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Laterality Across the Lifespan: The Effects of Task Complexity

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Introduction

Handedness has been defined as the hand an individual uses to perform different unimanual tasks throughout a normal day. In other words, it is the hand that an individual prefers to use most of the time (Bryden & Huszczynski, 2011). Typically, the preferred hand, usually the right hand, is more skilled than the non-preferred hand (Hausmann, Kirk & Corballis, 2004). Approximately 90% of the population prefers to use their right hand for such tasks as writing and drawing, therefore leaving the remaining 10% of the population preferring the left hand for such tasks (Gabbard & Rabb, 2004).

The development of hand preference has been highly studied throughout the literature from childhood to adulthood (see Archer, Campbell & Segalowitz, 1988; Bryden & Roy, 2004; Francis & Spirduso, 2000). Handedness is normally assessed using preference, performance and/or performance-based measures (see Annett, 1970; Bryden, 1977; Flowers, 1975; Bryden, Roy, Rohr & Egilio, 2007; Bryden, Roy & Spence, 2007). Several factors need to be taken into consideration when trying to classify hand preference during unimanual tasks. Three determinants of hand preference and performance measures include overall hand preference, preference of the individual and the task demands required to complete the task (Gabbard & Rabb, 2004). In previous literature, attentional information and how it relates to the demands of a task have been clearly demonstrated by the use of pegboards (Bryden, Pryde & Roy, 2000). Pegboards are used to measure hand skill by assessing the willingness of an individual to use the preferred hand to complete a task even when it becomes uncomfortable or awkward to do so (Bryden, Singh, Steenhuis & Clarkson, 1994).

The aim of the current thesis was to compare hand preference from four different age groups, each representing a time period within the lifespan, with an emphasis looking at how hand preferences continues into the years of life (over the age of 70 years). Specifically, this will be accomplished by utilizing an experimental paradigm to determine the effects of task complexity on hand use to establish a complexity switch-point. In the following sections, hand preference measurement techniques, the development of hand preference at various time points in the lifespan and the role task complexity plays on hand preference will be examined.

Measurement & Classification of Hand Preference

A number of techniques have been developed to measure hand preference for unimanual tasks. Such measures include self-report questionnaires, performance measures and observational measures (Bryden, et al., 2007). With any measure, there are advantages and disadvantages, however, the largest problem remains in finding a quantifiable means of comparing results across various measurements.

Preference Questionnaires

Some of the earliest and most widely-accepted methods used to measure hand preference involve the use of questionnaires. Preference questionnaires require participants to reflect on everyday unimanual tasks where they would be required to select one of their hands to perform an activity. A plethora of preference questionnaires exist, including the Crovitz-Zener Inventory (Crovitz & Zener, 1962), the Annett Handedness Questionnaire (Annett, 1970), the Edinburgh Handedness Inventory (Oldfield, 1971) and the Waterloo Handedness Questionnaire (Bryden, 1977) which have been developed to determine preferred hand use, as well as the degree (how strongly lateralized an individual is) of hand preference. Self-report questionnaires are easy to administer with a fairly high degree of report reliability when accompanied by appropriate instructions and have also been shown to correlate with performance measures for the same activity (Bishop, Ross & Daniels, 1996). Unfortunately, handedness classification can vary dramatically from one inventory to another, which could potentially have a major impact on the results of the studies.

The Crovitz-Zener Inventory questionnaire includes a 14-item scale where participants are required to indicate which hand is preferred (e.g. right always, right usually, equal, left usually, left always) for each item (Bishop, et al., 1996). There are two major assumptions associated with this inventory. First, the inventory assumes that people can rate strength, as well as the direction of preference for a given activity and can therefore distinguish between which hand they use "always" and "most of the time" for a given activity. Secondly, the Crovitz-Zener Inventory assumes that an exclusive, but weak preference for one side is equivalent to both right and left-hand responses. This assumes that a person who answered exclusively "right always" to all items could potentially achieve the same score as someone who responded "right always" to most items, but also gave "left" or "both hands" responses to other items (Bishop, et al., 1996).

The Edinburgh Handedness Inventory (EHI) asks participants to indicate preference in hand use in an inventory of twenty unimanual (writing or drawing) and bimanual tasks (striking a match or open a box lid) by placing either a single plus sign (+) or a double plus sign (++) in either the right or left hand category. A double plus sign would indicate that the preference is so strong for that task that a participant would never use the opposite hand to perform the task, unless forced to do so (Oldfield, 1971). Rather than summing the scores, a laterality quotient is computed where points for the right and left hand responses are given according to strength and direction of preference (Bishop, et al., 1996). Unfortunately, the laterality quotient is not able to differentiate those with strong and weak preferences as a person with a mixture of right and left hand responses cause the strength of preference to influence the quotient in one direction (Bishop, et al., 1996).

The Waterloo Handedness Questionnaire (WHQ) is a 20-item questionnaire that requires individuals to indicate which hand they would use to perform a variety of unimanual tasks (Brown, Roy, Rohr & Bryden, 2006). The questionnaire includes both skilled (i.e., writing) and relatively unskilled performance (i.e., turning on a light switch) questions where participants are required to rate the frequency with which they would use a particular hand for each activity based on a 5-point scale (right always, right usually, equal hand use, left usually and left always) (Brown, et al., 2006). For each of the five responses, a score of +2, +1, 0, -1 and -2 are given respectively and then a dependent handedness measure can be calculated which represents the total composite score of each individual response. This means that right-handed individuals would acquire a positive score, while left-handed individuals would produce a negative score (Brown, et al., 2006).

Although preference questionnaires are relatively easy and convenient to administer, it is difficult to compare measure across questionnaires, as they do not measure hand preference in the exact same manner. With any self-report questionnaires, there is an inherent subjectivity that is associated as they rely on the participants' interpretation of the question and the ability to imagine oneself performing a task (Brown, et al., 2006). Regardless of the limitations associated with preference measures, self-reported hand preference is strongly correlated when paired with performance measures, especially in typically-developing young individuals (Kalisch, Wilimzig, Kleibel, Tegenthoff & Dinse, 2006).

Performance Measures

Performance measures involve an objective, quantitative measurement to determine the degree of motor preference between the two hands. Some of these quantitative measurements include tasks that involve manual dexterity, aiming, precision and grip strength (Flowers, 1975). The two most commonly used assessments include the Grooved Pegboard where participants are required to move key-shaped pegs into similarly shaped holes (Bryden, et al., 2007) and the Tapley-Bryden Dot Marking Task (Tapley & Bryden, 1985) which examines the preferred and non-preferred hand by marking a dot in each circle as accurately as possible within twenty seconds.

In a study by Bryden, et al., (2007), thirty right-handed volunteers aged 18-24 years were recruited and tested on hand performance on four versions of the Grooved Pegboard. Two Grooved Pegboards were used to create four different movement conditions which required participants to move 25 small key-shaped pegs, one at a time from a starting position (either the receptacle or hole) to an end position (receptacle or hole). Participants were timed on speed for moving 25 pegs, one at a time for five trials for each hand for a total of 20 trials. The results showed that movement time for moving the pegs to the receptacle was significantly faster than moving the pegs to the holes. The left hand was found to be significantly slower than the right hand, specifically when starting in the receptacle compared to starting in the holes and when placing the pegs in the holes compared to the receptacle (Bryden, et al., 2007).

A second commonly used performance test is the Tapley-Bryden Dot Marking Task. The study conducted by Tapley and Bryden (1985) tested the hand performance of 1556 undergraduate students on the Tapley-Bryden Dot Marking Task. Participants were told to mark a dot in each circle following a specific pattern as quickly as possible within twenty seconds. In order for the dots to be included, they could not lie outside or on the edge of the circle, but must be fully within the circle circumference. Four trials were completed which included using the preferred and non-preferred hand moving in a left to right direction starting from the top and then using the preferred and non-preferred hand moving from a right to left direction starting from the bottom. The results showed that females tended to perform better with their right hand compared to their male counterparts. However, there were no differences in performance between females and males when using the non-preferred left hand. Although females performed better with their right hand compared to males, regardless of sex, the preferred right hand was still significantly more accurate at placing dots in holes compared to the left hand (Tapley & Bryden, 1985).

As with preference measures, performance measures also have some limitations. One major problem with performance measures of hand skill is that they do not often correlate well with hand preference questionnaires (Bryden, et al., 1994). Preference questionnaires typically ask individuals to rate their hand use on a Likert scale on a variety of unmaniaul tasks. When comparing the questions on a preference questionnaire to task that are examining performance measures, there is an issue with correlating the questions asked to the performance measure being assessed. Preference questionnaires typically involve questions that ask the individual to imagine him or herself performing a particular task (e.g. painting a wall) and to rate how often they would use a particular hand to complete that task. A lot of the questions can be difficult to imagine which therefore makes rating the activity on a scale difficult. Performance measures of hand skill usually only correlate with hand preference measures when they are assessing the same activity and can therefore put restrictions on the type of questions asked. For example, people who respond with a "preferred hand always" response for throwing a ball on a questionnaire show a greater performance skill difference between the preferred and non-preferred hand than a person who only claims they usually use the preferred hand to perform the task (Bryden, et al., 1994).

Performance-Based Measures

Performance, or observational-based methods consist of assessing participants' hand preference while performing a wide range of activities. These activities generally include activities performed during every day life such as writing one's name or opening a drawer (Bryden, et al., 2007). Observational-based methods allow participants to perform everyday, natural activities in a time-constraint-free setting allowing for a more natural and accurate observation of hand performance. For example, a study conducted by Steenhuis and Bryden (1999) observed participants (n=52) hand use for tasks such as drawing, opening a jar lid and using scissors and found that for both left and right-handers the non-preferred hand was used to pick up an object, while the preferred hand was used to manipulate and interact with the object. As well, the location of the object played a role in which hand was selected for the task as objects placed on the dominant and non-dominant side of the body resulted in more preferred hand use, even if it meant crossing the body's midline (Steenhuis & Bryden, 1999).

A commonly used observational method to assess hand selection is the WatHand Cabinet Test (WHCT) (Bryden, et al., 2007). Bryden and colleagues (2007) utilized the WatHand Cabinet test on 548 participants, including children aged 3-11 years old and young adults aged 19-24 years old. The WHCT is a cabinet divided into an upper and lower compartment where the upper compartment is covered by a door that opened with a handle positioned at the bottom middle of the door, while the bottom compartment is uncovered (Bryden, et al., 2007). The WHCT allows three scores to be computed including a skilled score, a consistency score and a bimanual score. The skilled score involves calculating all unimanual tasks completed with the right and left hand and then calculating a laterality quotient. The consistency score is the average number of times a participant lifts the door handle with the right hand for a possible 0 out of 4 rating. Finally, the bimanual score is calculated by recording whether the hand that was used to open the cabinet door to pick up the object behind it was the same hand that initially opened the door. Finally, a total score can be computed using the laterality quotient [((R-L)/(R+L))*100] where all of the unimanual tasks are used to compute the score (Bryden, et al., 2007).

The results of the study found that the WHCT was strongly correlated with the Waterloo Handedness Questionnaire and the Annett pegboard, therefore validating the cabinet as a reliable measure of hand preference. The WHCT was found to be valid for administering to both children and young adults as it is quick and easy and offers a wide variety of sub-scores (Bryden, et al., 2007).

Development of Handedness

The development of handedness has been widely studied at various time points within the lifespan. In the literature, it has been assumed that handedness is a specific trait, much like eye or hair colour, therefore able to categorize individuals as simply right or left handed (Gesell & Ames, 1947). However, handedness should be viewed as a continually-developing aspect of human movement within the lifespan. The developmental onset of handedness in children is somewhat controversial throughout the literature. There has been debate throughout the literature as to when handedness develops in children, though the most persistent belief about the establishment of handedness is that it does not fully develop until the ages of 8 to 10 years (see Gesell & Ames, 1947; Archer et al., 1988; De Agostini, Pare, Goudot & Dellatolas, 1988). The inconsistencies that are present in the literature are mainly due to the fact that children show instability in hand preference, where they have a tendency to switch back and forth between right and left hand use to complete everyday tasks (Archer, et al., 1988). During development, children are learning how to navigate their environment and experimenting with both the right and left hand in order to determine which hand is most comfortable and efficient to complete tasks.

An early laterality study by Gesell and Ames (1947) followed children longitudinally from 8 weeks to 10 years of age (n = varied between 12 and 45 dependent on age analyzed). It was found that children aged 3 and under showed more bilateral hand use and were classified as "mixed handed". With increasing age, the authors found that children four years and older tend to display a preference for one hand, but some children as old as seven years still show a period of no preference or bimanual hand use. Overall, the longitudinal study did not show a clear defined age where dominant hand use was apparent in all children, as there tends to be a shift between preferred hand use and non-preferred or bimanual hand use between the ages of 2 and 8 years (Gesell & Ames, 1947).

Archer and colleagues (1988) also followed children longitudinally for a one-year period starting from 18 to 20 months of age (n=49). Children were tested at approximately 18, 24 and 30 months of age, allowing for a six-month interval between testing sessions. A handedness inventory was developed in order to test the children on both unimanual and bimanual tasks. Seven of the items on the inventory were unimanual questions (stir with spoon, comb hair, bang with hammer, push a train, stack blocks, draw with crayon and put button in a bottle) with the remaining four being bimanual task questions (place cap on bottle, bang two plastic rods together, pull tape from a roll and push a straw through a hole). The results of the inventory showed a clear preference for the right hand at all ages (18, 24 and 30 months). The authors were also interested in determining if hand preference remained stable at all time points (children who showed a right hand preference continued to display this preference at each time frame). From 18 to 24 months, 73% of females and 81% of males maintained a stable hand preference and from 24 to 30 months, 77% of females and 70% of males maintained a stable right hand preference (Archer, et al., 1988). Therefore, the results of this study demonstrated that children as young as 18 months of age display a preference towards the use of one hand when performing tasks, and continued with a stable hand preference at each 6-month interval (Archer, et al., 1988).

A developmental trend has been observed in relation to crossing the body's midline for unimanual movements in typically developing children. A study by Carlier, Doyen and Lamard (2006) look at 432 children between the ages of 3 and 10 years of age during a card-reaching task at seven different regions of hemispace. Cards were placed in front of the children, each at a distance of 40cm from the mid-point of baseline in thirty-degree intervals. Three positions were situated to the left side of the body and three were positioned on the right side of the body, with the fourth spot located at the body's midline (Carlier, et al., 2006). Participants were asked to pick up one of three cards at one of the seven positions and place it in a central box using whichever hand felt most comfortable. The results of the study showed that with increasing age, children were more likely to reach across the body's midline compared to younger children. The authors therefore concluded that younger children (aged 3-4) are more likely to reach equally with the right and left hand alluding to bilateral hand use during a simple reaching task compared to older children (7 years and older) (Carlier, et al., 2006).

In a similar study, Gabbard, Helbig and Gentry (2001) examined preferential reaching in 66 right-handed and 48 left-handed children aged 5-7 years in nine different regions of hemispace. There were nine marked positions, ranging from 10 to 70 degrees from the midline, which was located at 90 degrees. Participants were initially blindfolded until a cue was given instructing the children to remove the blindfold with both hands and return their hands to the "rest" position and keep their eyes closed until an "okay" signal was given. Upon the signal, children were instructed to open their eyes and pick up a cube using one hand and place it in a box positioned at the midline. Both groups (right and left-handers) used their dominant limb more frequently compared to their non-dominant limb in ipsilateral space. This was shown to be significant for all positions as the majority of participants chose their ipsilateral hand to perform the reaching movement when the object was closest to and on the same side of that limb. When the stimulus was presented in contralateral space, participants switched to their non-preferred limb to perform the reaching movement (Gabbard, et al., 2001).

In contrast, a study conducted by Hill and Bishop (1998) compared four groups of children between the ages of 5 and 11 on the Quantification of Hand Preference (QHP) task. The four groups included children with specific language impairment (SLI; n=20), developmental co-ordination disorder (DSD; n=12), typically developing children (n=36) and a younger group of children aged 5 to 6 years (n= 17) (Hill & Bishop, 1998). There were seven reaching positions; each placed 30 degrees apart from one another with specific cards at each position. Children were asked to pick up a card at various positions, and place it in the central box located at the body's midline. Children within the specific language impairment, developmental coordination disorder and younger age groups were significantly different compared to the age-matched control children showing a tendency to use the non-preferred hand in a task that involved reaching across the midline. The age-matched control group was more likely to use their preferred hand, regardless of the position in hemispace, whereas the younger age group was more likely to reach into contralateral space with their non-preferred hand (Hill & Bishop, 1998).

As older children's hand preference progresses over the years, the emergence of adult-like patterns of hand use becomes apparent. More mature hand and arm movements are guided not solely by hand preference, but primarily by movements that involve biomechanical efficiency (Bryden & Roy, 2006). That is to say, whichever limb will afford the most energy efficient movement for the body will be chosen, regardless of hand preference. A consensus for adults when reaching in hemispace is that the preferred hand is used more often for midline and ipsilateral reaches, although right-handed individuals are more likely to continue to use their right hand for reaches in contralateral space (Mamolo, Roy, Rohr & Bryden, 2006). In general, right-handers are more likely to use their preferred hand in hemispace as the task demands increase unlike left-handers who do not use their preferred hand as frequently for reaches in contralateral space and at the midline (Gabbard, Iteya & Rabb, 1997).

The development of handedness from childhood and into the adult years of life (over the age of 17) has been well documented throughout the literature (see Bryden & Roy, 2006;

Bryden, Mayer & Roy, 2010), but beyond young adulthood (18-25 years), there has been little research that has looked at how hand preference continues into the older adult years of life (over the age of 65). It is clear that with increasing age, a decline in hand function and performance may occur due to changes such as decrease strength and muscle mass, decreased dexterity and fine motor control as well as sensory deficits (Kalisch, et al., 2006). Along with these age related declines in hand performance and hand function, little is known about possible changes in hand preference with increasing age. It is believed that once an individual reaches the more "mature" adult-like pattern of hand use (where hand preference has become fully established), hand preference does not change during the remaining lifespan (Kalisch, et al., 2006).

Kalisch and colleagues (2006) examined sixty volunteers designated into four age groups, including 25 years (n=14), 50 years (n=14), 70 years (n=18) and 80 years (n=14) which was in accordance with the average age of the groups. Participants were required to perform various tasks involved in the execution of fine motor control including steadiness, line tracing, aiming and tapping on a test board that contains holes of varying diameters, two rows of small contact plates, two large square contact plates and long grooves. For the majority of tasks, there was a clear decline in performance with increasing age. Specifically, with increasing age, there was an increase in the number of contacts with surface during the steadiness component, an increase in errors for the right hand during line tracing, and an increase in movement time during the aiming task. Self-reported hand preference was compared to the results of the fine motor movement tests, which indicated an equalization of hand preference. The authors defined an equalization of hand preference as a decline in right hand preference, and a shift toward a more balanced performance by both the right and the left hand. Interestingly, the adults within the older age group (80 years) were unaware of the increased equalization of hand preference in daily life as they all reported strong right hand preference for a wide variety of motor tasks on a self-report questionnaire (Kalisch, et al., 2006).

It has been well established throughout the literature that seniors show deterioration in the capacity to control fine motor movements (Krampe, 2002; Francis and Spirduso, 2000; Kalisch, et al., 2006). The findings from Kalisch and colleagues (2006) are in accordance with previous studies regarding the deterioration of fine motor control in both the preferred and non-preferred hands. However, the authors also found that the differences between the preferred and non-preferred hand seem to diminish between young adulthood (18-25 years) and older adulthood (over the age of 65 years). This therefore alludes to the fact that with later adulthood, hand preference may have more of an equal representation between right and left hand use (Kalisch, et al., 2006). It is still unclear as to why there may be an equalization in hand preference with increasing age, therefore more research does need to be done in this area to determine if there is this equalization, and what is driving it.

Factors that Influence Hand Selection

Within the current literature, there are two main hypotheses that suggest that hand selection is dependent on object location during unimanual tasks. First, the Kinestheic Efficiency hypothesis states that hand selection is limited by the biomechanical constraints that are placed on the movement (Gabbard, Iteya & Rabb, 1997). In other words, individuals are equally as likely to use either their preferred or non-preferred hand during a wide variety of tasks to ensure the most energy efficient movement is selected. More specifically, reaching to the furthest point of contralateral space with the preferred right limb is arguably less biomechanically efficient compared to reaching with the hand in closest proximity to the object (Gabbard & Rabb, 2000). This hypothesis could help explain why individuals chose to use the non-dominant limb to perform reaches in contralateral hemispace compared to a reach with the dominant hand that would require increased effort and movement (Gabbard & Rabb, 2000).

The second hypothesis, the Hemispheric Bias theory states that hand selection is based on the spatial equivalence between the limb and the object, therefore selecting the limb which is in closest proximity of the object (Bradshaw, Willmott, Umilta, Philiphs, Bradshaw & Mattingley, 1994). Each hand typically performs optimally when acting in an ipsilateral fashion, in the same side of hemispace. For example, both reaction and movement times are typically faster when the right hand performs in right hemispace and the left hand performs in left hemispace compared to the right hand in left hemispace and the left hand in right hemispace (Gabbard & Rabb, 2000). Research suggests that movements made by the hand ipsilateral to the target afford greater advantages for older children, young adults and seniors including both shorter reaction and movement times and increased accuracy (Bryden, Scharoun, Rohr & Roy, 2012).

Task Complexity & Hand Preference

Hand preference tends to vary depending on the task, however the actual mechanism as to why this occurs is not well understood. There are various aspects of a task that could affect the degree of hand preference, however throughout the literature the complexity of the task has been well documented as a possible cause (Hausmann, et al., 2004). In general terms, the more complex a task is, the stronger the preference is toward using the preferred hand to perform the task. It should be noted that there is no explicit definition of task complexity and therefore it becomes very difficult to quantify. Task complexity can be defined in different ways by different researchers, depending on the task.

Tasks that require a high level of manual skill have been suggested to be composed of a fairly complex sequence of motor events, whereas unskilled tasks are those which do not require a complex sequencing of motor events (Bryden, 2000). Therefore, it is believed that skilled tasks are more lateralized, as they require a higher degree of precision to execute the motor program that would be acquired through increased practice by the preferred hand. For tasks that require less skill due to decreased motor sequencing patterns, the preferred hand has been found to be used less often to perform the task (Steenhuis & Bryden, 1989).

When an individual performs a simple reaching movement, a number of processes occur in order to allow for the movement to be performed accurately and precisely. During the execution of a simple reaching movement, an individual must plan the movement they are going to make before reaching to perform the actual movement. This requires some degree of on-line control of the movement in order to be able to adjust and change trajectory patterns if necessary during the movement (Wu, Yang & Honda, 2010). Typically, when performing a movement, both visual feedback regarding the target and information regarding one's hand movement are available for both movement planning and the on-line control of the movement. The on-line control of movement relies on the information that is provided by various sensory systems including vision, proprioception, audition and the vestibular system (Sarlegna & Mutha, 2014). Previous research has suggested that accuracy of a movement increases when visual feedback of the moving limb is available. However, if no visual feedback of the moving limb is available, individuals are still able to successfully complete a movement from the memorized position of the target. However, the success rate for this is greatly decreased compared to when visual feedback is available (Wu, et al., 2010).

It is difficult to compare results across different studies that look at the role task complexity plays on hand preference when there is no clear definition of task complexity. Due to the inconsistencies throughout the literature for defining task complexity, Fitts in 1954 proposed the speed-accuracy trade-off as the relationship between movement time and the difficulty of the task (Wu, et al., 2010).

Fitts' Law

Unimanual hand use, especially pointing and interacting with objects and the environment in every day life are common human motor behaviours. If the amount of accuracy required to perform a task is high, then the speed that the movement can be performed is decreased (Wu, et al., 2010). Fitts was the first researcher to propose the speed-accuracy trade-off and its relationship between movement time and an index of difficulty (Wu, et al., 2010). In the studies conducted by Fitts and colleagues, participants were asked to make unimanual-reaching movements with their preferred hand between two targets that varied in width (size of target) and amplitude (distance between starting point and target). The relationship between the width of the target and the amplitude between the target and the starting position was termed the index of difficulty (ID). As the ID increases, the difficulty of the movement task also increases ($ID = \log_2 (2A/W)$). The ID is therefore able to quantifiably measure the overall difficulty of the task (Wu, et al., 2010).

One of Fitts' earliest studies involved three different experimental designs, which examined various aspects of hand performance and skill (Fitts, 1954). The first experiment utilized a reciprocal tapping task where participants had to alternately tap between two fixed metal plates varying in widths of 2, 1, .5 and .25 inches and amplitudes of 2, 4, 8 and 16 inches. Sixteen, right-handed college males were told to focus on accuracy rather than the speed of the movements (Fitts, 1954). There were error bars placed on either side of the metal plates to account for under and overshoots. Sixteen right-handed college men participated in this study on two consecutive days using a lighter stylus (1 ounce) on the first day and a heavier stylus (1 pound) on the second day. The results of this study showed that the average number of errors were small when participants used either the lighter stylus (1.2%) or the heavier stylus (1.3%). However, the greatest number of errors occurred during the condition utilizing the smallest plate width (.25 inches) and the largest amplitude between plates (16 inches) for both lighter (3.6%) and heavier (4.1%) styluses (Fitts, 1954). Movement time increased progressively as both movement amplitude and category of widths increased indicating that participants did not scale their movements quite as much as necessary to account for the increased accuracy required during each increase in width and amplitude (Fitts, 1954).

The second experimental design Fitts used to test hand performance in relation to task complexity utilized a disc transfer task where participants were required to transfer plastic washers from one pin to another as the amplitude and washers varied in size. Similarly to the previous study, there were four different amplitudes (4, 8, 16 and 32 inches) and four different sizes of washer holes (.5, .25, .125 and .0625 inches). Sixteen different right-handed college men participated in this study, which required participants to transfer a washer to a pin in two consecutive cycles from left to right. The results again showed that movement time increased with increased movement amplitude and decreased washer hole size in correspondence to the results found in experiment 1 (Fitts, 1954). The final experimental design in Fitts' study required participants to transfer pins from one set of holes to another where errors were not allowed. Again, the size of pins varied from 1/4, 1/8, 1/16 and 1/32 inches and amplitudes varied from 1, 2, 4, 8 and 16 inches for a total of 20 task conditions. Twenty right-handed college males and females participated in this study, which required transferring pins from one hole to another in a random order on three separate days. The results showed improvements in the rate of task performance from day one to day two, but there was little further improvement in performance on day three. Movement time again increased progressively as the requirements of the task became more difficult with increasing movement amplitude and decreased pin size (Fitts, 1954).

Task Complexity & Hand Performance

Throughout the literature, there have been inconsistent findings as to whether the complexity of a task affects hand preference or hand performance. One of the first documented studies on task complexity conducted by Flowers (1975) found that there were small differences between hand selection during simple tasks, but much larger differences in hand selection for more complex tasks which hypothetically involved more skill. The first experiment, following Fitts law, required participants (young adults) to tap two targets alternately from left to right with a stylus as accurately and quickly as possible within 10 seconds. Participants were classified as right-handers (n=10), left-handers (n=8), right-ambilaterals (n=11), left-ambilaterals (n=16) and mixed-handed (n=11) after answering an eight-item unimanual and a ten item bimanual questionnaire. An error plate was mounted on either side of the targets to calculate under and overshoots. Targets varied in width by 1, 2 and 4cm and amplitudes of 4 (ID values 1,2 and 3), 8 (ID values 2, 3 and 4), 16 (ID values 3, 4 and 5) and 32cm (ID values 4, 5 and 6). The results of this study showed that the two lateralized groups (right and left handers) performed at a faster rate of movement with the preferred hand compared to all other groups for all ID levels (Flowers, 1975). No differences were seen between the groups for the non-preferred hand for all conditions.

In the second experiment conducted by Flowers (1975), a tapping task was used that required participants to tap out rhythms repetitively as fast as possible without aiming movements to a particular point. The same group of young adults from the first experiment was also tested in the second experiment. There were six tapping conditions: (1) spot tapping as quickly as possible in one spot, (2) tapping in pairs with a pause between taps, (3) tapping in triplets with a pause between sets, (4) groups of four tapping with alternating single taps and a pause between each set, (5) tapping in pairs and triplets with a pause between groups and (6) single, double and triple taps with a pause between each set (Flowers, 1975). There were no significant differences found between any of the groups with either hand on any condition.

The conclusions that Flowers made for the first reciprocal tapping experiment was that there was relatively small differences between the groups for the preferred hand on conditions of ID 1 through 3 and a noticeable and significant difference between groups for ID values above 4 (Flowers, 1975). Overall, the data suggested that in right and left-handers there is a difference in performance between the preferred and non-preferred hand on controlled aiming task (as seen in experiment 1), but these differences are not seen in tasks that require ballistic movements that do not require online monitoring (as seen in experiment 2) (Flowers, 1975).

A study by Annett, Annett, Hudson and Turner (1979) investigated the performance of the two hands across task difficulty by manipulating difficulty using Fitts' Law. The authors hypothesized that the speed difference between the preferred and non-preferred hands may account for the lateral differences in efficiency. There were a total of 48 participants recruited and grouped into one of four groups. Group 1 consisted of undergraduate females and used only 1.27cm holes set at each of the three distances. Group 2 also consisted of undergraduate females and used only 1.91cm holes set at the same three distances as group 1. Group 3 was comprised of female university staff and students and used only 2.54cm holes at all three distances. Finally, group 4 included both male and female university staff and students and was tested on all three-tolerance levels at the shortest distance (20.32cm) only (Annett, et al., 1979). The participants were required to move a row of 10 wooden dowels from one row of holes to another row closer to the participant. There were three different distance possibilities between the two rows including 20.32cm, 30.48cm and 40.64cm apart. The IDs ranged from 4.0 to 8.0 bits by using tolerance in the calculation of difficulty (Annett, et al., 1979). A single trial consisted of moving all 10 dowels from the furthest to the closest row of holes as quickly as possible. Both the preferred and non-preferred hand in an alternating order performed five trials. If a dowel was dropped during a trial, the trial was restarted (Annett, et al., 1979). A total of 48 participants separated into four independent groups of 12. All participants were right-handed as determined by the Annett (1970) Handedness Questionnaire.

As the hole-to-peg ratio decreased, and therefore the difficulty of the task increased, the authors found that the difference between the hands became greater. The difference between the hands was due to the non-preferred hand simply making more errors than the preferred hand. There were no differences in insertion-time or in the movement speed of the two hands (Annett, et al., 1979). The authors therefore concluded that the difference between the hands was due to the non-preferred hand being more variable when performing the task (Annett, et al., 1979).

The amount of skill required to perform a task has been linked to not only hand preference determinants, but also as an important factor in determining the degree of asymmetry in hand performance (Bryden, et al., 2007).

Task Complexity as a Factor in Influencing Hand Selection

The differences the role task complexity plays on hand preference found throughout the literature may be attributed to the fact that no definitive method of quantifying task complexity exists, as task complexity is multidimensional. The overall degree of task complexity and the methodology implemented in various studies has been very inconsistent and therefore Bryden et al., (2000) developed a preferential reaching task that allowed for the manipulation of the demands of the task, or its overall complexity, while the proximity of the reaches involved in the task were maintained. A main outcome of the study was to determine if a "switch point" existed during reaches done in both contralateral and ipsilateral space. A switch point was considered to be the point in space in which the task became increasingly awkward (and therefore more difficult) and would cause an individual to switch hands in order to complete the task (Bryden, et al., 2000). One hundred and two right-handed, and twenty left-handed undergraduates participated in this study. The preferential reaching task involved seven dowels, placed at thirty-degree intervals from ninety degrees to the left and right of the participant (Bryden, et al., 2000). Five tasks, including pointing to the dowel, picking up the dowel, knocking the dowel over in a sweeping motion, tossing the dowel and reposition the dowel in a receptacle were completed in combination with one of the seven task positions. It had been assumed that if an individual truly prefers one hand to perform a unimanual task to the other, he or she will continue to use the preferred limb, even in increasingly awkward positions (Gabbard, et al., 2001).

Bryden and colleagues (2000) found that both right and left-handed individuals were more likely to use their preferred hand during reaches in ipsilateral space and at the midline, although left-handed individuals did show a switch to their non-preferred hand at the midline about one third of the time. However, in contralateral space, both right and left-handed individuals chose to use their preferred hand, even though their non-preferred hand would have allowed for a more biomechanically efficient reach (Bryden, et al., 2000). In regards to the actual complexity of the task, there were no differences in right hand use across the five tasks.

Conversely, a study performed by Bryden and colleagues (1994) had participants use a modified Long Pegboard, which required moving pegs with down the length of a board starting with either the left or right hand, until a certain point in which the task became increasingly difficult, requiring a switch to opposite hand. Unlike the study by Bryden and colleagues (2000) mentioned previously, which manipulated task complexity and maintained task proximity, the study by Bryden, et al., (1994) manipulated task proximity, while maintaining task complexity. Forty-six undergraduate students participated in the study, with 21 right-handed individuals and 25 left handed individuals. Participants were seated at the end of a long table in front of a Long Pegboard, which contained a row of holes with alternating large and small diameters. When seated at the far left end of the board, the first large hole was aligned with the participant's midline. Participants were instructed to begin the task by using their left hand to move the first large peg and position it in the next large hole to the right by "leapfrogging" the large peg over the small peg which was positioned in the second hole at the far left end of the board. Participants were instructed that they had to use their left hand to start the task while seated at the left end of the board, but were allowed to switch to using the right hand at anytime it felt appropriate to do so. However, once the initial switch was made (from left to right), participants were not allowed to switch back to using the left hand during the remainder of the trail (Bryden, et al., 1994). Therefore, the complexity of the task remained constant and quantifiable, while the proximity of the reaches was manipulated. In

general, left-handers moved further to the right with their left hand compared to right-handers who switched to use their dominant hand as the task became more difficult (Bryden, et al., 1994).

Task Complexity and Aging

A recent study by Gooderham and Bryden (2013) utilized a similar paradigm to the Bryden and colleagues (2000) study where object proximity was maintained, but task difficulty was manipulated. Four age groups were recruited for this study in order to look at the development and continued progression of hand preference from various time points in the lifespan. The four groups included young children aged 2-4 years (n=20), older children aged 10-14 years (n=20), young adults aged 18-25 years (n=20) and seniors over the age of 65 years (n=20). Like Bryden and colleagues (2000), the authors of the current study were interested in determining if a complexity switch point would emerge when performing a task of increasing difficulty (Gooderham & Bryden, 2013). Simultaneously, the authors were also interested in determining what happens to the progression of hand preference with increased age. Within the literature, there has been thought that there may be a move towards ambidexterity with increasing age, with less of a reliance on hand preference and more of an equalization of hand use (Kalisch et al., 2006).

In order to determine if a switch point would emerge with increasing task difficulty, identical task gradients were setup in both ipsilateral and contralateral space, with the participant seated at the midline between the two gradients. The task gradients included eight tasks that increased in difficulty from a simple first task, to a more complex eighth task. Participants started on the contralateral side and were asked to complete the first task with whichever hand felt more comfortable and appropriate to complete the task. Following completion of the first task on the contralateral side, participants then completed the same task on the ipsilateral side, again utilizing whichever hand felt most appropriate to complete the task. Progression of the remaining seven tasks continued in this alternating pattern (Gooderham and Bryden, 2013). Progression through the gradient was measured by the highest task completed before switching to use the opposite hand for both ipsilateral and contralateral sides of the gradient. The results of the Task Complexity Gradient revealed that young children differed significantly from the older children and that the older children differed significantly from the adults and that the adults did not significantly differ from the senior population. When performing in ipsilateral space, all age groups completed all tasks within the gradient with the proximal right hand, with the exception of the youngest age group whom completed seven of the eight. When performing in contralateral space, children performed the highest number of tasks (6 out of 8) while older children performed the fewest tasks (1.6 out of 8) with the proximal left hand. The adults and the seniors performed similarly (approximately 4 out of 8) in contralateral space completing more tasks than the older children with the left hand, but less than the young children.

The study by Gooderham and Bryden (2013) was successful in determining a complexity switch point when performing tasks of increasing difficulty, however there was a major limitation in the study that was addressed by the authors. Although the complexity gradient increased in difficulty with every added task, there was no quantifiable way of measuring the change of gain between the tasks. There was no objective measure to determine that one task was more difficult than another. Therefore, it is difficult to determine where a switch point may have emerged and the overall degree that task complexity played on the study. Further research needs to be completed which utilizes a computable way to measure task complexity in order to further the understanding on the role task complexity plays on hand selection.

Purpose

The interest of the current study involves a similar paradigm utilized by Gooderham and Bryden (2013) where the aim is to produce a "complexity switch point" by maintaining task proximity and manipulating task complexity. This observed switch point would represent the point in which task complexity overrides the ability to utilize a movement that is more biomechanically efficient. Much like the complexity gradient utilized by Gooderham & Bryden (2013), the current study incorporated a gradient of increasing difficulty by using Fitts' Law in order to investigate the effects task difficulty plays on hand selection and in hopes of identifying a complexity switch point. The newly developed Hand Selection Complexity task includes six indexes of difficulties, which are randomly presented to participants in both ipsilateral and contralateral space. In addition to uncovering a complexity switch point, the current study will also allow for a further examination of how hand preference progresses into the older adult years of life. Specifically, the aim of the current study was to overcome one of the previous limitations within the literature described by Gooderham and Bryden (2013) in trying to quantify task difficulty, while maintaining task proximity.

There were two main research questions in which the current study hoped to answer for the Hand Selection Complexity Task. First, with increasing age, is there an equalization in hand preference? That is, with increasing age, is there less of a reliance on the preferred hand and a more a shift towards using the right and left hands more equally in order to perform a unimanual task? And secondly, does the increasing complexity of a task override a movement that is more biomechanically efficient in order to utilize the preferred hand in order to complete the task? For the long pegboard task, the current study hoped to determine the role task proximity played on hand preference when task complexity remained consistent.

Hypotheses

In regards to the first question, it was hypothesized that seniors would have less of a reliance on the preferred hand when completing a unimanual task. Specifically, seniors would utilize the preferred and non-preferred hand equally when performing unimanual tasks. For the second question, it was hypothesized that based on the Kinesthetic Efficiency hypothesis and the Hemispheric Bias theory (both mentioned previously), that individuals would chose to perform a task located on the contralateral side with the hand that is in closest proximity to the target (non-preferred hand) and therefore utilize the preferred hand on tasks located ipsilaterally (Gabbard, et al., 1997). However, if the task were of increased difficulty, individuals would choose to perform a less biomechanically efficient movement in order to maintain the use of the preferred hand to ensure the successful completion of the task (Bradshaw, et al., 1994). Finally, for the long pegboard task, it was hypothesized that when starting from the far right end of the board, participants would complete more peg jumps using the right hand, before switching to use the left hand to complete the task. It was also hypothesized that when starting from the far left end of the board, participants would switch to their right hand early during the task.

Methods

Participants

A total of 81 participants, including 9 left-handers and 72 right-handed individuals (M = 31, F = 50) participated in the current study and were arranged into 4 groups, dependent on age (Refer to Table 1). The young children, aged 3-7 years old (n = 18, mean age = 5.33, M =12, F =5) and the older children, aged 8- to 12-years old (n =31, mean age = 10.03, M =10, F =21) all of whom were typically-developing children, were recruited from the Brainworx camps held at Wilfrid Laurier University and a local childhood development center – Inspiring Minds Early Learning Centre, Wellesley, Ontario. The young adults, aged 18- to 25-years old (n =20, mean age = 22.65, M =8, F=12) were recruited as a convenience sample from the undergraduate and graduate population at Wilfrid Laurier University. The senior population, all over the age of 70-years (n = 12, mean age =77.17, age range = 70-87, M =1, F=11) were recruited from a local retirement home – Royal Palisade Retirement Community, Stratford, Ontario and a local fitness class – Waterloo, Ontario. The exclusion criteria included any motor deficit that may have affected dexterity and any cognitive deficits that could have affected comprehension of instructions. Individuals suffering from severe arthritis were excluded (those with mild-to-moderate arthritis were included).

Voluntary informed consent was obtained from all participants. The study was reviewed and received full ethical clearance by the Research Ethics Board at Wilfrid Laurier University.

Table 1: Participant Demographic Information

Age Group	Mean Age (years)	Females: Males	Right: Left	n
Young Children 3-7 Year Olds	5.33	6:12	13:5	18

Older Children 8-12 Year Olds	10.03	21:10	28:3	31
Young Adults 18-25 Year Olds	22.65	12:8	20:0	20
Seniors Over 70+ Years	77.17	11:1	11:1	12

Apparatus

All participants completed the newly designed Hand Selection Complexity Task, the Long Pegboard task and the Waterloo Handedness Questionnaire. Tasks were presented in this order to ensure that the results obtained on the Hand Selection Complexity task were not biased by the results of the preference and performance measures.

Hand Selection Complexity Task

The Hand Selection Complexity Task (HSCT) was designed as an observational method used to investigate the effects of task difficulty on hand selection. Participants were seated at a table with both hands resting comfortably, near the midline on the table in front of them. The same task complexity gradient was placed in both ipsilateral and contralateral space. From the edge of the table, the gradients were displayed on an 8x11 piece of paper, which were located 30 cm laterally in both directions from the midline and 21 cm anteriorly (See Figure 1) (Gooderham & Bryden, 2013). This was the same setup for all participants within the study. There were three different conditions presented within the task complexity gradients, which included the manipulation of target amplitude, target width, and finally, the manipulation of both target amplitude and target width concurrently. Within each condition, six different difficulties were presented randomly to each participant. Each participant received the same random order of difficulties for each of the 3 conditions. For example, when starting on the contralateral side for the first condition, each participant would begin with the 4th hardest difficulty level. Participants would then complete the identical task (therefore, same difficulty level) on the ipsilateral side. Random presentation of the difficulties continued in this fashion where all participants received the same ordering of difficulties. The six difficulties used were determined by utilizing Fitts Law, which looked at the relationship between target width and target amplitude, referred to as the index of difficulty (ID). In the condition that manipulated target amplitude, the width of each target was maintained at 1cm, while the amplitude between targets included 0.8, 1.2, 2, 3.7, 7.2 and 13.8cm. The amplitude between the two targets was measured from the furthest outside point of one target to the same point in the second target. In the condition that manipulated target width, the amplitude of each target was maintained at 12.8cm (again, measured from the 2 outside points of each target), while the target widths varied by 8.6, 4.2, 2.2, 1.2, 0.6 and 0.3cm. In the final condition, both target amplitude and target widths were varied concurrently where target amplitude varied by 7.3, 10.2, 12.1, 5.1, 3.5 and 6.4cm and target width by 0.1, 0.5, 1.1, 0.8, 1.8 and 2.7cm.

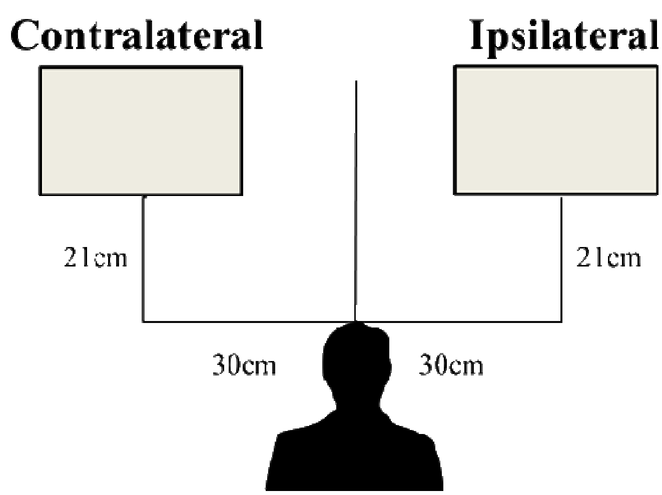

Figure 1: Schematic representation of the Hand Selection Complexity Task set-up. Participants are seated at the midline with hands resting comfortably in front of them. An identical task gradient is positioned in contralateral and ipsilateral space, 30cm laterally and 21cm anteriorly.

Participants were asked to complete the HSCT located on the contralateral side with whichever hand felt most comfortable and appropriate to complete the task. They were instructed to perform 10 reciprocal tapping movements between the two targets as fast and as accurately as possible. The time it took for the participant's to complete the reciprocal tapping task was recorded on a stop watch. After completion of the contralateral gradient, participants then completed the same gradient located on the ipsilateral side, again tapping 10 times between two targets as fast and as accurate as possible utilizing whichever hand felt most comfortable and appropriate to complete the task. Participants continued in this alternating fashion through the presentation of the six different difficulties for each of the three conditions. After the completion of each gradient, the hand selected to perform the task was recorded. Finally, any errors that may have occurred during the task were also recorded. An error in performance included any targets that were missed by the participant (too far inside or outside of the target).

Long Pegboard

The long pegboard is a useful tool in determining the point in space at which a unimanual movement becomes increasingly difficult or awkward to complete with the starting hand and therefore causes the participant to switch hands in order to complete the task. The long pegboard allows for a behavioural measure of hand preference and is significantly correlated with overall strength of hand preference. When performance measures such as the long pegboard are utilized in conjunction with hand preference questionnaires, both measures have been shown to be reliable to other measures of hand preference (Bryden, M.P., et al., 1994).

To begin, participants were seated at the far left end of a table with the long pegboard's starting hole positioned in line with the participant's midline. The pegboard contained 15 large holes (1.5cm in diameter) and 15 small holes (0.75cm in diameter), which were oriented in an alternating large hole, small hole pattern, separated by a center-to-center distance of 5cm

(Bryden, et al., 1994). Due to the length of the board, young children and older children had a different starting hole position compared to the young adult and senior populations. When the board was positioned in either the left or right direction, young children and older children started at hole 9, while young adults and seniors always started at hole 1. A large peg was positioned in the furthest large hole to the left, with a small peg positioned next to the large peg in the furthest small hole to the left. When seated at the far left end of the board, participants were required to begin peg movements by using the left hand. Starting with the larger peg in the starting hole, participants were instructed to move the large peg into the next large hole by "leapfrogging" the large peg over the small peg. After placement of the large peg into the next large hole to the right, participants were then instructed to move the small peg into the next small hole to the right by "leapfrogging" over the recently moved large peg. Participants were instructed to continue following this alternating "leapfrogging" movement until the last hole on the far right end of the board was reached. Prior to beginning the task, participants were informed that they were allowed to switch from using their left hand to using their right hand at any time it felt appropriate to do so in order to complete the task. Once the switch was made from using the left hand to using the right hand, participants were not allowed to switch back to using their left hand. The point at which participant's switched hands was recorded, along with the time it took to complete the movement of the pegs from the far left end of the board to the far right. Following the completion of the left-end start, participants then completed the same task starting on the far right end of the board where they were instructed to utilize the right hand to start the task. Again, participants were allowed to switch from using the right hand to using the left hand anytime it felt appropriate to do so. Two trials were completed for both left hand and right hand starts (Bryden M.P., et al., 1994).

The traditional way to measuring performance on the long pegboard task is to express the right and left hand values as a (R-L)/(R+L) ratio where (L) was represented as the number of pegs moved by the left hand before a right hand switch occurred and (R) was the number of pegs moved by the right hand before a left hand switch occurred (Bryden, M.P., et al., 1994). However, within the current study, the data from the long pegboard was expressed as a proportion of how far down the length of the board a participant went with their starting hand (either right or left) until the time they chose to switch to use the opposite hand in order to complete the task. For example, if a participant started with the right hand and completed 15 out of 30 holes with their right hand, this would be represented as the participant going 50% of the way down the length of the board before switching.

Waterloo Handedness Questionnaire

The final assessment utilized was the Waterloo Handedness Questionnaire, which provided an overall measure of hand preference. Participants were asked to complete the 20-item version of the questionnaire indicating how often they would use their hands to complete everyday tasks. Each of the 20 questions asked participants to rate their response on a 5-point scale, which included left always (LA), left usually (LU), equal right and left (EQ), right usually (RU) or right always (RA) responses. Each of these responses were then given a numerical score ranging from -2, -1, 0, +1 and +2 respectively. A total score was calculated for all participants by summing all items on the questionnaire. Therefore, right-handers were expected to have positive scores, while left-handers were expected to have negative scores (Bryden, et al., 2007).

The questionnaire was administered to the young children and older children (below the age of 12 years) by reading each item aloud and then providing an explanation to the question if necessary. Children were then asked to indicate which hand they would use to perform the indicated task or if they would use both hands, and if a hand preference was given, the children were asked the frequency in which that hand would be used (e.g. usually or always). This therefore maintained the consistent 5-point scale for both children and adults. Originally, children younger than 4 years of age were not going to be asked to complete the questionnaire, but rather their parents would answer the questionnaire on their behalf. However, due to a low response rate from the parents of these children, the children under 4 years of age were read the questions like the other children younger than 12 years and their response was recorded, if one was given. It should be noted that oral administration of the WHQ has been done in previous studies for children under the age of 12 years, and is therefore considered a valid method of administration (Bryden, et al., 2010). As well, a total score was also computed for both questions that involved skilled hand use (writing, drawing, etc.) and questions that involved unskilled hand use (picking up objects, opening drawers, etc.). For skilled hand use, a total of 8 questions were included for a total possible score out of 16, and for unskilled hand use, a total of 12 questions were included for a total possible score out of 24 (Refer to Table 3) (Bryden, et al., 2007).

Table 2: Skilled and unskilled questions included in the Waterloo Handedness Questionnaire

Skilled Questions
2. With which hand would you hold a paintbrush to paint a wall?
7. Which hand would you use to draw a picture?
10. Which hand would you use to throw a ball?
11. In which hand would you hold a needle while sewing?
13. With which hand would you use the eraser at the end of a pencil?
18. With which hand would you use a pair of tweezers?
19. Which hand do you use for writing?

20. Which hand would you turn the dial of a combination lock with?
Unskilled Questions
1. Which hand would you use to spin a top?
3. Which hand would you use to pick up a book?
4. With which hand would you use a spoon to eat soup?
5. Which hand would you use to flip pancakes?
6. Which hand would you use to pick up a piece of paper?
8. Which hand would you use to insert and turn a key in a lock?
9. Which hand would you use to insert a plug into an electrical outlet?
12. Which hand would you use to turn on a light switch?
14. Which hand would you use to saw a piece of wood with a handsaw?
15. Which hand would you use to open a drawer?
16. Which hand would you turn a doorknob with?
17. Which hand would you use to hammer a nail?

Result

Since the purpose of the present study was to compare hand preference between age groups, with a specific emphasis on how task complexity may affect hand preference, it was decided to analyze all tests independently of one another and between the four age groups. The

HSCT time and switch point components were analyzed using a repeated measure ANOVA, while both the long pegboard time and switch components and the WHQ were analyzed using a one-way ANOVA. All post hoc analyses were multiple comparisons that were corrected using the Bonferroni adjustment ($p < 0.05$). The analysis was conducted using SPSS 20.0.

Hand Selection Complexity Task

A 6 (task difficulty) x 4 (age group) x 3 (task condition) x 2 (hand used) repeated measures ANOVA was performed on the Hand Selection Complexity Task time component, which showed a main effect of age ($F_{(3,76)} = 5.15$, $p < 0.05$). Post hoc analysis revealed that 3-7 year olds differed significantly from both the older children (8-12 year olds) ($p < 0.05$) and the young adults (18-25 year olds) ($p < 0.01$), but did not significantly differ from the seniors (over 70 years) as both the young children and the seniors required more time to complete each difficulty of the HSCT (Refer to Figure 2 and 3). The partial eta squared revealed that 65% of the total variance was attributed to the difficulty associated with the task (Refer to Table 2).

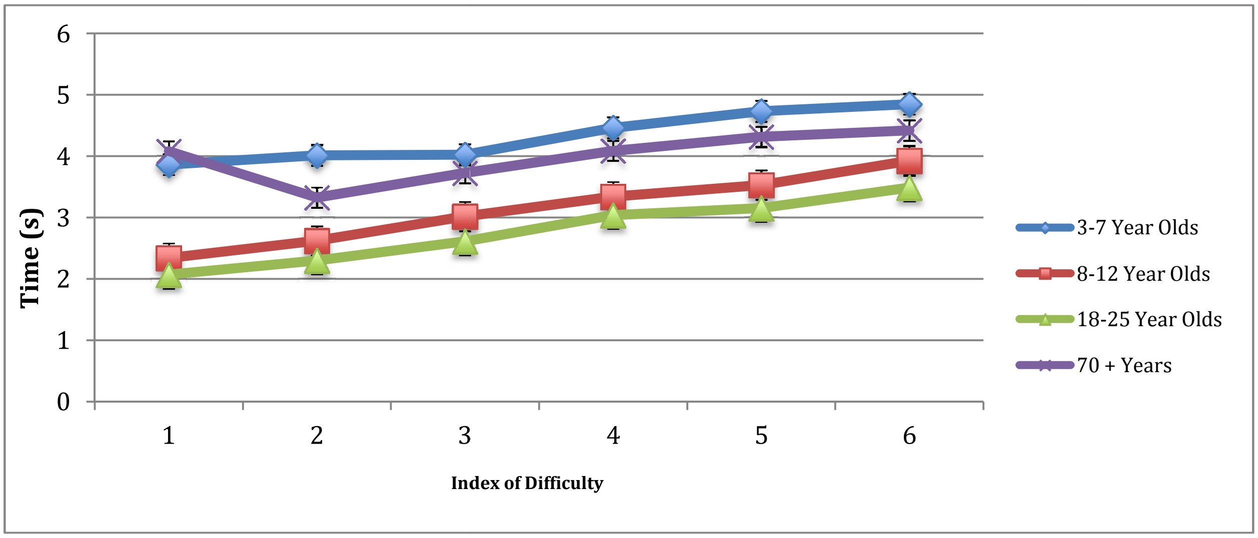

Figure 2: Time to complete the 6 difficulties across the all 3 conditions on the Hand Selection Complexity Task on the ipsilateral side. Young children and seniors required significantly more time to complete all ID's compared to older children and young adults

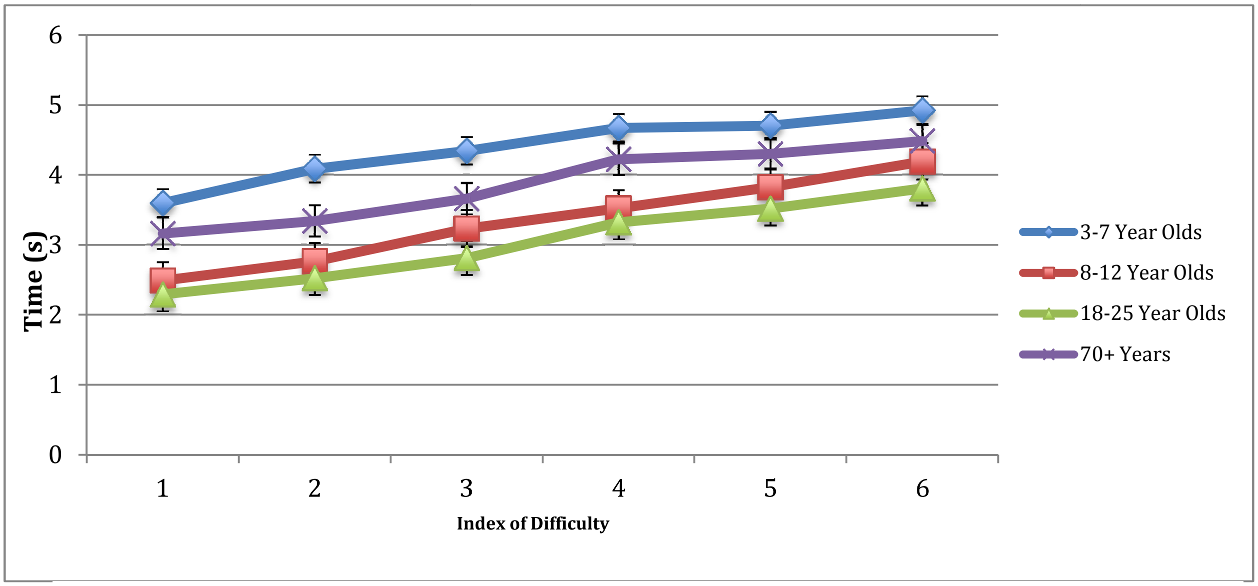

Figure 3: Time to complete the 6 difficulties across all 3 conditions on the Hand Selection Complexity Task on the contralateral side. Young children and seniors required significantly more time to complete the HSCT compared to older children and young adults

A 6 (difficulty) x 4 (age group) x 3 (condition) x 2 (hand used) repeated measures ANOVA was performed on the HSCT accuracy component, which showed a main effect of age ($F_{(3, 76)} = 12.15$, $p < 0.05$). Post hoc analysis revealed that young children were significantly different when compared to older children, young adult and senior populations ($p < 0.05$). Young children made significantly more errors for all difficulties and across all conditions when compared to the other 3 age groups.

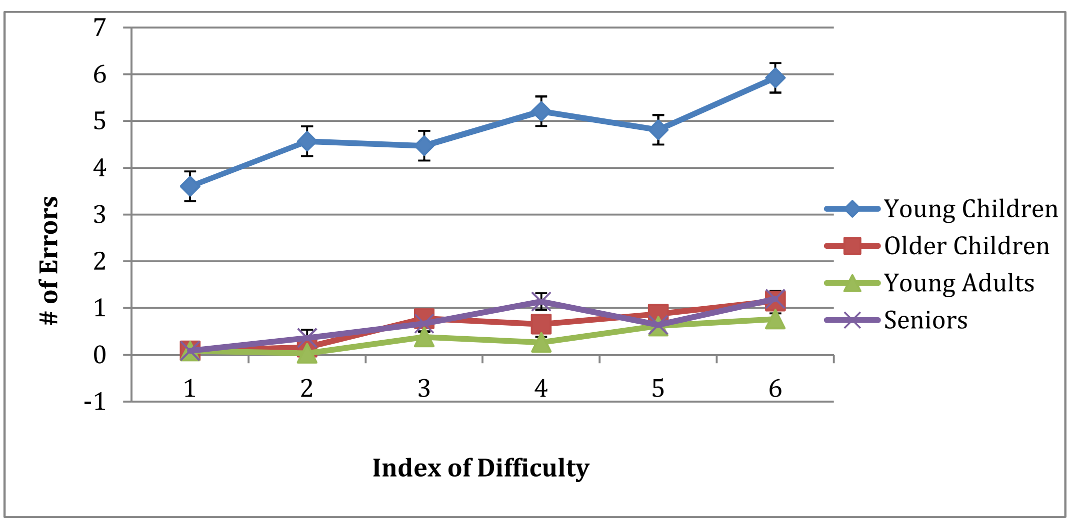

Figure 4: Accuracy in performing the HSCT in ipsilateral space. Young children performed significantly more errors when compared to the older children, young adults and seniors. This was found across all 6 difficulties and 3 conditions

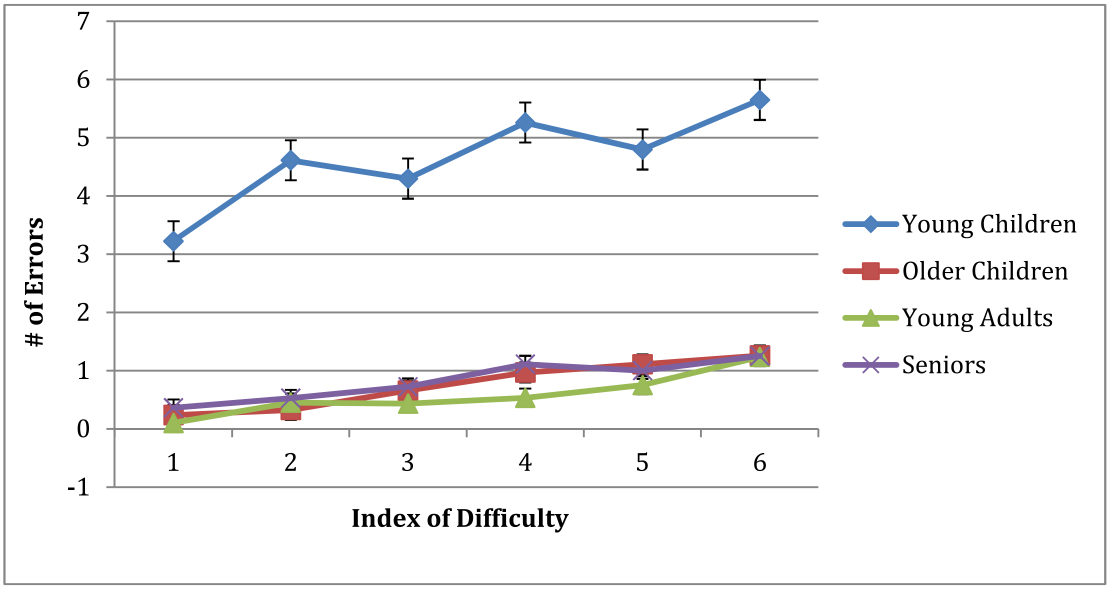

Figure 5: Accuracy in performing the HSCT in contralateral space. Young children performed significantly more errors when compared to the older children, young adults and seniors. This was found across all 6 difficulties and 3 conditions

A 4 (age group) x 2 (side) repeated measures ANOVA was performed on the HSCT switch component, which showed a main effect of side ($F_{(3, 76)} = 45.32$, $p < 0.01$), as well as a significant interaction between side and age group ($F_{(3, 76)} = 4.33$, $p < 0.05$). Post hoc analysis revealed that 3-7 year olds and 8-12 year olds were not significantly different from each other, but older children differed significantly from both the young adults ($p < 0.05$) and the seniors ($p < 0.03$) where older children performed more switches in contralateral space. There was no significant difference found between the young adults and the seniors (Refer to Figure 4). The partial eta squared revealed that 37% of the variance was attributed to the side in which the task was completed on (Refer to Table 2). The same results were found for all three task conditions (change in target amplitude, change in target width and changing both target amplitude and width) and therefore it was decided to collapse the results across all conditions.

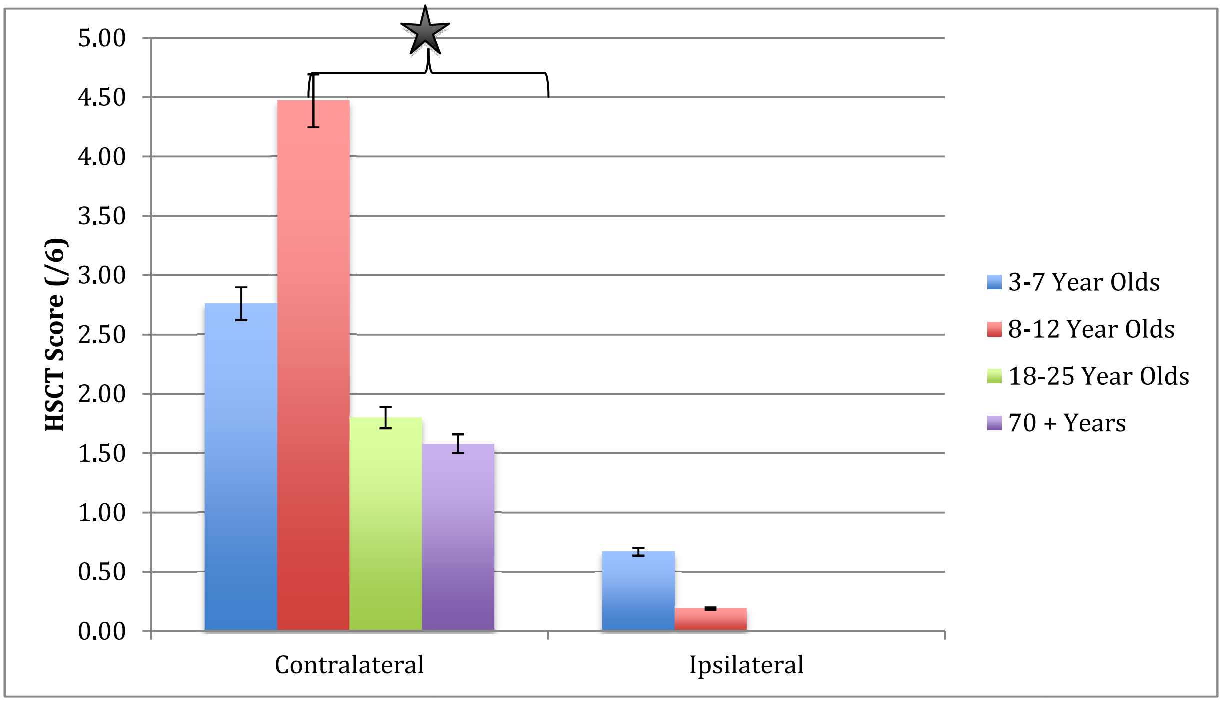

Figure 6: Switch-point in peripersonal space collapsed across all three conditions for the HSCT for both ipsilateral and contralateral space. Older children performed significantly more switches in contralateral space compared to both young adults and seniors. There were no significant differences in switches between young children and older children. Switch points did emerge in ipsilateral space, however none were found to be significant.

Long Pegboard

Analysis of the Long Pegboard task time component showed a main effect of time to complete the left-hand side ($F_{(3, 72)} = 14.08$, $p < 0.01$) and to complete the right-side ($F_{(3, 72)} = 11.21$, $p < 0.01$). Post hoc comparisons revealed that 3-7 year olds differed significantly between older children ($p < 0.01$), and young adults ($p < 0.01$), but did not significantly differ from seniors where young children and seniors required more time to complete the pegboard task for both the right and the left hands (Refer to Figure 5).

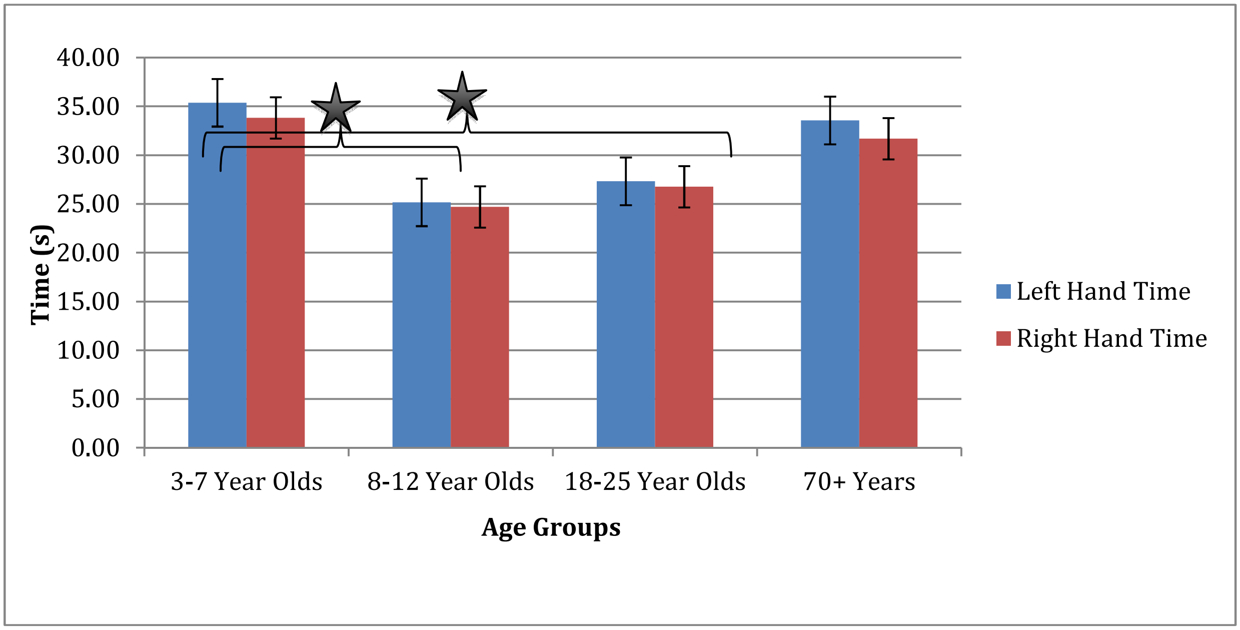

Figure 7: Time to complete the long pegboard task for both the right and left hands. Young children and seniors required significantly more time to complete the long pegboard task from both right and left-end starts compared to older children and young adults.

Analysis of the switch point component of the Long Pegboard again showed a main effect of age ($F_{(3,72)} = 5.33$, $p < 0.02$) for right-hand switches only. Post hoc analysis showed that 3-7 year old children did not differ significantly from the older children, the older children differed significantly from the young adults and the seniors ($p < 0.02$), where young children and older children made more switches to utilize the preferred right hand to complete the task and the young adults did not differ significantly from the seniors (Refer to Figure 6).

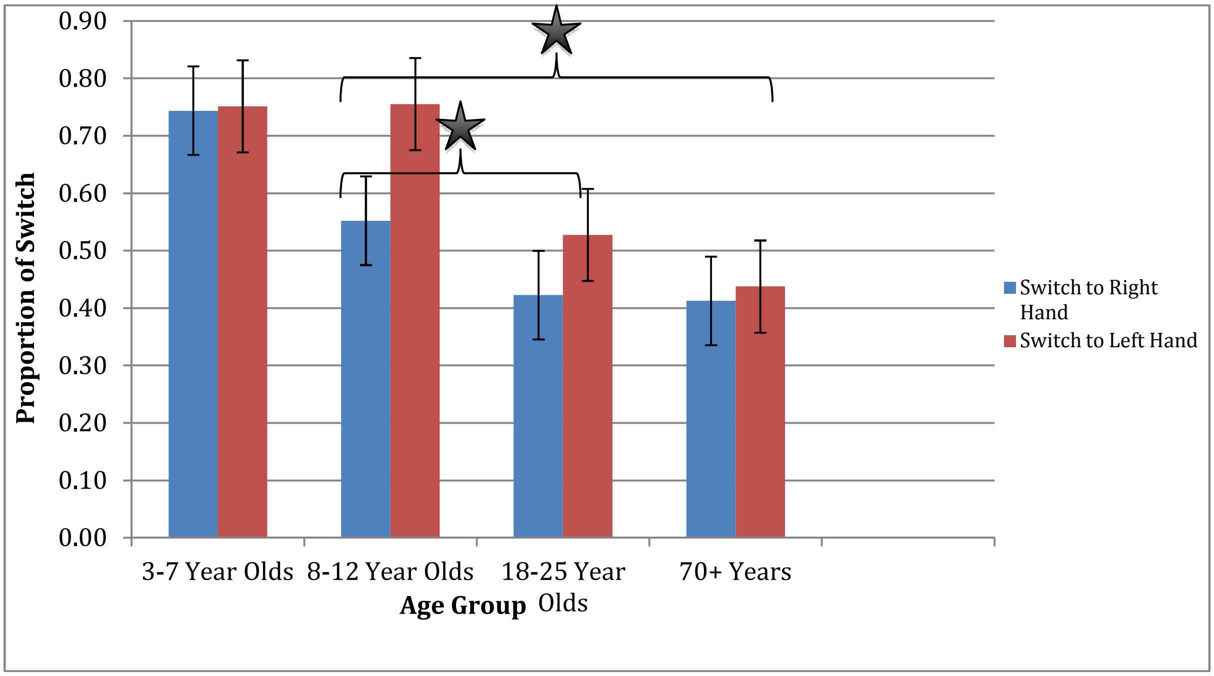

Figure 8: Switch-point for the long pegboard task for both the right and left hand. Percentage of switch refers to how far down the board the participant went before switching hands. Starting from the far right-end of the board, young children and older children went further down the board with the right-hand before switching to use the left-hand to complete the task. Young children and older children went significantly further down the pegboard with their right hand before switching to the left hand

Waterloo Handedness Questionnaire

Finally, a one-way ANOVA was performed on skilled scores, unskilled scores and a total score from the Waterloo Handedness Questionnaire revealed a main effect of age ($F_{(3,72)} = 3.51$, $p < 0.05$). Post hoc comparisons showed a significant difference between young children and older children ($p < 0.05$), but no significant difference was found between the older children and the young adults, or the young adults and the seniors.

Discussion

The purpose of the current study was to examine hand preference and how it progresses at various time points within the lifespan; with a specific emphasis on the role task complexity plays on hand preference. It was hypothesized that young children and seniors would take longer to complete the Hand Selection Complexity Task compared to older children and young adults.

It was also hypothesized that as the difficulty of the task increased, the number of switches made in contralateral space would also increase in order to utilize the preferred right hand. The long pegboard was an important aspect of the current study as it provided a measure of hand performance where the complexity of task remained consistent, while the proximity changed. It was hypothesized that when starting from the far right end of the board, participants would perform an increased number of jumps down the board in order to utilize the preferred hand. It was also hypothesized that when starting from the far left end of the board, participants would switch to using their right hand during the earlier peg holes.

Aging

Age was found to have a significant effect on all three assessments within the current study. However, the purpose of the study was to examine differences found between the age groups in relation to the role task complexity plays on hand preference and performance. For the Hand Selection Complexity Task time portion, significant differences were found between the young children and seniors when compared to older children and young adult populations. Young children and seniors performed the tapping task significantly slower compared to the other two populations (Refer to Figures 2 and 3). This was true for all three conditions and in both contralateral and ipsilateral space and between the six different indexes of difficulties. For the HSCT accuracy component, it was found that young children performed significantly different when compared to all other age groups. The young children performed significantly more errors across all 6 difficulty levels and 3 conditions. The HSCT switch point portion revealed a significant difference between the older children group and the young adults and senior population, where the older children preferred to switch to utilizing the preferred hand in contralateral space significantly more often, compared to all other groups.

In terms of the participants within the senior population, there was an even split of participants from two very distinct populations of individuals. Half of the senior population was recruited from a retirement home setting, while the other half the participants were recruited from a group of individuals who took part in a weekly dance class. When the individuals within the senior population were divided into two distinct groups (retirement home vs. dance class) there were observable differences within the data. For the HSCT time component across all conditions and difficulties, the seniors that took part in a weekly dance class tended to have a faster performance when compared to the seniors who were from a retirement home setting. In terms of the HSCT switch point component, there were no observable differences between the two populations of seniors.

The long pegboard task again showed significant differences between the young children and the seniors when compared to the older children and young adult populations. The young children and seniors performed significantly slower on the pegboard task when moving in both right and left directions down the length of the board (Refer to Figure 5). There were no significant differences found between age groups on the point in space where a participant chose to switch from using the starting hand to switching to use the alternate hand to complete the task (Refer to Figure 6). Finally, the Waterloo Handedness Questionnaire showed a significant difference between young children and older children, but no significant difference between young adults and seniors.

The results of the three assessments indicate that there may be evidence of ambidexterity with increasing age, where there may be less of a reliance on the dominant hand, with an increased usage of the non-dominant hand to perform tasks. On the Hand Selection Complexity Task, seniors performed similarly to the young children as both populations required an increased amount of time to complete all ID levels within the task, for all three conditions.

These results are therefore suggesting that seniors perform similarly to young children on tasks that require fine motor control, contrary to previous literature by Gooderham and Bryden (2013), which found that seniors performed similarly to young adults on a gradient with increasing complexity. The results found in the current study are in accordance with the study conducted by Kalisch and colleagues (2006) which revealed that seniors required an increased amount of time to complete a variety of different tasks that require more fine motor control and dexterity, when compared to younger adults. Within the literature, it has been well established that there is an overall age-related decline (slowing) in the performance of fine motor movements, especially when examined on tasks of increasing difficulty. The age-related decline observed in more complex motor movements is thought to be due to changes within the central cognitive process, which slow with increasing age. These cognitive processes are therefore thought to affect motor movements that require repetitive coordinated movements, like tapping (Kalisch, et al., 2006).

When looking at the results of the accuracy component for the HSCT, it was found that young children performed significantly more errors when compared to all other age groups. This was true across all 6 difficulties and 3 conditions. This difference between young children and the other age groups may be explained by the speed-accuracy trade-off and the relationship it has with movement time and accuracy. In order to maintain accuracy, the speed at which the movement is performed must decrease (Fitts, 1954). The young children tended to focus more on performing the task as quickly as possible, without much regard for the number of errors that were occurring because of this. The older children, young adults and senior populations performed each level of increasing difficulty accordingly, so as the difficulty of the task increased, the amount of time to complete the task also increased in order to ensure that the number of errors were low.

Task Complexity

It was hypothesized that the newly developed Hand Selection Complexity Task would overcome previous limitations within the literature and provide further insight into the significance of task complexity and the role it plays on hand selection. The current study was important in trying to overcome the previous limitations in the study by Gooderham & Bryden (2013), which also looked at the role task complexity played on hand selection. The Hand Selection Complexity Task utilized Fitts' Law to ensure a quantifiable way to measure task complexity by manipulating target amplitude, target width and both target amplitude and width at the same time. The aim of the Hand Selection Complexity Task was to uncover a complexity switch-point, which would provide the point in space in which the task became too difficult to complete with the proximal hand and would therefore override a more biomechanically efficient movement in order to utilize the dominant hand.

Within the HSCT, participants had unrestricted vision of their limb moving within both regions of hemispace. This allowed for participants to utilize visual feedback in order to ensure their movement was being performed accurately. As mentioned previously, having visual feedback available while performing a movement allows for a much more accurate movement to occur compared to when vision is restricted. Recent research has emerged suggesting that when information in regards to the target, as well as information from the environment is available, it is able to be utilized during on-line control of movements (Sarlegna & Mutha, 2014). Having information from the entire visual scene within the environment may allow for greater accuracy since the individual may be able to more accurately plan their movements prior to its execution. After performing the task on the contralateral side, the participants may have used the prior knowledge of performing the task in order to improve their movement trajectories to allow for a more accurate movement. All participants within the study completed the 6 difficulties much faster when performing in ipsilateral space. This was most likely due to the fact that the majority of participants preferred to use the right hand to perform tasks and therefore had faster performance times when utilizing the preferred hand. However, there may be another contributing factor for these results. Since participants completed the task first in contralateral space, they may have had the opportunity to use on-line control of movement planning in order to better execute the task when performing in ipsilateral space (Sarlenga & Mutha, 2014). The participants within the current study always had a full view of the task in both contralateral and ipsilateral space that may have allowed prior planning before the movement was executed in order to ensure that the movement required for the task was precise and accurate.

The current task was successful in revealing a task complexity switch-point, surprisingly in both ipsilateral and contralateral space (Refer to Figure 4). In contralateral space, older children demonstrated a significantly greater number of switch-points, compared to all three age groups. In contralateral space, older children utilized the preferred right hand approximately 75% of the time (4 out of 6 difficulties per condition). Young children, young adults and seniors still demonstrated a switch-point in contralateral space, however it was not found to be significant (Refer to Figure 4). Previous work demonstrated a complexity switch-point in contralateral space, but never in ipsilateral space (Gooderham & Bryden, 2013). The current work revealed non-significant switch points in ipsilateral space in both young children and older children, with no switches made in ipsilateral space by either the young adults or seniors.

Some of the results found on the performance of the HSCT in terms of a switch point are not all that surprising. The hemispheric bias theory states that an individual will utilize the hand that is in closest proximity to the task. Therefore, if the task was being performed in contralateral space, then an individual should utilize the left hand since it is in closest proximity to the task. However, this wasn’t always the case. Older children tended to switch to utilize the preferred when performing in contralateral space approximately 4 out of the 6 presented difficulties, even though according to the hemispheric bias theory, individuals should be more likely to use the hand that is in closest proximity to the task (Gabbard & Rabb, 2000). When each hand performs ipsilaterally in its own region of hemispace, both reaction and movement time tend to be faster compared to switching to use the opposite hand in both sides of hemispace. This is especially true for older children, young adults and seniors as performing ipsilaterally tend to afford the most advantages in terms of movement time and accuracy. Therefore, it is very interesting that older children chose to switch to use the preferred hand in contralateral space when research suggests that a decrease performance would occur by doing this (Gabbard & Rabb, 2000). A similar hypothesis, the Kinestheic Efficiency hypothesis states that movements are based on the biomechanical restraints that are placed on them. This means that there is an equal chance to use the right or the left hand to perform a task in order to ensure that the most energy efficient movement is selected. Again, it would be likely that performing a movement in the respective sides of hemispace would afford the most efficient movement compared to reaching across the body's midline to perform the task (Gabbard, Iteya & Rabb, 1997). Again, according to the hypothesis, older children were more likely to utilize the hand in its respected region of hemispace since it would afford the most efficient movement. However, this was not the case. Once older children have established a preferred hand preference, they tend to utilize the preferred hand to perform all unimanual tasks, regardless of spatial location (Gabbard, et al., 2001).

Within the current study, both right and left-handed individuals were recruited as participants, with an uneven distribution of left-handed individuals within each age group. As mentioned previously, there were five left-handed individuals in the young children population, three left-handers in the older children population and one left-hander in the senior population.

It is not surprising that older children demonstrated the highest proportion of switch-points in contralateral space compared to all other populations, as this age group is strongly reliant on their dominant hand and therefore will choose to utilize the dominant, regardless of spatial location (Carlier, et al., 2006). Although the aim of the current study was to determine if a switch-point does exist with increasing task difficulty, the study was also interested in examining hand preference with increasing age. In the Hand Selection Complexity Task, there was no significant difference found between young adults and seniors on switch-points in both contralateral and ipsilateral space. It was hypothesized that seniors would perform differently when compared to young adults, where seniors would utilize an increased amount of switch-points as the difficulty of the task increased. Seniors actually performed fewer switch-points in contralateral space than young adults did; however these results were not found to be significant.

The Hand Selection Complexity Task was successful in uncovering a complexity switch-point in contralateral space for the majority of older children, and for a portion of participants within the other age groups. These findings suggest that task complexity does play an important role in determining hand selection when performing a task of increasing difficulty. At a certain point, task complexity will take precedent over object proximity and therefore biomechanical efficiency in completing a movement with the dominant hand. By utilizing the dominant hand in contralateral space, one is choosing to cross the body's midline and go against the biomechanical efficiency hypothesis (Gabbard et al., 1997). Therefore, the findings within the current study provide further insight into the role task complexity plays on hand selection.

Limitations

There are a few limitations within the current study that need to be addressed. First, although the Hand Selection Complexity Task utilized a quantifiable measure of testing task difficulty, it is hard to say if the tasks used were of high enough difficulty to truly distinguish a difference between age groups. All age groups did require an increased amount of time to complete each task of increasing difficulty. However, if a task is truly complex and more difficult than any of the previous tasks, then hand preference should override the ability to produce a more biomechanically efficient movement. If this were true, than a definitive switch-point should have emerged within the Hand Selection Complexity Task which would have been the task that was too difficult to complete with the proximal hand therefore a switch would occur. Once a switch-point had emerged, any other tasks with increased difficulty would also produce a switch to utilizing the dominant hand. Interestingly, it was found that once a participant made the decision to switch hands to perform the task, the participant continued to utilize the dominant hand, regardless of task difficulty. For example, in contralateral space, if the participant switched hands when an ID of 4 was presented during the first trial, the participant would also switch to the dominant hand when any other ID level was presented for that condition. This therefore suggests that the Hand Selection Complexity Task may not have had adequate difficulty to allow for a true switch-point to emerge. There was enough difficulty between the tasks when performed in ipsilateral and contralateral space to allow for participants to prefer to switch to using the dominant hand in contralateral space, as represented by the senior population.

A second limitation within the HSCT is how the difficulties were randomized for the participants within the study. Each participant within the current study received the identical ordering of difficulties presented in both contralateral and ipsilateral space for the HSCT. For example, when starting on the contralateral side, each participant would begin with difficulty level 4 and once the task was completed, the participant would then complete the same task (level 4) on the contralateral side. The ordering in which the remaining difficulties were presented were presented in the exact same order to every participant. The problem with this is that all participants started at the same difficulty level and may have simply selected a method in which to perform the task and continued to perform the remaining difficulties in that manner which may not have been representative of the actual difficulty of the task. It would have been beneficial if presentation of the difficulties were randomized differently for all participants in order to try and ensure that participants were performing the task in regards to how difficult it was and not some other varying factor.

The setup for the HSCT also needs to be considered. Every participant had the same setup where the HSCT gradients were positioned 30cm laterally and 21cm anteriorly when seated at a table (Refer to Figure 1). This may have been an issue for both the young children and senior populations. Both of these populations are shorter in height compared to the other 2 populations, which also means that they have a decreased arm length compared to the older children and young adult populations. Since the HSCT was positioned at a distance that was kept constant for every position, this may have put the young children and seniors at a disadvantage because they may have been fully extending their arm in order to reach the targets where the older children and younger adult populations likely had a greater degree of motion, with their arm/hand in a more relaxed and comfortable state.

Further limitations within the current study lay within the population of participants. A portion of the young children and older children were recruited from a local daycare and Wilfrid Laurier summer and day camps. The young children and the older children recruited from the camps at Wilfrid Laurier University were selected from a pool of candidates who may not be actually representative of the general population. The young children and the older children age groups were recruited from summer camps and an early childhood education centre which is indicative of individuals with a higher social economic status (SES). The young adult population was recruited as a convenience sample from the undergraduate and graduate population at

Wilfrid Laurier University. The participants within this age group are not entirely representative of the general population as individuals within this population again have a higher chance of coming from a higher SES. The senior population was recruited from both a local dance class and a retirement home. The seniors over the age of 70 years may represent only a subset of individuals within this population. The seniors recruited from the dance class participated in a weekly one-hour session of various movements and techniques that would require a certain level of functional ability. As mentioned in the aging section of the discussion, the seniors recruited from the dance class did perform the HSCT faster when compared to the seniors recruited from the retirement home. This was true for all 6 difficulty levels and across the 3 conditions. As well, the majority of participants in the senior population were female (11 out of 12). This study could benefit from further recruitment of more male participants, community dwelling seniors, as well as seniors from other various forms of physical activity programs to see if similar results would emerge.

Finally, the current work included both left and right-handed individuals, however left-handed individuals were only represented in the young children, older children and senior populations. In order to fully examine the differences between right and left-handed populations, left-handers would need to be recruited into the young adult age group in order to compare hand preference at various time points within the lifespan and any differences that may be present between the right and left hand. It is thought that left-handers are less lateralized than right handers (Mamolo, Roy, Rohr & Bryden, 2006) so it would be interesting to see if a well-defined switch point would emerge in ipsilateral space for left-handers as it does in contralateral space for right-handers.

Implications and Future Directions

One of the main purposes of the current study was to further examine how hand preference develops at various time points within the lifespan. Previous studies within the literature have found conflicting results on what happens to hand preference with increasing age. Kalisch and colleagues (2006), had participants complete a variety of unimanual tasks that required varying degrees of fine motor control. The authors found that with increasing age, the participants performed these tasks significantly slower, and with an increased amount of errors (and therefore decreased amount of accuracy) when compared to their younger adult counterparts. Conversely, in the study by Gooderham and Bryden (2013), the authors found that hand preference remains consistent with increasing age, as seniors performed similarly to young adults on a task of increasing complexity that revealed a complexity switch-point.

The results of the current study revealed similar findings to the Kalisch, et al., (2006) study, as well as the Gooderham and Bryden (2013) study. The current work was also successful in uncovering a complexity switch-point similar to the switch-point found in the Gooderham and Bryden (2013) study, where seniors performed similarly to younger adults on a similar task complexity gradient. Unlike the results found by Gooderham and Bryden (2013), the current study identified similar hand use when comparing young children to senior populations. Seniors performed similarly on the Hand Selection Complexity Task when compared to young children where both age groups required an increased amount of time to complete all difficulties within each condition when compared to the older children and young adult populations. The same results were also found for the amount of time required to complete the long pegboard task. These results are in accordance with the findings of Kalisch and colleagues (2006) which found that with increasing age, the amount of time necessary to complete unimanual tasks that required more fine motor control also increased.

When comparing the current study to the work by Gooderham and Bryden (2013), it is not surprising that a complexity switch-point emerged in both studies as similar task paradigms and age groups were utilized. Both studies revealed that the young children and senior populations performed significantly more switches in contralateral space when compared to the younger adult and senior populations. No significant differences in performance of switch-points were found between the young adults and seniors. However, the Gooderham and Bryden (2013) study did not record the time it took for participants to complete each level of the task gradient in ipsilateral and contralateral space, where participants in the current study were measured on the time it took to complete each index of difficulty in every condition. The time portion of the analysis is where the main differences were found between the populations. Young children and seniors required more time to complete each ID level within each condition when compared to the older children and young adult populations. The same findings were also found when analyzing the amount of time required to complete the long pegboard task. Young children and seniors required significantly more time to complete the task when compared to the other two populations. The time to complete a task needs to be considered when examining the role task complexity plays on hand preference.

When comparing the results between the current study and the findings by Kalisch et al., (2006), age was found to be a significant factor on task performance in both studies. Participants in the Kalisch et al., (2006) study were comprised of young adults (mean age of 24) and three senior age groups with the mean age of 50, 70 and 80 years of age. In this study, participants were asked to complete a variety of task requiring fine motor control such as line tracing, aiming, steadiness and tapping. The authors found that with increasing age, more time was required to complete each task, which is in accordance with the current study. However, the main difference between the two studies is that the current study only utilized tapping and aiming for the HSCT and aiming when performing the long pegboard task. As well, participants in the current study only utilized their own fingers to perform the tasks, while the participants in the Kalisch, et al., (2006) study utilized a stylus to perform each task.

Although the current study and the two previously mentioned studies all contained similar age groups, tasks that required similar fine motor control and comparable measurements when examining hand preference, a number of different results were found in each study. The current study found similar results to the Gooderham and Bryden (2013) when examining the role task complexity plays on hand preference and uncovering a complexity switch-point, but it also found similar results to the Kalisch, et al., (2006) study in regards to the role age plays on hand performance. The current study is therefore suggesting that task complexity does play an important role on hand preference and that there may actually be a shift toward equalization of hand preference with increasing age.

In order for a study to truly look at a “lifespan approach of hand preference” age groups from across various time points within the lifespan need to be included in order to examine what is happening to hand preference at each stage of the lifespan. The current study only included 4 different age groups of individuals, with a large gap between the young adult population (18-25 year olds) and the senior population (over 70 years). Future studies should include a middle-aged group of participants (30-40 year olds) in order to truly encompass all age groups within the lifespan and allow for a better look at what is happening to hand preference. The senior population within the current study also incorporated a large range of ages where all of the participants were over the age of 70 years. This allows for a large gap in ages between the participants within the senior population. Therefore, future studies should include a further subdivision of senior populations that have a smaller age range of participants. For example, including separate groups for 50-60 year olds, 60-70 year olds and 70-80 year olds would allow for a better representation of what is occurring to hand preference at various stages of aging.

Future studies should also consider how aging is defined within each population of participants. It has been suggested that utilizing an individual's chronological age to divide participants into groups may not be the best method as there may be a large range of skills within each age group. For example, within the young children age group in the current study, the ages ranged from 3-7 years, which is a large span when considering the developmental skills that have occurred at various age. It is likely that a 3 year old would have a different set of skills in terms of hand use compared to a 7 year old that has had more experience utilize both hands to perform tasks. In a study by Bryden, Mayer & Roy (2010) tested participants on a reaching task where a task manipulation took place in various regions of hemispace. There were 5 different age groups of individuals including 3-5 year olds, 6-7 year olds, 8-9 year olds, 10-12 year olds and 18-22 year olds. The authors found that the younger children (3-5 year olds) only used their preferred hand approximately 49% of the time; while children aged 7-12 used their preferred hand approximately 77% of the time. Therefore, future studies should consider how participants are divided into groups, with less of a reliance on chronological age, and perhaps more a shift towards skill level or the number of years an individual has predominately used one hand to perform unimanual tasks.

In conclusion, the current study was able to utilize a paradigm that was able to quantify task difficulty with the ability to uncover a complexity switch point within individuals. This complexity switch point represents the point in space where a task becomes too difficult to complete with the proximal hand and therefore overrides the ability to make a biomechanically efficient movement in order to utilize the dominant hand. The current work also suggests that with increasing age, there may be a move towards the equalization of hand preference as depicted by the time required to complete a reciprocal tapping task and a task that involves moving doweling pegs down the length of a board. Future studies should examine whether the proposed equalization in hand preference is present in tasks that involve both a time and skill requirement.

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