedness was hypothesised to affect their reaction times when using them to measure interhemispheric interaction. 40 male and female participants filled out an Edinburgh Handedness Inventory and took part in a simple reaction time experiment on a computer. A crossed-uncrossed difference was calculated and a mixed analysis of variance was carried out. The study found a crossed-uncrossed difference of -3.8 milliseconds (ms), while right handers were found to react faster, -2.7ms, than left handers, -4.9ms. No main effect of handedness was found, 0.277 (p=> 0.05) and no interaction between hand and visual field was found, 0.241 (p=> 0.05). Implications and possible methodological limitations of the study are discussed along with alternative explanations for the results found.

Ethical Statement

This study conformed to both the BPS and the University of Plymouth's ethical guidelines for conducting research with human participants. Each participant was given a brief and consent was gained from them by signing the consent form once they had read the brief. The brief contained an outline of the study and informed the participants that their results would remain anonymous and that they had the right to withdraw from the experiment at any time. Once they had carried out the experiment they were given a debrief which provided them with extra information on the study, reminded them they still had the right to withdraw and their participant number. They were also thanked for their time.

The experiment itself posed minimal risk to the participants as it consisted only of an Edinburgh Handedness Inventory asking them about their hand preference and a computer based reaction time task. Participants were asked before the start of the experiment whether they suffered from any medical conditions which would affect them participating. Also while the experiment was carried out it was ensured that no discomfort was experienced by them. During the computer based part of the task there were breaks which allowed the participants to rest if they wished to. At the end of the experiment it was checked that they were happy with what had taken place and that they had felt no discomfort.

There was no deception involved in this experiment as participants were told from the beginning that what was being measured was their level of handedness and their reaction times from the computer based task and what their results were being used to measure. After the task was completed any questions or queries that participants had were answered as accurately as possible and they were asked that they were happy with what had occurred during the experiment.

All the participants were reminded of their right to withdraw before and after the experiment had taken place. All participants were given a participant number linking them to their data, so if they wanted their data to be withdrawn at a later date then that was possible. All results gathered will remain completely confidential, which the participants were made aware of. Data is only identifiable through a participant number, of which the participant was notified at the end of the experiment on their debrief sheet. This is the only link between a participant and their data and it ensures that all the data gathered will remain anonymous.

All the data in this study was collected and analysed by the author, with no assistance from anyone else and with no sharing of data.

Introduction

An essential skill which humans possess is the ability to actively interact with the environment around them. This includes basic functions such as being able to scan the environment for danger and to travel around their environment safely. More complex functions which humans are able to carry out are the manipulation of current objects and the creation of new ones. Thousands of years ago humans began to make tools, which allowed them to hunt more effectively. Nowadays we use our hands to do many intricate tasks including writing, which is a key part of modern society and communication. Generally people have a dominant hand with which they choose to carry out complex activities, such as writing. In order for a person to be able to interact with their environment in such a detailed way, they need to make use of all the sensory information they receive and react to it efficiently.

All input coming in through the senses, whether it is visual, auditory or tactile information reaches the two hemispheres of the brain. Sensory input travels either to the ipsilateral or contralateral hemisphere depending of what type of information it is. Each hemisphere has functions in which it is more skilled than the other hemisphere. For instance it has been found that for most people their left hemisphere is dominant for language and motor control.

Most information which is transferred across the two hemispheres is transferred via the corpus callosum. This is a mass of nerve fibres which connect homotopic and hetertopic areas of both hemispheres (Cook 1984, 1986). Gazzinga (1989) and Hamilton (1982) have both found evidence that different areas of the corpus callosum are used for the transfer of specific types of information: the posterior for the transfer of visual information, the anterior for auditory information and the inferior for tactile information. Those findings have been supported through split brain patients whose corpus callosum have been split in surgery to stop epileptic fits spreading from one hemisphere to the other, but it also stops the transfer of certain information between the two hemispheres (Myers and Sperry 1985).

The organisation of systems using this interhemispheric interaction has implications for the outputs produced. The primary motor cortex is found anterior to the central sulcus and controls most motor functions. The secondary motor cortex and pre-motor cortex are also important in motor control (Rosenbaum, 1990). Motor outputs are produced by the hemisphere contralateral to the movement itself. As the left hemisphere is generally dominant for language and motor control, right handedness could be more common due to this, allowing it to control more complex movements.

The organisation of the visual system is similar to that of motor control. This is because visual information from the visual half field of each eye is sent to the occipital lobe in the contralateral hemisphere (Hellige, 2001). In order to interact with the world around us visuo-motor coordination is required. This coordination can require the transfer of information across the two hemispheres. Iacoboni and Zaidel (2004) found evidence that the right superior parietal cortex plays an important function in the interhemispheric transfer of visuo-motor information.

Poffenberger (1912) was the first to suggest a measure of the duration of interhemispheric interaction. He designed an experiment which measured the transfer of information between the two hemispheres. He proposed that uncrossed conditions, where the visual stimulus and the hand responding to it were on the ipsilateral side of the body should produce a faster reaction time than an uncrossed condition. A crossed condition consisted of the visual field and the hand being used to respond being on contralateral sides of the body.

Poffenberger (1912) suggested that this crossed condition would take longer because if, say, the stimulus was presented to the left visual field and the hand responding to it was the right hand then the visual stimulus would come through the left half of the visual field and therefore reach the right hemisphere. However, the hand responding is controlled by the motor cortex in the left hemisphere. This means that in order to respond, the information needs to be transferred from the right hemisphere to the left hemisphere via the corpus callosum. It is this extra process of transferring the information between the hemispheres which increases the time it takes for the reaction to be produced.

Poffenberger (1912) proposed that if the crossed time was taken away from the uncrossed time the difference between the reaction times would indicate the time which the transfer takes between the two hemispheres. This measure is known as the crossed-uncrossed difference. Braun and Laroque (2004) supported the idea that the paradigm Poffenberger (1912) put forward is a measure of relay time. While Iacoboni and Zaidel (2004) suggested that in this experiment it is information of motor intention which is transferred between the two hemispheres.

It has generally been found that crossed-uncrossed differences range between 2 and 6 milliseconds (ms). For instance Marzi, Bisiacchi and Nicoletti (1991) carried out a meta-analysis and found the average crossed-uncrossed difference was 4ms, although the range of results from the experiments was between 1ms and 10ms. In studies on split brain patients, however, they have been found to show longer transfer times of around 30-60ms (Marzi et al, 1991). It has been suggested that this is because information is transferred via sub-cortical structures which takes much longer than the transfer of information across the corpus callosum (Sergent 1983, 1990).

It has been found more complex tasks have been linked to a reduced crossed-uncrossed difference, potentially because for complex tasks both hemispheres work together (Hellige, 2001). It has also been found that the hand which people use in these experiments effects the reaction times recorded (Fendrich, Hutsler and Gazzinga, 2004).

Handedness refers to the preference which people have for generally using one hand over the other for skilled tasks such as writing. It is generally stated that around 90 percent of individuals are right handed (Hellige, 2001). However this is not necessarily the whole story. Handedness is not a dichotomy, of either left or right, as it is sometimes treated. It is in fact a continuum with people ranging across all possibilities of hand preference (Annett, 1994). It is generally said that 4 percent of individuals are truly left handed, 30 percent are mixed handed and 66 percent are right handed. Mixed handedness allows for the fact that people are neither completely left nor right handed, which is much truer to life. Curt, Mesbah, Lellouch, and Dellatolas (1997) found that the frequency distribution of hand preference is generally J-shaped, as such it shows bimodal distribution, but with a greater number of right than left handers, creating this uneven shape of distribution.

It has been found that a person’s handedness is generally related to which of their hemispheres is dominant for language. The Wada test (1949) was one of the original methods of establishing hemispheric dominance for language. Segalowitz and Bryden (1983) studied subjects who had suffered unilateral brain injury. Through this he found evidence that 95 percent of right handed individuals were left hemisphere dominant, with the other five percent being right hemisphere dominant for language.

This provides evidence that the left hemisphere generally being dominant for the motor control of hands and a large proportion of the population being right handed could be linked. Due to the motor cortex controlling the contralateral side of the body and the strength of control increasing the further along the limb from the hemisphere controlling the movement, hands are under the strongest motor control (Hellige, 2001). Trope, Fishman, Gur, Sussman and Gur (1987) however found that both the contralateral and ipsilateral hemispheres can control the body, but to a lesser extent on the ipsilateral side.

The frequency of the left and right handers has been found to be consistent across cultures as well as throughout history. Paintings from thousands of years ago depict right handers in nearly all cases and show the proportion of left handers is consistent with those found nowadays. Ogle (1871) found evidence that women were less likely to be left handed than men. The lateralization in the brains of women has been found to be less, which further suggests a link between handedness and lateralization (Amunts, Jancke, Mohlberg, Steinmetz and Zilles, 2000).

People generally state that their dominant hand is more skilled than their non-dominant hand. McManus and Bryden (1993) however found that with right handers the dominant hand's skill is related to the performance of their left hand. They suggested that as the left hand's performance decreases the right hand becomes preferred. This indicated that preference is based on the proficiency of the non-dominant hand. Corey, Hurley and Foundas (2001) found performance measures show unimodal distribution of handedness while preference measures show bimodal distribution. This suggests researchers may need to be careful if using just one measure, perhaps both preference and performance should be used as an index of handedness.

Handedness is a difficult characteristic to measure as everyone displays it to varying degrees, therefore measures which allow for this continuum of handedness need to be used. Generally today there are two main methods which are used to measure handedness. One of these is self report, through a questionnaire for instance, which measures preference. The other is through measuring performance of each hand while carrying out a manual task, such as peg moving, and comparing the performance of both hands.

One of the most common self-report questionnaires used to measure handedness is the Edinburgh Handedness Inventory (Oldfield, 1971). This is a questionnaire which asks participants to rate how strongly left or right handed they are at either twenty selected skilled and unskilled manual tasks, or the shorter twelve item scale. The participant's answers are then scored and this gives a laterality index, or measure of their handedness which an experimenter can then utilise.

It has been suggested that non-right handers show less laterality than right handers and that this increases the interaction which takes place between the hemispheres. Some of the evidence for this comes from physical differences in the asymmetries in the brains of right and non-right handers.

Hochberg and LeMay (1975) for instance found the sylvian fissure was higher in the right hemisphere of right handed people in 67 percent of cases, equal in 26 percent of cases and higher in the left hemisphere of 7 percent of cases. The proportions in left handers however were different; they were 22 percent, 71 percent and 7 percent respectively. Cunningham (1892) also found that the upward curl of the sylvian fissure was larger in the right hemisphere of right handers. This upward curl allows Wernicke's area (1874), which is strongly associated with language and is underneath the sylvian fissure to become larger. This may suggest why the left hemisphere tends to be dominant for language and the majority of the population is right handed. Scheibel, Fried, Paul, Forsythe, Tomiyasu, Wechsler, Kao and Slotnick (1985) found less asymmetry of dendrite branching in the left hemisphere speech areas in non-right handers.

Witelson (1985) found another asymmetry which varied with handedness. He found in the corpus callosum the midsigital area was on average 11 percent larger in non-right handers. Witelson and Kigar (1987) also found the posterior of the corpus callosum, involved with the transfer of visio-spatial information, was on average 19 percent larger in non-right handers. This may suggest the corpus callosum has a slightly different role in non-right handers. Habib, Gayraud, Oliva, Regis, Salamon and Khalal (1991) found evidence of non-right handers having a larger corpus callosum than right handers. The size of the corpus callosum may be linked to the asymmetry within the brain which is more connected in non-right handers due to the increased transfer of information if they are more bihemispheric.

Evidence suggests that hemispheric asymmetry of cognitive function is related to hand preference. This could be due to non-right handers being found to have less hemispheric asymmetry, but showing a greater number of connections between hemispheres (Witelson, 1985, 1989). Both anatomical and behavioural asymmetries are greater in right-handers. Perhaps this suggests non-right handers use both hemispheres together, (Hellige, 2001). Therefore maybe hand preference is related to the extent of hemispheric asymmetry.

Potter and Graves (1988) found non-right handers performed better than right handers on tasks which need both hemispheres to work together. Also Cherbuin and Brinkman (2006) found extreme left handers showed more efficient transfer of information than right handers between the two hemispheres. Basso, Vecchi, Kabiri, Baschenis, Boggiani and Bisiacchi (2006) suggested that a different organisation of pathways could explain the differences in performance between right and non-right handers. Solodkin, Hlustik, Noll and Small (2001) carried out a brain imaging study and found that left handers showed more bihemispheric interaction then right handers. The research of Fendrich et al (2004) found smaller crossed-uncrossed differences from the left hand indicated people were responding faster than with the right hand. Finally Marzi et al (2001) suggested that the transfer of information from the right to the left hemisphere could be faster than in the other direction, therefore accounting for this faster reaction time from the left hand. However a cause for this difference in laterality and handedness has been difficult to find.

For many years there have been suggestions and debates as to what produces an individual's hand preference. Some have suggested historical, environmental or genetic models. For instance Froude (1884) put forward the sword and shield theory, which indicated people held their shields in their left hand, protecting their vital organs and therefore leaving their right hand free to use their sword and that over generations this has lead to the right hand being preferred for manual activities.

Geschwind and Galaburda (1987) put forward an environmental theory, suggesting that high levels of testosterone in the foetus promotes right hemisphere development and this creates higher levels of left handedness. Another environmental factor suggested was by Bakan (1977) which was due to stress around the time of birth. Gregor Mendel's (Orel, 1996) theory of genetic inheritance was discarded because the distribution of handedness, which would lead to 25 percent of people being right handed, 50 percent mixed handed and 25 percent left handed, does not fit the distribution of handedness found in the data.

The most widely accepted explanation of what produces an individual's handedness is Annett's (2002) right shift theory, which she first proposed in 1972 (Annett, 1972). It is based on genetic heredity where a child receives one of two alleles of a gene for handedness, one allele from each of its parents. Alleles can either be recessive or dominant. The alleles are RS+ and RS-, RS+ being the dominant of the two and RS- the recessive. Annett suggested that the RS+ does not create right handedness directly in itself, but it biases a person towards normal cerebral asymmetry, with the left hemisphere dominant for language, and this means being right-handed is more likely. The RS- allele however does not promote right hemisphere dominance; Annett in fact suggested that it simply has no bias in one direction or the other. The hemisphere dominance and also handedness of a child who receives two RS- alleles is therefore left to chance and environmental factors, meaning there is an equal chance for either hand to become dominant.

This suggests that children who receive RS+ + and RS+ - will be right handed while children with RS- - will have an equal chance of either of their hands becoming dominant. Combined with Mendel's (Orel, 1996) inheritance which theory proposed 25 percent of the population would get two dominant alleles, RS+ +, 50 percent would get one allele of each, RS+ - and the final 25 percent would get two recessive alleles, RS- -. Due to the fifty-fifty chance of the RS- - genes, this means that left handedness should occur in 12.5 percent of the population, which is very similar to the proportions found in the population. This also indicates that the strongest bias for right handedness will come from a child receiving RS+ + from their parents.

Annett's (2002) theory does not suggest a change to the unimodal distribution of handedness, it simply moves where it starts from across to the right, hence the name the right shift theory. This slightly shifted distribution then shows the patterns of results which are found in the population for handedness. Annett (1998) also suggested that there are subgroups of handedness along the continuum, rather than there are being just two classes of handedness, left and right.

Previous research has shown that left handers are less lateralized than right handers and that they display an increased level of bihemispheric interaction. Annett's (2002) right shift theory can explain this lack of lateralization due to left handers not receiving the genetic mechanism for cerebral asymmetry from their parents. It could be this lack of normal cerebral asymmetry which produces the bihemispheric interaction in left handers which has been previously demonstrated.

The aim of this study is to investigate whether handedness affects reaction times and therefore interhemispheric interaction. A faster reaction time is expected from left handers' responses due to the association between lateralization and interhemispheric interactions. An interaction between the responding hand and visual field the stimulus is presented to will also be expected as this is a measure of the significance of the crossed-uncrossed difference, which is expected to be around 4ms.

Method

Participants

In total 40 participants (6 male and 34 female) took part in the experiment. The participants were first and second year students studying Psychology at the University of Plymouth. Participants volunteered via an online sign-up system. There were no restrictions on the participants such as age or gender. To gain a natural sample of handedness there were no restrictions or requirements on the handedness of participants, thereby reducing the risk of a biased sample. Each participant carried out both a questionnaire about their handedness and a computer based reaction time task. There was one between participant condition, which was their handedness score, and two within participant conditions in this experiment, which were the hand used to respond to the stimulus and the visual field to which the stimulus was presented.

Materials

The experiment included the Edinburgh Handedness Inventory (Oldfield, 1971) and a computer based reaction time experiment run on E-Prime (http://www.pstnet.com/products/e-prime/). The Edinburgh Handedness Inventory used was the 12 item version, but it had been modified by removing the questions about name, age and sex and replacing them with the question, “Have you ever had any tendency to left-handedness?” from the 20 item scale. This was to investigate whether participants believed themselves to be left handed and whether this differed from the score they received after completing Edinburgh Handedness Inventory. For the computer based part of the experiment the participant rested their head on a chin rest. The chair which they sat on was adjustable in height; this meant that the chin rest could stay in the same position for each participant. The chin rest was 57 centimetres (cm) away from the screen which meant that every 1cm on screen related to 1^{o} visual angle. A brief (see appendix A) was given at the beginning of the experiment and the participant signed a consent form (see appendix B and for signed consent forms see the envelope attached to the back of this project). They then began the handedness questionnaire (see appendix C) after which they completed the reaction time experiment. Once they had done this they were given a debrief (see appendix D). The reaction times were saved on the computer automatically while the Edinburgh Handedness Inventory score was calculated later by the experimenter.

Design and Procedure

Each participant experienced the same procedure throughout the experiment. First the participant was given a brief and a consent form to read and to sign if they agreed. Then they were given the Edinburgh Handedness Inventory to fill in. They were instructed to place two plus’s in the right hand column if they were strongly right handed and one plus if they were slightly right handed or two minus’s in the left hand column if they were strongly left handed or one minus if they were slightly left handed. This produced the measure of each participants perceived hand preference which would be used later.

Next the participants took part in the reaction time task run on the computer using E-Prime. The participants placed their head on a chin rest which was measured at 57cm away from the screen. They then read the on screen instructions informing them of what to do, once they had read and confirmed they understood these instructions they began the task. The experiment consisted of two blocks each of 200 trials, one block which the participants would respond by pressing the spacebar with the left hand and one block with the right. The hand which they started with was randomised by the program. After the first 200 trials they were given the opportunity to take a break and the hand which they were using to respond to the target was switched. As a reminder the hand which they were meant to be using was written at the bottom of the screen along with the trial number.

Each individual trial needed to be started by the participant pressing the spacebar to indicate that they were ready. When they did this a black fixation point appeared as a cross in the centre of the screen against a grey background. The stimulus onset asynchrony was between 500 and 2000 milliseconds at 500 millisecond increments. The target the participants were to respond to was a white box with onscreen dimensions of 50 by 50 pixels (or 23 by 23 millimetres). The target was horizontally in line with, and the inner edge was 175 pixels away from, the fixation point (which also relates to 83 millimetres or a visual angle of 8.3^{o}).

The target was presented for approximately 500ms and the participants were asked to react by pressing the spacebar with the required hand as soon as they saw the target. This produced the reaction times recorded by the computer. The reaction times were displayed after each trial to the participants after they had reacted. This was repeated by each participant for each of the 200 trials contained in both blocks. This gave the reaction times which were gathered and later analysed. Once the participant had completed all of the trials they were thanked for their participation and debriefed.

Results

The hypotheses of the study were that reaction times in left handers would be reduced due to greater interaction between hemispheres. An interaction between hand and visual field was also expected, as this shows the crossed-uncrossed difference. The average crossed-uncrossed difference was expected to be around 4 milliseconds.

Before the crossed-uncrossed difference scores were produced any reaction times which were above or below the expected 'normal' range were removed. In this study these excluded times were any reaction times below 200 milliseconds or above 800 milliseconds.

The results were then gathered by getting each participant's average reaction time for each of the 4 possible hand and visual field combinations. These were then used to produce a crossed-uncrossed difference for each participant. Then the overall crossed-uncrossed difference for all participants was found and a crossed-uncrossed difference for both of the two groups of handedness was also calculated. The two groups were split due to their scores from the Edinburgh Handedness Inventory. Group 1 contained the twenty most right handed participants with group 2 containing the twenty most left handed. Two participants at the separation point had the same scores, so to fairly decide which group they went into, a coin was tossed and the second of the participants was placed in the first group.

A mixed analysis of variance (ANOVA) was carried out on the data to find any main effects or interactions which might be present. The ANOVA had one between factor (handedness) and two within factors (hand and visual field). The data which was used in the ANOVA was each participant's average reaction time for each of the four different possible hand and visual field combinations. Participants' raw results from the reaction time experiment and the results from the ANOVA can be found on the attached CD. For individual participants' results from the Edinburgh Handedness Inventory see appendix E.

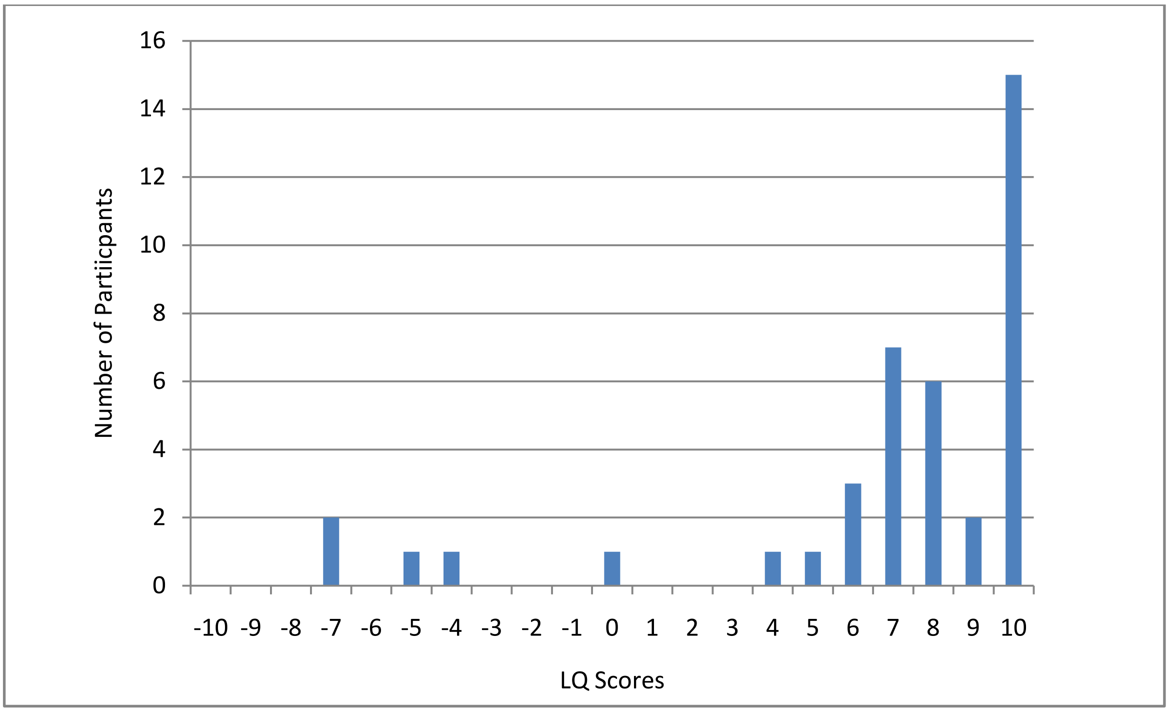

Figure 1: shows the distribution of hand preference from the participants Edinburgh Handedness Inventory scores, (LQ score).

The distribution in Figure 1 demonstrates bimodal and asymmetric distribution, in addition it shows a J-shaped distribution, both of which were expected. It also indicates that more right handers took part in the study than left handers and that the right handers generally had a stronger preference for their dominant hand than the left handers.

For each participant's average reaction time for each hand and visual field combination, the handedness group which they were allocated to and right, left and overall crossed uncrossed differences, see appendix F.

Table 1: *Descriptive statistics from the ANOVA.*

Hand/Visual Field Combination	Group	Mean (ms)	SD	N
RightRight	1	310.2	39.9	20
	2	325.3	37.7	20
RightLeft	1	311.8	36.8	20
	2	323.1	43.1	20
LeftRight	1	313.4	37.1	20
	2	328.0	50.5	20
LeftLeft	1	317.7	34.2	20
	2	330.7	45.1	20

This table shows that the fastest average reaction times came from group 1, the right handers, when the stimulus was presented to their right visual field and they responded with their right hand, 310.2ms. This is not surprising as this is an uncrossed condition where the participant is responding with their dominant hand. The slowest average reaction time however came from group 2, the left handers, when the stimulus was presented to their left visual field and they responded with their dominant left hand, 330.7ms. This is surprising as this is also an uncrossed condition and therefore should produce a faster reaction time than a reaction time from a crossed condition.

Table 2: *Mean reaction time for each combination of hand and visual field in milliseconds.*

Hand	Visual Field	Mean Reaction Time
Right	Right	317.7
	Left	317.4
Left	Right	324.2
	Left	320.7

It can be seen from this table that reaction times when using the left hand are on average slightly slower, 324.2 milliseconds (ms) and 320.7ms than when using the right hand, 317.7ms and 317.4ms.

Table 3: *Right and left hand and the overall crossed-uncrossed differences in milliseconds.*

	Crossed-Uncrossed Difference
Right	-0.3
Left	-3.5
Overall	-3.8

These results show that the left crossed-uncrossed difference which was found to be -3.5ms is larger than when the right hand was responding, -0.3ms. The overall crossed-uncrossed difference was expected to be around 4ms, however the result gained in this study was -3.8ms.

Table 4: *Crossed-uncrossed difference for group 1 and group 2 in milliseconds.*

	Crossed-Uncrossed Difference
Group 1	-2.7
Group 2	-4.9

Left handed participants, group 2, crossed-uncrossed difference reactions were expected to be less than right handers, group 1, showing evidence of increased bihemispheric interaction in left handers. However the crossed-uncrossed difference of right handers, group 1, was -2.7ms was found to be faster than left handers, group 2, -4.9ms. This shows that participants in the right handed group were faster at reacting to a stimulus on either side of the visual field than participants who were in the left handed group.

For the output from the Analysis of Variance see Appendix G or the attached CD. The results from the assumptions of variance are as follows. The Shapiro-Wilks test for normality showed that none of the results were significant. The significance for overall crossed-uncrossed difference for group 1 and 2, D(20) = 0.999, p=> .05 and D(20) = 0.716, p=> .05, shows that there is a normal distribution in the sample. Maulchey's test for sphericity showed no result (significance was reported as ' .   '). This means sphericity cannot be assumed and potentially the results need to be taken with caution. It also means that when looking at the tests of between subject effects Greenhouse-Geisser will need to be used to allow for sphericity not being assumed. The Levene's test is related to the between subject factors only. It showed none of the results were statistically significant. The significance levels being, right hand right visual field was F(1,38) = 0.941 (p=> 0.05), right hand left visual field was F(1,38) = 0.505 (p=> 0.05); left hand right visual field was F(1,38) = 0.153 (p=> 0.05), and left hand left visual field was F(1,38) = 0.219 (p=> 0.05). This means that homogeneity of variance can be assumed.

The test of within subject effects was expected to show an interaction between hand and visual field. However a significant interaction was not found with a significance of F(1,38) = 0.241 (p=> 0.05). This means that the crossed-uncrossed difference which was found was not statistically significant. None of the other tests of within subject effects in fact showed any significance. The significance levels found were; hand F(1,38) = 0.163 (p=> 0.05), visual field F(1,38) = 0.324 (p=> 0.05), hand and group F(1,38) = 0.932 (p=> 0.05), field and group F(1,38) = 0.402 (p=> 0.05), and finally hand, field and group F(1,38) = 0.728 (p=> 0.05). This shows that there were no interactions between hand, field and group.

The test of between subject effects was looking for a main effect of the two groups of handedness on the reaction times produced. The result of this, however, was also not significant, F(1,38) = 0.277 (p=> 0.05). These results indicate there was no main effect of handedness in this study, showing that the handedness of a participant responding to the visual stimulus had no statistically significant effect on the reaction times which were elicited.

The results collected do not support the hypotheses which were proposed in this study. This could mean that the hypotheses were wrong or incomplete. It could also suggest the results gathered are not representative of what is found in similar experiments. These possibilities and potential reasons for them will now be discussed.

Discussion

The results of this study did not confirm the hypotheses which had been proposed based on previous research which has been carried out. One hypothesis of the study was that left handers would show a decrease in reaction times when responding to stimulus due to an increased level of bihemispheric interaction which was caused by a lack of normal cerebral asymmetry. The crossed-uncrossed difference was expected to be around 4 milliseconds (ms). An interaction between hand and visual field in the analysis of variance (ANOVA) was also expected to be found. Potential reasons for the lack of supporting results for the hypotheses will now be discussed.

The results did not confirm the hypothesis or previous research which had shown that left handers show faster reaction times due to an increased level of bihemispheric interaction. This had been proposed by Solodkin, Hlustik, Noll and Small (2001). It was in fact found that right handers' responses showed a decrease in reaction times compared to left handers. This implies that the proposal by Solodkin et al (2001) of an increased level of bihemispheric interaction in left handers may not be reliable in this study.

These results do not disprove the idea of Solodkin et al (2001), it may merely suggest that when using visual stimuli similar to that which was used in this study it may not activate a left hander's bihemispheric interaction. This means that the right handers who were well practiced by always using interhemispheric interaction which was elicited by the stimulus presented, produced faster reaction times than the left handers in the study. This may be due to the fact that left handers do not always use normal interhemispheric interaction due to their increased levels of bihemispheric interaction, created by their lack of normal cerebral asymmetry (Annett, 1998), and are therefore slightly slower at the task than right handers.

Annett's (1998) right shift theory suggested that a non-right hander is produced by chance environmental factors after not receiving a bias for left hemisphere dominance from their parents. She also proposed that this lack of bias causes non-right handers to not develop the normal cerebral asymmetry seen in right handers and this leads to less laterality. This lack of lateralization, she proposed, may lead non-right handers to become bihemispheric, therefore reducing reaction times. As this current study found that, in fact, right handers were reacting faster it perhaps suggests this bihemispheric interaction might not be common to all non-right handers, only occurring in left handers with the strongest preference. This study however did not contain any very strong left handers, so if that is the case, it could explain why evidence of bihemispheric interaction was not found.

It was also found that the right hand responding produced faster reaction time than when the left hand was responding, which supports the idea that the transfer of information is faster from the right to the left hemisphere as was proposed by Marzi, Bisiacchi and Nicoletti (1991). They had also previously proposed a second potential cause of this advantage. The right hand's supremacy over the left was produced because the right hemisphere is dominant for simple visual stimuli while the left hemisphere is dominant for motor control. They put forward the idea that this created the advantage of the right hand, especially when stimuli were presented to the left visual field. Bisiacchi, Marzi, Nicoletti, Carena, Mucignat and Tomaiuolo (1994) and Fendrich, Hutsler and Gazzinga (2004) also supported this proposal for the cause of faster reaction time in the right hand.

The crossed-uncrossed difference had been expected to be around 4ms based on the previous research by Marzi et al (1991). However a negative crossed-uncrossed difference was found. Some research has in fact found a negative crossed-uncrossed difference, for instance Lines, Rugg and Milner (1984) and Braun, Mailhoux and Duresne (1996), but it is not the result which this study had hypothesised. Milners and Lines (1982) put forward the suggestion that interhemispheric interaction may need to be determined by a more precise measure than reaction time. Fendrich et al (2004) however suggested that negative crossed-uncrossed difference results may be indicating a natural variability in people's reactions.

Saron, Foxe, Simpson and Vaughan (2003) put forward an idea which may suggest why the result of this study did not support the hypothesis. In their study 57 percent of participants results were in the direction predicted. From this Saron et al (2003) proposed that interhemispheric transfer time cannot be measured from reaction times due to the fact that reaction times imply that only one pathway is used for the transfer of visuo-motor information. Where there are in fact many different pathways which would be used for the transfer or activation. Clarke and Zaidel (1989) support this idea of multiple pathways which information can follow. This is a valid point and could explain why the results of the crossed-uncrossed differences across studies are so varied.

The possibility of there being multiple pathways which information could take during the transfer between hemispheres is clear. It is an interesting suggestion that reaction times may not be able to discriminate these different pathways, because it is too simple a measure. The amount of research which has been done using functional magnetic resonance imaging (fMRI) and other similar imaging techniques has been increasing recently. As techniques improve it may become possible to map the exact pathways which information takes, therefore allowing a better measure of transfer time than reaction times to be created and used. This may then allow the crossed-uncrossed differences to be better understood and for more reliable and consistent results across studies to be gathered.

The ANOVA was expected to find an interaction between the hand used to respond and the visual field to which the stimulus was presented. This is a measure of the significance of the crossed-uncrossed difference, however an interaction was not found. This suggests that the combination of hand and visual field which the participants were reacting to did not affect the reaction times which were elicited. This may mean that there is another factor which produces the crossed-uncrossed differences which are produced from this type of reaction time experiment.

No main effect of hand was found in the between subject condition. This suggests that the handedness of participants did not affect their reaction times. This might imply that the hemispheric interaction between right and left handers is similar. This may also explain why left handers' proposed bihemispheric interaction were not shown through faster reaction times. This is another indication that left handers do not show an increased level of interaction between the two hemispheres, or at least not in the conditions produced in this study.

The hand preference distribution was the J-shaped curve which Curt, Mesbah, Lellouch and Dellatolas (1997) suggested should be found in a distribution of hand preference from a measure such as the Edinburgh Handedness Inventory. It also shows the bimodal distribution which Oldfield (1971) proposed. The distribution, however, was not as consistent as either Curt et al (1997) or Oldfield (1971) found, but this could be explained by the relatively small sample size that was used in this study, as this meant that the distribution was slightly more spread.

There are wider implications of the findings of this study. For instance it may be suggested that not all left handers possess a large degree of bihemispheric interaction. Perhaps the processes in which these bihemispheric interactions were found in studies are for the rare occasions in which it occurs in left handers. This study however may have used methods which did not require left handers to use bihemispheric transfer of information and so they use interhemispheric interaction as right handers also did in this study, meaning that the results were very similar for both groups of handedness. In future research different types of stimulus could possibly be used to see if this obtains a difference between groups, indicating left handers might be using bihemispheric interaction.

The results of this study may also support a faster transfer of information from right to left hemispheres as Marzi et al (1991) proposed may occur, especially in relation to the simple visual stimulus information which was being transferred in this study. The left and right hemispheres have been suggested as dominant for processing different types of information. The stimulus in this experiment therefore may be a necessary input to create this faster reaction time from the right to the left hemisphere, suggesting why the left handers reaction times were not faster as was hypothesized.

Another implication may be that the crossed-uncrossed difference is not as robust as it may have originally been proposed by Poffenberger (1912). As many other studies have found negative results from the crossed-uncrossed difference it may suggest that there is some aspect of interhemispheric interaction which Poffenberger (1912) has not taken into account, such as the multiple pathways which interactions may take as indicated by Saron et al (2003). Further research obtaining consistent results from crossed-uncrossed differences would imply that Poffenberger's theory is correct, however the conflicting results which are gathered from studies currently may suggest the measure is not an accurate one in certain circumstances.

The study carried out had various strengths to its methodology. One such strength is that, although the participants were all Psychology undergraduate students from the University of Plymouth, there were no restrictions, such as age and gender, as to who could participate in the study. Handedness was also not restricted, meaning that any bias which could have potentially been created was reduced. This natural sample which was produced should mean that the results which were found can be generalised to the whole population.

In the study both the Edinburgh Handedness Inventory (Oldfield, 1971) and the reaction time task were very simple to carry out. This has several advantages, for instance there is very little chance that any of the participants would not understand what was required from them, and therefore there is less chance of mistakes and anomalous results. Another advantage is that it did not take very long for each participant to carry out the experiment, making it time effective for the researcher. This also has important implications for future research if experimenters want to increase the number of participants taking part.

A final advantage is that very little input was required from the researcher while the handedness questionnaire was filled in and once the reaction time experiment on the computer had begun. This means that any possible researcher effects and demand characteristics, which could have been produced, were reduced and this is important for the validity of the results.

Although the results from the Edinburgh Handedness Inventory produced the range of distribution which had been expected, it was only a measure of the preference each participant's handedness. It does not take into account their motor performance with either hand. Brown, Roy, Rohr, Snider and Bryden (2004) indicated that using just one measure may not show the true nature of a person's handedness. This false indication of a participant's handedness may affect the results which were found and could suggest in future studies it may be advisable to carry out a measure of both performance and preference. This is because carrying out both has been found to be the best indicator of a participant's handedness (Corey, Hurley and Foundas, 2001).

Another suggestion for improving the experiment is to increase the number of participants taking part in this study. Negative crossed-uncrossed differences have generally been found in studies with smaller sample size, for example Fendrich et al (2004) whose sample only had eight participants. This may suggest that there are extraneous variables which affect the results of smaller sample sizes. By increasing the number of participants carrying out the experiment this would reduce the effect of the variables which potentially cause the negative results found in this and other experiments and would also increase the statistical significance. Iacoboni and Zaidel (2000) proposed that to gain reliable reaction times thousands of participants are required. In most cases however using thousands of participants is not a viable option due to time and money. In this case however the study only had forty participants, this means increasing the number of participants should not increase the time the study would take by a huge or troublesome extent and could potentially improve the results themselves and the reliability of them as well.

Another limitation of this study could have been the method used to create the two groups relating to handedness. Splitting the participants into two groups of equal numbers due to their laterality index from the Edinburgh Handedness Inventory was the fairest way to create the groups. However it created a rather uneven distribution of hand preference. Group two contained the twenty most left handed individuals. However due to the method of splitting the groups, some of the participants in the group were still relatively strongly right handed. A suggestion to resolve this problem in future research is to not split the participants into groups of equal numbers. Instead they could possibly be split at a cut off score in the laterality index score. This would ensure that right handers would not end up in the group which should contain mixed and left handers.

The study gained a relatively good sample of right, left and mixed handers in the population. Rather than gathering a natural sample future research could investigate strong left and right handers. Although this could not be generalised to the whole population, it would allow for the difference in hand preference on crossed-uncrossed differences to be measured. In this case the expected faster reaction times of left handers may be found, implying that it is strong left handers who possess bihemispheric interaction.

A factor which may need to be taken into account is that not many male participants took part in the study, only six out of the forty participants were male. It has been shown that males are more likely to be left handed than females and they also show more lateralization than females (Amunts, Jancke, Mohlberg, Steinmetz and Zilles, 2000). If males are more lateralized this may mean they are more likely to be bihemispheric. A lack of male participants in this study therefore may explain why the left handers were not shown to have faster reaction times than right handers. For any future research more male participants may be necessary to investigate whether this potential gender difference is indeed the case.

Another limitation of the current study is that the reaction time experiment which the participants carried out contained two long blocks of 200 trials each, one hand responding continuously in each block. This could potentially become very repetitive for the participants taking part. If the participants lost interest or became tired during the task then this could have affected their reaction times and could explain the lack of significant findings in the study. A way of rectifying this potential problem could be to have more blocks, but with fewer trials in each block. Therefore the blocks of each hand would be shorter and the more frequent alternating between hands may help to keep the participants carrying out the reaction time experiment interested in the task itself.

This solution may also help to improve another limiting aspect of the study. This other aspect is the hand with which a participant responds to the first block of trials. This was randomised by the computer programme which ran the reaction time task. However by the time a participant got to the end of the first block of trials they may have become tired and bored and therefore the second block of trials reaction times may have been effected and increased and this would have an impact on the results gathered. Increasing the number of blocks there are in the study should hopefully help to reduce this effect.

An extra measure could also be added to the experiment. Participants could be presented with a stimulus to both visual fields simultaneously. This could then be used to investigate the differences in reaction times when a stimulus is presented to one visual field compared to both, as this will lead to both hemispheres receiving the visual input of the stimulus simultaneously. It may provide further evidence for the way interhemispheric interaction which occurs when a stimulus is presented to either visual field in the crossed condition compared to either visual field in the uncrossed condition.

The method used to split the participants in to two equal groups for handedness may be the most likely cause for the lack of results supporting the hypotheses of the study. There were only five out of twenty of the left handed group which were indeed left handed. This means that the left handed group itself was heavily outweighed by right handers and could therefore provide an explanation for the unexpected results.

The study did not find results to support the original hypotheses; however this does not mean that the study was not useful. There has been other research which supports the findings of the study and this may suggest that the original hypotheses may have been wrong or incomplete or that the results gathered are not representative of the population. The methodology of the study did have some strengths, however, and its limitations were also able to be used to provide suggestions for improvements and proposed further methods of research which could be used in future studies into this area of research. The unexpected results of the study have also indicated that more research may need to be carried out in this area before we can fully understand the nature of the effect of handedness on interhemispheric interaction.

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