INCREASED AGE LEADS TO DECREASED DEXTERITY:

IS IT REALLY THAT SIMPLE?

by

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ABSTRACT

It is commonly believed that with increased age, movement dexterity becomes slower and increasingly clumsy when performing simple every day tasks. In the General Introduction of this PhD thesis (Chapter 1), literature that supports evidence for this relationship was reviewed. In addition, literature that has attempted to understand co-variance factors that may influence the age and dexterity relationship were also presented. From this, the general thesis hypothesis raised was that other factors such as sense of touch, attention ability or strength might also correlate with age and so possibly could also explain the reduced dexterity variable. Five empirical chapters present the experiments conducted to address the hypothesis, and the data from these are discussed in the General Discussion (Chapter 7).

The empirical chapters consisted of three main areas of experimentation. That is, Chapter 2 ran preliminary screening data, Chapters 3 and 4 tested the effects of selective attention ability on the age - dexterity relationship and Chapters 5 and 6 tested the effects of strength on the age - dexterity relationship. In more detail, Chapter 2 used standard clinical measurements to assess the effects of age on fine and gross movement dexterity, sense of touch, selective attention and strength. The data showed that all factors declined with increased age, but that strength and selective attention seemed particular relevant to general upper limb dexterity. In Chapter 3, the impact of selective attention ability was assessed using a modified and motion tracked dexterity task. This demonstrated that the age and dexterity relationship was not generalised across all movements, but instead was specific for phases of action that contained a selective attention component. Chapter 4 followed up these data by showing evidence of impaired selective attention and inhibition with increased age. Chapter 5 sought to clarify the impact that strength had on the age and dexterity relationship. The findings showed that while age and strength were related, age explained more of the

data’s variance for steadiness and movement tracking dexterity, whereas strength explained more of the data’s variance for aiming and tapping dexterity. In Chapter 6, the findings of Chapter 5 were tested by directly manipulating hand grip strength and measuring the resultant effects on tapping dexterity. The data supported Chapter 5 and confirmed that hand grip strength had a clear impact on the age and dexterity relationship. Together, the data presented in the PhD thesis suggest that other factors contribute to the effects of age on dexterity, and support the idea that better management of these confounding factors may allow for a better understanding of the age and dexterity relationship and furthermore, help older adults enjoy better movement dexterity.

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CHAPTER 1 - GENERAL INTRODUCTION

In mid-2007, the resident population of the UK was estimated at 60,975,000 (UK National Statistics, 2008) and the number of people aged 65 years and older was 9,165,000. In comparison with previous years, the fastest growing age group within the population was those aged 80 years and older (2,749,507 which accounts for approximately 4.5% of the total UK population; UK National Statistics, 2008). The main reason for these changes were attributed to improvements in older age mortality during the second half of the twentieth century. For example, the mortality rate for the population aged over 75 years has fallen from 137 deaths per thousand in 1911-1915 to 83 deaths per thousand in 2006-2007. With continual increases in the proportion of the older population, it is important to have a better understanding of the relationships between increased age and movement dexterity so that good standards of living can be maintained in these later years.

This chapter will introduce the field of study in which the thesis experiments and discussions were based on. The main focus will be to review the literature showing evidence that increased age is related to reduced speed and coordination dexterity and discuss the sensory and physiological factors that have been shown to explain or co-vary with the age and dexterity relationship. At the end of the review, a summary of the culmination of the studies and findings made over the three years of my PhD studies is presented.

1.1 Factors of Ageing and Dexterity

Irrespective of our age or physical makeup, the way in which we move during every day activities is often achieved without any thought or consideration for the number of processes involved (Milner and Goodale, 1995). As we grow older, our bodies change and the effects of ageing on movement change our dexterous ability (Coello & Delevoye-Turrell, 2007). Despite being unaware of changes in our own dexterity over time, realisation that human movement dexterity changes with increased age are obvious when observing the movements made by older compared to younger family members. The contrast can be startling where in, for example, a simple chasing game in the garden, the child makes fast and sporadic changes of direction and speed, whilst the grandparent almost seems to be too slow and clumsy too match or mirror the movements of the young child. The results from research studies that address movement control help to characterise how the motor system of older adults changes with increasing age. In the literature, these tend to report the effects of age on movement speed, coordination and strength in movements that match daily activities such as those used in reaching, fine hand manipulation and lifting movements (Bryant et al., 2007; Desrosiers et al., 1999; Hollman et al., 2007; Krampe, 2002).

A theory of generalised slowing with increased age was postulated by Birren (1974) and restated by Salthouse (1985). It suggests that with increased age, all fundamental neural events become slower, and that this causes both cognitive and motor functions to become measurably slower. Evidence that possibly supports the theory comes from simple and choice reaction time and also daily living movement experimentation.

In the simplest examination of age and dexterity relations, the reaction time (RT) taken to initiate a response to a single stimulus event has been typically reported to be longer with increased age. The most comprehensive analysis of the effects of age on simple RT was conduced by Fozard et al. (1994). The reported data from a longitudinal study that tested 1265 particpants over a 28 year period at two-yearly intervals, and reported that simple RT reduced by 0.5 ms each year. Other studies have report similar findings. For example, Welford (1984) reported that RT slowed by 1.5ms per year, or increased by 26% between the ages of 20 and 60 years of age (see also Amrhein et al., 1991; Cerella, 1985; Kauranen & Vanharanta, 1996; Walker, Philbin & Fisk, 1997).

Studies that have measured choice RT show similar slowing with increasing age. In choice RT, typically two or more stimuli are presented and the participant has to choose an appropriate response. For example, in Brass et al. (2000), participants were required to make responses with their index or middle finger to either the presentation of a '1' versus '2' stimulus. In general, data show that the addition of the number of choices requires additional processing time to identify the stimulus, select the appropriate response and then initiate the action. Research that has tested the effects of age on choice RT typically show that older aged adults were 29-60% slower than younger aged adults (Amrhein et al., 1991; Jordan & Rabbitt, 1977; Kauranen & Vanharanta, 1996; Seidler & Stelmach, 1996; Welford, 1984). In the same longitudinal study as that reported for simple RT above, Fozard et al. (1994) showed that choice RT increased at a rate of 1.6 ms per year, which was slightly higher than the rate of slowing reported for simple RT. In addition, they also reported that the increased time for choice RT was amplified by an increase in the number of choices. This effect has become known as Hicks law (Hick, 1952). This suggests that selection of action, or simply that the cognitive processes involved in selection are slowed in older compared to younger aged adults (Cerella, 1985; Fozard et al., 1994; Kauranen & Vanharanta, 1996), and it is this factor that causes the slower response times.

Evidence for general slowing with increased age for common activities of daily living are numerous. For example, older compared to younger adults have been shown to make slower movements on reaching and grasping (Bennett & Castiello, 1994; Vandervoort et al., 1998) point to point movement (Amrhein et al., 1991; Cerella, 1985; Cole, Rotella & Harper, 1999; Stelmach et al., 1988) and continuous movement (Greene & Williams, 1996; Pohl et al., 1996; Wishart et al., 2000) tasks. In addition, within these tasks, it has also been shown that increased task difficulty can cause even greater slowness for older compared to younger aged adults (Stelmach et al., 1988). While movement time measures provide important information about differences in total time to carry out a task, they do not necessarily explain the reasons for the identified slowness. In order to understand these differences, thorough kinematic analysis of separate movement components is required.

Through using kinematic analyses of movement, research has typically demonstrated that when younger compared to older aged adults make ballistic coordinated movements, their reach velocity profile was shaped similar to a bell, representing an almost balanced acceleration and deceleration phase, while the older aged adults displayed a reach velocity profile that was lop-sided, with a relatively short acceleration phase (similar to that in the younger aged adults), but a much longer deceleration phase (Bennett & Castiello, 1994; Brown, 1996; Cole et al., 1999; Darling et al., 1989; Goggin & Stelmach, 1990; Marteniuk et al., 1987). As the deceleration phase constitutes a slowing down of the movement as it reaches a desired position (Ketcham & Stelmach, 2001), many researchers have suggested that the lengthened deceleration phase provides older aged adults with increased time to use feedback or corrective control in order to successfully achieve the goal (Bellgrove et al., 1998; Brown, 1996; Cook et al., 1989; Darling et al., 1989; Pratt et al., 1994; Seidler & Stelmach, 1996). That is, the movement was not generally slowed, but rather slowed to allow more time for sensory and cognitive feedback processes to correct any errors in the action.

Similar data to this was reported by Morgan et al., (1994). They assessed continuous point-to-point movements that were constrained by movement speed, and had no accuracy constraints. They reported that under such conditions, the older and younger aged adults performed similarly. From this, they concluded that movement slowing in older aged adults was related to hesitation and movement correction rather than the movements themselves. Further support for this suggestion can be found in research that has addressed kinematics by separating movements in primary and secondary submovements (e.g., the optimisation model proposed by Meyer et al. 1988). In general, these studies that have reported that older aged adults make more corrective secondary submovements as they approach a target when compared to younger aged adults (Ketcham et al., 2000; Hsu et al., 1997; Pohl et al., 1996; Pratt et al., 1994; Seidler & Stelmach, 1996; Seidler-Dobrin et al., 1998; Walker et al., 1997). From these studies, it can be suggested that either the increased time given to feedback constitutes a compensation for slower cognitive processes of sensory motor correction, or that older compared to younger aged adults have a deficit in the generation of sufficient force to move their limbs. On the basis of this latter suggestion, extensive research has been conducted that measures the effects of age on force control.

The control of force and its production is an elementary component of movement production and coordination. In order to reach and grasp an object, the coordinated forces produced within each muscle guides the hand to the object, and furthermore, the forces produced in the hand allows for an object to be lifted, but at the same time, not damaging the object (e.g., grasping an egg). Researchers have consistently report that with increased age, force production and its regulation decreases, and that such changes limit the ability to make fast and accurate movements (Brown, 1996; Clamann, 1993; Darling et al., 1989; Doherty et al., 1993; Gilles & Wing, 2003; Izquierdo et al., 1999; Milner et al., 1995; Roos et al., 1999;

Singh et al., 1999) and limit the ability to successfully regulate fine motor skills such as precision grip (Cole & Beck, 1994; Cole et al., 1999; Kinoshita & Francis, 1996; Lazarus & Haynes, 1997).

Kinoshita and Francis (1996) investigated the age related changes in the control of precision grip force during lifting and holding of objects with slippery (silk) and nonslippery (sandpaper) surface texture. They reported that the elderly adults (aged 80-93 years) had a larger number of fluctuations in grip force and a long force application time compared to younger aged adults. It was concluded that the decline observed in older aged adults' ability to control precision grip force were due mainly to age-related changes in skin properties and cutaneous sensibility functions, with a lesser part due to slowed central nervous system function. Support for this comes from data showing that older aged adults produce force in a stepwise ramp fashion, as opposed to the smooth ramp as produced by younger aged adults (Brown, 1996; Clammann et al., 1993; Darling et al., 1989; Galganski et al., 1993). The stepwise bursts of force were particularly apparent when low levels of force production and control were required, suggesting that the fidelity or smoothness of force production was an issue of control (Galganski et al., 1993). That is, in order to compensate for poor force control, the older aged adults produce more force than was necessary in order to provide a safety margin for any undetected error through poor sensory perception (Cole et al., 1999; Gilles & Wing, 2003). This has been shown in data where older aged adults used approximately twice the force used by younger aged adults (Cole, Rotella & Harper, 1998; Cole et al., 1999; Kinoshita & Francis, 1996; Gilles & Wing, 2003). Consistent with a force control issue, data has also been reported showing that older compared to younger aged adults have increased latency in force modulation in the time from start of grasp to the beginning of lift for an object (Cole et al., 1999; Kinoshita & Francis, 1996). For example, Cole et al., (1999) showed the force production of older compared to younger aged adults to be delayed by approximately 250ms when asked to release an object slowly. From these data, it was suggested that differences between older and younger aged adults could be attribute to peripheral decrements such as tactile insensibility, muscle reorganisation and slow afferent information processing (Cole et al., 1999; Cole & Beck,1994; Kinoshita & Francis, 1996; Lazarus & Haynes, 1997). For example, Gilles and Wing (2003) argued that the higher grip force in older compared to younger adults was due to a lower coefficient of friction caused by skin changes with increasing age, rather than the processing of tactile feedback.

So far in this review, the data reported show a consistent relationship between increased age and decreased dexterity. Some literature appear to suggest that the slow dexterity results from reduced speed of cognitive processes (such as sensory feedback and motor correction; visual guidance) that result in compensatory slow movements to allow more time for the cognitive processes. An alternative view, though somewhat related is that peripheral or physiological factors reduce with increased age, and through such, sensory information from these factors leads to slow movements to compensate for the decrements. Besides the peripheral hand decrements associated with force control (e.g., tactile insensibility, muscle reorganisation, slow afferent information processing; Cole et al., 1999; Cole & Beck,1994; Kinoshita & Francis, 1996; Lazarus & Haynes, 1997), other physiological factors that reduce with age have also been suggested. These include neuroanatomical reductions (Salat et al., 2004; Sowell et al., 2003), muscle physiology changes (Aniansson et al., 1986; Doherty et al., 1993; Lexell, 1996; Roos et al., 1997; Singh et al., 1999; Welford, 1984) and decrements in sensory motor integration processes (Hurley et al., 1998; Lord et al., 1999; Lord & Sturnieks, 2005; Pai et al., 1997; Petrella et al., 1997; Stelmach & Worringham, 1985).

It might be conceivable that reduced cognitive capacity with age is associated with physiological changes that occur in the brain's structure with increasing age. Evidence for motor area neural degeneration with age has been identified in many areas of the brain, including the motor areas: the basal ganglia (Mortimer, 1988; Naoi & Maruyama, 1999; Pirozzolo et al., 1991); cerebellum (Bickford, Shukkitt-Hale & Joseph, 1999; Jernigan et al., 2001; Luft et al., 1999; Thach, 1998); and motor cortex (Mirai et al., 1996; Salat et al., 2004; Sowell et al., 2003). Such degeneration of these areas might be related to changes in the speed by which motor performance and function behaviours of older aged adults can be processed. For example, the basal ganglia is thought to be involved in the initiation, timing, planning and learning of complex movements (Alm, 2004; Mortimer, 1988; Naoi & Maruyama, 1999; Pirozzolo et al., 1991). In Parkinson's Disease, patients have reduced function in the basal ganglia due to dopamine deficiency and this has been shown to result in reduced motor function, especially showing deficits in the initiation and timing coordination of complex movements (see for example Spencer et al., 2005). Degeneration in the basal ganglia in normal healthy ageing adults (Naoi & Maruyama, 1999; Pirozzolo et al., 1991) could be assumed to lead to similar changes in movement slowing (Mortimer, 1988; Pirozzolo et al., 1991). Similarly, the cerebellum is thought to be involved in the coordination and timing of complex movements, contributing to the maintenance of muscle tone, stretch reflexes, gait, postural control, sensory integration and motor learning (Bickford, Shukkitt-Hale & Joseph, 1999; Jernigan et al., 2001; Thach, 1998). It has been proposed that cerebellum neuronal atrophy with age can be associated with the increased number of falls observed in the elderly, as the cerebellum regulates equilibrium in the control of muscles involved in posture, modality, balance and smooth movements (Bellgrove et al., 1998; Ivry et al., 1988; Jernigan et al., 2001; Lord et al., 1999; Luft et al., 1999; Pirrozzolo et al., 1991). Finally, atrophy in the motor cortex activity has been suggested to cause weakness and deficits in the control of force during motor function (Mirai et al., 1996; Salat et al., 2004; Sowell et al., 2003).

From these studies, it is evident that their are clear changes in movement related brain regions that lead to progressive deficits in motor function. Further understanding of how brain structures can provide insight into the behavioural decrements observed in older compared to younger aged adults needs investigation. However, its important to note that despite comprehensive research on brain structures and function, it remains difficult to relate direct changes that occur in comparitive brain structure differences to motor control performance (Ketcham & Stelmach, 2001).

Other physiological factors associated with age and dexterity, other than tactile sensory perception and brain atrophy, include aspects of musculoskeletal strength, muscle fibres and muscle mass loss (Desrosiers, Bravo & Hébert, 1997; Dutta et al., 1997; Hunter et al., 1998; Kallman, Plato & Tobin, 1990; Kolber & Cleland, 2005; Lexell, 1995; 1997; Shiffman, 1992; Welford et al., 1969; Young and Skelton, 1994). Reduced strength leads to a decline in the functional ability to manipulate objects, mobility and physical frailty (see Bennett et al., 1996; Enoka et al., 1992; Grabiner & Enoka, 1995; Grimby, 1995; Harridge & Young, 1998; Kell et al., 2001; Kolb et al., 1998; Spirduso, 1995). Muscle biopsy research in older compared to younger aged adults has shown that a large portion of the muscle fibre loss occurs in type II fibres (fast twitch; by up to 40% reduction), rather than type I fibres (slow twitch) (Aniansson et al., 1986; Lexell, 1996; Singh et al., 1999; Welford, 1984). Much of the data presented in the literature that has tested the relationships between age and strength has tended to focus on the lower limb, particularly the knee extensors. Typically, these studies have reported a 20-40% decline in knee extensor strength for participants aged 70-80 years of age compared to younger adults (Larsson et al, 1979; Murray et al, 1980; Murray et al, 1985; Young et al., 1984; 1985), with the decline reaching as high as 50% for adults aged 90 years and older (Doherty, 2002). While this age associated muscle loss does not alone explain the changes in motor coordination typically observed in older aged adults, muscle tissue loss has been associated with neurological changes that influence both muscle control and voluntary force production through degeneration and reorganisation of existing motor units within the muscle (Doherty et al., 1993; Roos et al., 1997). Such changes in motor unit organisation have been said to combine with a reduced ratio of motor units to relative muscle mass, and lead to stepwise force increments rather than the smooth ramped forces typically found in younger aged adults (Brown, 1996; Clamann et al., 1993; Darling et al., 1989; Galganski et al., 1993), and furthermore, lower levels of force production (Doherty et al, 1993; Roos et al, 1997; Roos et al, 1999).

From the data presented, it seems that the relationship between increased age and decreased dexterity could be caused by either reduced cognitive processes or decreased physiological function. At present, the literature does not favour either rationale for explaining the main effects. This is likely due to the complex integrative nature that these factors have for dexterity. This is exemplified when considering how sensory perception is integrated when coordinating action. For example, visual, proprioceptive and vestibular sensory receptor information, all known to deteriorate with advanced age, is crucial in order to perform coordinated movement (Hurley et al., 1998; Lord et al., 1999; Lord & Sturnieks, 2005; Pai et al., 1997; Petrella et al., 1997; Stelmach & Worringham, 1985). Teasing these factors apart becomes difficult. For example, it was suggested by Stelmach and Worringham (1985) that older aged adults were slower due to poor use of priopriception, however, Chaput and

Proteau (1996 a, b) found that older adults were able to effectively use proprioceptive information to make target pointing movements, but instead appeared to have impaired sensorimotor integration when several modes of feedback were being used. That is, older aged adults appeared able to process each sensory stream adequately, but only have difficulty when integrative information was being combined and processed.

Data showing examples of impaired sensory motor integration have been demonstrated in pointing and postural type movements. For example, Warabi et al. (1986) asked participants to move both their eyes and a laser pointer attached to their wrist to a target presented on a screen. During the response, the target could randomly disappear for one second following the first saccade of the eye. It was found that older aged adults took significantly longer to make corrective movements to the target compared to younger aged adults on all conditions, and that older aged adults were significantly slower when target information was removed from either movement condition. They suggested that the slower corrective adjustments were a result of reduced ability to integrate sensory information (Pohl, Winstein & Fisher, 1996; Warabi et al., 1986). Similar data was reported for sensory motor integration in postural movements. These data typically show that presenting visually conflicting information or occluding vision or proprioception information tends to result in greater postural sway and notable declines in postural stability for older compared to younger aged adults (Chaput & Proteau, 1996a; Lord et al., 1991; Lord et al., 1994; Lord et al, 1999; Lord & Sturnieks, 2005; Woollacott, 1993). For example, Hay et al., (1996) manipulated vision using liquid-crystal goggles and proprioception by means of tendon vibration of both antagonistic ankle muscles to distort incoming information. They observed that the delayed postural response, normally existent with increased age, became even worse after vibration of the ankle muscles, resulting in more varied and faster changes of centre of pressure in the older aged adults, and that these changes became amplified when combined with visual occlusion.

These deficits in sensory motor integration likely explain the first issue discussed in this review. That is, increased deceleration of movement causing apparently slower overall movements were suggested as being a consequence of extra time needed to process sensory information. In fact, all of the factors suggested appear to co-vary in dexterity. That is, reduced cognition, force production, sensory processes, brain, muscle and integration all appear important, and furthermore, because of these multi-faceted causes of reduced function with increased age, it has been suggested that older compared to younger adults have an increased reliance on visual feedback during movement control (e.g., Chaput & Proteau, 1996; Gottlob & Madden, 1999; Ketcham & Stelmach, 2001; Larish & Stelmach, 1982; Seidler-Dobrin & Stelmach, 1998; Slavin et al., 1996; Yan, Thomas & Stelmach, 1998). Evidence for this was shown by Haaland, Harrington & Grice (1993). They found that when visual information on arm position was removed during an aiming task, older aged adults displayed increased movement duration and greater end point errors compared to that of younger aged adults. Similarly, Chaput & Proteau (1996b) reported that older compared to younger aged adults showed movement times that were 100ms longer and errors that were 9.3mm larger in a point-to-point movement task (see also Larish & Stelmach, 1998; Pohl et al., 1996; Slavin et al., 1996; Woollacott, 1993; Yan et al., 1998).

Whilst age related declines are commonly reported, there are some papers that refute such a generalised age effect, such as that by Krampe and Ericsson (1996) where dexterity was retained in aged elite musicians, despite the participants exhibiting typical cognitive slowing. Furthermore, in a review by Krampe (2002) in which it is argued that experimental approaches aiming at the decomposition of fine motor skills provide evidence for the dissociability of timing, sequencing, and executive control components that show differential rather than general age-related changes. Whilst studies on cognitive-motor expertise demonstrate that age-related changes in critical skill components depend on individuals' time investments into specific practice activities. It is important to also note that studies have also found an inverse relationship between activity levels and cognitive decline. For example, Yaffe et al. (2001) found an inverse relationship between the distance walked per week, energy expenditure and cognitive decline as assessed by performance on a general test of cognitive function, the Mini Mental State Examination, indicating that cognitive performance increased with increasing levels of reported activity. This study involved 5,925 women over 65 yr of age over the course of a 6- to 8-yr period (see also Weuve et al., 2004). In combination, these literature suggest that continued physical practice and sustained physical activity may deter the age associated slowing discussed earlier in the introduction.

In summary of this review, the main clear finding in all of the literature was that with increased age, dexterity was reduced. The other main finding was that the reasons for the age - dexterity relationship were not that clear, and instead that many of the factors raised seem to co-vary and form interdependent relationships that have multi-faceted factors. However, from the review, it seems that neuroanatomical/cognition, peripheral sensory perception (e.g., sense of touch)/sensory motor integration, and strength/reduced muscle size and fibre type all appear to be important contributors to the age and dexterity relationship. Data show that changes in these factors with age manifest in slower simple and choice reaction times, slower corrective feedback during aiming movements, longer movement times and greater error in localisation.

1.2 PhD Thesis Summary

The collective purpose of the current thesis was to further delineate the behavioural influences of ageing on performance dexterity using techniques typically used in experimental, behavioural and cognitive psychology, biomechanics and clinical assessment. To do so, the studies involved measuring the relative involvement that cognition, sensory perception (e.g., sense of touch) and strength had on the age and dexterity relationship.

On the basis of the data presented in this review, the aim of Chapter 2 was to measure the effects of age, hand grip strength, sense of touch and selective attention (i.e., cognition) on movement dexterity. From the review, each of these factors were important, and so considering them together in the same participants might be informative about the relative impact that each has. Therefore, the chapter was aimed at gaining a holistic understanding about the effect of age on fine and gross dexterity, hand grip strength, sense of touch, and selection attention, and was tested using five commonly used clinical measurements. The data from the chapter showed that the factors of hand grip strength and selective attention (or cognition) were particularly important or interesting to follow-up. Therefore, Chapters 3 and 4 tested the effects of age and selective attention, and Chapters 5 and 6 tested the effects of age and strength on dexterity. Finally, Chapter 7 discussed the overall findings of the thesis and presents some suggestions of future avenues of research.

CHAPTER 2 - THE EFFECTS OF AGE ON SCREENING MEASURES OF MOVEMENT DEXTERITY, SENSE OF TOUCH, GRIP STRENGTH AND VISUAL SELECTIVE ATTENTION.

2.1 ABSTRACT

The purpose of this study was to quantify the effects of age on movement dexterity, sense of touch, grip strength and visual selective attention using standard clinical screening measures. We tested sixty adult participants that were separated into young-aged (22-33 years), middle-aged (50-57 years) and older-aged (62-84 years) adult groups. All participants were assessed using standard clinical measures. These were the Purdue Pegboard and Box and Block Tests for measuring fine and gross dexterity, the Two-Point Discrimination test for measuring sense of touch, a Hand Grip Dynamometer for measuring hand grip strength and the Trail Making Test for measuring selective attention. The tests were administered in a single testing session, and carried out at the University of Birmingham. The results showed significant main effects of age in all of the tests, whereby performance declined with increased age. The data are discussed in terms of the likely causes of movement decline with increased age and proposes some future directions of testing.

2.2 INTRODUCTION

As reviewed in the General Introduction of this thesis (Chapter 1), there is much literature showing that motor performance and function declines with increased age. Most of this literature has focussed on understanding the effects of increased age on lower limb movements, whereas, relatively few papers have considered upper limb movements. For these reasons, data are limited for normative age measures of upper-limb manual dexterity performance (Wolf et al., 2006) with the exception of data collected using a few clinical measurement instruments such as the Purdue Pegboard Test (Desrosiers et al., 1995; Mathiowetz et al., 1986; Tiffin and Asher, 1948), the Box and Block Test (Desrosiers et al., 1994; Mathiowetz et al., 1985), the Jebsen-Taylor Test of Hand Function (JTT) (Jebsen et al., 1969), and a recently published, the Manual Function Test (MFT) (Michimata et al., 2008).

2.2.1 Contributors to Dexterity

A definition of dexterity can be simply stated as the skill in performing tasks especially with the hands, either individually or together, that are intricate in nature. For example, fine motor skills such as writing, knitting, sewing, entering a key into a lock etcetera, rely on manual dexterity. Bernstein's book "On Dexterity and its Development" (Bernstein, 1996), originally written in the 1940's in Russian, was the first comprehensive literal composition to provide an informative insight along with many practical examples and illustrations of dexterity in motor control, learning in sport and daily life.

Impairments with age in the coordination of the hands during manual dexterity tasks is usually identified by slow and clumsy movements typically in object manipulation tasks (Smith et al., 1999). These impairments have been explained by a generalised age related multiple factor argument (Salthouse, 1985). However, there are some papers that refute such a generalised age effect, such as that by Krampe and Ericsson (1996) where dexterity was retained in aged elite musicians, despite the participants exhibiting typical cognitive slowing. That is, the factor contributing to reduced dexterity may be particular rather than of general age related causes. While the mechanisms and causes responsible for age-related changes in dexterous function are currently unknown (Cole et al., 1999), it is evident that a decline in manual dexterity is commonly reported in healthy older compared to younger aged adults (Hackel et al., 1992; Williams et al., 1990). Therefore, investigations are needed that define why dexterity reduces with increased age.

There are a number of factors that may be hypothesised as being specifically linked to dexterity. These might involve the normal ability to have a sense of touch, use strength or be able to visually attend and select objects for action. In the present study we propose that any of these factors might contribute to the effects of age on manual dexterity specifically. That is, in order to successfully perform a manual dexterity task, an individual must have an adequate level of sensory feedback (i.e. touch) to manipulate objects, strength to grasp and lift the object, and visual attention ability in order to select and guide object grasp and manipulation. Additionally, each of these factors have been cited as possible explanations for slower movement dexterity in healthy older adults, though very few have considered all of the factors in one study on the same participants. In the next sections, the importance of each factor and a review of the measures used to assess the factor will be briefly discussed.

2.2.2 Dexterity Screening Tests

There are a number of established tests that can be used to measure dexterity, though the two most common tests reported in the literature are the Box and Block (Cromwell, 1965) and the Purdue Pegboard Tests (Tiffin, 1968). These two tests are complementary, as they measure gross versus fine dexterity respectively by measuring 'power grip' versus 'pinch grip' (Haward & Griffin, 2002). Both tests are simple and easy to administer and have high test-retest reliability (see for example Desrosiers et al., 1994; Desrosiers et al., 1995; Tiffin & Asher, 1948). Other manual dexterity tests exist in the literature that assess an individual's ability to manipulate objects with their hands such as the Jebsen Taylor Test (Jebsen et al., 1969), 9-Hole peg test (Sharpless, 1982) and Roeder manipulative Aptitude test (Roeder, 1958). However, key limitations to using such tasks are a paucity of the comparative published literature.

An example of a paper that tested the effects of age on upper extremity performance is that of Desrosiers et al. (1999). They used a variety of measures including the Box and Block and Purdue Pegboard Tests. They tested 360 participants (179 Women) aged 60 years and above, over a three-year period, and reported a significant decrease in both gross (Box and Block, 13-14%) and fine (Purdue Pegboard test, 7-8%) manual dexterity performance. Therefore, the advantage of using these measures was that they were very sensitive to small within participant changes over the three-year period, and furthermore, replicated other findings of age related decline in performance in the literature (Desrosiers et al., 1994; Desrosiers et al., 1995 a, b; Mathiowetz et al., 1985; Michimata et al., 2008).

2.2.2 Sense of Touch Screening Tests

In the literature, one of the reasons commonly cited to explain reduced dexterity with increased age is reduced sense of touch. That is, the participant might be less able to use haptic feedback when interacting with objects, and as a consequence, the speed and precise control of movement is reduced (see for example, Cole, 1991; Cole & Beck, 1994; Kinoshita

& Francis, 1996; Lazarus & Haynes, 1997; Shiffman, 1992; Spirduso & Choi, 1993). While evidence for the relationship between sense of touch and dexterity with age is perhaps lacking, there is clear evidence that sense of touch is associated with normal dexterity (Cole et al., 1999; Johansson, 1996; Moberg, 1962) and that sense of touch reduces with increased age (Gescheider et al., 1994; Stevens and Patterson, 1995).

A number of methods exist in the literature for the assessment of sense of touch. These range from the very simple to the quite complicated. The most common and simplest measure is the two-point discrimination test (Goldstein, 1999; Moberg, 1990; Stevens, 1992; Van Nes et al., 2008). The test uses a mechanical calliper (aesthesiometer) that can either have both points touching to produce one point, or be separated at different distances to create two points of different magnitudes. The sense of touch threshold is established by determining the smallest separation between two points that can be perceived as two rather than one point by the participant. For example, Van Nes et al., (2008) reported normative data for 427 healthy control participants in a clinical trial experiment. They were aged 20-80+ years and grouped by gender and age (i.e. 20-39; 40-49; 50-59; 60-69; 70-79; ≥80 years). They reported 95th percentiles of two-point discrimination test for each age group using a static and dynamic assessment. For the static examination, the ends of the arms of the aesthesiometer were applied to one point of the participant's skin on the distal phalanx. The dynamic examination was performed by placing the ends of the aesthesiometer arms on the skin surface and gently moving from the proximal to the distal end (over a distance of 1 cm) of the distal phalanx. Contact with the skin was maintained while the ends were moved perpendicular to the gap between the two points. Typically, participants were able to discriminate smaller distances between the two arms of the aesthesiometer during the dynamic examination (i.e., 20-39: 4.0, 3.5; 40-49: 4.5, 4.0; 50-59: 5.0, 4.0; 60-69: 6.0, 5.0; 70-79: 7.0, 6.0; ≥80: 8.5, 6.5; for age in years: static and dynamic distance; mm). The general findings were that tactile discrimination reduced (i.e., the two point discrimination increased in magnitude) with increased age, independent of gender and static versus dynamic assessments.

More complicated methods have also been developed. For example, the INCAT Sensory Sumscore (ISS) (Merkies et al., 2002) is a clinical measure that comprises of sense of vibration, sense of pinprick and sense of a two-point (aestethiometer) discrimination measure. The test has been reported as having problems in that it uses an arbitrary scoring system that leads to variable measures and as a result, has a low consistency of findings in the literature (Van Nes et al., 2008). An alternative method to the two-point discrimination test was introduced by Van Boven et al. (1989, 1991). The test used eight different hemispherical acrylic domes called “JVP domes” (JVP Domes, Stoelting Co.) that have small equidistant groove and ridge width gratings. Each dome is positioned at the end of a columnar handle that is used with participants to test their ability to judge tactile spatial acuity from the set of eight grating domes, the equidistant groove and bar widths are equal to 3.0, 2.0, 1.5, 1.25, 1.0, 0.75, 0.50 and 0.35 mm respectively. Each grating is presented in a sequence of random trials in one of two orthogonal orientations. The gratings are presented either along or across the participants fingertip for 1-3 s, and participants are asked to report the orientation of the grating domes. Participants’ discrimination threshold is determined by the grating width at which participants correct responses fall below 75%. Despite the potential use of the measure, Tremblay et al. (2000) demonstrated that the measurement was flawed for use with healthy elderly participants (i.e. >60 years) since they were unable to obtain reliable reports of grating orientations from participants even when presented with the widest settings available. Therefore, due to reliability of test and availability of supportive literature, the two-point discrimination test appears to remain the best measure for sense of touch.

2.2.3 Strength Screening Tests

Another common explanation for the cause of reduced dexterity with increased age is reduced strength. That is, the participant has less strength available with increased age for manipulating objects (Desrosiers, Bravo and Hébert, 1997; Kolber and Cleland, 2005; Sperling, 1980; Shiffman, 1992; Welford et al., 1969). A distinctive feature of dexterous movements is the ability to accurately control the forces produced by the digits of the hand when interacting with objects. Within the literature, a number of studies have investigated hand control and coordination in ageing at the level of the muscle (Enoka et al., 2003), multiple digit force (Shinohara et al., 2003a, b, 2004), individual digit force (Cole and Rotella, 2001), fingertip force (Cole, 2006) and continued grasp force modulation (Voelker-Rehage and Alberts, 2005). Generally, these studies reported that older adults have an impaired ability to control, regulate and modify force when compared to younger adults.

Similar findings to these effects have been reported for grip strength measures. For example, Mathiowetz et al. (1985) reported that peak grip strength was achieved between the ages 25-39 years, and that peak pinch grip strength was reached between the ages 20-59 years. Subsequently, both grip and pinch grip strength showed gradual decline with the older aged participants. Similarly, Kallman, Plato and Tobin (1990) reported data for 847 participants aged 20-100 years for summed hand grip strength (i.e. dominant + non dominant measure). The hand grip strength data was distributed across the age span and showed a curvilinear decline in grip strength beyond 49 years of age and that muscle mass was correlated with the decline in grip strength (i.e. Grip Mean Strength: 20-29: 100 kg; 30-39: 104 kg; 40-49: 101 kg; 50-59: 95 kg; 60-69: 88 kg; 70-79: 75 kg; 80-89: 66 kg).

The hand contains eleven intrinsic and fifteen extrinsic muscles that produce the force required for gripping objects (Carmelli, Patish and Coleman, 2003). Because of the number of muscles involved, it is inherently difficult to measure individual muscle strength due to their integrated function (Olafsdottir, Zatsiorksy and Latash, 2008). Instead, the majority of literature has tended to focus on hand grip strength as the most salient and easiest measure (Carmeli, Patish and Coleman, 2003). The most common method of measuring hand grip strength has been to use a hand grip dynamometer. Typically, the measure involves recording the highest grip strength that can be achieved out of three maximal efforts, interspersed with periods of rest. A key feature of the measure is the reliability. In a review by Bohannon (1999), it was found that hand-held dynamometry has a good test-retest reliability coefficient typically above 0.7, with the highest reliability correlation coefficient value reported by Mathiowetz (1984) at 0.99.

There are few alternative measures for the assessment of power grip strength, also these tend to be less reported in the literature. One example, is the Rotterdam Intrinsic Hand Myometer (RIHM) test has that been recently developed to measure intrinsic muscle strength of the hand in a clinical setting (Schreuders et al., 2006). The RIHM has been designed to measure a wide range hand movements, such as the abduction and adduction strength of the little finger and index finger, the opposition, palmar abduction (anteposition) and opposition strength of the thumb, and intrinsic muscles of the fingers combined in the intrinsic plus position. Reported studies have shown the RIHM potentially provides a more sensitive measure of muscle force/strength compared to existing power and pinch grip measurement techniques, up to 12 weeks post surgery, whilst potentially being a useful measurement tool for hand therapy, rehabilitation and clinical practice (Schreuders et al., 2006; 2008). However, currently published information provides no directly comparable data as these studies have focussed on efficacy of measurement to date. For such a reason, in the study presented here, maximal hand grip strength test (power grip) will be used because it is the most commonly reported test in the literature and it has high reliability.

2.2.4 Visual Attention Selection Screening Tests

A final explanation for the cause of reduced dexterity with increased age could be that the ability to visually attend and select objects for action is slowed (Stelmach, Goggin & Garcia-Colera, 1987). Therefore, with slowed selection, subsequent dexterity is slowed. While there is much evidence showing that visual attention and selection processes slow with age, evidence of this effect in direct relation to dexterity has to our knowledge not been measured. For example, experiments show that simple and choice reaction time increases with age (Kauranen & Vanharanta, 1996; Salthouse, 2000; Welford, 1988; Yan, Thomas, Stelmach & Thomas, 2000), and that indirectly, increased age leads to slow movement planning and increased reliance on online visual feedback of hand position perhaps stemming from visual attention selection problems (Haaland, Harrington & Grice, 1993; Ketcham et al., 2002; Lyons et al., 1996; Seidler-Dobrin & Stelmach, 1998).

One of the most widely used assessments in neuropsychology to measure a variety of functions including visual selective attention is the Trail-Making Test (Periáñez et al., 2007). It originated as part of the Army Individual Test Battery (1944), and was soon after validated as a sensitive general indicator of brain damage (Reitan, 1958). The behaviour measured by the test varies according to different authors. For example, it is thought to test speed of processing, sequence alteration, cognitive flexibility, visual search, motor performance and executive functioning (Arbuthnott & Frank, 2000; Crowe, 1998; Gaudino, Geisler, & Squires, 1995; Kizilbash, Warschausky, & Donders, 2000; Kortte, Horner, & Windham, 2002; Lezak, 1995; Miner & Ferraro, 1998; Ríos, Periáñez, & Munoz-Céspedes, 2004; Spreen & Strauss, 1998; Stuss et al., 2001; Szoke et al., 2005). The Trail-Making Test consists of two parts (A and B) that must be performed as quickly and accurately as possible. Trail-Making Test -A requires participants to sequentially draw a line between twenty-five circled numbers in ascending order that are randomly distributed across a sheet of paper (e.g. 1-2-3-4, etc.). Trail-Making Test B is similar, but requires that the line to connect both numbers (1-13) and letters (A-L) in an alternate and ascending order (e.g., 1-A-2-B-3-C, etc.). For the present paper, we considered the Trail-Making Test as the best assessment of selective attention in dexterity as the task combines a visual search, selection and movement.

2.2.5 Hypotheses

In the present study, the aim was to first assess the relationships between fine and gross movement dexterity and age, and then further test relationships between age and sense of touch, hand-grip strength and visual attention selection within the same groups of participants. Therefore, by testing the same participants on the range of measures selected, these data might provide a holistic measure of the relationship between age and movement dexterity and a number of related factors.

The main hypothesis of the study was that increased average age would show decreased average dexterity performance. We also predicted supplementary hypotheses whereby increased average age would also show decreased sense of touch, hand grip strength and visual attention selection. Importantly, if any of the latter hypotheses were particularly strong, or alternatively, non-existent, it would be informative to understanding the relative interactions that sense of touch, hand grip strength and visual selection has on the relationship between age and movement dexterity.

2.3 METHOD

2.3.1 Participants

Sixty adult participants were recruited from the West Midlands of England and divided into three age groups. These were younger-aged adults aged 22-33 years (26.2 ± 3.3 years: n = 20); middle-aged adults 50-57 years (52.9 ± 2.2 years: n = 20) and older-aged adults aged 62-84 years (71.2 ± 7.4: n = 20). Groups were balanced for gender, though there was a slight female bias: young-aged adults (11 females, 9 males); middle-aged adults (11 female, 9 males); and older-aged adults (14 females, 6 males).

The younger adults were mostly students from the University of Birmingham, whereas the other adults were recruited from within and around the City of Birmingham (West Midlands, UK). Participation inclusion criteria was that participants were aged above 18 years, had normal or corrected-to-normal vision and were physically healthy as assessed using a self-report medical history questionnaire. Within the medical history questionnaire, none of the participants reported any musculoskeletal hand or neurological problems that might have affected manual dexterity. The School of Sport and Exercise Sciences, University of Birmingham Ethics Board approved the experiments in accordance with the 1964 Declaration of Helsinki.

2.3.2 Apparatus

Five separate pieces of apparatus were used within the experiment. These were needed for the different measures taken. For movement dexterity, the Purdue Pegboard and Box and Block tests were used, for sense of touch, a Two Point Discrimination test was used, for hand grip strength, a Hand Grip Dynamometer was used and finally to measure selective attention, the Trail Making Test (parts A and B) was used. Each of these are well-established measures. In the rest of this section, more detail about each test is provided.

2.3.3 Purdue Pegboard Test

The Purdue Pegboard test is an established test used to measure fine manual dexterity (Tiffin, 1968). The task involves picking up small pegs, washers and collars from separate wells and placing them together such that the peg is first placed in a hole, then a washer is placed over the peg, and then a collar is placed over the peg on top of the washer. Participants are instructed to use the index finger and thumb of one hand, and to construct as many of the peg, washer and collar arrays as possible within a sixty second period. Within the running of the task, participants are given a demonstration and are allowed to practice for 20 seconds before testing. Both hands are usually tested and the total number of complete pegs constructed within the sixty seconds is recorded as the score.

2.3.4 Box and Block Test.

The Box and Block test is another established test of manual dexterity. Unlike the Purdue Pegboard test, it is used to evaluate gross movement speed. In the test, participants are instructed to move one-inch (2.54 cm) wooden cubes, one at a time, with one hand, from one side of a partition to the other side within a 60 second period (Desrosiers et al., 1999; 1995). The test is usually performed with the participant standing. After a demonstration, the participants are typically allowed to practice for 10 seconds. Typically, both hands are tested individually. The number of wooden cubes moved within the sixty-second period is used as the score.

2.3.5 Two-Point Discrimination Test (Tactile Sensitivity).

The Two-Point Discrimination Test uses a mechanical caliper and measures the participant's ability to detect one versus two points of sensation (see Moberg, 1990). The caliper has a precision of 1 mm and is applied with minimum pressure such that minimal blanching of the skin appears around the prong points. Testing usually commences with the points together (i.e., with a 0mm gap between the two points of the caliper). As the test continues, the gap between the two points of the caliper is gradually increased until the participant is able to perceive two points instead of one. For each application of the caliper, the participant is required to say 'one' when they can only perceive the sensation of one point and say 'two' when they were able to perceive the sensation of two points. Participants perform the test with their eyes closed. The distance between points at which the participant reports perceiving two stimuli for three consecutive trials is used as the minimum distance score for two-point discrimination. The measure can be used on any part of the body. Here, the index finger and thumb was measured since they have the highest relevance to manual grasping dexterity.

2.3.6 Hand Grip Dynamometer

The most common assessment of grip strength is carried out using a Hand-Grip Dynamometer. The dynamometer works by measuring the force generated by a participants hand grip upon a strain gauge device and provides a measurement via calibrated electronic display. Typically, participants are positioned sitting upright and holding the dynamometer in the test hand, with the arm elbow at a right angle and by the side of the body. The handle of the dynamometer is adjusted for comfort, so that the base of the dynamometer is positioned with the rest on first metacarpal (heel of palm), and the handle rest on middle of the four fingers. Participants are instructed to squeeze the dynamometer with maximum effort and maintain the squeeze for approximately 5 seconds. Typically both hands are tested separately, at least three times, with a minimum of 60 seconds between each attempt. The highest result for each hand is recorded as maximum hand grip strength.

2.3.7 Trail Making Test

The Trail Making Test is an established measure of selective attention (Reitan, 1958; 1992). There are two parts to the test (A and B). For both parts, participants were presented with a white sheet of paper on which circles were distributed. In part A, the circles were number from 1 to 25 and the participants are asked to sequentially connect by drawing a line with a pencil the 25 encircled numbers that are randomly distributed on the sheet of paper in ascending order (i.e. 1-25). In part B, the circles contained numbers from 1 to 13 and letters from A to L. Participants are asked to connect the numbered and alphabetically lettered circles in a sequential order by alternating between the two sequences (i.e. 1-A-2-B …-13, L). In both parts of the test participants are instructed to connect the circles as fast as possible. When an error is made, the participant is instructed to return to the where the error occurred and continue until the test is complete. The total time to complete parts A and B respectively are then recorded, and represent TMT-A and TMT-B scores (seconds). Both TMT-A and TMT-B are complete once per participant using the dominant writing hand.

2.3.8 Procedure

Before starting the experiment, participants were made accustom to the laboratory and the procedures before informed consent was acquired. After obtaining informed consent participants were given three questionnaires to complete (a comprehensive health questionnaire (Appendix 1); an arthritis assessment (Appendix 2); and the Edinburgh Handedness Test (Oldfield, 1971). The participants were then given a brief explanation of the study and a demonstration of each of the experimental apparatus to be used. They were also given an opportunity to ask any questions. Throughout the study, participants were consistently told that they should aim to do the best they possibly can (e.g. be as quick as possible or try as hard as possible).

All experimental tests were undertaken in the same order: (1) Purdue Pegboard; (2) Box and Block Test; (3) Two-Point Discrimination; (4) Hand Grip Strength and (5) Trail Making Test. The order of testing was designed to place the tests that cause the largest level of physical fatigue towards the end of the assessments. Each hand was tested with first one then the other on all tests (counterbalanced) with the exception of the Trail Making Test, for which only the dominant writing hand was tested. The duration of the total experiment was approximately 60 minutes. At the end of the overall experiment, the participants were provided verbal feedback about their test performance.

The following section provides the procedural instructions given to the participant's before for each test. In all cases, they were given the instructions and given some time to familiarize themselves with the task.

Purdue Pegboard Test

Participants were instructed to use the index finger and thumb of one hand, and to construct as many of the peg, washer and collar arrays as possible within a sixty second period. Participants were given a brief demonstration and allowed to practice for 20 seconds before testing begun. The total number of complete pegs constructed within the sixty seconds and recorded as the score.

Box and Block Test

Participants were instructed to move as many wooden cubes as possible from one side of a partition to the other within a 60 second period. They were instructed to only move one cube at a time, using only one hand. The tests were performed with the participant standing next to a standard wooden table. Participants were given a brief demonstration and allowed to practice for approximately 10 seconds before testing began. The total number of blocks moved within the sixty-second period was used as the score.

Two-Point Discrimination Test (Tactile Sensitivity)

The demonstration of the task was conducted on one of the participant's hands with their eyes open. Once the participant was familiar with the testing procedure, they were instructed to close their eyes and testing began. Testing commenced with the points together (i.e., with a 0mm gap between the two points of the caliper). As the test continued, the gap between the two points of the caliper is gradually increased until the participant is able to perceive two points instead of one. The measure was undertaken for three consecutive trials for each for each digit. The order of measurement for each hand or index finger and thumb was random. The minimum score for two-point discrimination was recorded for each digit.

Hand Grip Dynamometer

Participants were positioned sitting upright and holding the dynamometer in the test hand, with the arm elbow at a right angle and by the side of the body. The handle of the dynamometer was adjusted for comfort and correct fit. Participants were then instructed to squeeze the dynamometer with maximum effort and maintain the squeeze for 5 seconds. A rest period of 60 seconds was given between each attempt. All attempts were recorded, although the highest result for each hand is recorded as hand grip strength.

Trail Making Test

Participants were positioned sat at a wooden table and presented the tests in order: part A and then part B. Time started as soon as the participant received the sheet of paper and stopped upon reaching the final character. When an error was made, the participant was instructed to return to the where the error occurred and continue.

2.3.9 Data Analysis

The independent variables were age group (young vs. middle vs. older aged adults) and hand dominance (dominant versus non dominant hand) where appropriate. The dependent variables were the scores for each test. Therefore, the total number of peg, washer and collars constructed in the Purdue Pegboard Test, and blocks moved in the Box and Block Test within the sixty-second period. Sense of touch was the minimum distance for two-point discrimination. Hand grip strength was the maximum recorded using the Hand Grip Dynamometer, and selective attention was the time taken to complete the Trail Making Test parts A and B (note that in the Trail Making Test analysis, the tests were analysed using an additional independent variable for the A vs. B component).

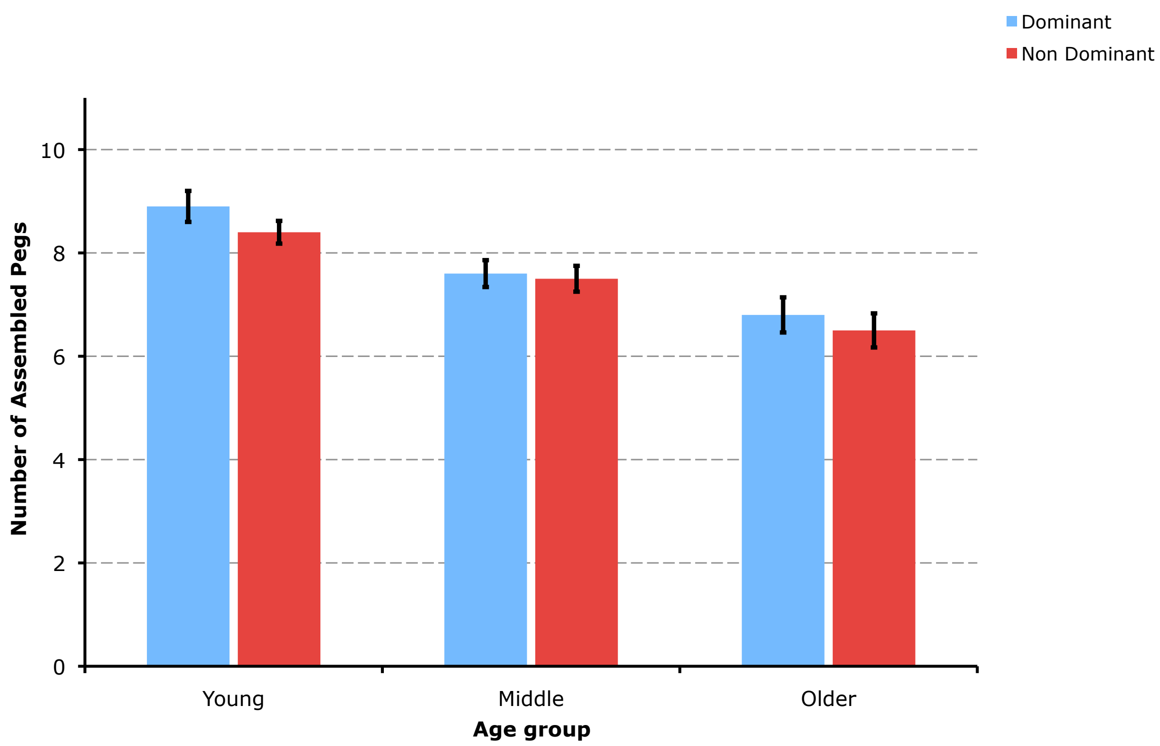
A mixed design Analysis of Variance with repeated measures was used to analyse the data. The between groups factor was age groups, hand dominance (and A vs. B in the Trail Making Test). Posthoc analyses used Bonferroni with correction (significance level of $p < 0.05$). All statistical analyses were performed using SPSS v16.0 (SPSS Inc. Chicago, Illinois, USA). The data are reported under headings of dexterity, sense of touch, hand grip strength and selective attention.

2.4 RESULTS

2.4.1 Dexterity

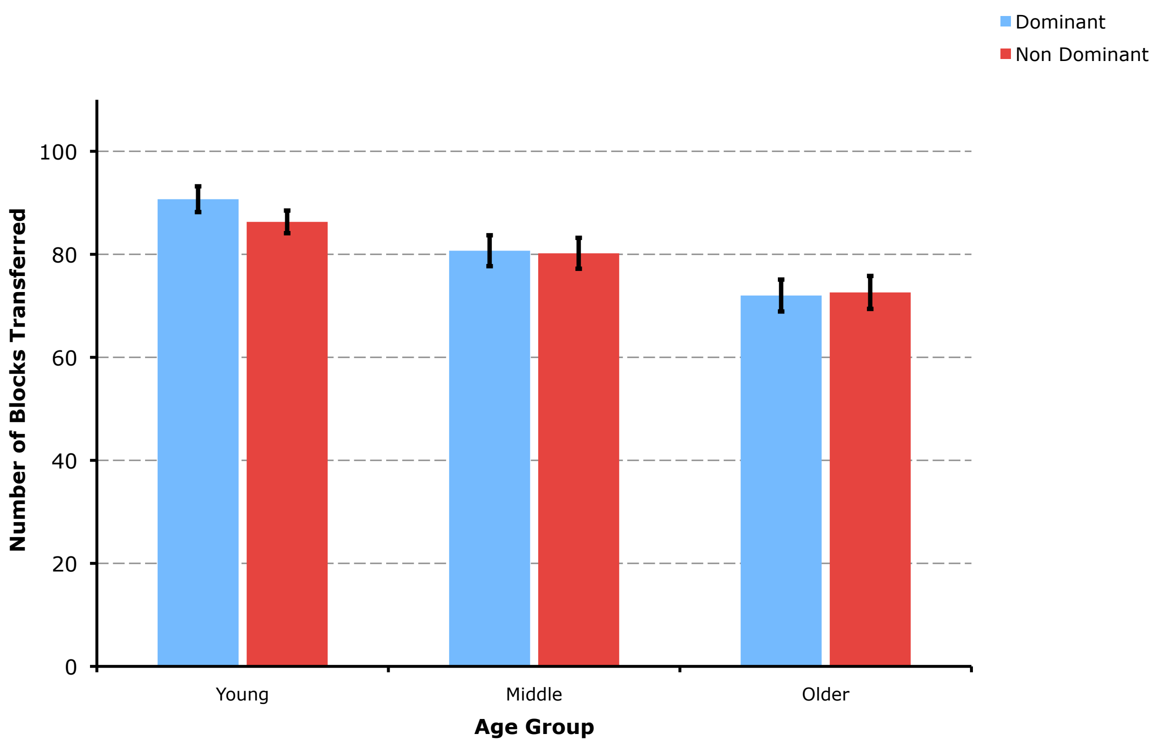
Analysis of the Purdue Pegboard Test performance showed significant main effects for age group ($F[2,57] = 14.59$, $p < 0.001$) and hand dominance ($F[1,57] = 5.51$, $p < 0.05$), and no interaction ($F[2,57] = 1.31$, $p = 0.36$). The Bonferroni post-hoc analyses for age group showed that all groups were significantly different from each other in performance ($p < 0.05$) (see Figure 2.1).

Figure 2.1: The mean ± Standard Error number of assembled pegs in 60 s for the Purdue Pegboard Test for both the dominant and non-dominant hands as a function of age: young group (22-33 years old), middle-aged group (50-57 years old), and older aged group (62-84 years old).



Analysis of Box and Block Test performance similarly showed significant main effects for age group ($F[2,57] = 10.52$, $p < 0.001$) and hand dominance ($F[1,57] = 8.97$, $p < 0.01$), and no interaction ($F[2,57] = 0.76$, $p = 0.47$). The Bonferroni post-hoc analysis of age group showed that young were significantly different from the middle and older aged adult groups ($p < 0.05$), but that there was no difference between the middle and older aged adult performance ($p>0.05$) (see Figure 2.2).

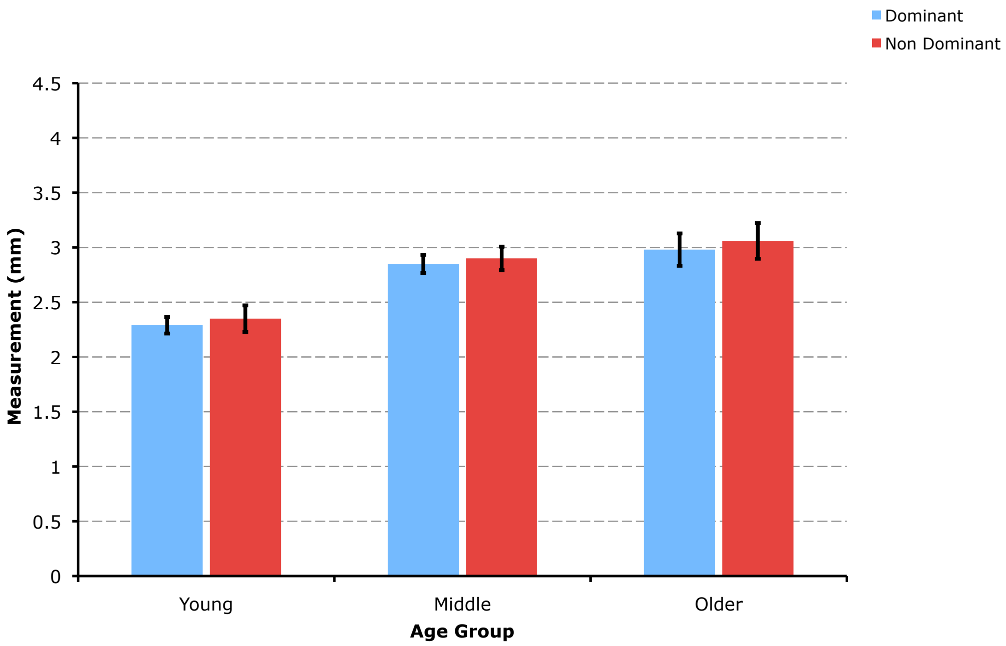
Figure 2.2: The mean ± Standard Error number of blocks moved in 60 s for the Box and Block Test for both the dominant and non-dominant hands as a function of age: young group (22-33 years old), middle-aged group (50-57 years old), and older aged group (62-84 years old).



2.4.2 Sense of Touch

Analysis of the Two-Point Discrimination Test showed a significant main effect for age group ($F[2,57] = 11.71$, $p < 0.001$), but no effect of hand dominance ($F[1,57] = 0.69$, $p = 0.41$) or an interaction ($F[1,57] = 0.03$, $p = 0.97$). This showed that younger adults had a more sensitive touch with the finger and thumb than older adult groups, and that no difference existed between the dominant and non-dominant hand. A Bonferroni post hoc analysis for age group showed that younger aged adults were significantly more sensitive than both the middle aged and older aged adult groups ($p < 0.05$), but middle-aged adults were not significantly different from older aged adults in discrimination ($p > 0.05$) (see Figure 2.3).

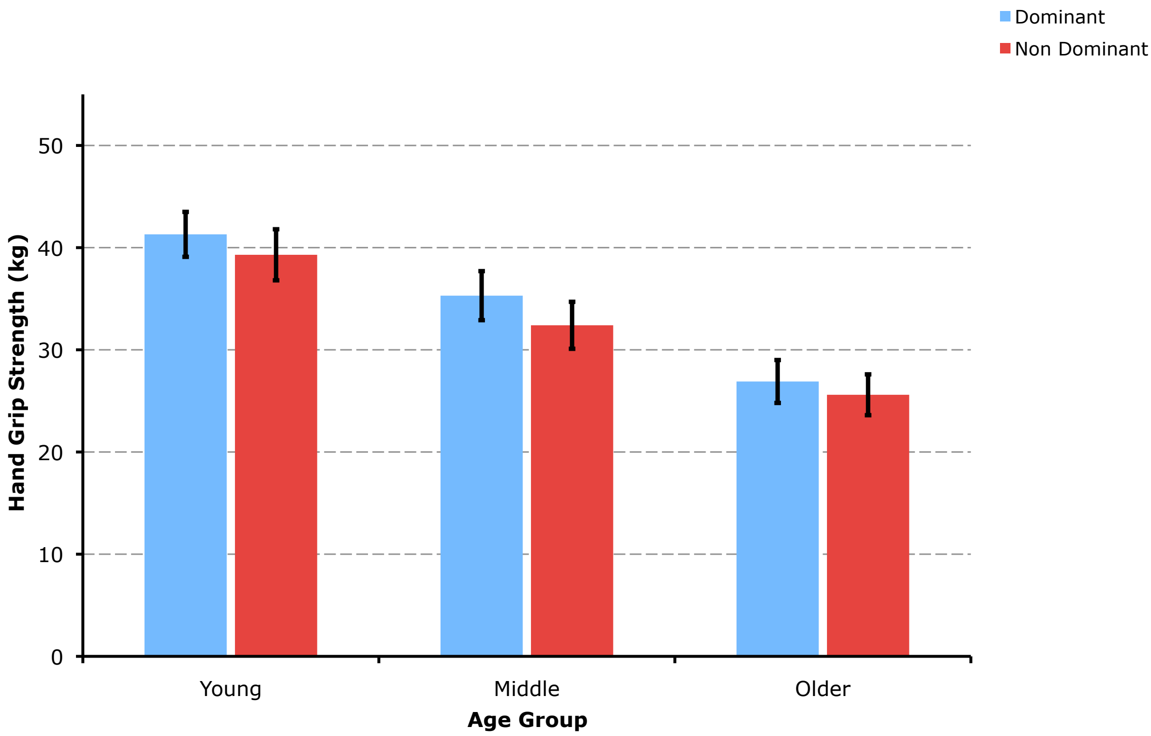
Figure 2.3: The mean ± Standard Error Sense of Touch measurements for both the dominant and non-dominant hands as a function of age: young group (22-33 years old), middle-aged group (50-57 years old), and older aged group (62-84 years old).



2.4.3 Hand-Grip Strength

Analysis of hand grip strength from the Hand Grip Dynamometer test showed significant main effects for age group ($F[2,57] = 9.97$, $p < 0.001$) and hand dominance ($F[1,57] = 17.14$, $p < 0.001$), and no interaction ($F[2,57] = 1.03$, $p = 0.37$). The Bonferroni post-hoc analysis of age group showed that the young and middle aged adults were significantly stronger than the older aged adult group ($p < 0.05$), and that there was no difference between the young and middle aged adults (see Figure 2.4).

Figure 2.4: The mean ± Standard Error Hand Grip Strength for both the dominant and non-dominant hands Results as a function of age: young group (22-33 years old), middle-aged group (50-57 years old), and older aged group (62-84 years old).

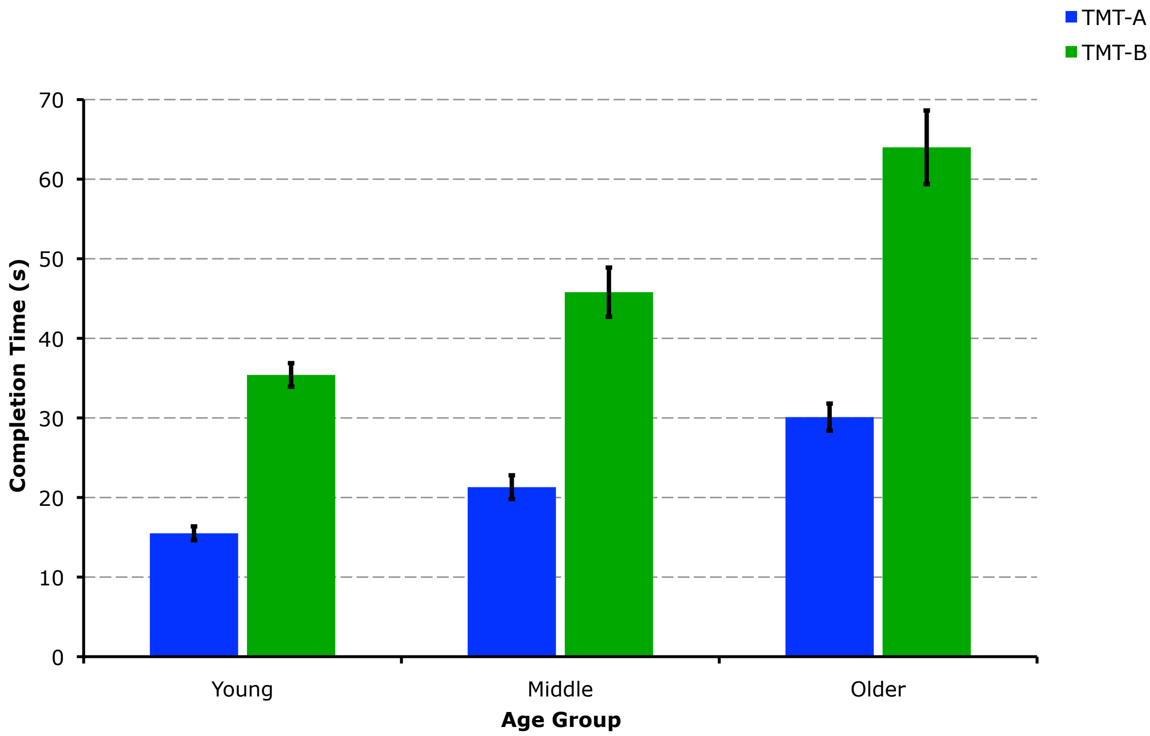


2.4.4 *Selective Attention*

Analysis of the Trail Making Test performance showed significant main effects for age group ($F[2,57] = 26.41$, $p < 0.001$), and Trail Making condition (A vs. B) ($F[1,57] = 25.28$, $p < 0.001$). The Bonferroni post-hoc analysis of age group showed that all groups were significantly different from each other in performance ($p < 0.05$) (see Figure 5).

There was also a significant interaction between age group and Trail Making Test condition ($F[2,57] = 6.26$, $p < 0.001$). The interaction was further analysed by running separate ANOVAs for each Trail Making Test condition. These analyses both showed significant main effects for age group (TMT-A: $F[2,57] = 27.59$, $p < 0.001$ and TMT-B: $F[2,57] = 18.86$, $p < 0.001$). However, the Bonferroni post-hoc analyses for age group showed different results. In Trail Making Test condition A; all age groups were significantly different from each other ($p < 0.05$). However, in Trail Making Test condition B, the young and middle-aged adults were significantly faster to complete the test than the older aged adult group ($p < 0.05$). However, there was no difference between the young and middle-aged adults (see Figure 2.5).

Figure 2.5: The mean ± Standard Error for time to complete the Trail Making Test's both TMT-A and TMT-B as a function of age group: young group (22-33 years old), middle-aged group (50-57 years old), and older aged group (62-84 years old).



2.5 DISCUSSION

The present study assessed the effects of age on movement dexterity, sense of touch, hand grip strength and visual attention selection. The main hypothesis of the study was that increased average age would show decreased average dexterity performance, and furthermore, that increased age would also show decreased sense of touch, hand grip strength and visual selection ability. The results are first discussed in relation to these hypotheses and literature, followed by some limitations of the study and suggestions of thesis direction.

The main hypothesis of the study was that increased average age would show decreased average dexterity performance. To test this, we measured movement dexterity using the Purdue Pegboard (fine dexterity) and Box and Block (gross dexterity) tests. Overall, both types of assessment showed reduced dexterity performance with increased average age. However, within the post-hoc analyses, the two tests showed slightly different, though still compatible results. That is, in the Purdue Pegboard assessment, the older-aged adult participants group was significantly slower overall than both the middle- and younger-aged adult groups, whereas in the Box and Block assessment, both the older- and middle-aged adult groups were significantly slower than the younger-aged adult group. The data also showed significant hand dominance effects for both fine and gross dexterity. In both cases, the non-dominant hand showed reduced dexterity than the dominant hand.

These findings of a relationship between increased age and decreased dexterity are consistent with the literature presented in the Introduction of this chapter, and the General Introduction of this thesis (Chapter 1) (e.g., Bennett & Castiello, 1994; Cromwell, 1965; Desrosiers et al, 1994; Desrosiers 1995; Desrosiers et al., 1999; Falconer et al., 1991; Jebsen et al., 1969;

Mathiowetz et al., 1985; Shiffman, 1992). Furthermore, the effect of hand dominance, where the non-dominant hand has less dexterity than the dominant hand has also been previously reported (see for example Desrosiers et al., 1995a, b; Wolf et al., 2006). The strength of this chapter therefore is in understanding the relative contributions that sense of touch, strength and visual attention selection has on the age and dexterity association, within the same group of participants.

In the measure of sense of touch, a two-point discrimination task was used to measure finger and thumb sensitivity (i.e., the digits used in pinch grasping). The data showed that sense of touch reduced for the older-aged adults compared to the younger- and middle-aged adults. There was however no differences in sense of touch between finger and thumb or between the dominant and non-dominant hand. As in the dexterity findings, these findings were also consistent with previous literature (Desrosiers et al., 1999; Gilles & Wing, 2003; Van Nes et al., 2008).

Analysis of hand grip strength data using a hand grip dynamometer showed similar age effects to the previous measures, with the older-aged adults showing less strength than the younger- and middle-aged adults. There was also a significant main effect of hand dominance, showing weaker strength in the non-dominant than dominant hand. As before, these data are consistent with the previous research findings (Bassie & Harries, 1993; Desrosiers et al., 1995 a, b, 1999; Mathiowetz et al., 1985; Kallman, Plato & Tobin, 1990; Ranganathan et al., 2001).

Finally, the measure of visual selective attention used the Trail Making Task (A and B). The data also showed significant age effects, though the effects slightly differed for each test. In Trail Making Task A, the older-aged adults were slowest, followed by the middle-aged and then younger-aged adults (all significant from each other). In Trail Making Task B, the older-aged adults were significantly slower than the two other groups, with no difference between the younger- and middle-aged groups. These findings are consistent with those presented in the Introduction (see Perianez et al., 2007 & Tombaugh, 2004).

Together, these data appear to show that the increased age and reduced dexterity relationship could be a consequence of sense of touch, strength or selective attention. In all tests, the older-aged adult group performed worse than the younger-aged adult group, suggesting that all of the factors seem important for dexterity.

The effect that selective attention ability showed reduced performance was interesting in that we think it might suggest that decreased movement dexterity with increased age could possibly be caused by attention alone. That is, slow dexterity within the Purdue Pegboard and Box and Block tests might actually be caused by the older-adult being slow to visually select the object that they intend to move and interact with. It might actually be that participants are slow to select, but then make normal speed actions (i.e., no differences between age groups) within the task. Therefore, the apparently slower movements could in fact be caused by longer times in selection of what to act to rather than in acting (these two variables are combined within the current measure). In order to address this point further, it would be necessary to re-run a dexterity test such as the Box and Block test, but measure the actions made using accurate motion tracking methods. By doing so, the time taken to make movements in comparison to the time taken to select and programme actions could be separated.

There was another finding that we considered of interest. That was with respect to the hand dominance finding in dexterity. In the dexterity measures, the non-dominant hand performed slower than the dominant hand. Yet, sense of touch showed no differences in hand dominance whereas strength of hand grip did. This might suggest that strength is more important for movement speed in dexterity (i.e., largely reach and grasp coordination) whereas sense of touch is more important for object interactions with the hand (i.e. gripping an object and preventing slippage for example; see Cole et al., 1998; Gilles & Wing, 2003; Johansson, 1996). Thus, sense of touch might intuitively have limited association with speed of dexterity. On this basis, we think that it might be of more interest to understand the relationship between age, dexterity and strength in greater detail, as hand grip strength might have more association with dexterity speed than sense of touch.

From the two areas of interest raised from these data presented here, we decided to run two parallel avenues of research for the PhD thesis (i.e., carried out at the same time and so not necessarily informing each other from this point). To test the effects of selective attention on movement dexterity across the age groups, we tested the same participants from the study presented here (Chapter 2) on a modified Box and Block test. The test was designed such that the blocks were presented and moved to set positions on a table (see Chapter 3). By doing so, every participant made the same actions (i.e., moved the blocks over the same distance), and so the time to make the actual actions could be measured. Furthermore, by using motion analysis, we could determine relative differences between action types (e.g., reach to an object, transfer of an object and return to start position) and any time where selection might be occurring. To assess the relative relationships between age, dexterity and strength, we used a number of new dexterity measures in a regression analysis in order to understand the relative relationships between the three variables (see Chapter 5).

CHAPTER 3 - EFFECT OF STIMULI CONFIGURATION COMPLEXITY ON OBJECT PREHENSION DEXTERITY ACROSS AGED ADULTS.

3.1 ABSTRACT

The purpose of the present study was to test whether the relationship between age and dexterity could be explained by a similar relationship between age and attentive object selection for action. That is, dexterity is not directly slowed with age, but rather that attentive object selection is and that this slows movement. In order to test this, the experiment presented here manipulated stimuli configuration complexity in object prehension dexterity based on the Box and Block Test. The test was modified such that the stimuli were placed and moved to fixed positions enabling sub-movements of the routine to be analysed using motion analysis. The aim of carrying out the modification was to determine whether different components of the action were slower than others (e.g., in the selection, and reach to grasp the target object vs. transfer the target object to a new location vs. return the hand to the end position), and furthermore, whether stimuli configuration complexity and increased age modified these effects. We tested sixty adult participants that we separated into young-aged (22-33 years), middle-aged (50-57 years) and older-aged (62-84 years) adult groups. All of the participants performed the task and movement kinematics were recorded. The results showed that the overall time to complete the task was not significantly influenced by the participant age group, though there was a significant effect of stimuli configuration complexity whereby movements were slower to the complex versus simple configurations. Analysis of separate movement components showed that the time taken to select, and reach to grasp the target object was slower for the older than younger age groups, whereas actions in the transfer of the target object to the new location and the return the hand to the end position showed no effects of age. The data are discussed in terms of the effects of ageing on slowing object selection for action and proposes some future directions of testing.

3.2 INTRODUCTION

In Chapter 2, we tested a large sample of participants in young-, middle- and older-aged groups on standard clinical screening measures of movement dexterity, sense of touch, grip strength and visual selective attention. The data showed that dexterity in the Purdue Pegboard and Box and Block dexterity tests replicated the literature in that they showed that older aged adults performed slower than the younger aged adult group. In the discussion of Chapter 2, we suggested that one of the reasons that might cause the slowness could be a deficit in selective visual attention. That is, the screening data showed that participants were slow on the Trail Making Test (used in Chapter 2 for measuring selective attention), and so the slow movement data could potentially be explained by a deficit in the attention selection of the object for action rather than a consequence of the movements themselves being slow. Therefore, in the present chapter, we aimed to test whether this was the case.

The literature contains many examples of experiments showing that with increased age, movements are slower (see, for example, Desrosiers et al., 1999; Dustman, Emmerson, & Shearer, 1994; Lord & Sturnieks, 2005; Lord, Lloyd, & Keung Li, 1996; Menz, Lord, & Fitzpatrick, 2003; Polich, 1996; Salthouse, 1995; Salthouse, 2000; Skelton, Greig, Davies & Young, 1994; see also Chapter 1). While much evidence for this relationship comes from research carried out on lower-limb action, there is also evidence that upper-limb actions follow the same trend (see, for example, Aniansson et al., 1980; Bryant, Trew, Bruce, & Cheek, 2007; Desrosiers et al., 1994; 1999; Kauranen, 1996; Smith et al., 1999; Waddington & Adams, 2004; Welford, 1958; see also Chapter 2). In this Chapter, we aimed to replicate the finding between dexterity and age, and further to test whether the effects of age were general and shown for all aspects of movement irrespective of the nature of the action, or whether the relationship was influenced by other factors such as reduced functioning of visual selective attention. If the latter was the case, we might expect that different aspects of movement within a task might show different grades of slowing depending upon whether visual selective attention was needed in order to perform the action. In order to make these effects salient, we manipulated object position configuration, so manipulating visual selective attention difficulty without increasing task demands on movement (i.e., the objects were always placed in the same area).

Much of the research carried out on the effects of ageing on upper-limb actions have tended to measure differences in movement time for younger vs. older aged adults (see for example Cerella, 1990; Haward & Griffin, 2002; Sarlegna, 2006; Voelcker-Rehage & Alberts, 2005). While this method is simple, in our opinion, the effects reported could be caused by various confounds that co-factor with age and differ for the two selected participant groups (e.g. health, exercise and strength etc.). For this reason, a better method to address age effects on movement would be to test the same participants over time. In the literature, there are very few longitudinal design studies addressing this question. One such study was that by Desrosiers et al., (1999). The objective of the research was to measure changes in the upper extremity performance of 264 elderly participants over a three-year period. They measured gross and fine manual dexterity, upper extremity global performance using TEMPA, motor coordination, grip strength, tactile recognition, two-point discrimination, touch/pressure threshold, and tactile localisation. Generally, the study found that upper extremity performance significantly decreased over the three-year period, and of relevance to the present study, this included the data for both gross and fine dexterity measures.

The reason that there are relatively few longitudinal studies probably stems from time commitment and funding issues that tend not to support such studies. For example, a longitudinal method would not be possible to carry out for this PhD thesis as the time elapsed would not be great enough to test any age differences reliably (i.e., in order to test nearly three hundred participants over a three-year period, approximately five years would be needed). Therefore, we think that a possible compromise between the usual two group (younger versus older) and longitudinal method design would be to test three groups of aged adults. Importantly, inclusion of a middle-aged group of adults would present adults that are older than the younger-aged adults, but who are likely to be equally active through work. As with the longitudinal methods design, there are only a few examples of papers were multiple age groups have been reported (see Desrosiers et al., 1995; Kallman, Plato & Tobin, 1990; Mathiowetz et al., 1985; Rantanen et al., 1998; Skelton et al., 1994; Smith et al., 2005). These typically show that rates of physical and functional decline appear to be linear with increasing age. For example, Skelton et al., (1994) reported a cross-sectional study that examined the effects of healthy ageing on muscle strength, power and related functional ability (i.e., dexterity). They assessed one hundred participants aged 65 - 89 years. In order to test the age effect, they grouped the participants into five groups. The data showed a stepwise linear increase in the effects of age on isometric strength and leg extensor power, and furthermore a decline in chair rise time and step height dexterity measures. Therefore, based on these data, using a compromise of three groups to assess ageing effects would lend more support that any differences were a result of age over and above other potential confounding factors.

As far as we can tell, to date, no literature has tested whether reduced ability in visual attentive selection impacts upon the relationship between ageing and movement dexterity. The possible reason for this is that ageing research appears to have been divided into two distinct literatures, one that addresses the effects of ageing on the ‘mind’ and another that addresses the effects on the 'body' (Potter & Grealy, 2006) (e.g., psychology vs. physiology). Research from psychology has shown that working memory and inhibitory function typically reduce with increased age (Allen, 1991; Garden, Phillips & MacPherson, 2001; McDowd, 1994; Salthouse, 1991). For example, Garden, Phillips & MacPherson (2001) reported that increased age lead to reductions in working memory and planning abilities when performing everyday tasks such as remembering a shopping list or planning a shopping route. As such, it is possible that these factors have some contribution toward generalised slowing (Birren & Fisher, 1995). However, it appears that no studies have tested whether working memory, inhibition or planning cognitive processes impact on the established relationships between physical performance and ageing and its interaction with muscle strength (Vandervoort, 1992), flexibility (Hay, 1996), balance (Tang & Woollacott, 1996), speed of movement (Amrhein, 1996), motor coordination (Greene & Williams, 1996), and visual guidance of action (Patla, Prentice & Gobbi 1996).

On the basis of these points, the first modification to the experimental design presented here was to test three groups of adults across the age span. The second modification involved the use of motion tracking to record the sub-movement timings. In the data presented in Chapter 2, we reported that increased age lead to slower movements with the Purdue Pegboard and Box and Block Tests. We also showed that the finding was consistent with the literature (Dean, 1988; Desrosiers et al., 1995; 1999; Mathiowetz, 1985; Michimata et al., 2008). While this was an interesting finding, it was not certain whether a particular component of the movement was more effected by age than another. For example, the reach to an object requires first selecting the object for action, then transporting the hand to the object and at the same time shaping and coordinating the grasp component to the size of the object (e.g., Haggard & Wing, 1998; Jeannerod, 1986; Jeannerod et al., 1995; Pelisson et al., 1986;

Sarlegna, 2006; Voelcker-Rehage & Alberts, 2005). The transfer of the block to a new location requires dynamic grip force coordination (Gilles & Wing, 2003) and selecting the location to place the object. Once the object is released from grip, the hand needs to be retracted back to a start position. Given these varied components, if ageing causes generalised slowing, then all of the movement components should be slow. However, if other factors influence the movement speed, then one component may be more slowed in comparison to other components of the same overall movement task. For example, if selection of where to grasp or place objects is particularly influenced by age (perhaps involving cognitive inhibition and planning processes), then only the reach to and transfer with the object ought to be slowed with age. Alternatively, if older aged adults have increased difficulty in gripping objects, then only the transfer of the object in hand ought to be slowed with age. Based on these issues, we considered that tracking movements would allow for a finer grained analysis of movements. The third modification was to manipulate the complexity of the task by using different stimuli configurations for object placement (e.g., predictable alignment, predictable unaligned and unpredictable unaligned object locations). By increasing the complexity of the configuration, attentive object selection demands would also increase. Therefore, if attentive object selection relates to the age and dexterity relationship, manipulation of configuration will modulate the relationship.

3.2.1 Hypotheses

The main aim of the motion tracked simple (modified box and block) movement response task was to test the effects of stimuli configuration complexity on the age and dexterity relationship reported in the literature and in Chapter 2. We created different components of the action (e.g., selection, reach and grasp of the target object vs. transfer the target object to a new location vs. return the hand to the end position) and expected that the taken to complete the overall movement (i.e., a sum of the components) would replicate the literature and Chapter 2 and show that with increased age, dexterity was slower. We also expected that action components requiring selection of an object would particularly be slowed with increased age (i.e., selection, reach and grasp of the target object and transfer the target object to a new location compared to return the hand to the end position) and furthermore that increased configuration complexity would increase this effect.

3.3 METHOD

3.3.1 Participants

The same sixty adult participants that were recruited for the screening experiments presented in Chapter 2 were also tested on the experiment here (Chapter 3). The participants were divided into the same three age groups. This consisted of young-aged adults (mean and range: 26.2 ± 3.3 years and 22-33 years; n = 20); middle-aged adults (mean and range: 52.9 ± 2.2 years and 50-57 years; n = 20) and older-aged adults (mean and range: 71.2 ± 7.4 years and 62-84 years; n = 20). As in Chapter 2, the groups were balanced for gender for the young-, middle- and older-aged groups (11 females and 9 males; 11 females and 9 males; and 14 females and 6 males respectively).

The inclusion criteria was that participants had normal or corrected to normal vision, did not report any muscular skeletal or neurological problems on a self-report medical history questionnaire, scored greater than 27/30 on the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975), and were ambulatory and living independent of social care. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971) and all participants were right hand dominant. Ethical approval was granted from the School of Sport and Exercise Sciences, College of Life and Environmental Sciences, University of Birmingham in accordance with the 1964 Declaration of Helsinki. All participants gave written consent before taking part in the study.

3.3.2 Apparatus and Stimuli

Participants sat at a testing table, seated on a wooden chair with back support. They were positioned so that the mid point of the table was the same as the participant's saggital axis. In the experiment, five identical wooden target objects were used (cubes with a side length =

5cm). These were placed in set positions on a table top using a stimuli position printed paper template with squares (side length = 5.25cm) marked to designate the required placement and relocation of the objects. The stimuli position markings were 10cm apart in the sagittal dimension away from the 'hand initiation reference' marker, and 10cm from the sagittal axis in the lateral dimension. All of the templates used were symmetrical so that the five wooden target objects could either be moved from the left to right or right to left. All actions were made with the right hand only. There were two templates used, one for a predictable aligned stimuli, one for predictable unaligned and one for unpredictable unaligned stimuli displays (i.e., the stimuli configuration complexity condition). In all templates, the target objects started in a linear aligned position (either on the left or right of the saggital axis). In the predictable aligned stimuli, participants simply had to move the object from one side of the saggital axis to the other, placing the object in the opposite marked position. In the predictable unaligned and unpredictable unaligned stimuli conditions, participants moved the object and placed them in the positions marked with 'X' for the predictable unaligned condition or 'Z' for the unpredictable unaligned condition (see Figure 3.1).

Participant's movements were recorded using a Vicon motion analyses system (Vicon, Oxford, UK, 120 Hz). Participants were fitted with three reflective markers (5mm diameter), one marker was placed on the trapezium of the right hand, and the second marker was placed on the index finger nail and the third marker was placed on the thumb finger nail (Figure 3.2).

Figure 3.1: A schematic of the experimental set up from overhead. In each condition, a template was used that was attached to the table surface and the participants were informed that they had to move five objects from one side to the other. The five objects were placed on the table positioned in the blank squares and either moved to simple predictable aligned (A), predictable unaligned or unpredictable unaligned configurations (B), both right to left (I) and left to right (II). In all conditions actions started from the hand initiation marker, reached to and grasped the target object, transferred the object across the saggital axis, placed the object in the defined location, and then returned the hand to the start condition, before performing the same sequence again until all objects were relocated.

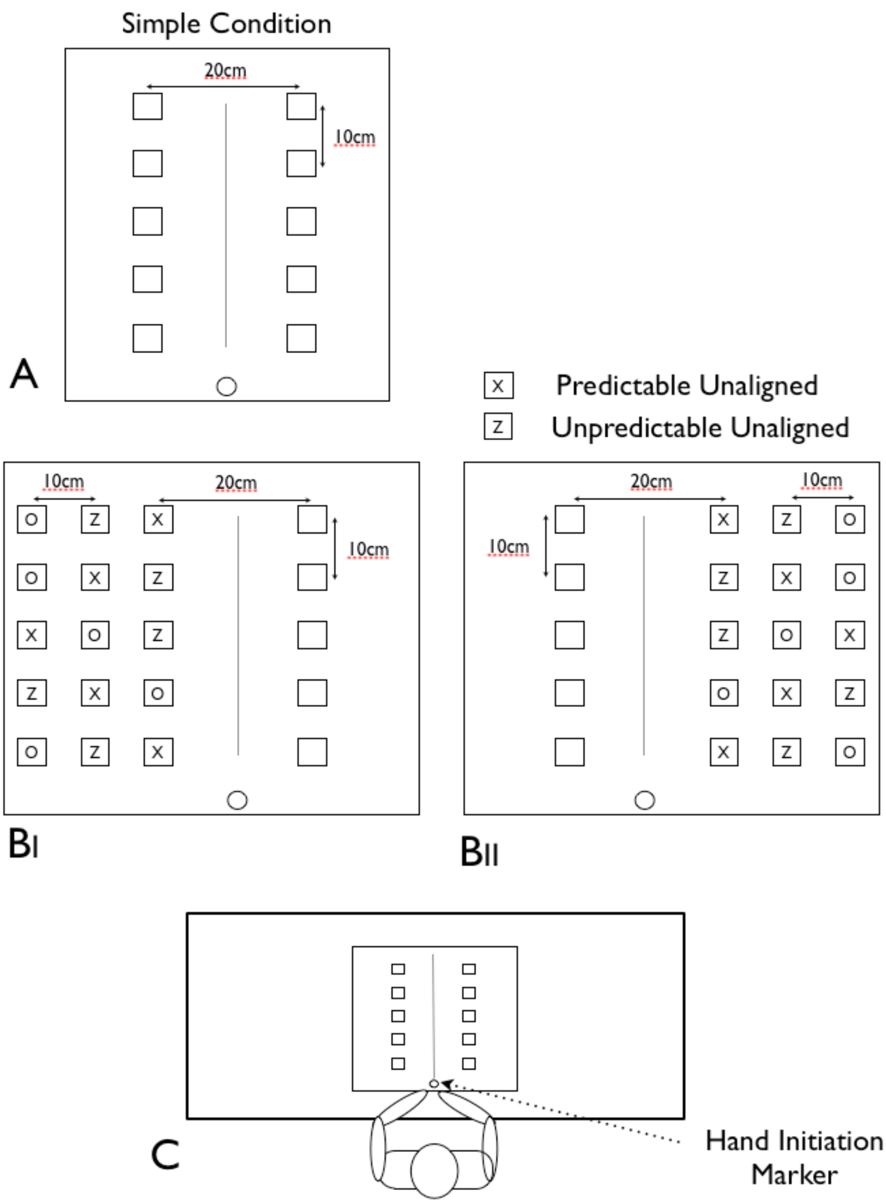
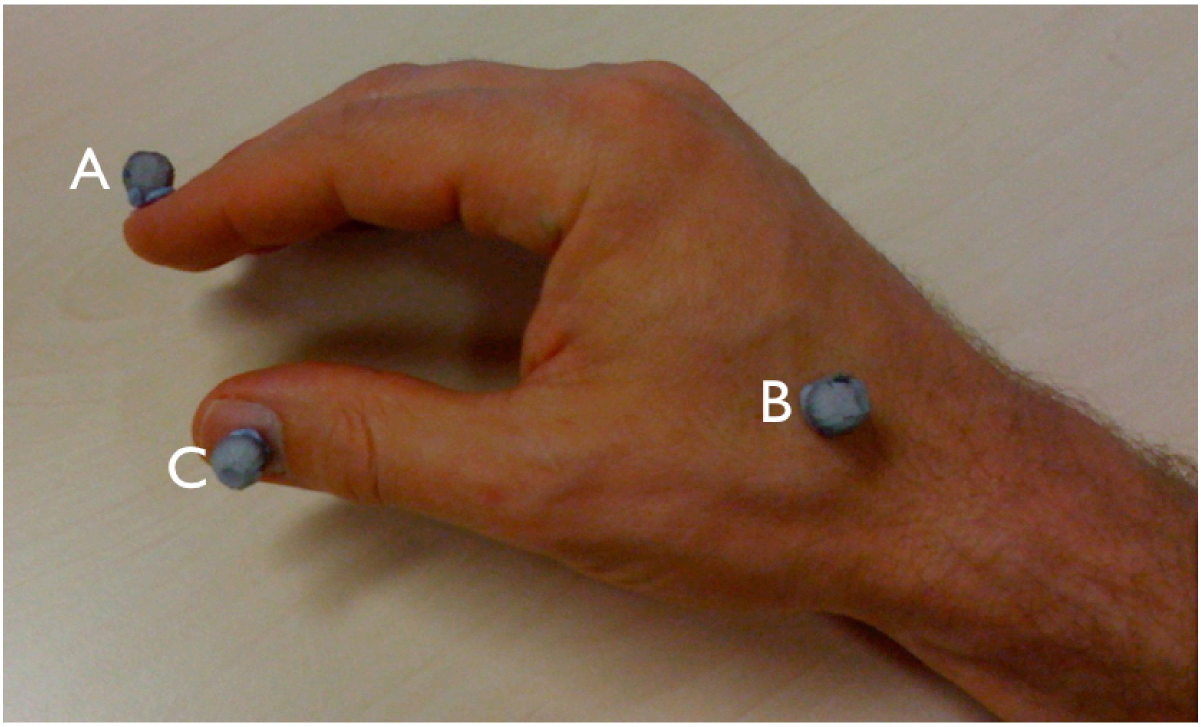


Figure 3.2: The picture shows how the motion tracking reflective markers (A-C) were attached on the participant's hand . The reflective markers were positioned on the tip of the index finger (A), the trapezium (B) and on the tip of the thumb (C).



3.3.3 Procedure

At the beginning of the experiment, participants were given the task instructions and time to familiarise themselves with the wooden objects used in the experiment. They were then provided with a single practice of the experimental task to allow the participants a chance to familiarise themselves with the general instructions. Participants were told that they should aim to complete the task as quickly as possible ensuring that all objects were positioned correctly within the template.

Within the stimuli configuration complexity conditions, the movements of the five objects were considered as five separate responses. For each task, participants initiated their movement from the hand initiation reference, reached, grasped and lifted the furthest target object and transferred it to the opposite side of space, placing it within the marked square, and then returned their hand back to the 'hand initiation marker' and touched it with their index finger. Following completion of each response, participants then started the second response and moved the next furthest object. Therefore, within the task, all five objects were moved in this way with the participant initiating the task themselves (such that the movement of five objects was the overarching aim of the activity, as in the original box and block test). The end of the task occurred when the participant placed their index finger tip on the hand initiation marker after moving the fifth object.

Each stimuli configuration condition was repeated twenty times (with half of the repeats being for movements made from left to right and vice versa). Therefore, each participant conducted the task sixty times (twenty repeats of each configuration condition). The order of these were randomised across participants.

3.3.4 Data Analysis

The independent variables were age group (younger- vs. middle- vs. older aged adults) and complexity condition (predictable aligned vs. predictable unaligned vs. unpredictable unaligned). The dependent variables were Total Time taken to complete the overall movement (i.e., time taken to move all five objects), Reach Time encompassing object selection, reach and grasp, Transfer Time encompassing the removal of the object from one side to the other side of the template, and Return Time encompassing the time taken to return the hand from the object placement to the hand initiation reference marker (ms).

The movements were captured for each complete task. The capture was later separated using computer based waveform analyses to identify and segment the recording into the five responses (i.e., movement of object 1, 2, 3, 4 and 5) and within these, the separate dependent measures. The first part of this was done by segmenting the time from initiation to return of the hand on the hand initiation reference marker for each object movement (with movement start and movement end defined as the point at which the index finger was lifted from the hand initiation reference, reached, grasped and lifted then transferred the target object and returned to contact the hand initiation reference with the index finger). Once the responses were separated, individual components of each response were then separated for each dependent variable component. This included the components: (i) reach to the object (defined as the time between movement initiation from the hand initiation reference marker and object grasp until object lift), (ii) transfer of the object and placement within the position template (defined as the time between object lift until time of object release, after object transfer and placement), and (iii) return of the hand to the start (defined as the time between object release and return to the hand initiation reference).

The mean time Total Time was calculated from the twenty repeats of each condition, and the mean Reach, Transfer and Return times were calculated from the five responses and twenty repeats of each condition. Any data for the separated dependent variables with the overall time outside of a 2.5 standard deviation confidence interval from the mean were removed from all of the analyses to remove outliers. A mixed design Analysis of Variance was used to analyse the data, with between age groups and repeated stimuli configuration complexity condition measures, and a corrected Bonferroni post-hoc analyses were made ($p < 0.05$). In the event that any of the dependent measures showed a significant effect of age group, further analyses were planned that would assess the effects of age for the mean response to each object trial (i.e., 1, 2, 3, 4 and 5)[1]. Analyses were performed using SPSS v16.0 (SPSS Inc. Chicago, Illinois, USA).

3.4 RESULTS

The results are first reported for the Total Time taken to complete the overall movement, followed by the separated analyses of Reach, Transfer and Return Time.

3.4.1 Total Time

Analysis of the Total Time to move all five objects showed no effect of age ($F[2,57] = 0.61$, $p = 0.55$), but did show a significant main effect for stimuli configuration complexity ($F[2,56] = 7.68$, $p < 0.01$). A Bonferroni post-hoc analysis of stimuli configuration complexity showed that the unpredictable unaligned condition was significantly slower than both the predictable aligned and predictable unaligned ($p < 0.05$), but that the predictable unaligned was not significantly slower than predictable aligned ($p = 0.09$). There was no interaction ($F[4,112] = 0.45$, $p = 0.77$) (See Figure 3.3a).

3.4.2 Component Analyses

Analysis of the Reach Time showed a significant main effect of age ($F[2,57] = 3.91$, $p < 0.05$), but no effect of stimuli configuration complexity ($F[2,56] = 0.65$, $p = 0.53$). A Bonferroni post-hoc analysis of age group showed that the older adults were significantly slower than the young and middle-aged adult groups ($p < 0.05$). There was no significant interaction ($F[4,112] = 0.66$, $p = 0.62$) (See Figure 3.3b).

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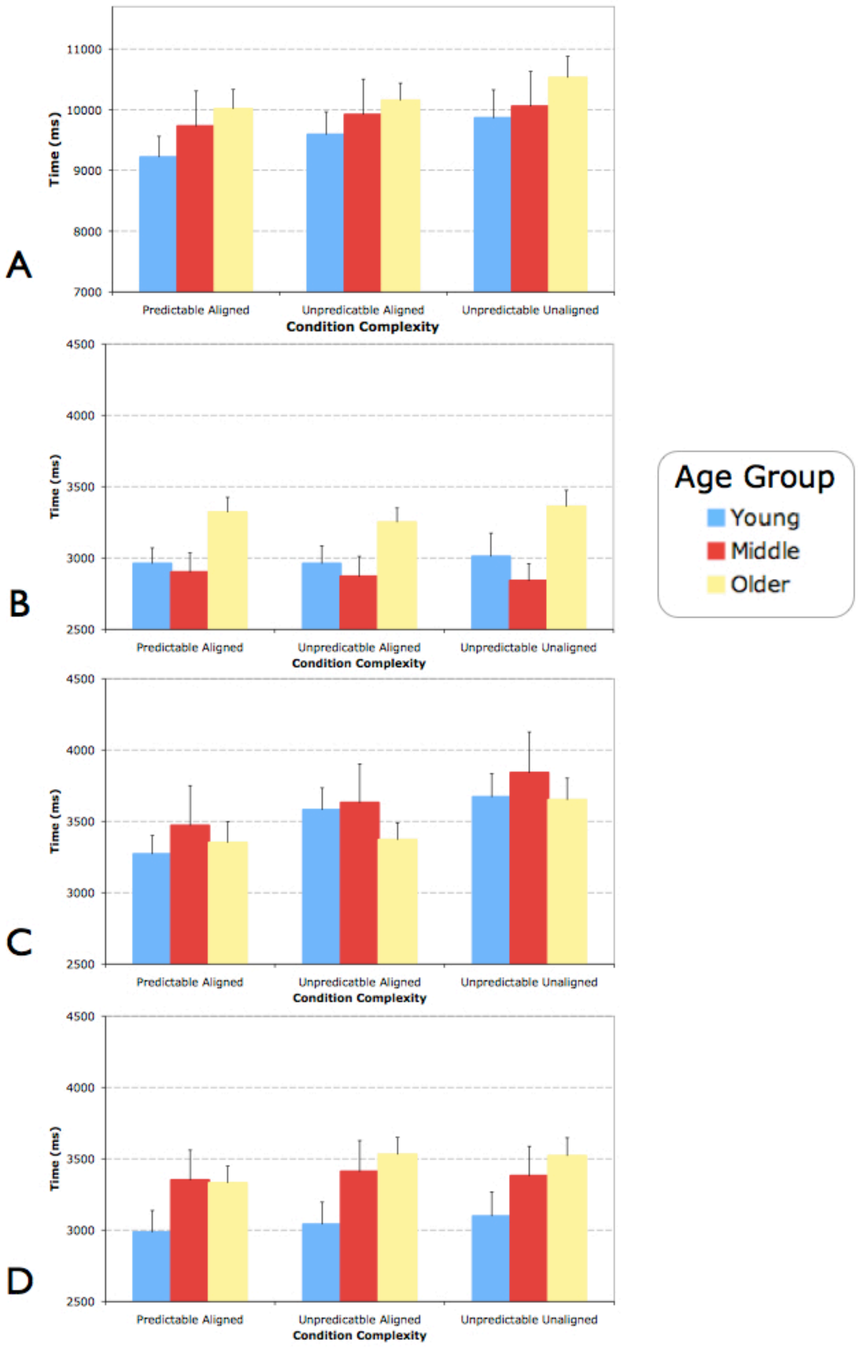
[1] This analysis was not carried out routinely as it was considered that the number of trials per type would be too few for the analyses.

Analysis of the Transfer Time showed no effect of age ($F[2,57] = 0.61$, $p = 0.55$), but did show a significant main effect for condition complexity ($F[2,56] = 19.26$, $p < 0.01$). The Bonferroni post hoc analysis for stimuli configuration complexity showed increasingly slower Transfer Times with condition complexity ($p < 0.05$). There was no significant interaction ($F[4,112] = 1.76$, $p = 0.14$) (See Figure 3.3c).

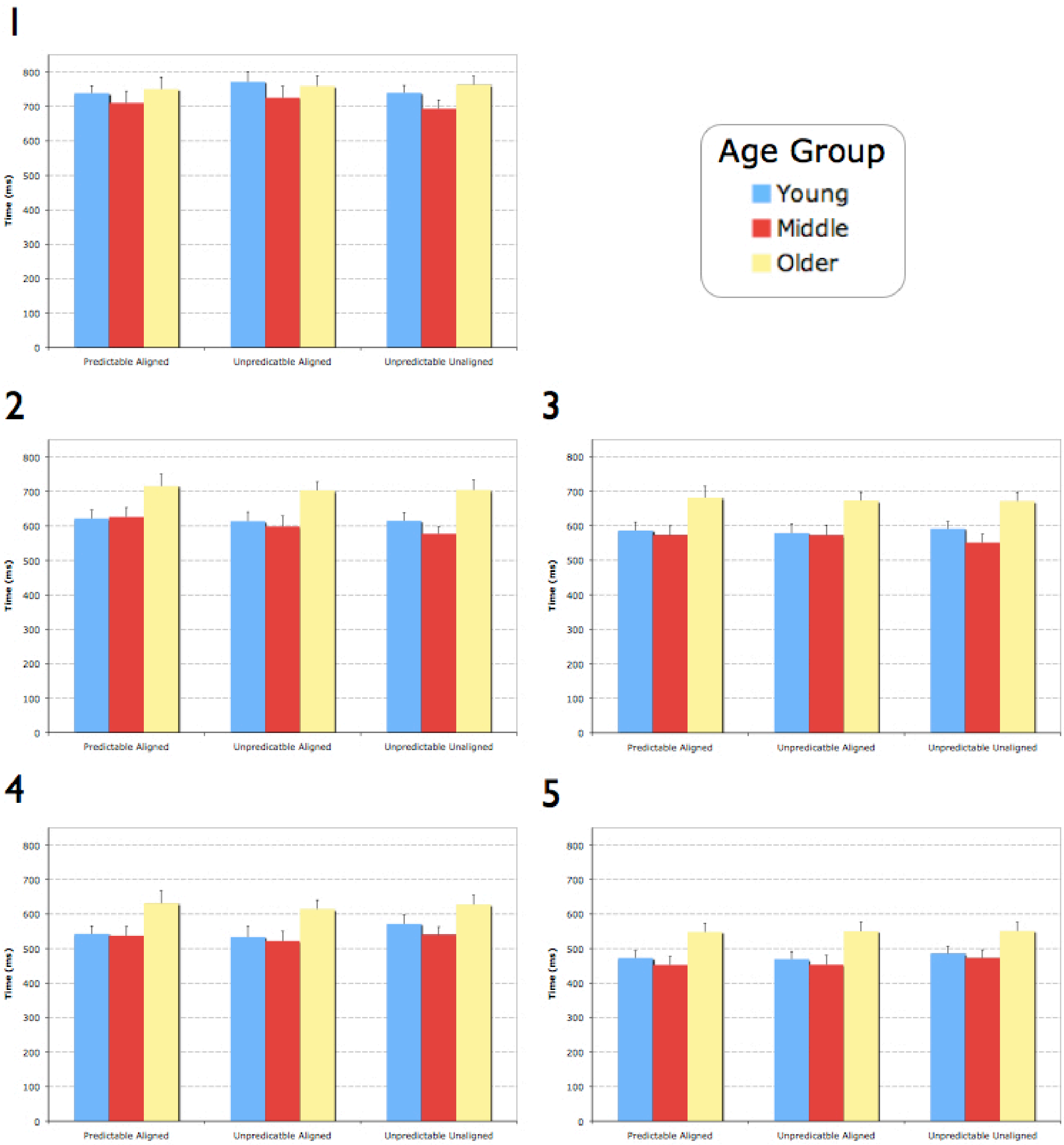
Finally, the analysis of Return Time showed no effect of age ($F[2,57] = 1.90$, $p = 0.16$), but did show a significant main effect for condition complexity ($F[2,56] = 4.39$, $p < 0.05$). The Bonferroni post hoc analysis for condition complexity showed a significant difference between the predictable aligned and unpredictable unaligned conditions ($p < 0.05$). There was no significant interaction ($F[4,112] = 0.94$, $p = 0.45$) (See Figure 3.3d).

Figure 3.3: Mean time to complete the movement for four repeated tasks to the five objects for the stimuli configuration complexity conditions (with Standard Error bars): (A) Total Time; (B) Reach Time: select, reach and grasp the five objects; (C) Transfer Time: time to transfer and relocate the five objects; (D) Return Time: time to reach back to the hand initiation marker after object relocation.



In all of the analyses, there was only a significant effect of age group on Reach Time. As planned, a further analysis of the age effect was conducted by considering the effect of age for each response (i.e., for actions to objects 1, 2, 3, 4, 5; with the dependent measure mean based on the twenty repeats of each trial and separate ANOVAs conducted on each response). The analyses showed no significant effect of age for actions to object 1 ($F[2,57] = 1.00$, $p = 0.37$) but did show significant age group effects for actions to objects 2, 3, 4 and 5 (object 2: $F[2,57] = 5.34$, $p < 0.01$; 3: $F[2,57] = 5.89$, $p < 0.01$; 4: $F[2,57] = 3.75$, $p < 0.05$; 5: $F[2,57] = 4.49$, $p = 0.05$). The Bonferroni post hoc analyses for age group effects showed slower reach times for responses made to objects 2, 3 and 5 between the older adult group and both the young and middle aged adult groups ($p < 0.05$), whereas the post hoc analysis of reach time for object 4 only showed a significantly slower reach time between the older and middle aged adult groups ($p < 0.05$). There were no significant differences between the young and middle adults groups for responses to all objects (2: $p = 1.00$; 3: $p = 0.56$; 4: $p = 1.00$; 5: $p = 1.00$) (See Figure 3.4).

Figure 3.4: Mean reach time (with Standard Error bars) for responses to the five objects, for the different age groups and for each stimuli configuration complexity condition. Responses to objects 1 – 5 are labelled (1); (2); (3); (4); (5); respectively.



3.5 DISCUSSION

Based on the data from Chapter 2, and from the literature, in the present chapter we developed a simple movement response task based on the box and block test that in addition varied stimuli configuration complexity. We hypothesised that movements would generally be slower with increased age, but expected that the first and second phases of movement (i.e., selection, reach and grasp of the target object or transfer the target object to a new location respectively) might be slower than the third (i.e. return the hand to the end position) as they contained visual attentive selection components that may be influenced by age related changes independent to movement. Additionally, we hypothesised that with increased age participants would become even slower when responding in the complex stimuli configurations, as selection would be of greater difficulty.

The data were not completely consistent with these expectations. That is, analysis of total movement time showed no significant age group effect. However, analysis of the mean total reach time did show a significant effect of age, whereby the older-aged adult group were significantly slower than the younger and middle-age adult groups. Analyses of the mean total transfer and mean total return times showed no effects of age. This suggests that the age effect on movement speed was not general and was rather based on an additional factor. In a planned post-hoc analysis, we tested responses to each object response. For reach time there were significant age group effects for actions to objects 2, 3, 4 and 5, but not to object 1. Bonferroni analyses of reach time to these objects on the whole showed that the older-aged adult group were slower compared to the young and middle-aged adult groups. This finding suggests that the slower movements might correspond to a cognitive resource selection difficulty with increased age. That is, when selection was required to be made online and within the ongoing movement, there was slowing.

In these data, we also tested whether stimuli configuration complexity further modulated the age effect. The data showed significant effects of stimuli configuration complexity on the overall total time taken, with the slowest movement made to the most complex condition (unpredictable unaligned) and the fastest made to the simplest condition (predictable aligned). There was however no effect of stimuli configuration complexity for the dependent measure of reach time to the object or return time, but there was an effect for transfer time. Therefore, the overall slow movement in the total time measure appeared to be caused by the slower transfer time of the object. Interestingly, there were no interactions between age and stimuli configuration complexity. This latter finding is at odds with the suggestion made in the previous paragraph. That is, the clear and consistent effect of age was only observed in the mean reach time (encompassing object selection, reach and grasp). The effect was a consequence of the older aged adult group having slower reach time movements for objects 2,3,4, and 5 but not 1, it was proposed that the slower movements were due to selection difficulties with increased age. The rationale for this proposal was made since all objects 1-5 required a similar reach and grasp response, however, the absence of a slower reach time for object 1 was likely due to the participants opportunity to pre-plan object selection before initiation of hand movement at the beginning of each task. This differs to responses made to objects 2,3,4 and 5 where online visual selection was required. This interpretation is also supported by the findings from Chapter 2 of this thesis (i.e. that selection might underlie the slower movement with increased age effect, as suggested by Trail Making Task data). Therefore, the fact that complexity of the stimuli configuration appeared to be independent of age might be explained by the older participants choosing a strategy to move slower on the responses to objects 2-5 in reach time allowing more time for selection irrespective of the stimuli configuration complexity condition (i.e., so no age interaction with stimuli configuration complexity found). It is worth noting that all adults were slower on the transfer time, showing that the complexity of the stimuli configuration did determine the speed of movement.

These data clearly demonstrated that the relationship between age and movement dexterity could be modulated by visual attentive selection factors. This is potentially interesting for further studies as it could be the case that other cognitive deficits associated with ageing might also impact on movement speed. That is, these data showed no effect of age or stimuli configuration complexity on the return time dependent measure, suggesting that the age and dexterity relationship might not be as generalised as originally considered. As well as reduced function in selective attention (and inhibition), older compared to younger adults might also have reduced cognitive capacity and function reducing the effective use or speed of online feedback for guidance or correction (i.e., due to slower visual feedback processes; Carnahan et al., 1998; Sarlegna et al., 2006). Also, with increased task demands, reduced cognitive capacity for planning might also cause apparent motor slowness that is not actually a movement issue, but rather caused by the lack of cognitive resource to carry out the task (Ketcham et al., 2002; Light & Spirduso 1990; Salthouse 2000). Further support for this suggestion can be drawn from observations in previous studies that have shown an increased dependence of older aged adults on visual feedback in the control of actions such as aiming and posture (Chaput & Proteau, 1996 a, b; Hay et al., 1996). Chaput & Proteau (1996) suggest that given enough time, older aged adults are able to use online visual information to guide and correct the position of their hand in relation to an object. Similar to our suggest of a selective attention deficit with age, one could argue that older aged adults slow movements purposefully in order to allow more time to use sensory information effectively (Teasdale et al., 1991). On the basis of the findings, we suggest that more studies need to be carried out that consider the effects of ageing on cognition, and how these effects relate to the relationship between ageing and movement dexterity. At the very least, we suggest that all future studies that aim to measure the relationships between age and movement dexterity should test participant's cognitive processing ability, including general speed in measures of attention, selection or inhibition. These measures could be used as a covariate to help moderate the effects of cognition on the age and dexterity relationship.

One issue in the data presented here was that it did not overall replicate Chapter 2 or the literature in that here there was no effect of age on the total time to complete the task. The likely reason for this effect was because there were not enough responses within the task to cause the effects. That is, if in Chapter 2, the slower movements in the box and block task were due to reduced selective attention with increased age causing slowed actions in the reach to the object only, then the fact that many blocks were moved within the task likely lead to an overall total time that was slow. Here, only five objects were moved, and perhaps this was not enough for the sum of the reach time to cause a significant increase in total time. For example, previous studies that have shown age effects for many object relocations over time periods of 30 seconds in the Purdue Pegboard or 60 seconds in the Box and Block Tests, whereas in the present study, the average total movement time ranged between 8-13 seconds. Therefore, in order to improve the measure in the future, either the task should involve moving more blocks (e.g., 10-30) or have a more older participants to increase the power of the analyses. Also in would be interesting to be able to categorise older adults into 10 year age groups (i.e. 60-70, 70-80 and 80+ years) to look for possible changes that may be occur between young old, middle old and older old aged adults.

In the study conducted here, we opted to use three groups of different aged adults. In the Introduction to this chapter, we explained the rationale for choosing this. The data showed the value of the method as we found that the age effect was caused by the older-aged group being slower than the younger and middle aged adult groups. By comparing these groups, we were able to understand that the effects were not necessarily gradual, but rather reflect a change that occurred only in the older adult group. To test this further, future studies should consider separating the age groups into smaller discrete age groups (e.g., 20-30, 50-60, 60-70, 70-80 years) and testing how the measured effects vary across the groupings (i.e., whether the effects are gradual or discrete).

In conclusion, the current study suggests that the age effect on movement speed dexterity seems to be specific rather than general movement slowing, and perhaps attributable to a attention selection difficulty with increased age. When selection was required to be made online, these data showed that only the older adults movements were slowed. However, the experiment needs some improvements to demonstrate the effect more robustly and further clarification is needed to understand how other cognitive processes related to ageing impact on movement dexterity.

CHAPTER 4 - EFFECT OF PREVIEW ON VISUAL SEARCH ACROSS DIFFERENT AGED ADULTS

4.1 ABSTRACT

The ability to select and process visual stimuli for action requires attention. In order to select a particular stimulus from an array of distracters, the stimuli to be selected is thought to be marked and the distracter items inhibited. This is considered to be a top-down process that is mediated through selective attention. Previous research in the literature has shown that attention ability decreases with increased age. On the basis of the data from Chapters 2 and 3, we hypothesised that older-aged adults would show impairment in selective attention compared to younger-aged adults. We tested this using a standard visual search with preview paradigm whereby participants are advantaged by inhibiting preview distracters. If there is any deficit in selective attention, the inhibition of preview items will be impaired and as such, the speed of selection reduced. We report one experiment that compared simple and preview search tasks for a younger- and older-aged adult participant group. The results showed that the older aged adult group had slower reaction times, had less efficient search slopes and made more time-out errors for both the simple and preview conditions compared to the younger aged adult group. The findings are discussed in terms of how slower less efficient search may reflect a general slowness in selective attention, and how this may impact on dexterity.

4.2 INTRODUCTION

In Chapter 2, we reported data showing that older-aged participants made slower actions on the Purdue Pegboard and Box and Block standard dexterity measures compared to participants from younger aged and middle-aged groups. Furthermore, in Chapter 3, we reported data showing that the slower movements were not general, but rather related to actions that required object selection (i.e., reach time). This was shown by reach time being particularly slow during the ongoing movement (i.e., for movements with the 2nd, 3rd, 4th and 5th objects in a sequence) and by the finding that transfer time and return time showed no age effects (i.e., participants of all ages moved at the same speed for these phases of action). From these data, we suggested that the slower movements reported in Chapter 2, and similar in the literature (e.g., Desrosiers et al., 1995, 1999; Perianez et al., 2007) might be a consequence of deficits in selective attention of the object to act to rather than a motor impairment. That is, we suggested that the older adult participant group might be slower because of slowness in object selection for action. This suggestion is supported from the data in Chapter 2, where older aged participants were slow in the Trail Making Task, a task that measures aspects of selective attention. On the basis of these data, we aimed to test whether participants of increased age show impairments in selective attention.

In everyday life, we continuously view an enormous amount of visual information. In order to interact with items that we see, it is necessary to limit information processing by selecting or focussing attention to the item that we intend to interact with. Doing so is believed to optimise attention resource that is capacity limited (Allport, 1987). Evidence in support of this idea comes from experiments showing attention resource competition (e.g., Stroop, 1935) or an inability to detect changes within complex successive visual scenes or real world interactions (e.g., Simons, 1996; Simons & Levins, 1997, 1998). In both examples, resource limitation leads to selective attention of the target stimuli (i.e., word or scene), with either the distracter stimuli competing for attention resource, or rendering the participant blind to changes in distracter information.

A common measure of selective attention is visual search (Watson & Humphreys, 1997). In these tasks, participants are presented with a single target and various numbers of distracters. Typically, the participant searches the display and responds to the target (usually a choice of two possible items). There have been various manipulations of the task for different aims. In the introduction here, I will focus on the modifications that have used preview items to measure processes of selective attention or inhibition (of preview items). The first paper to report the effects of preview on search was that by Watson & Humphreys (1997). They argued that the ability to select and process new visual stimuli would be advantageous in generating and maintaining an up to date internal representation of the world for early detection of potential stimuli. They demonstrated this by comparing the performance in a single feature condition (search for a blue H among blue A's), a conjunction feature condition (search for a blue H among green H's and blue A's) and a preview feature condition that was identical to the conjunction condition, but with a preview of distracter items (the green H's) presented 1000ms prior to the appearance of the other items (search for a blue H among blue A's and the previous presented green H's). The results showed that search reaction time was improved or benefited from the preview in comparison to the conjunction condition, in which all elements were simultaneously presented. Importantly, search efficiency (i.e. defined as the minimum time to search and select a visual item) in the preview condition was similar to that of the single feature condition. These data provided evidence that participants were able to select and inhibit the preview stimuli allowing participants to prioritise selective attention to the new stimuli. They proposed that the visual system prioritised new information through 'visual marking', where the preview stimuli location or properties were inhibited so that they no longer competed for attention (see also Braithwaite, Humphreys, & Hulleman, 2005; Watson & Humphreys, 1997, 1998, 2000, 2002, 2005; Watson, Humphreys, & Olivers, 2003).

Consistent with the data reported in Chapters 2 and 3, and in some of the Discussion of Chapter 3, the literature show the general finding that as participants age, attention capacity appears to decrease (see for example Talsma, Kok, & Ridderinkhof, 2006; McDowd & Shaw, 1999). Hasher and Zacks (1988) suggested that the apparent reduction in attention capacity might rather reflect decline in the efficiency of inhibitory processes. On this basis, Watson and Maylor (2002) suggested that visual marking should be impaired given that the process are thought to be based on inhibitory selection processes. The consequences of being unable to inhibit distracters, especially in preview, would lead to resource competition for attention, resulting in increased time to search for a new target (i.e., as more distracters will need to be searched through). Evidence in support of this comes from a number of studies that have used the visual search and marking / inhibition paradigm with participants of different ages (e.g., Humphreys & Kramer, 1997; Kramer & Atchley 2000; Kramer et al., 2000; Folk & Lincourt, 1996; Plude & Doussard-Roosevelt, 1989; Treisman & Sato, 1990; Watson & Maylor, 2002). For example, In experiments that tested older compared to younger aged adults, Kramer & Atchley (2000) reported reduced efficiency in search slopes, Folk and Lincourt (1996) reported less efficient inhibition of distracters defined by common coherent motion, and Kramer et al., (2000) reported less efficient inhibition of eye movements towards task irrelevant abrupt luminance onsets. It is argued by Watson and Humphreys (1997) that an additional cost in overall RT during the preview conditions exists due to visual marking requiring the allocation of limited capacity attentional resources that led to a delay in the initiation of search when new items appear. Watson and Humphreys (2002) provided similar results showing that older participants could fully ignore old items and restrict their search to new stimuli in static displays. However, they observed that older participants were not able to inhibit new items in moving displays, suggesting that the increased attentional demand in moving displays was too great for older participants. From these findings, it seems that ageing likely influences visual marking since it relies on selective or inhibitory attention processes.

4.2.1 Hypotheses

From these data, it follows that reduced attention or inhibition ability with age will lead to an increased demand on attention resources, which will cause the participant to respond at a slower speed. Therefore, the primary purpose of this study was to further investigate the effects of ageing on selective attention through established experiments measuring the speed of visual search and the relative benefit of preview stimuli. We hypothesised that older compared to younger-aged adults would be generally slower to select target objects in a search display, show more errors when making the search, and not normally benefit from the preview items due to impairments in selective and inhibitory attention processes.

4.3 METHODS

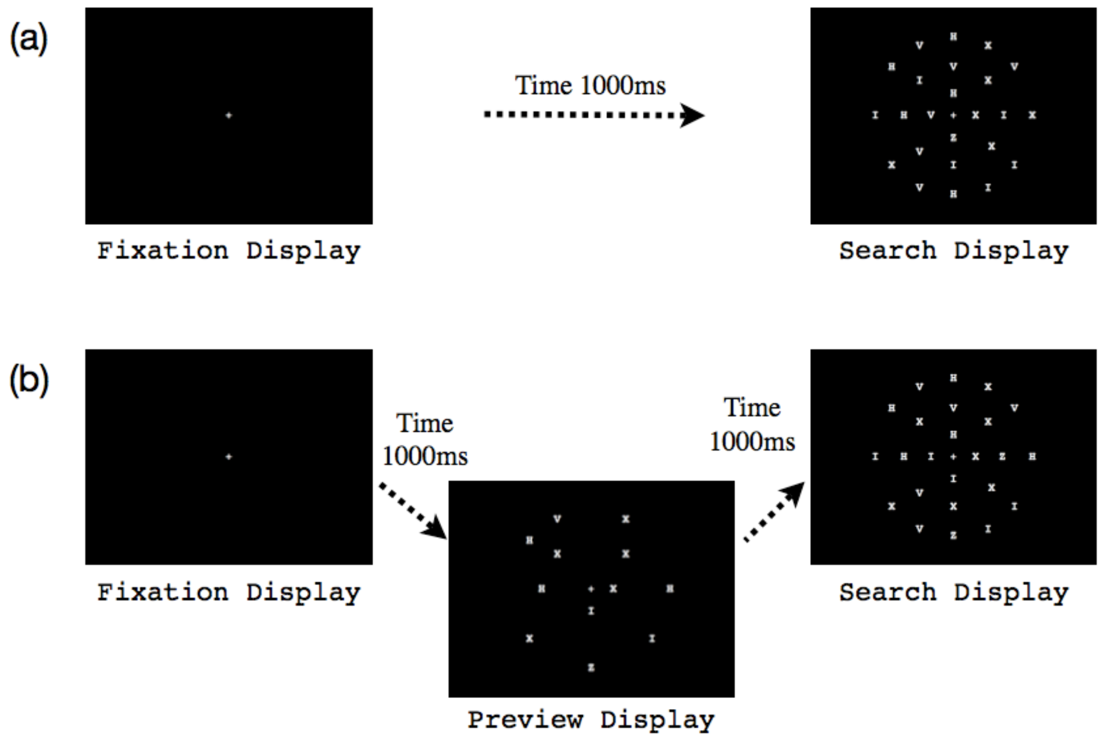
4.3.1 Participants

The study tested 54 participants that were separated into a younger and older age group. The younger adult age group contained 28 participants (16 male, 12 female) aged 22.4 ± 3.3 years, and the older adult age group contained 26 participants (10 male, 16 female) aged 65.0 ± 10.2 years. The younger adults were mostly students from the University of Birmingham and the older adults were recruited from within and around the City of Birmingham (West Midlands, UK). The participation inclusion criteria was that participants were aged above 18 years, had normal or corrected-to-normal vision and did not report any muscular skeletal or neurological problems on a self-report medical history questionnaire (see Appendix 1). The School of Sport & Exercise Sciences, University of Birmingham Ethics Board approved the experiments in accordance with the 1964 Declaration of Helsinki.

4.3.2 Stimuli and Apparatus

Stimuli were generated and presented using a custom computer programme that was written in Turbo Pascal (v7) and run on a 1-GHz Pentium III-based PC and a 17-inch super VGA monitor at a resolution of 800 X 600 pixels with a 75-Hz refresh rate (as used in Braithwaite & Humphreys, 2003; 2007). Participants sat directly in front of the monitor at a viewing distance of approximately 75cm. Responses were made using computer keyboard placed directly in front of the participant.

Figure 4.1: An example of the simple (a) and preview (b) search stimuli. In both, participants were required to search for the target letter (Z or N) that always appeared in the final search display. Both types of trial started with a fixation cross display. In the simple search trials, all of the search stimuli were presented 1000ms from the start of the trial. In the preview search trials, preview stimuli were presented 1000ms from the start and the rest of the search stimuli were presented 1000ms later (i.e., 2000ms from the start). In both types of trial, the search display was presented for 10 seconds, or until a response was made by the participant.



The stimuli consisted of luminance-matched (white) letters displayed on a plain black screen background. The letters had an approximate width of 6mm and height of 8mm. The letters were randomly assigned to an invisible 48-character item cell, circular matrix consisting of three concentric circular ring grids. The distance from the central fixation to the middle of the cells of the first, second and third rings were approximately 20, 40 and 60mm (and contained 8, 16 and 24 cells respectively; See Figure 4.1). In each stimuli display, one target and between three and forty-seven distracters were displayed. The target stimulus was either an upper case N or Z letter (equally presented across the experiment). The distracter stimuli consisted of the upper case H, I, V and X letters. Search displays were generated by randomly positioning the letters within the middle of individual cells within the matrix. For each display, any distracter letter could repeatedly occur with the restriction that at least one distracter of each type was presented (with the exception of the four item display size). The stimuli consisted of 4, 8, 12, 16, 24, 36 and 48 display items, with the more distracter items increasing the complexity of the search task.

4.3.3 Procedure

The experiment consisted of two separate conditions that tested simple versus preview search. The simple search stimuli consisted of a single target presentation with the randomly selected distracter letters (e.g. consisting of one target and either 3, 7, 11, 15, 23, 35 or 47 distracters). The preview search stimuli were similar to the simple search, but half of the distracter letters were displayed 1000ms before the target and remaining distracters (i.e., providing a preview display of these first distracters) (see Figure 1). Before each condition was run, a short practice block of 20 trials was given to the participant to familiarise them with the study.

At the beginning of each trial, the participant was asked to fixate on the fixation cross. In the simple search condition, they were asked to remain fixated on the cross until the search stimuli were presented. The participants were then able to freely move their eyes to search the visual display. In the preview search, participants were asked to remain fixated on the cross through the fixation and preview displays, and only move their eyes to begin search when the search display was presented. In both simple and preview search conditions, once the participant had identified the target (N or Z), they had to press the corresponding letter on the keyboard as quickly and accurately as possible. Reaction times were calculated as the time interval between the onset of the first letter displayed in the search display and the keyboard response (ms).

Each participant completed 420 experimental (i.e., 30 trials for each trial type) and 40 practice trials. The experimental conditions were run in a counterbalanced manner across participants (i.e., with half of the participants first receiving the simple and then preview search condition and vice versa). Trials were randomised for each condition.

4.3.4 Data Analysis

In the first part of the analysis, the effects of age group (younger vs. older group), search condition (simple vs. preview) and display size (4, 8, 12, 16, 24, 36, 48 items) independent variables on visual search performance was tested using the dependent measures of reaction time[2] (RT; ms), percentage of correct responses (%), percentage of errors caused by pressing the incorrect key (key error; %) and percentage of errors caused by making no response within the 10s display limit (timeout error; %) . For these analyses, a mixed, between (age) and repeated (condition and display size) measures Analysis of Variance was used.

The second part of the analysis used methods more commonly used in the visual marking literature. We calculated the slope and intercept of RT as a function of display size for age group and search conditions. Search slope was used as a measure of search efficiency (i.e., a

[2] Mean reaction time was calculated from trials where the participant made a correct response.

shallower search slope would mean better search efficiency) and intercept was used to establish the speed by which the search began (as carried out in Watson & Humphreys, 1997; Watson & Maylor, 2002). For these analyses, a mixed, between (age) and repeated (condition) measures Analysis of Variance was used. In addition correlations of RT and display size were calculated for each visual search condition, though no analyses were carried out on these.

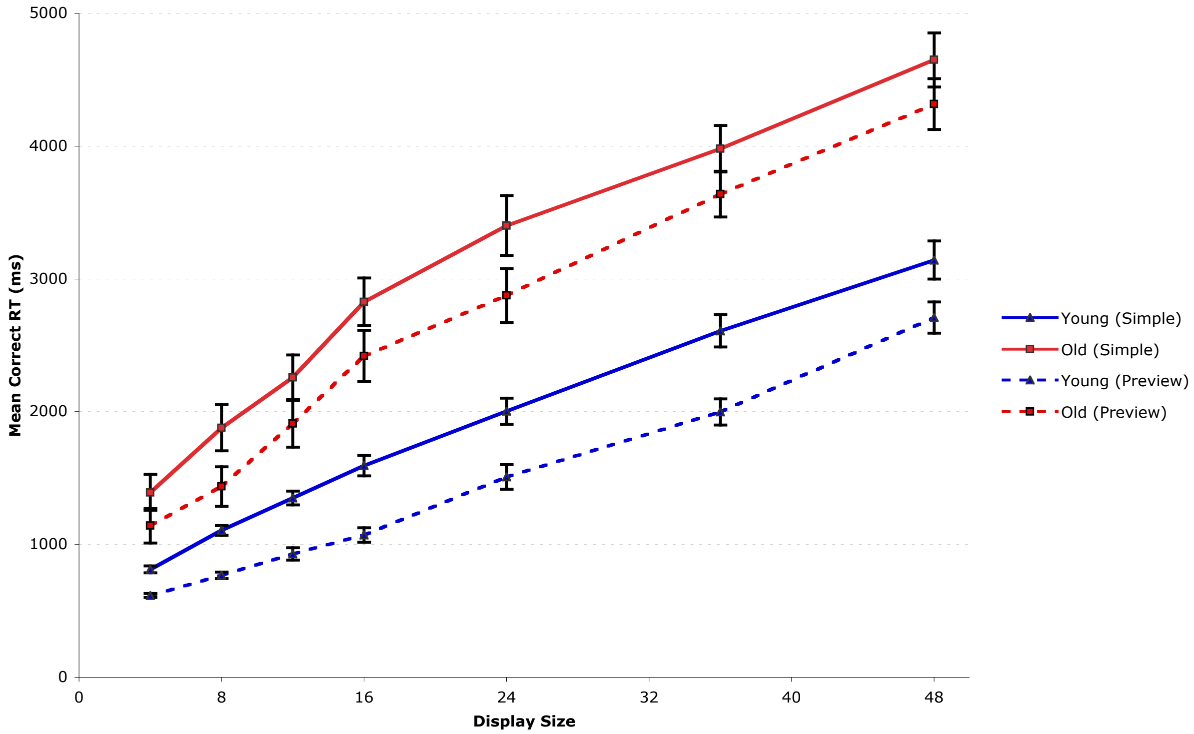
In the visual search and preview conditions, search slopes were calculated using the true number of items in the search display. With this procedure, if search efficiency in the preview condition were lower than the simple search baseline, then this would show evidence of the ability to inhibit the preview items. Alternatively, if search efficiency in the preview condition match those of the baseline, then this would show evidence that the preview items were not inhibited and search instead was made to both the new and preview items. The most sensitive measure of visual marking is to compare preview search with the corresponding baseline for each group separately, thus using a within subjects analysis (Watson & Maylor, 2002). Any reaction time data faster than 200ms or outside of a 2.5 standard deviations confidence interval were deleted from all of the analyses.

4.4 RESULTS

4.4.1 Reaction Time and Error

Analysis of reaction time showed significant main effects for age group ($F[1,52] = 50.8$, $p < 0.001$), search condition ($F[1,52] = 118.7$, $p < 0.001$) and display size ($F[6,47] = 464.5$, $p < 0.001$). This showed that there was a faster reaction time for the younger than older aged adults, and for preview than simple search conditions. Bonferroni post hoc analyses for display size showed that reaction time increased linearly with increased display size ($p < 0.05$). There were two significant interactions. These were between age group and display size ($F[6,47] = 19.3$, $p < 0.001$) and between search condition and display size ($F[6,47] = 2.4$, $p < 0.05$). To analyse the interactions, separate ANOVAs were run for each display size. For the age group and display size interaction, all individual analyses for each display size showed significant age group effects (display size 4: $F[1,53] = 18.7$, $p < 0.001$; 8: $F[1,53] = 21.4$, $p < 0.001$; 12: $F[1,53] = 32.3$, $p < 0.001$; 16: $F[1,53] = 50.8$, $p < 0.001$; 24: $F[1,53] = 42.0$, $p < 0.001$; 36: $F[1,53] = 70.9$, $p < 0.001$, and; 48: $F[1,53] = 50.1$, $p < 0.001$). Similarly, the search condition and display size interaction also showed significant search condition effects for each display size (display size 4: $F[1,107] = 4.5$, $p < 0.05$; 8: $F[1,107] = 8.7$, $p < 0.01$; 12: $F[1,107] = 6.3$, $p < 0.05$; 16: $F[1,107] = 6.4$, $p < 0.05$; 24: $F[1,107] = 6.0$, $p < 0.05$; 36: $F[1,107] = 5.6$, $p < 0.05$, and; 48: $F[1,107] = 3.0$, $p = 0.09$) (see Figure 4.2).

Figure 4.2: The data show the mean reaction time (RT) with standard error for correctly detecting the searched target stimuli. The figure presents age group (younger-adult vs. older-adult), search condition (simple vs. preview), and display size (4, 8, 12, 16, 24, 36 and 48 items).

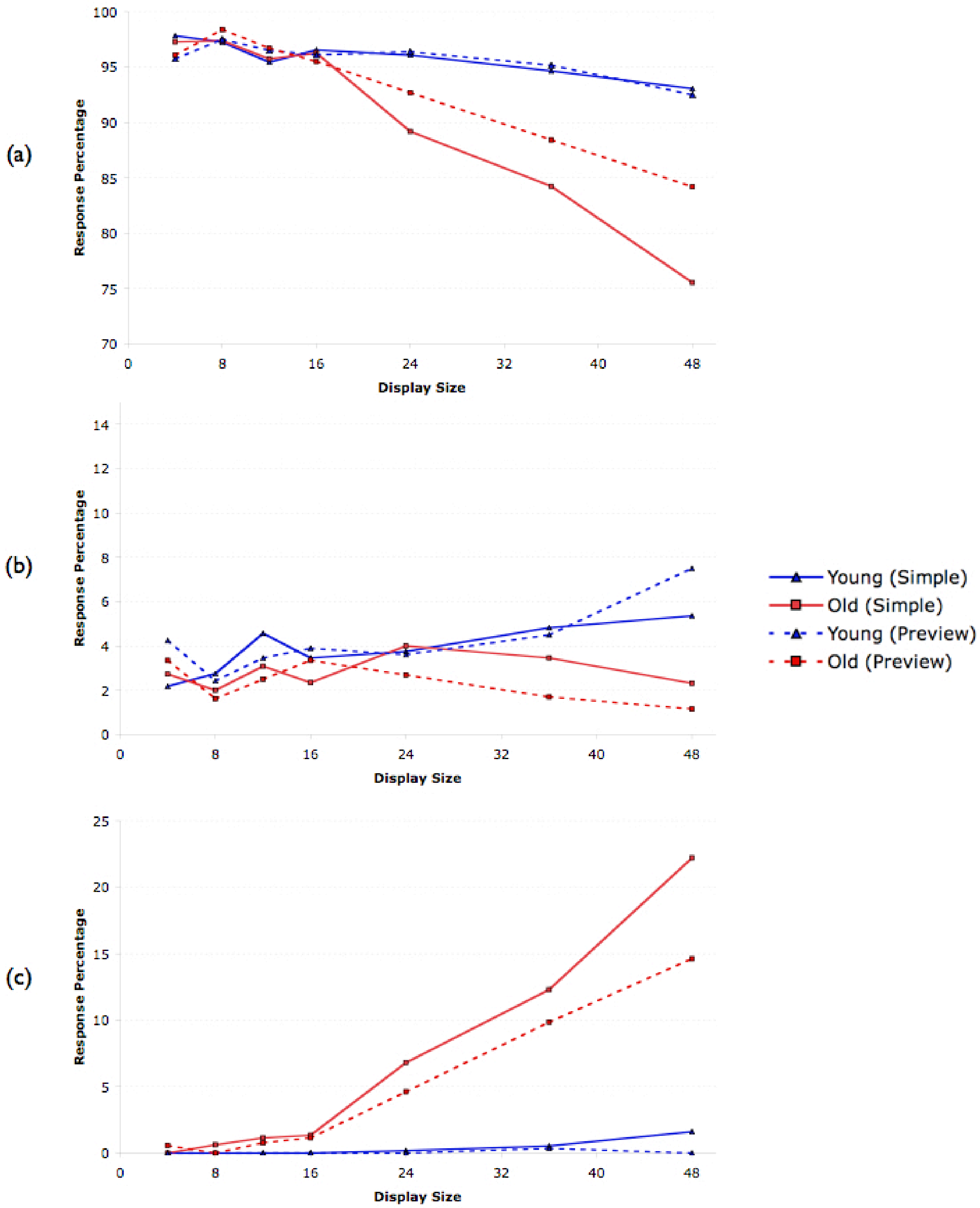


Analysis of the percentage of correct responses showed significant main effects for age group (F[1,52] = 7.9, p < 0.01) and display size (F[6,47] = 18.8, p < 0.001), and no effect of search condition, (F[1,52] = 2.2, *p* = 0.14). A Bonferroni post hoc analysis for display size showed that percentage of correct responses decreased with increased display size (p < 0.05). The analysis showed one significant interaction between age group and display size, (F[6,47] = 6.6, p < 0.001). This was analysed by running separate ANOVAs for each display size. These analyses only showed significant age group effects for display sizes of 24 items or greater (display size 4: F[1,53] = 0.0, p = 0.92; 8: F[1,53] = 0.4, p = 0.56; 12: F[1,53] = 0.1,

$p = 0.82$; 16: $F[1,53] = 0.1$, $p = 0.75$; 24: $F[1,53] = 7.7$, $p < 0.01$; 36: $F[1,53] = 9.8$, $p < 0.01$, and; 48: $F[1,53] = 28.0$, $p < 0.001$) (see Figure 4.3a).

To test the types of error made by the participants, the percentage of errors caused by pressing the incorrect key (key error) or by making no response within the 10s display limit (timeout error) were analysed. The analysis of key error percentage showed significant main effects for age group ($F[1,52] = 7.9$, $p = < 0.01$) and display size ($F(6,47) = 3.1$, $p < 0.05$), but no effect for search condition ($F[1,52] = 2.2$, $p = 0.14$). Analysis of timeout error percentage showed significant main effects of age ($F[1,52] = 31.2$, $p < 0.001$), display size ($F(6,47) = 15.7$, $p < 0.001$) and search condition ($F[1,52] = 5.1$, $p < 0.05$). In both analyses Bonferroni post hoc analyses showed that error responses increased linearly with increased display size ($p < 0.05$). In both key and timeout error percentage analyses, there were significant interactions between age group and display size (key error: $F[6,47] = 6.6$, $p < 0.001$ and timeout error: $F[6,47] = 12.8$, $p < 0.001$). As in the previous data, the interactions were analysed by running separate ANOVAs for each display size. For the key error analyses, there was only one reliable effect of age on the largest display size (display size 4: $F[1,53] = 0.1$, $p = 0.87$; 8: $F[1,53] = 1.3$, $p = 0.25$; 12: $F[1,53] = 1.4$, $p = 0.24$; 16: $F[1,53] = 0.5$, $p = 0.50$; 24: $F[1,53] = 0.1$, $p = 0.8$; 36: $F[1,53] = 3.0$, $p = 0.09$, and; 48: $F[1,53] = 18.2$, $p < 0.001$). For the timeout error analyses, there were reliable age effects for all of the display sizes above 12 items (display size 4: $F[1,53] = 1.1$, $p = 0.30$; 8: $F[1,53] = 2.0$, $p = 0.16$; 12: $F[1,53] = 5.2$, $p < 0.05$; 16: $F[1,53] = 7.8$, $p < 0.01$; 24: $F[1,53] = 14.1$, $p < 0.001$; 36: $F[1,53] = 20.5$, $p < 0.001$, and; 48: $F[1,53] = 63.8$, $p < 0.001$) (see Figure 4.3b and 4.3c).

Figure 4.3: Mean percentage of (a) correct, (b) key error, and (c) timeout error responses. The figure presents age group (younger-adult vs. older-adult), search condition (simple vs. preview) and display size (4, 8, 12, 16, 24, 36 and 48 items).



4.4.2 Search Slope and Intercept.

Analysis of the search slope showed a significant main effect for age group ($F[1,52] = 38.6$, $p < 0.001$), no main effect of search condition ($F[1,52] = 1.95$, $p = 0.17$) and no interaction between age group and search condition ($F[1,52] = 1.86$, $p = 0.18$). Overall the analysis showed a more efficient search slope for the younger than older aged adults. Analysis of search slope intercept showed significant main effects for both age group ($F[1,52]$ 18.48, $p < 0.001$) and search condition ($F[1,52]$ 70.12, $p < 0.001$), and no interaction between age group and search condition ($F[1,52] = 0.41$, $p = 0.53$). This showed that younger adults were faster to begin visual search than older adults and that both groups were faster to begin search in the preview than simple search condition (see Table 4.1 and Figure 4.2).

Table 4.1: Descriptive Statistics for Search Slope for Each of the Conditions.

Group	Descriptive Statistic	Simple Search Condition	Preview Search Condition
Young adults	Slope (ms/item)	52.3	47.2
	Intercept (ms)	696.2	372.6
	R^2	0.995	0.995
Older adults	Slope (ms/item)	72.0	72.0
	Intercept (ms)	1389.8	1012.6
	R^2	0.964	0.980

4.5 DISCUSSION

The present study hypothesised that older aged participants would be slower to visually select target objects within an object stimuli display than younger aged participants, as they would be less able to inhibit attending to the other object distractor items. We expected that the effect would manifest by slower reaction times and increased errors when performing the visual search task. For the same reason, we hypothesised that preview stimuli items would exhibit no benefit in search efficiency (on the basis of the search slope of RT as a function of display size) for older compared to younger adult age groups. In the discussion, I present each of the findings for the time and error analyses separately and for each, discuss the findings with that presented in the literature. Later, I provided some details about how the study could be improved and finally discuss how the data here related to that reported in Chapters 2 and 3.

4.5.1 Reaction Time and Search Slope

Consistent with the hypotheses, these data showed that the older compared to younger aged adult groups were both slower overall and demonstrated a reduced search efficiency. Analysis of reaction time showed significant effects of age, search condition and display size. This showed that reaction time was slower for the older than younger aged adults, in the simple than preview search condition, and increasingly slowed as display size increased. Analysis of search slope intercept were consistent with the effects for reaction time in that the older compared to younger aged adult groups and the simple compared to preview search showed a higher intercept (i.e. showing a slower time to begin search).

The analyses of search slope efficiency were very interesting. They showed no difference for simple compared to preview search, and no interaction between search condition and age.

This suggests that the preview benefit in search simply manifests in a search time saving, irrespective of the age group (i.e., the slopes are parallel for these factors). However, the finding that older compared to younger aged adults showed a significantly steeper search slope (i.e., slower search efficiency) suggests that the older aged adults had more difficulty in search as the display size increased than the younger aged adults (i.e., they became exponentially slower with increased display size). This latter effect suggests that the older compared to younger aged adults were not just slow (as suggested in the literature; Folk & Lincourt, 1996; Plude & Doussard-Roosevelt, 1989; Watson & Maylor, 2002), but were increasingly slowed as the display size increased. That is, the slowed search behaviour seemed to be amplified with the increase in the number of items that needed to be searched. Therefore, for this effect to occur, the older compared to younger aged adults must have some impairment in attention ability, beyond simple slowness, that caused the reduced search efficiency.

4.5.2 Error Analyses

The analyses of error revealed some interesting results. In the overall analysis of the percentage of correct responses there were significant effects for age group and display size, and furthermore, a significant interaction between the two variables. This showed no differences between age groups for the smaller stimuli displays, but as the displays became larger, the older aged adults started to make a lower percentage of correct responses than younger aged adults. There were no effects or interactions with condition. In the analyses of errors, the data showed similar effects. As before, analysis of key error responses only showed age differences on the larger displays, though interestingly, this showed that the younger adult group made more key error responses than the older adult group. The opposite was the case for timeout errors. As in the percentage correct responses, the analyses showed that the older compared to younger adult groups made more timeout errors on the larger displays.

Therefore, these data show that the percentage correct findings can be explained by the percentage of timeout errors. That is, with the larger displays, older aged adults make more timeout errors than the younger aged adults. A possible explanation for this, that is consistent with the literature, is that older aged adults might be less able to inhibit attending to distracting stimuli, and so with large display stimuli (>16 items), the attentional requirements become very high and as such, performance would be dependent on attentional efficiency.

It is possible that older aged adults accommodate their deficit in attentional inhibit when visual search task load is increased by revisiting visual stimuli to recheck or verify its validity several times. This behaviour has been identified by Watson, Maylor and Bruce (2005) who reported age related differences in eye movement performance showing that older aged participants increased the number of fixations to objects within the visual search task. They suggested that this was done in order to compensate for increased task load. It is clear that such behaviour would require the older adults to need more search time in order to successfully search and select difficult stimuli arrays.

We suggest that the observed age-related effect here cannot be explained by a simple account of generalised slowing since the older aged adults mean reaction time were not simply a linear transformation from the young aged adults. That is, the search slope was greater in the older than younger aged adults. Furthermore, older age has been suggested to have the effect of decreasing attentional resources and the speed with which they can be utilised. It is then possible that older adults require more time to inhibit the preview items. In the present study, and in that of Watson and Maylor (2002) and Kramer and Atchley (2000), a fixed preview interval of 1000 ms was used. While a preview interval time of 1000 ms has been previously shown to provide a reliable preview benefit effect for search displays of 16 items or less in younger adult age groups (see Watson & Humphreys 1997), it might be that older aged adults with larger stimuli displays require more preview time to inhibit the distractor stimuli. This point was made by Watson and Maylor (2002) who speculated that the effect of ageing may result in older aged adults requiring at least 800 ms to mark or inhibit the preview stimuli. As such this suggestion serves to highlight the difficulty of excluding generalised slowing accounts in such a multiprocess system. Therefore, in the study presented here we might assume that the larger display sizes were more attentionally demanding and because of reduced attention capacity with age, the time course of inhibiting the preview items were particularly slowed.

Although these data support much of the existing literature, they also present a possible new direction in visual search. Further research should be undertaken with the focus of manipulating the preview interval from 1000 ms, providing older aged adults less and more time in both small and large display sizes with difficult to select stimuli. This manipulation will provide an answer to the question of whether older adults are slower to be able to inhibit when given a preview, in addition to being slower to search and select as identified at baseline, or explain whether it is simply that older aged adults cannot efficiently inhibit, a conclusion that contrasts to Watson and Maylor (2002) and Kramer and Atchley (2000). A cross sectional study of participants between 40 and 80 years of age would be useful and provide interesting evidence into the onset of the effects observed in this and previous studies. It is likely that the decline in attentional ability has a slow and progressive onset through adult life, it may be useful to identify the initial point of change from young to old, this in turn would answer the question if changes in search, selection and preview benefit are a gradual decline observed through a generalised slowing and attentional inability with increased age or not.

In Chapters 2 and 3, we consistently reported data showing that older compared to younger aged adults made slower actions, were slower in selective attention and were also particularly slow in movements that required selective attention. In the discussion of Chapter 3, we suggested that the older participants were perhaps slower because of slowness in attentive object selection for action and that the slowness had an impact on the movement speed. In the data present here, we can support this claim and furthermore, illustrate that the slowness evident in older aged adults in selection may be due to an inability to efficiently inhibit distractor items with large and complex visual field displays. This latter effect is similar to the post hoc analysis in Chapter 3 that showed an age group difference in reach, selection and grasp for responses to objects 2-5, but not for the first object. That is, with increased task demands (where participants had to select and plan online), the older adults had less capacity to perform as well at object selection and as a result, actions were slower.

CHAPTER 5 - THE RELATIONSHIPS BETWEEN AGE, STRENGTH AND MOVEMENT DEXTERITY

5.1 ABSTRACT

The relationship between increased age and decreased movement dexterity has been widely suggested in the literature and the effect has been replicated in Chapters 2 and 3. This shows that movements become slower (or decrease in dexterity) with increased age. In the literature, some suggest that the relationship results from reduced strength with increased age, in that there is good evidence that strength reduces with increased age. Surprisingly, it appears that the relationship between age, strength and movement dexterity has received little investigation, especially using accurate movement recording methods. In the data reported here, we tested 107 adults between 18 and 93 years of age on a variety of fine motor ability movement dexterity measures. In each dependent measure, we first tested the relationships between: (i) age and strength; (ii) age and movement performance, and; (iii) strength and movement performance, and then use multiple linear regression models to determine which of age and strength accounts for the greater variance. The results showed clear relationships between increased age and decreased strength, increased age and reduced movement performance, and decreased strength and reduced movement performance. Standard multiple linear regression analyses showed that both age and strength made significant contributions to the data variance. Moreover, post-hoc analyses showed that age explained more of the variance for steadiness and line tracking movement tasks, whereas strength explained more of the variance for aiming and tapping movement tasks. The data are discussed in terms of the relationships between age and strength on the resultant movement performance, and the importance of measuring strength when considering the effects of age on dexterity and movement performance.

5.2 INTRODUCTION

So far in this thesis, we have presented data that replicate the literature showing a relationship between increased age and decreased movement dexterity (see Chapters 1, 2 and 3). At the beginning of the thesis (Chapter 2), we ran a series of tests and found two additional relationships. That was, a relationship between increased age and reduced speed of selective attention, and between increased age and reduced strength. In Chapters 3 and 4, we tested whether the slower dexterity with increased age was a consequence of attention selection (or inhibition). This showed that the proposed complex relationship was correct in that increased age was related to the speed of movements in those that required selection of an object or space for action. Therefore, the speed of attention selection was related to the speed of dexterous movement. At the same time as running the experiment presented in Chapter 3, the experiment presented here was also conducted. This aimed to follow up the other relationship found in Chapter 2 and address the impact that strength has on the age and movement dexterity relationship.

In the literature, the relationship between increased age and reduced movement dexterity is widely reported from both clinical observations and experimental data (see for example Aniansson et al., 1980; Desrosiers et al., 1995; 1999; Hackel et al., 1992; Jebsen et al., 1969; Kauranen, 1996; Kolb et al., 1998; Potvin et al., 1980; Smith et al., 1999; Welford, 1958; see also Chapters 1-4). In these papers, it is typically reported that older compared to younger adults have slower movements. However, few papers have attempted to test what the exact biological causes for the effects are. Instead, the common explanation provided to explain the relationship is that movements are likely slowed because of a decline in musculoskeletal strength and mass, and that this change leads to the decline in function, mobility and an increased physical frailty (see Bennett et al., 1996; Enoka et al., 1992; Grabiner & Enoka, 1995; Grimby, 1995; Harridge & Young, 1998; Kell et al., 2001; Kolb et al., 1998; Spirduso, 1995). These claims are somewhat supported by related literature in that increased age has been shown to be associated with declines in musculoskeletal architecture (Dutta et al., 1997; Lexell, 1995; 1997), peripheral and central nerve conduction (Dorfman and Bosley, 1979; Kurokawa et al., 1999; Mackenzie & Philips, 1981), proprioception (Kaplan et al., 1985) and neuromuscular coupling (Delbono, 2003; Lexell, 1997). Similarly, research has directly measured the effects of increased age on strength and typically report that increased age exhibits higher muscle co-activation, reduced muscular force or power, and reduced ability in force regulation (Cole & Rotella 2001; Darling et al., 1989; Enoka et al., 2003; Ketcham et al., 2004; Shinohara et al., 2003, 2004). Therefore, the claim that slow dexterity with increased age is linked to reduced strength seems intuitive, despite not actually being tested to date. In the next section of this introduction, we review the literature in more detail that report evidence for the relationship between increased age and reduced strength.

Much of the data presented in the literature that has tested the relationship between age and strength has tended to focus on the lower limb, particularly the knee extensors. This is likely due to their functional importance in day-to-day mobility. Such studies have tended to report a 20-40% decline in knee extensor strength for participants aged in their seventh and eighth decade compared to younger ages (Larsson et al, 1979; Murray et al, 1985; Murray et al, 1980; Skelton et al., 1994; Young et al., 1984; 1985), and a greater loss of 50% or more has been reported for adults aged 90 years and older (Doherty, 2002). Similarly, Young & Skelton (1994) reported that strength declines at a rate of 1.5% per annum for older adults aged between 65-84 years, and that power declines at a higher rate of 3.5% per annum.

Although there are fewer papers covering upper limb movement, the data reports similar rates of muscle decline. For example, decline in flexors and extensors of the elbow, and the muscles of the hand have all been reported (see Bassey & Harries, 1993; Cunningham et al., 1987; Davies et al., 1986; Doherty et al., 1993; Fisher & Birren, 1947; Kallman et al., 1990; McDonagh et al., 1984; Vandervoort & McComas, 1986). With relevance to the present chapter, the nature of the decline in grip strength has been reported as curvilinear, with the rate of decline getting steeper with increased age (Burke et al., 1988; Kallman et al., 1990; Mathiowetz et al., 1985; Michimata et al., 2008; Rantanen et al., 1998). That is, after the age of 60 years, it has been reported that there was a rapid decline in hand-grip strength by 20-25%, even though the decline started from the age of 30 years (Kallman et al., 1990; Rantanen et al., 1998).

Despite these findings, the rate of strength decline with ageing remains largely unknown (Doherty, 2003), and surprisingly almost no research appears to have been undertaken that directly addresses the relationship between strength and movement speed across the age span. The only paper that we could find that reported such was that from Ferucci et al., (2002), though for lower limb movements. They reported data showing that knee extensor strength was a strong predictor of walking speed, with lower strength causing a slower walking speed. We could find no similar evidence for upper limb dexterity. Therefore, the present study aimed to test the relationships between age, hand-grip strength and upper limb dexterity.

5.2.1 Hypotheses

The hypotheses of the study were that we expected relationships between: (i) age and strength; (ii) age and movement dexterity, and; (iii) strength and movement dexterity (where dexterity was measured using a number of fine motor ability tests). A multiple regression was used to determine which of the independent variables age and strength accounted for the greater variance in dexterity.

5.3 METHODS

5.3.1 Participants

A total of one hundred and seven participants were investigated, sixty of whom were women. The participants were aged between 18 and 93 years old (female: 18-86, mean 50 and male: 20-93, mean 48 years of age). All of the participants were recruited from the City of Birmingham (West Midlands, UK) population by means of advertising the project and giving short presentations at local community groups. An inclusion criterion was used so that only 'healthy' participants were tested[3]. The inclusion criteria were that participants had to be over the age of 18 years old, able to travel to the University of Birmingham unaided (i.e., by driving or using public transport) and reported no muscular skeletal or neurological problems on the self-report medical history questionnaire (Appendix 1). Ethical approval was granted from the School of Sport and Exercise Sciences, University of Birmingham in accordance with the 1964 Declaration of Helsinki.

5.3.2 Apparatus

A set of questionnaires was presented to participants at the beginning of the experimental session. One was a simple self report medical history questionnaire (Appendix 1) that comprised simple health questions for the easy identification of any medical history or

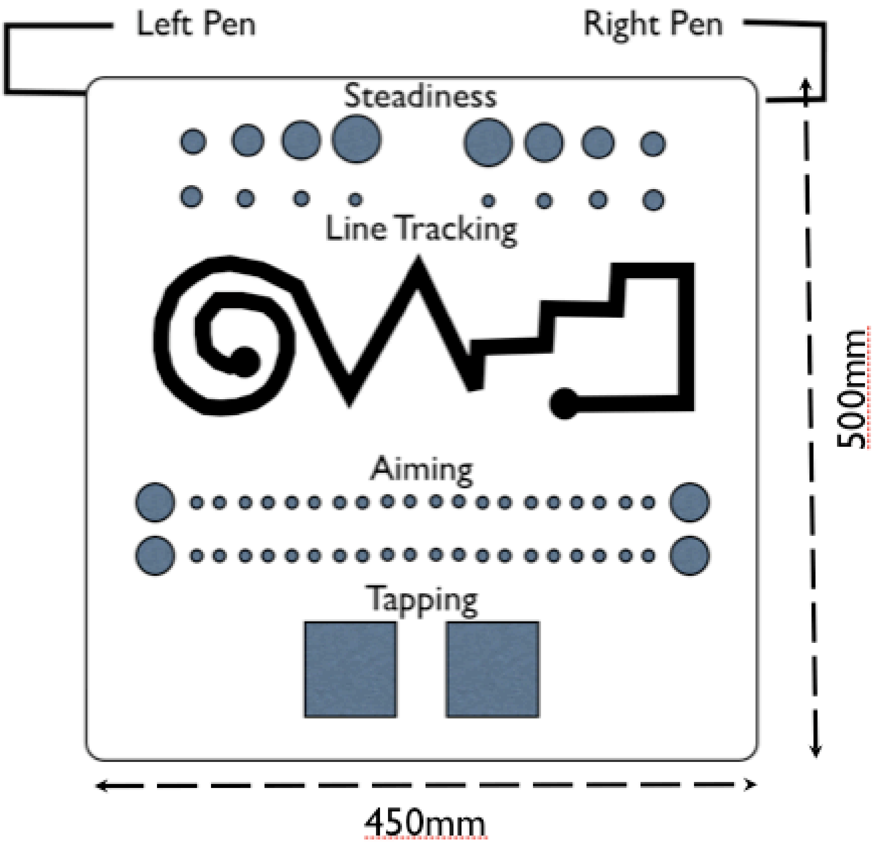
[3] In order that any of the effects reported were not confounded by health status that might also influence movement speed.

current treatments that allowed volunteers to be classified as physically healthy. Physically healthy was classified as the absence of any diagnosed physical diseases, mental illnesses, recent surgeries or hospitalisation, and feelings illness, a criterion used in published literature (see for example: Potter & Grealy, 2006). A purposed designed arthritis questionnaire (Appendix 2) was provided to participants to assess for any symptoms of arthritis. The questionnaire was designed to identify any symptoms for the whole body, although participants were encouraged to highlight any undiagnosed hand or upper limb symptoms that may influence dexterity performance. Hand dominance was determined using the Edinburgh handedness Inventory (Oldfield, 1971). The inventory contains 10 questions that help classify a persons dominant hand through preferred use of daily objects (e.g. preferred had for writing, drawing, using a toothbrush etc...). Volunteers were screened cognitively using the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975). A high score of 27/30 was used to ensure participants were cognitively intact. Previous literature has used lower criterion of >23/30 (Potter & Grealy, 2006) to declare participants as not cognitively impaired.

Hand grip strength was measured using a hand grip dynamometer (Takei Scientific Instruments Co., Ltd, Japan). Participants were positioned as close to sitting upright, holding the dynamometer in the hand to be tested, with the arm at right angles and the elbow by the side of the body. The handle of the dynamometer was adjusted for comfort as required, so that the base of the dynamometer is positioned with the rest on first metacarpal (heel of palm), with the handle rest on middle of the four fingers. The results were recorded as kilograms taken from the digital display of the dynamometer to the nearest 0.1 kg. The digital display of the dynamometer displayed the maximum strength within a trial and the value was reset to zero before each measurement.

Movement dexterity was measured using fine motor ability tests from the computerised 'Vienna Test System' (Dr. G Schuhfried, GmbH, Mödling, Austria) (see Figure 5.1). The Vienna Test System is a standardised test battery used for the diagnosis of movement deficits in neuropsychology (Raczek, Waskiewicz & Juras, 1997). It consists of a main computer with test interface management software and a peripheral panel display that contains a variety of different tests (called the Motor Performance Series; developed by Schoppe 1974 and based on Fleishman's factor-analytic examinations of fine motor abilities in arms, Fleishman 1972). From the Motor Performance Series tests, we used measures of steadiness, line tracking, aiming and tapping (see the Procedure section). The Motor Performance Series peripheral panel was placed on a wooden testing table, and participants sat on a wooden chair with back support in a normal sitting posture with slightly bent forearms. Participant's were positioned at the mid point of the table, perpendicular to the Motor Performance Series peripheral panel and throughout the tests were instructed not to contact the wooden table or Motor Performance Series peripheral panel (i.e., so that additional postural support with any upper body parts was not achieved).

Figure 5.1 – A schematic diagram of the Motor Performance series Work Panel.



5.3.3 Procedure

At the beginning of the experiment, participants were given the series of questionnaires. These were a self-report medical history questionnaire (Appendix 1), arthritis questionnaire (Appendix 2), hand dominance questionnaire (Edinburgh Handedness Inventory; Oldfield, 1971) and the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975). These assessments were used for the participant inclusion criteria for the study.

Following completion of the questionnaires, participants were asked to perform the hand grip dynamometry assessment to measure maximal hand grip strength. The participant squeezed the dynamometer with maximum effort for at least 5 seconds. Both hands were tested for maximal hand grip strength, with each hand tested three times, with each hand tested in random order (Bohannon et al., 2006). Participants were provided with a minimum of 60 seconds between each repeated attempt to allow for some recovery. Maximum hand grip was recorded as the highest value[4] of the three trials for each hand.

Once the questionnaires and hand-grip strength were recorded, the participants were asked to complete a series of Fine Motor Ability tests using the Vienna Test System: Motor performance Series panel. Before commencement, all of the Motor Performance Series tests were explained to the participant and they were given a brief period to familiarise themselves with each Motor Performance Series test. The computer test management software controlled the order of the tests. Because of this, the same order of tests was run for all participants (i.e., as the software was unable to randomise the order). However, as the tests were run for dominant and non-dominant hand, the order of hand test was counterbalanced across participants. At the end of one test sequence (either dominant or non-dominant hand), a three-minute break was provided and then the participant repeated the test sequence a second time with their other hand.

The first test run within the test sequence was the steadiness test. This involved the participant vertically inserting a pen stylus (2mm diameter) into a pre-assigned hole (5.8mm diameter) and then holding the stylus as still as possible for 32 seconds without touching the sides or the bottom of the hole. If the participant touched the sides they simply had to correct and replace the stylus in the centre of the hole and continue until the end of the 32 seconds

[4] Maximum value was used rather than mean of the three trials. This was done so that the measure was independent of higher levels of fatigue that may have been prevalent with the weaker participants.

period, when they were asked to stop. Measurements recorded by the software programme were the number of times the stylus came into contact with the sides and bottom of the hole and the total duration of the contact time. Participants' performed the task with each hand separately, the hand order was randomised across participants.

The second test that was run was line tracking. This involved the participant inserting the pen stylus into the grooved track and tracing a pen stylus through the track without touching the sides or bottom. The test was undertaken at a self-selected pace. If the sides were touched, the participant had to correct the position of the pen stylus and continue along the grooved track until the end. Measurements recorded by the software programme were the number of touches with the side and bottom, the total duration of any touches and the total duration of the tracking. Participants' performed the task with each hand separately, the hand order was randomised across participants

The third test run was the aiming test. This involved the participant touching 20 brass disks (5mm diameter) that were arranged in a row with the pen stylus. The distance between each disk was 4mm. The participant was instructed to tap one circle in the row after the other using the pen stylus, moving from right to the left of the disks. Measurements recorded by the software programme were the number of correct taps, the number of incorrect taps, the total duration of any incorrect tap and the total duration.

The final task was that of tapping. This involved the participant tapping the square plate (40 mm^2) with the pen stylus as fast as possible within 32 seconds. The measurement recorded was the total number of taps made.

5.3.4 Data Analyses

The independent variables in the experiment were age and strength. The dependent variables were composite fine motor ability T-Scores calculated from the raw data and included measures of: (1) steadiness; (2) line tracking; (3) aiming; and (4) tapping (suggested by Hamster 1980, as a measure for fine movements). The composite T-Score was calculated based on the weight of the raw data variables in the single factor. Therefore, if a factor is loaded by only one single variable, then the factor's T-score equals the empirical T-Score of the variable. However, when a factor is loaded by several variables, the T-Score is equal to the weighted mean T-score of these variables (see Figure 5.2) where weighting is based on squared factor loading and Figure 5.3 for the composite T-Score dependent variable calculations). The equations present in Figures 5.2 and 5.3 and then used for the analysis are taken directly from the original literature by Fleishman (1953) and Fleishman and Ellison (1962). The Fleishman factor for each variable (i.e. *F, FD* and *TR*, see Figure 5.3) are the reported regression values to be used when calculating the T-score taken from the original literature.

Figure 5.2: The formula used to calculate the fine motor ability T-Score. Note that TF_j refers to T-Score of the Fleishman-factor j, a_{ij}, a_{kj} … a_{nj} refer to loading of variable i, k … n in Factor j, and T_i, T_k …T_n refer to empirical T-Score of the variable i, k … n).

$$TF_j = \frac{(a_{ij}{}^2 \times T_i) + (ak_j{}^2 \times T_k) + ... + (a_{nj}{}^2 \times T_n)}{a_{ij}{}^2 + ak_j{}^2 + ... + a_{nj}{}^2}$$

Figure 5.3: The formula used to calculate T-Score for the fine motor abilities of Aiming, Steadiness, Line tracking and Tapping. The Fleishman-factor is included in the numbers. The variables F (Error Amount), FD (Error Duration) and TR (Number of hits) refer to the raw scores.

$$\text{T Aiming} = \frac{(.87^2 \times F) + (.94^2 \times FD) + (-.59^2 \times TR)}{.87^2 + .94^2 + (-.59^2)}$$

$$\text{T Steadiness} = \frac{(.92^2 \times F) + (.92^2 \times FD)}{.92^2 + .92^2}$$

$$\text{T Line Tracking} = \frac{(.88^2 \times F) + (.88^2 \times FD)}{.88^2 + .88^2}$$

$$\text{T Tapping} = \frac{(-.56^2 \times TR)}{-.56^2}$$

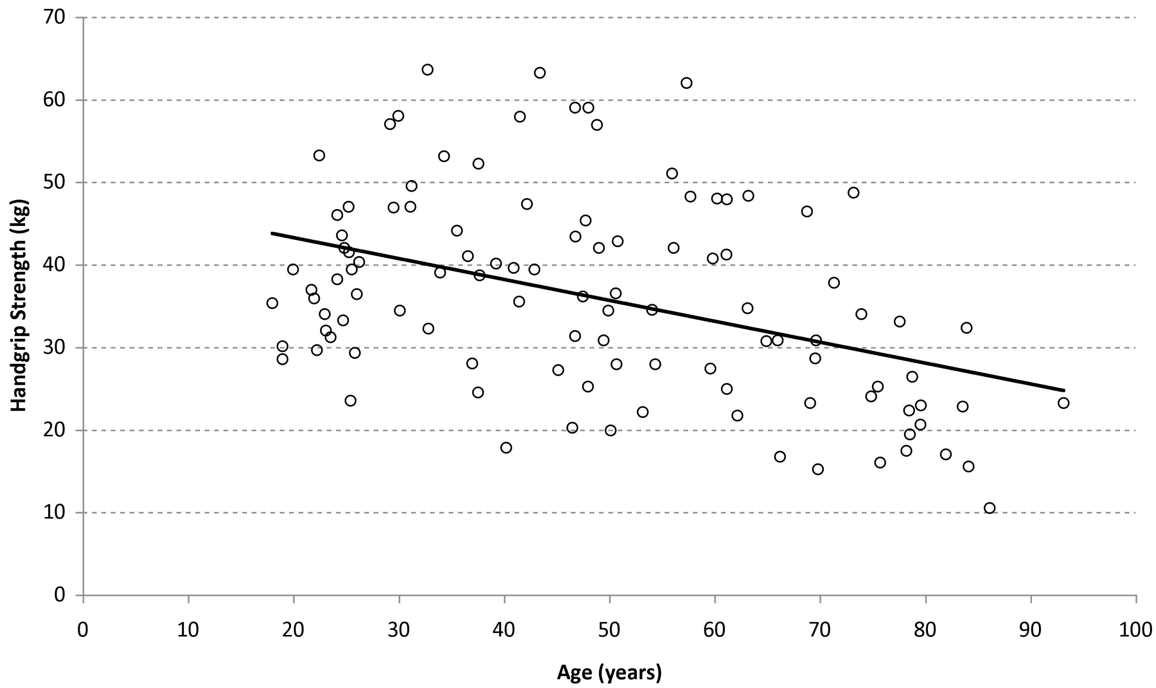
The data were first analysed using Pearson's correlation between the independent variables, and between either independent variable and each dependent variable. Following these analyses, Multiple Linear Regression (MLR) was run. The MLR was done so that the relationship between the independent variables of age or strength for each dependent measure was identified. Where both independent variables had a significant contribution to the dependent variable, an additional MLR analysis was undertaken using the mean centred cross product of age and strength to test for an interaction. In the presence of an interaction between the independent variables, further post hoc analyses were undertaken using the Simple Slopes Technique described by Aitken and West (1991). All statistical analyses were performed using SPSS v16.0 (SPSS Inc. Chicago, Illinois, USA). No participant trials were removed from the raw data set or analyses.

5.4 RESULTS

5.4.1 Relationship between Age and Strength

Analysis of the relation between age and hand grip strength was significant ($r = -0.42$, $p < 0.01$). This showed that increased age was related to decreased strength (see Figure 5.4).

Figure 5.4: The relationship between age and dominant hand-grip strength across all of the participants tested (n = 107).



5.4.2 Relationships between Age or Strength and Fine Motor Abilities

The correlation analyses between age or hand grip strength independent variables on each of the fine motor ability tests dependent variables is shown in Table 5.1. This showed that both age and hand grip strength were significantly related to each of the fine motor abilities and that all showed that performance reduced with increased age or decreased strength.

Table 5.1: Shows the Pearson correlation coefficients (r) between age and dominant hand-grip strength and the T-Scores for the measured fine motor dexterity abilities (** = $p < 0.01$).

	Age	Hand-Grip Strength (kg)
Steadiness	.558**	-.421**
Line Tracking	.607**	-.401**
Aiming	-.455**	.574**
Tapping	-.507**	.619**

5.4.3 Multiple Regression Analysis (MLR)

Results of a standard Multiple Linear Regression analysis for the dependent measures of steadiness, line tracking, aiming and tapping composite T-Scores , and with age and strength as independent variables are shown in Table 5.2. Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity. With the use of a $p < 0.001$ criterion for Mahalanobis distance, no outliers among the cases were found. Table 5.3 shows the analyses of the multiple linear regression interactions between the mean centred age and grip strength independent variables for each dependent variable.

Analysis of steadiness showed that the age and strength independent variables explained 35% of the variance (see Table 5.2). Of these, age showed the largest unique contribution, although both age and strength were statistically significant. Simple Slopes Technique post hoc analyses of mean centred independent variables (age, strength, age and strength) showed a significant interaction ($p < 0.05$). The interaction showed that for low and mean aged adults, greater strength resulted in better steadiness through reduced errors, whereas, higher aged adults showed no effect (see Tables 5.3, and Figure 5.5).

Analysis of line tracking showed that the age and strength independent variables explained 40% of the variance. As in the steadiness analysis, age showed the largest unique contribution, although both age and strength made a statistically significant contribution (see Table 5.2). The Simple Slopes Technique post hoc analyses of mean centred independent variables (age, strength, age and strength) showed no significant interaction ($p = 0.21$) (see Table 5.3, and Figure 5.6).

The analysis of aiming performance showed that the age and strength independent variables explained 39% of the variance, though unlike the steadiness and line tracking analyses, strength showed the largest unique contribution, although both age and strength made a statistically significant contribution (see Table 2). The Simple Slopes Technique post hoc analyses of mean centred independent variables (age, strength, age and strength) showed no significant interaction ($p = 0.74$) (see Table 5.3, and Figure 5.7).

Finally, the analysis of age and strength independent variables on tapping performance showed similar results to aiming performance. Firstly, the variables explained 46% of the variance and strength had the largest unique contribution, although both age and strength made a statistically significant contribution (see Table 5.2). As in the analysis of aiming performance, the Simple Slopes Technique post hoc analyses of mean centred independent variables (age, strength, age and strength) showed no significant interaction ($p = 0.44$) (see Table 5.3; Figure 5.8).

In summary, the results of the standard Multiple Linear Regression analyses for the four fine motor abilities dependent measure T-Scores showed that both age and strength independent variables made significant contributions to the data's variance. However, steadiness and line tracking dependent measures showed that age compared to strength explained more variance, whereas the aiming and tapping dependent measures showed that strength compared to age explained the greater variance. Only the analysis of steadiness showed a significant interaction with the Simple Slopes Post Hoc analyses. This showed that strength contributed to the variance of the younger and middle aged adults, but had no significant contribution to the older adults.

Table 5.2: Multiple Linear Regression analysis output detailing the analysis for each of the fine motor abilities. The Independent variables were Age and Strength.

Variables	Parameter B	Standardised β	Model R^2	sr^2 (unique)
Steadiness				
Intercept	1.757			
Age	0.171 ***	0.463		0.18
Strength	- 0.137 **	-0.228	0.35 ***	0.04
Line Tracking				
Intercept	6.832			
Age	0.275 ***	0.533		0.23
Strength	- 0.151 **	-0.178	0.40 ***	0.03
Aiming				
Intercept	32.262			
Age	- 0.064 ***	-0.262		0.06
Strength	0.187 ***	0.422	0.39 ***	0.18
Tapping				
Intercept	57.058			
Age	- 0.129 ***	-0.302		0.08
Strength	0.348 ***	0.494	0.46 ***	0.25

* $p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 5.3: Multiple Linear Regression analysis output for the assessment of Interactions between mean centred independent variables (Age, Strength and Age X Strength respectively) for each of the fine motor abilities.

Independent Variables	Parameter B	SE	Standardised β
Steadiness			
Intercept	4.394	0.631	
Age	0.141 ***	0.033	0.381
Strength	-0.121 *	0.052	-0.200
Age X Strength	-0.007 *	0.003	-0.222
Line Tracking			
Intercept	14.307	0.873	
Age	0.254 ***	0.046	0.494
Strength	-0.140 *	0.072	-0.165
Age X Strength	-0.005	0.004	-0.107
Aiming			
Intercept	35.792	0.421	
Age	-0.067 **	0.022	-0.272
Strength	0.188 ***	0.034	0.468
Age X Strength	0.000	0.002	-0.028
Tapping			
Intercept	63.508	0.691	
Age	-0.120 **	0.036	-0.279
Strength	0.343 ***	0.057	0.486
Age X Strength	0.002	0.003	0.062

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Figure 5.5. A plot illustrating the interaction of Strength and Steadiness Ability. Higher Strength corresponds to better Steadiness ability. Data plotted are Mean centred ± 1 S.D. Minus one standard deviation represents younger adults (Low Age) and plus one standard deviation represents older adults (High Age).

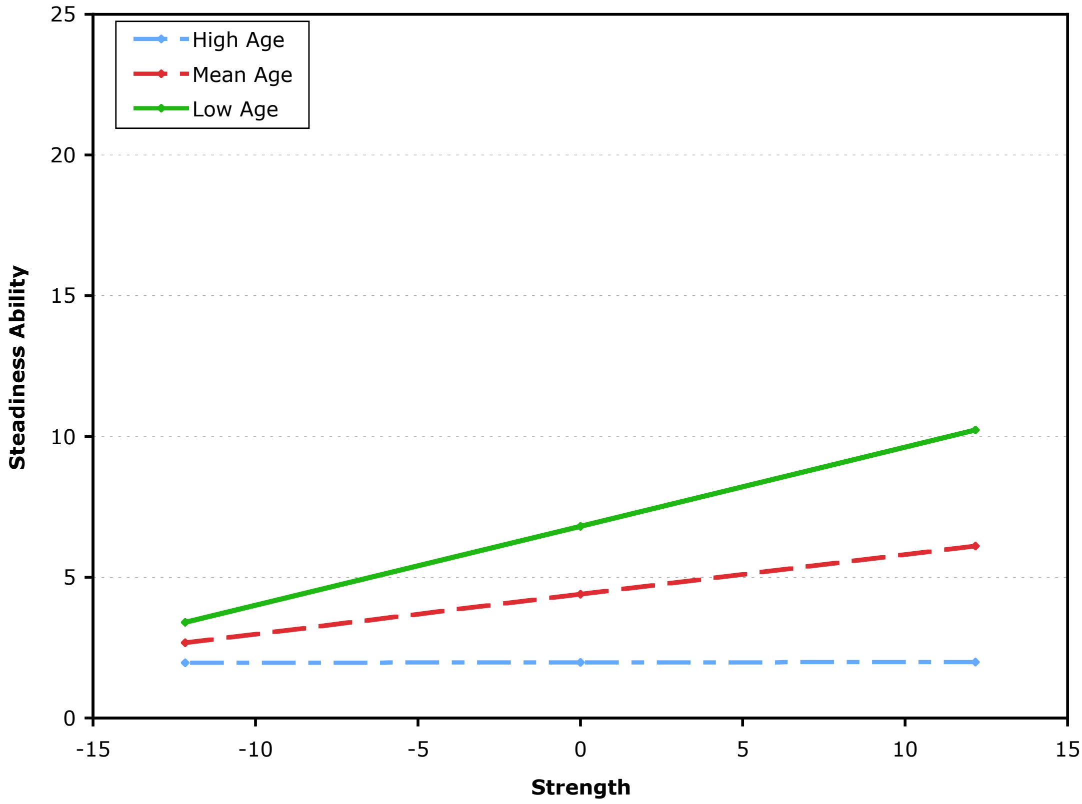


Figure 5.6: A plot illustrating the interaction of Strength and Line Tracking ability. Higher Strength corresponds to a higher score or better Line Tracking ability. Data plotted are Mean centred ± 1 S.D. Minus one standard deviation represents younger adults (Low Age) and plus one standard deviation represents older adults (High Age).

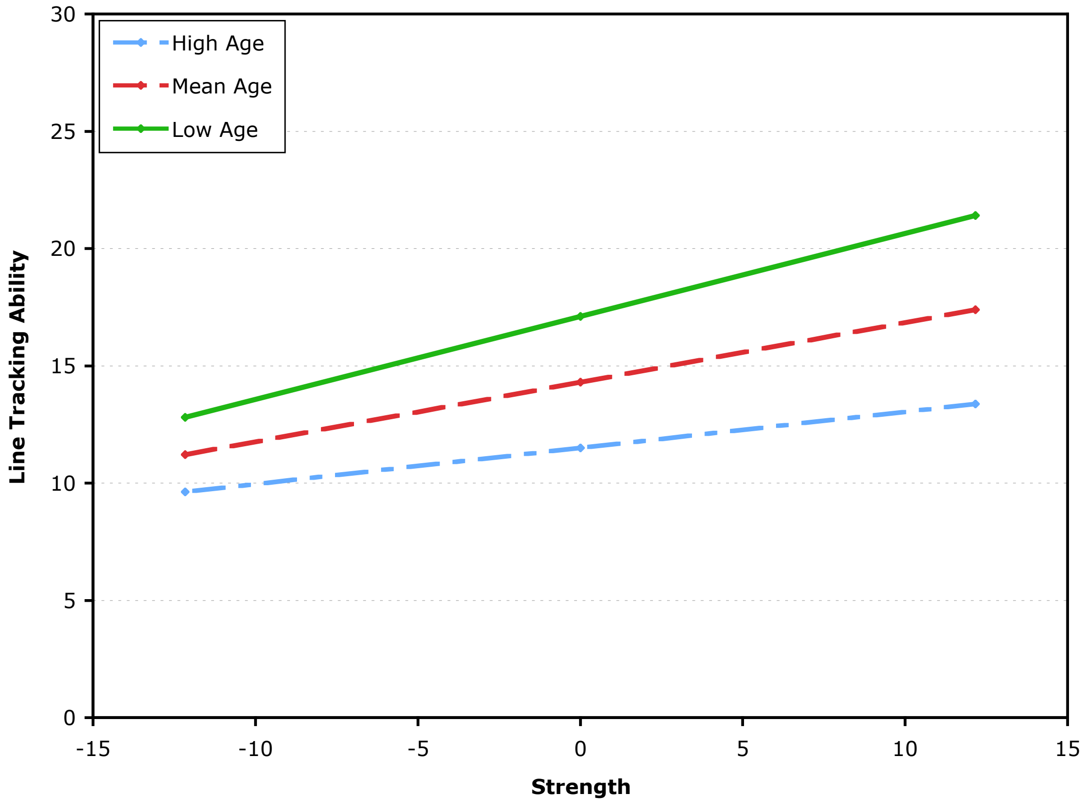


Figure 5.7: A plot illustrating the interaction of Strength and Aiming ability. Higher Strength corresponds to better Aiming ability. Data plotted are Mean centred ± 1 S.D. Minus one standard deviation represents younger adults (Low Age) and plus one standard deviation represents older adults (High Age).

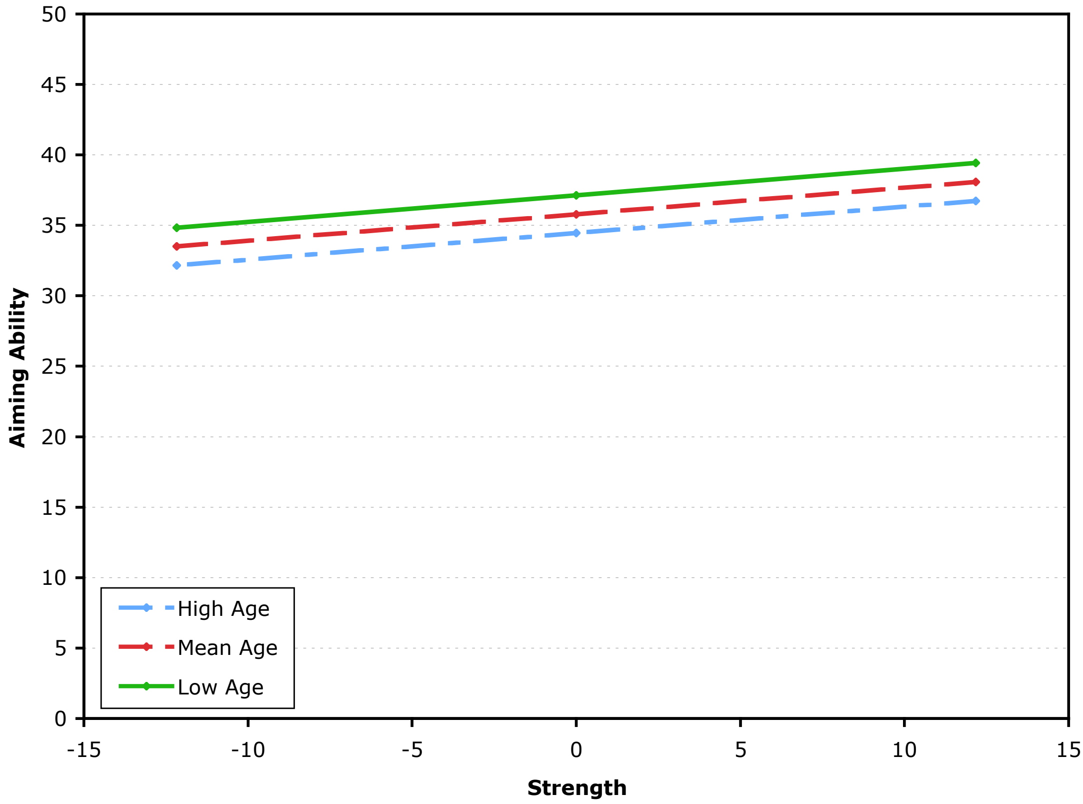
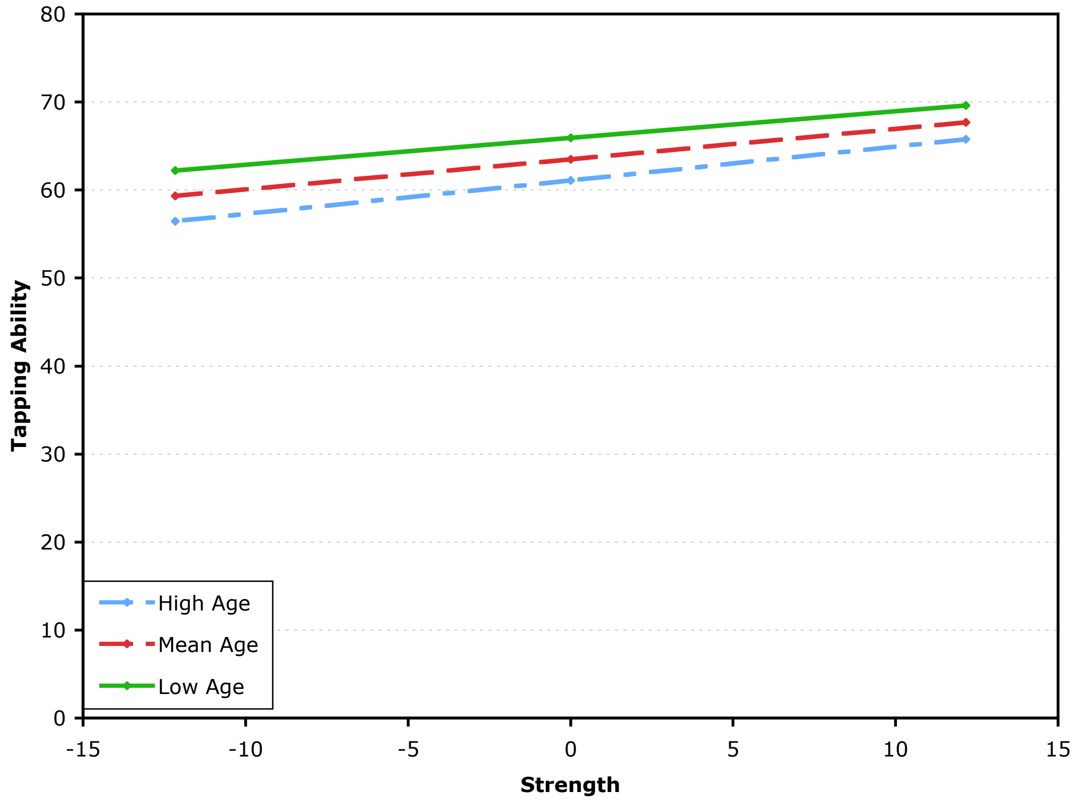


Figure 5.8: A plot illustrating the interaction of Strength and Tapping ability. Higher Strength corresponds to better Tapping ability. Data plotted are Mean centred ± 1 S.D. Minus one standard deviation represents younger adults (Low Age) and plus one standard deviation represents older adults (High Age).



5.5 DISCUSSION

The aim of present study was to test the relationships between age, hand grip strength and upper limb dexterity. Dexterity was measured using the Vienna Test Systems: Motor Performance Series Panel for fine motor ability composite T-Scores of: (1) steadiness; (2) line tracking; (3) aiming; and (4) tapping dexterity. The hypotheses of the study was that there will be relationships between: (i) age and strength; (ii) age and movement dexterity, and; (iii) strength and movement dexterity. We also used a Multiple Linear Regression analysis to determine which of the age and strength independent variables accounted for the greater variance, and also whether there was any interaction between the independent variables (age and strength). The interactions in regression slopes were analysed using the Simple Slopes Technique.

5.5.1 Relationships between Age, Strength and Movement Dexterity.

The data from this study confirmed all three hypotheses showing significant relationships between age and strength, age and movement dexterity, and strength and movement dexterity. The relationship for age and strength showed that as age increased, hand grip strength decreased. For the relationship between age and dexterity, all dexterity measures (steadiness, line tracking, aiming and tapping) showed that as age increased, performance decreased (i.e., increased number of errors or decreased movement speed). Finally, for the relationship between strength and dexterity, all of the dexterity measures (steadiness, line tracking, aiming and tapping) showed that decreased strength was associated with reduced performance (i.e., decreases in strength were associated with increases in the number of errors made or decreases in movement speed).

These results are somewhat consistent with the literature. That is, the literature presented in the introduction of this chapter, and in Chapters 1 and 2 showed evidence of a relationship between increased age and decreased dexterity performance (see Desrosiers et al., 1994; 1995a, b; 1999; Falconer et al., 1991; Hackel et al., 1992; Michimata et al., 2008; Smith et al., 1999; Williams et al., 1990). Also, as introduced in this chapter, some literature shows evidence for a relationship between increased age and decreased strength, supported by the data presented here (Bassey & Harries, 1993; Cunningham et al., 1987; Davies et al., 1986; Desrosiers, 1998; 1999; Kallman et al., 1990; Fozard et al., 1994 Doherty et al., 1993; Mcdonagh et al., 1984; Vandervoort & McComas, 1986; Vandervoort, 2002). The relationship that received little testing in the literature, but was nevertheless implied, was that between strength and movement dexterity (Carmeli, Patish & Coleman, 2003; Cole, 2006; Desrosiers et al., 1995; Krampe, 2002; Ranganathan et al., 2001; Voelcker-Rehage & Alberts, 2005). In the data presented here, we can say that the implied relationship between strength and dexterity was correct.

While these data are already of new interest, and supportive of the literature's implied relationship between increased age, reduced strength and reduced performance, by considering the data together, we were able to test which of the age and strength independent variables explains more variance, and furthermore test whether there were any interactions in regression. This type of analysis has not been considered in the literature, mainly because the relationships have never before been explored. To do this, we used Multiple Linear Regression and Simple Slopes Technique posthoc analyses (Aitken & West, 1991).

5.5.2 Relative Variance and Interactions between Age and Strength on Dexterity.

The analyses using Multiple Linear Regression showed that the age and strength independent variables significantly contributed to the dexterity dependent measures. Of interest, the dependent measures of steadiness and line tracking showed that age compared to strength explained more variance, whereas for aiming and tapping, strength compared to age explained the greater variance. There was only one interaction in regression with the steadiness dependent measure. This showed that strength only explained variance for mean and below mean aged adults, whereas above mean aged adults showed that strength did not significantly account for the variance.

On the basis of these findings, it suggests that the dependent measures of steadiness and line tracking may differ from aiming and tapping. Movements involving steadiness and line tracking likely represent the ability to take a certain arm-hand position and to keep it with as little change as possible over a long period of time. That is, steadiness involved holding the stylus as still as possible in a hole and line-tracking involved following a grooved line (path) across the board without touching the sides. Both of these movements may be dependent on processes of visual feedback and eye-hand coordination using a continuous collection of sensory information about the current movement in relation to the stimulus properties. Thus, the precision of movements and speed of corrective movement processing are key, and as such have little association with the strength of the muscle. Additionally, tremor has been shown to be a prevalent occurrence with increasing age (Elble et al., 1994; Elble, 1995, 2000) and this is likely to be an additive factor in these tasks compared to that caused by changes in strength.

Movements of aiming and tapping showed that strength explained more of the data's variance than age. These two movements could be argued to differ from the steadiness and line tracking data as they involved selecting the target and then co-ordinating the muscles involved in the movement to make a speeded coordinated action. This is particularly the case with the tapping task that required an ability to rapidly execute a sequence of oscillatory movements from the wrist or arm-hand that were perhaps less reliant on eye-hand co-ordination than some of the other dexterity tasks. Since this task was predominately motor it is perhaps not surprising that greater strength was related to greater ability. This can also be said for the aiming task where co-ordination and speed of the movement was also important.

One important point to raise here was that although strength accounted for some of the variance in all of the dexterity measures, and accounted for more variance than age with aiming and tapping, the factor of age always significantly accounted for some variance. That is, other factors associated with age, other than strength must cause some of the dependent variable effects. These could be factors such as selective attention (or inhibition) (see Chapters 2, 3 and 4), vision, tremor, sense of touch, eye-hand coordination and speed of corrective movement processing, each of which require further testing. Despite this point, understanding that strength is an important factor in the relationship between increased age and decreased dexterity explains literature reporting that individuals whom regularly practice skilled movements, such as expert musicians, do not display the same age related decrements in dexterity as those of age matched comparative non-musical counterparts (Krampe, 2002). This suggests that simply regular intensive use is sufficient to maintain dexterous ability.

The interpretation of our data is supportive of the notion that ageing likely leads to a number of effects that have consequences to different aspects of movement dexterity. As already presented in Chapters 3 and 4, we have shown that attention selection and inhibition is reduced with age and that this has an impact on movement speed dexterity. Furthermore, in this Chapter we have shown that strength has some contribution to reduced dexterity with increased age. Yet for both, it was not the only factor measured. In the next chapter of this thesis (Chapter 6), we aimed to isolate and manipulate the strength factor associated with ageing in order to determine the influence that modulation would have on dexterity. Based on the findings presented here, we conducted a strength training intervention with young and older aged adults to determine whether increased strength across participants of different ages would bring about improvements in tapping dexterity performance. According to the findings presented here, improving strength ought to benefit performance for all ages. However, the effects should be in parallel, showing that although performance is improved in the older aged adults, performance should remain less than that for the younger adults (i.e., there is still an age effect).

CHAPTER 6 - DOES INCREASED HAND GRIP STRENGTH IMPROVE DEXTERITY IRRESPECTIVE OF AGE?

6.1 ABSTRACT

In Chapters 2 and 5, we presented consistent data showing that increased age was related to decreased strength. Furthermore, in Chapter 5, we demonstrated that age and strength and strength and movement dexterity were also related, and that strength was particularly important for aiming and tapping dexterity tasks. In the study presented here, we examined the effects of simple hand-grip strength training versus a control condition on tapping dexterity movement performance. We tested twenty adult participants that were separated into two groups; young and older adults. There were three separate testing sessions, each spaced by approximately fourteen days. In these sessions, hand-grip strength and tapping performance on a variety of tasks were recorded. In the intervening fourteen days, participant's performed ball squeezing exercises with either their hand or foot. The results showed significant main effects of age group for hand-grip strength and tapping performance in all tasks. As in previous data, this showed that the older adults were weaker than younger adult participants and that older adults were slower at tapping than younger adults. The analysis of condition showed that strength training significantly increased hand-grip strength and single button tapping compared to the baseline and control conditions, irrespective of age. The data are discussed in terms of the relationship between age, strength and dexterity, and proposes future directions for strength interventions with aged populations to improve functional movement.

6.2 INTRODUCTION

In Chapter 5 of this thesis, we replicated existing literature and showed evidence that increased age was associated with reduced strength (see for example Bassies & Harries, 1993; Carmeli, Patish and Coleman, 2003; Cole, 2006; Desrosiers et al., 1994, 1995 a, b, 1999; Kallman, Plato & Tobin, 1990; Krampe, 2002; Ranganathan et al., 2001; Voelcker-Rehage & Alberts, 2005). We also conducted a unique analysis that allowed the influence of age and strength on dexterity to be assessed (rather than assumed). This analysis showed that both age and strength were important factors for dexterity, but that strength was of greater importance for tasks such as aiming and tapping. We suggested that this was because movements such as aiming and tapping require the ability to rapidly execute a sequenced wrist or arm-hand directed movement with a moderate level of precision, and that individuals with increased muscle strength would be able to execute such movements faster and more efficiently. In the chapter presented here, we aimed to isolate and manipulate strength across participants of different ages in order to determine the influence that strength-training modulation would have on dexterity. If strength is an important factor determining dexterity, then improvements in strength ought to bring about improvements in dexterity, irrespective of age. However, if age is still important, over and above strength, then we might expect an interaction between the strength modulation condition and age. The aim of the study was experimental, and merely focussed on testing whether increased strength would improve tapping dexterity in relation to age. However, the same data could be informative for exercise rehabilitation of older adults in speeded dexterity. Therefore, the rationale for this chapter is mainly based on material presented in Chapters 1, 2 and 5. In this introduction, we review the evidence that strength can be developed across people of different ages, and discuss the reported impact that this has on dexterity.

As already mentioned in the thesis, the relationships between reduced movement dexterity, with decreasing strength and increasing age have been typically linked to the degeneration of the neuromuscular system. This degeneration has been identified as hampering the ability to generate maximal force, rapidly develop force or control force production (Doherty et al., 1993; Enoka et al., 2003; Gilles & Wing, 2003; Larson et al., 1979; Lexell & Taylor, 1988; Narici et al., 1991; Metter et al., 1997). It has further been suggested that these deficits are likely expressed in the reduced ability to perform daily living activities (Enoka, 1995; Galganski et al., 1993; Giampaoli et al., 1999; Grabiner & Keen et al., 1994). For example, Skelton et al., (1994) indicated that in the latter stages of life, absolute values of maximal strength in women approach the minimal levels necessary to accomplish daily activities. These levels of strength to activity balance have been recognised as a major contributory factor to frailty in older adults (Bortz, 2002; Lipsitz, 2002; Morley et al., 2002). However, despite the impact that neuromuscular system degeneration has on force and movement, it has been reported that the aged neuromuscular system retains the capacity to adapt in response to a training stimulus (Vandervoort, 2002). For example, Hakkinen et al., (1988) and Fiatarone et al., (1990) both reported older adult development of muscle strength (maximal force) and power (rapid force development) through the completion of a resistance-training regime.

Resistance training programmes are based on the application of the overload principle, which states that a muscle worked close to its force-generating capacity will increase in strength (McArdle et al., 1996). Typically, the resistance training programmes used with older adults match that used with younger adults, and could for example have a duration of twelve weeks, and a frequency of three times per week, where participants perform four sets of eight repetitions at an intensity of 80% of one repetition maximal effort (Macaluso & DeVito, 2004). There is much literature that shows such training can improve strength in older adults (Frontera et al., 1988; Hakkinen et al., 1998 Harridge et al., 1999; Tracy et al., 1999; Scaglioni et al., 2002). For example, Frontera et al., (1988) reported that a heavy-resistance training programme led to an increase in strength of the quadriceps muscles of older men aged between 60 and 72 years. By the twelfth week of the training programme, knee extensor and flexor strength had increased by 107% and 227% respectively. This increase in strength was also accompanied by an increase in quadriceps muscle fibre size. A similarly finding was reported by Harridge et al., (1999). They reported a positive increase in older adults (aged 85-97 years) muscle strength after twelve weeks of training, where average knee extensor muscle strength increased by 134% , and there was a 10% increase in cross sectional lean muscle area. Similar, improvements have also been reported for muscles in the upper body. For example, Macaluso et al., (2002) reported that after six weeks of isometric training of biceps brachii muscles in young and older groups of women participants, there were increases in absolute force by 22.4% in the young and 13.4% in the older women (see Table 6.1 for a summary of similar studies).

Despite the good evidence showing that older adults can gain strength, relatively few papers have measured whether the increased strength showed any related improvement in everyday functional dexterity (Rantanen, 2003). Instead, it has only been suggested that resistance training induced alterations in muscle activation patterns have the potential to modulate movement performance. For example, Carroll et al., (2001) suggested a positive transfer between strength and function could be anticipated in circumstances where the specific muscle activation patterns reinforced through training match those required in the functional task context. In contrast, negative transfer may occur when the muscle activation patterns consolidated by training were maladaptive with respect to performance of a functional movement task (Carroll et al., 2001). Examples of such positive adaptations from resistance training programmes have shown improvements in balance, gait and movements such as rising from a chair (Alexander et al., 2001; Fiatorone et al., 1990; Judge et al., 1993; Taaffe et al., 1999; Rooks et al., 1997). However, no papers to date appear to have tested the effects of upper-limb strength training on dexterity.

Table 6.1: Summary of resistance training studies in older aged adults, with details of muscles trained, programme length, assessment of changes.

Authors	Subjects			Training Programme						% Change	
	Age	Gender	*N*	Exercise Movements	Duration (Weeks)	Sessions per week	Sets	Repetitions	% of 1RM	Strength	
										1RM	MVC
Lexell et al., 1995	70-77	M/F	23	EF KE	11	3	3	6	85	49 ± 16 163 ± 75	
Sherrington and Lord, 1997	64-94	M/F	21	GWBE	4	7	-	-	-	-	17
Hakkinen et al., 1998	70	M/F	20	KE	26	2	3-6	3-15	50-80	26	-
Harridge et al., 1999	85-97	M/F	11	KE	12	3	3	8	80	134	37
										Power Gain	
Jozsi et al., 1999	56-66	M/F	17	KE, AP	12	2	3	8-12	80	10-26%	
Izquierdo et al., 2001	64(2)	M	11	KE, HS, BP	16	2	3-4	8-15	50-80	21-37%	
Earles et al., 2000	77(5)	M/F	18	LP	12	3	3	10	50-70	22%	
Fielding et al., 2002	73(1)	F	30	LP	16	3	3	8-10	70	High velocity: 35% Low velocity: 33%	
Miszko et al., 2003	72.5 ±6.3	M/F	39	Whole body: Upper & Lower Body	16	3	3	6-8	50-70 and then 80%	Chest Press 14% Leg Press 23%	

6.2.1 Hypotheses

Taking into account the relationship between strength and dexterity (Chapter 5), the literature showing that strength can be improved in older adults with appropriate training, and that functional improvement achieved through strength training the exercises can transfer to movement performance, the aim of the present study was to test the hypothesis that improved hand-grip strength will improve tapping speed dexterity irrespective of participant age. Based on the previous findings in this thesis, we expected to find that the older aged adult group would have a weaker hand-grip strength compared to younger aged adult group and that the older aged adult group would have slower tapping dexterity compared to the younger aged adult group. Based on the literature presented here, we also expected that a hand-grip strength training would increase hand-grip strength for both the younger and older aged adult groups. Related to the findings in Chapter 5, we finally hypothesised that increased hand-grip strength would lead to improved movement speed of the hand (i.e., tapping dexterity).

6.3 METHODS

6.3.1 Participants

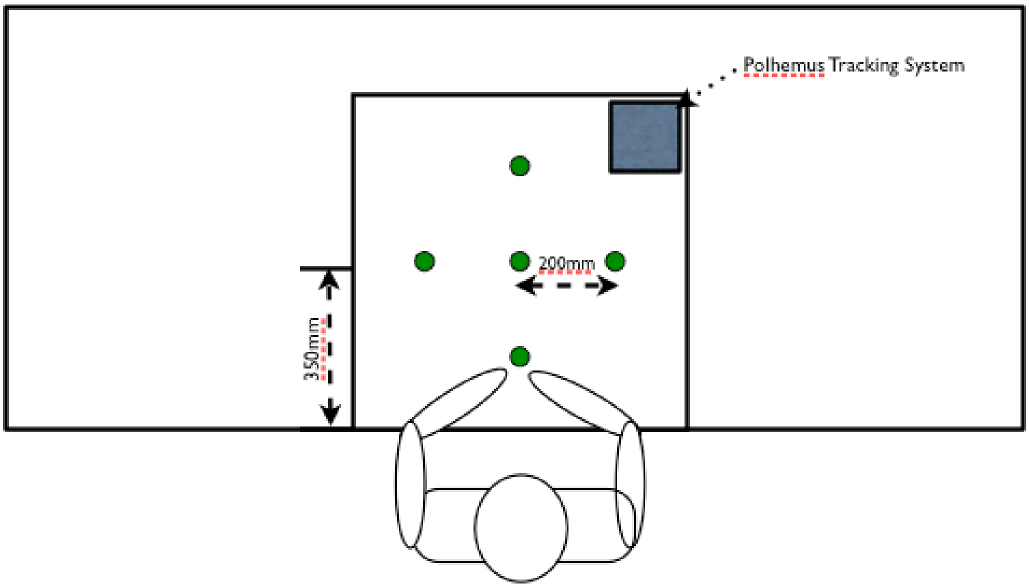
The study tested 20 participants that were separated into a younger and older aged group. The younger aged adult group contained 10 participants (1 male, 9 female) aged 23 ± 2 years, and the older aged adult group contained 10 participants (1 male, 9 female) aged 68 ± 11 years. The younger aged adults were students from the University of Birmingham and the older aged adults were recruited from around the City of Birmingham (West Midlands, UK). The inclusion criteria was that participants did not report any muscular skeletal or neurological problems on a self-report medical history questionnaire, had normal or corrected to normal vision, scored greater than 27/30 on the Mini-Mental State Examination (MMSE; Folstein, Folstein and McHugh, 1975), and were ambulatory and living independent of social care. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971) and all participants were right hand dominant. Ethical approval was granted from the School of Sport and Exercise Sciences, College of Life and Environmental Sciences, University of Birmingham in accordance with the 1964 Declaration of Helsinki. All participants gave written consent before taking part in the study.

6.3.2 Apparatus

Hand-Grip strength was measured using a portable hand-grip dynamometer (Takei Scientific Instruments Co., Ltd, Japan). Participants were positioned as close to sitting upright as possible, holding the dynamometer in the right hand, with the elbow flexed to approximately 90 degrees with the elbow positioned by the side of the body. The handle of the dynamometer was adjusted for comfort as required, so that the base of the dynamometer positioned with the rest on first metacarpal (heel of palm), with the handle rest on middle of the four fingers. The results were recorded in kilograms taken from the digital display of the dynamometer that presented measurements to the nearest 0.1 kg for the maximum strength achieved. After each recording, the dynamometer was reset to zero.

To measure the participant's tapping movement kinematics, the Polhemus Liberty electromagnetic tracking device (Polhemus, Colchester, VT, USA) was used. The Polhemus Liberty consisted of a low-frequency electromagnetic field transmitter and a maximum of four sensors. The sensors detect the field and determine relative position and orientation of the sensor relative to the transmitter over time. The reported root mean square accuracy of this system is 0.3–0.8 mm for position. In the present study, only one sensor was used on the tapping hand and 3D position was tracked at 240 Hz. In order to test tapping movements, we created a wooden console of five push buttons fitted equidistant from the centre of the console (see Figure 6.1). The console buttons were connected to the external sync on the Polhemus Liberty control unit so that the Polhemus Liberty software recorded every button pressed. The button console was placed onto a wooden testing table, with the Polhemus transmitter placed at the far top left of console. The participants sat on a chair with back support in a normal sitting posture with slightly bent forearms, at the mid point of the table, perpendicular to the button console (see Figure 6.1). During assessment, participants were instructed not to contact the wooden table or button console for additional postural support with any upper body parts.

Figure 6.1: A schematic of the experimental set up from overhead. The button tapping console placed on the table positioned central to the participants body mid-line. The Polhemus tracking system positioned in the farthest right corner (relative to the participant) of the button tapping console.



6.3.3 Procedure

At the beginning of the first baseline session, participants were given a series of questionnaires (i.e., the same as those used in Chapters 2-5). These included a self-report medical history questionnaire, the Edinburgh Handedness Inventory (Oldfield, 1971) and the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975). The self report medical history questionnaire comprised simple health questions that allowed easy identification of factors in the participant past or present medical history that would prevent the volunteers as being classified as physically healthy (see Appendix 1). Physically health was classified by the absence of any diagnosed physical diseases, mental illnesses, recent surgery or hospitalisation, and feelings of illness (see for example Potter & Grealy, 2006). Hand dominance was determined using the Edinburgh handedness Inventory (Oldfield, 1971). Participants were cognitively screened using the Mini-Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975) and a minimum high score of 27/30 was used to ensure participants were cognitively intact.

Upon completion of the questionnaires, the researcher asked the participants to perform the hand-grip dynamometry assessment. Both hands were tested alternatively in random order, and each hand was tested three times (Bohannon et al., 2006). The participant squeezed the dynamometer with maximum effort that was maintained for at least 5 seconds. Participants had a minimum of 60 seconds between each repeat attempt. Hand-Grip was recorded as the highest value[5] of the three trials.

Once the participant's hand-grip strength was recorded, they were asked to complete a series of button tapping tests using the 5 button-tapping console (Figure 6.1). Before the commencement, all of the tasks were explained to the participant and they were given a brief period to familiarise themselves with each and reminded that at all times during motor performance assessment they should not use the wooden table or tapping console for additional postural support of any upper body parts. The tests were run in the order presented in Table 6.2, and the same order was used in all three experimental testing sessions for each participant. Participants were instructed to repeat each tapping sequence as fast as possible for a time period of 60 seconds.

[5] Maximum value was used rather than mean of the three trials so as not to reflect a higher level of fatigue that may be prevalent with weaker participants.

Table 6.2: A description of the action required for each of the eight tapping dexterity measures.

Tapping Task	Description
1	Repeatedly, press a single button
2	Repeatedly, press the outer buttons parallel to the coronal plane (e.g. left button, right button, left button etc.) distance apart 200mm
3	Repeatedly, press the outer buttons parallel to the sagittal plane (e.g. top button, bottom button, top button etc.) distance apart 200mm
4	Repeatedly, press the outer buttons parallel to the coronal plane (e.g. left button, right button, left button etc.) distance apart 400mm
5	Repeatedly, press the outer buttons parallel to the sagittal plane (e.g. top button, bottom button, top button etc.) distance apart 400mm
6	Repeatedly, press the 3 buttons in the sagittal plane in sequence order. (Closest, middle, farthest, middle, etc.)
7	Repeatedly, press the 3 buttons in the coronal plane in sequence order. (right, middle, left, middle, etc.)
8	Repeatedly, press the 5 buttons in sequence order (middle, top, middle, right, middle, bottom, middle, left, middle, etc.)

Participants were tested on three occasions, spaced at least 14 days between each occasion, first at baseline, then after a hand ball squeezing task (experimental condition) or a foot ball squeezing task (control condition). The ball squeezing exercise tasks were run in a counterbalanced order, equally across participants. Following the baseline test, participants were randomly assigned to one of two exercise conditions, one that involved participating in a hand then foot ball squeezing task, and the other that involved foot then hand ball squeezing. The participants were ‘blind’ randomised using ballot envelopes after completing the baseline measurements. The ballot envelopes contained complete written instructions for each participant explaining all the detail of the experimental and training procedure they needed to follow for four weeks (i.e. either the experimental then control or control then experimental conditions; see Figure 6.2). Prior to drawing ballot envelope, the participants were instructed not to inform the researcher about the assigned exercise condition, unless a severe adverse problem occurred as a consequence of the exercise intervention (note that if any participant were to have informed the researcher, they would have been removed from the study).

Both the hand and foot (experimental and control) exercise conditions lasted for two weeks, with each exercise session lasting ten minutes, and repeated twice daily. Therefore, a total of 28 training sessions in 14 days were run. The researcher demonstrated and instructed each participant about both types of exercise activity at the baseline measurement session and repeated the same demonstration and instructions to each participant after the intermediate measurement session. Participants performed the exercise in their own home.

The hand ball squeezing condition was aimed at improving hand-grip strength and functional tapping ability, whereas the foot ball squeezing condition was a control exercise (i.e., having no influence on hand-grip strength and upper limb tapping dexterity; see Figure 6.3). In both tasks, the participants were required to maximally squeeze a training ball (Slazenger, Training Foam Ball: Tennis) either in their hand or under their foot while in a seated position. They were instructed to squeeze the ball for as many times as possible in a period of sixty seconds. The exercise was repeated five times with a minimum of sixty seconds rest between each bout of exercise. Therefore, each exercise session lasted ten minutes in duration (i.e., 5 x 1 minute exercise bouts and 1 minute rests for each hand or foot exercise) with each exercises session performed twice daily (i.e. once in the morning and once in the evening) to provide a combined total of 20 minutes exercise per day. Participants were instructed to warm up and cool down for three minutes either side of the exercise by performing a set of hand and foot stretches irrespective of the exercise performed. The participants were self-directed throughout the study using an instruction booklet and logbook. Participants were required to count the number of compression's attained within each of the sixty second exercise bouts and record the number in the logbook. Participants were instructed to report any adverse symptoms (i.e. excessive fatigue, pain, injuries) to the researcher. Participants were instructed to use both dominant and non-dominant limbs equally to encourage functional balance.

Figure 6.2: A schematic of the study design. Five participants from each group (young and older adults) followed the study in sequence A, while the other five participants from each group followed the study in sequence B.

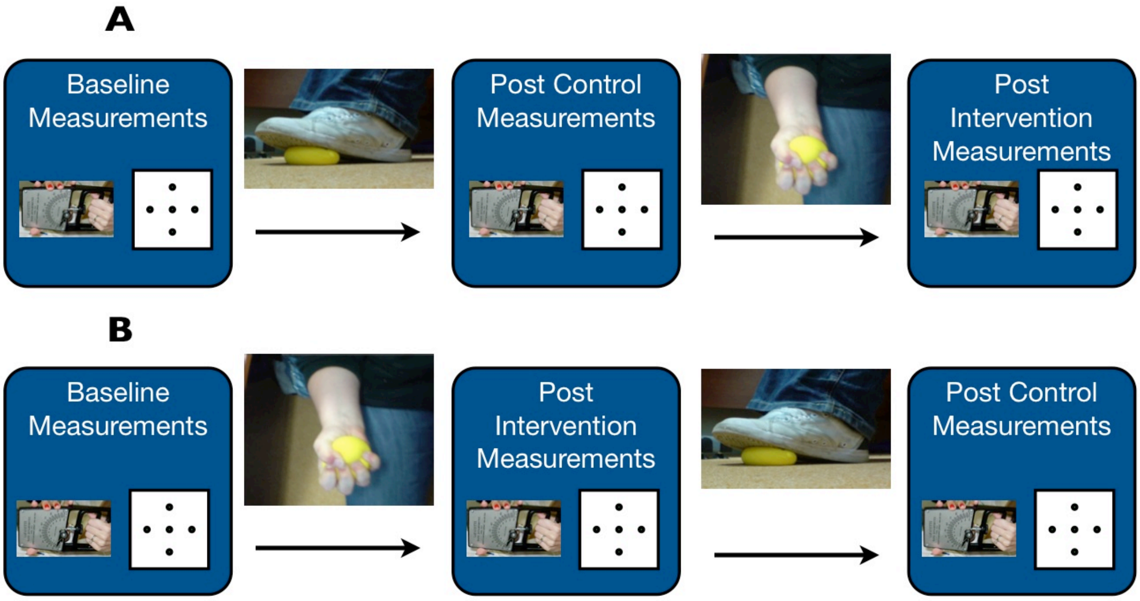


Figure 6.3: A sequence of images to show how participants were asked to squeeze the foam training ball during (A) the intervention condition and (B) the control condition.

6.3.5 Data Analysis

The independent variables tested were age group (younger vs. older aged adults) and condition (baseline vs. foot control vs. arm intervention). The dependent variables were hand-grip strength and the number of button taps completed within the 60-second test period for each of the eight tests measured. Therefore, a total of nine mixed design Analysis of Variance were used to analyse the data (between age groups and repeated condition). Any significant main effects of condition were analysed using Bonferroni post-hoc analyses, and any significant interactions were tested by running separate repeated measures ANOVAs for each age group. Analyses were performed using SPSS v16.0 (SPSS Inc. Chicago, Illinois, USA). The data are reported under headings of hand-grip strength and button tapping dependent measures results.

6.4 RESULTS

6.4.1 Hand Grip Strength

Analysis of hand grip strength showed significant main effects of age group ($F[1,18] = 5.418$, $p < 0.05$) and condition ($F[2,17] = 20.49$, $p < 0.001$), and no interaction ($F[2,17] = 2.639$, $p = 0.100$). The data showed that the older adults were significantly weaker than the younger aged adult group and that the hand exercise condition lead to stronger grip strength than the control and baseline conditions (see Figure 6.4).

6.4.2 Button Tapping Tasks

6.4.2.1 Tapping Task 1: Single button

As for hand-grip strength, analysis of tapping dexterity in the single button task showed significant main effects for age group ($F[1,18] = 5.42$, $p < 0.05$) and condition ($F[2,17] = 20.49$, $p < 0.001$), and no interaction ($F[2,17] = 2.64$, $p = 0.100$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group and that tapping after the hand exercise condition was significantly faster than after the control condition (foot exercise) ($p < 0.05$) and baseline ($p < 0.01$) conditions (see Figure 6.5).

6.4.2.2 Tapping Task 2: Double button with a short reach in the coronal plane (200mm apart).

Analysis of tapping dexterity in the double button short reach coronal plane task showed significant main effects for age group ($F[1,18] = 11.04$, $p < 0.01$) and condition ($F[2,17] = 5.18$, $p < 0.05$), and no interaction ($F[2,17] = 0.25$, $p = 0.78$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group, but that tapping after the hand exercise condition were not significantly faster than after the control ($p = 1.00$) or baseline conditions ($p = 0.10$) (see Figure 6.5).

6.4.2.3 Tapping Task 3: Double button with a short reach in the sagittal plane (200mm apart).

Analysis of tapping dexterity in the double button short reach sagittal plane task showed a significant main effect for age group ($F[1,18] = 9.54$, $p < 0.01$), but no effect for the condition ($F[2,17] = 1.13$, $p = 0.35$), and no interaction ($F[2,17] = 0.25$, $p = 0.78$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group ($p < 0.05$) (see Figure 6.5).

6.4.2.4 Tapping Task 4: Double button with a long reach in the coronal plane (400mm apart).

As for task 2, analysis of tapping dexterity in the double button long reach coronal plane task showed significant main effects for age group ($F[1,18] = 13.67$, $p < 0.01$) and condition ($F[2,17] = 6.56$, $p < 0.01$), and no interaction ($F[2,17] = 0.18$, $p = 0.84$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group and that tapping after the hand exercise condition were not significantly faster than after the control ($p = 1.00$) and baseline conditions ($p = 0.14$) (see Figure 6.5).

6.4.2.5 Tapping Task 5: Double button with a long reach in the sagittal plane (400mm apart).

Analysis of tapping dexterity in the double button long reach sagittal plane task showed similar results to task 3 with a significant main effect for age group ($F[1,18] = 33.90$, $p <$

0.001), no effect of condition ($F[2,17) = 0.99$, $p = 0.39$), and no interaction ($F[2,18) = 0.63$, $p = 0.52$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group ($p < 0.05$) (see Figure 6.5).

6.4.2.6 Tapping Task 6: Triple button in the coronal plane.

Analysis of tapping dexterity in the triple button coronal plane task showed significant main effects for age group ($F[1,18) = 14.48$, $p < 0.01$) and condition ($F[2,17) = 21.19$, $p < 0.001$), and an interaction ($F[2,17) = 8.00$, $p < 0.01$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group and that tapping after the hand exercise condition were significantly faster than after the baseline condition ($p < 0.05$), but were not significantly faster than the control condition ($p = 0.38$), indicating that the effect was likely a consequence of practice (see Figure 6.5).

6.4.2.7 Tapping Task 7: Triple button in the sagittal plane.

Analysis of tapping dexterity in the triple button sagittal plane task showed a significant main effect for age group ($F[1,18) = 19.24$, $p < 0.001$), no main effect for condition ($F[2,17) = 0.69$, $p = 0.52$), and no interaction ($F[2,18) = 0.25$, $p = 0.78$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group ($p < 0.05$) (see Figure 6.5).

6.4.2.8 Tapping Task 8: Five button sequence.

Finally, analysis of tapping dexterity in the five button task showed a significant main effect for age group ($F[1,18) = 34.75$, $p < 0.001$), though not for condition ($F[2,17) = 2.97$, $p = 0.08$), and no interaction ($F[2,18) = 0.82$, $p = 0.46$). Analysis of age group showed that the older adults were significantly slower at tapping than the younger aged adult group ($p < 0.05$) (See Figure 6.5).

Figure 6.4: Hand-grip strength measurements (Mean ± Standard Error) for younger and older aged adults at baseline, and after the hand exercise and control exercise conditions.

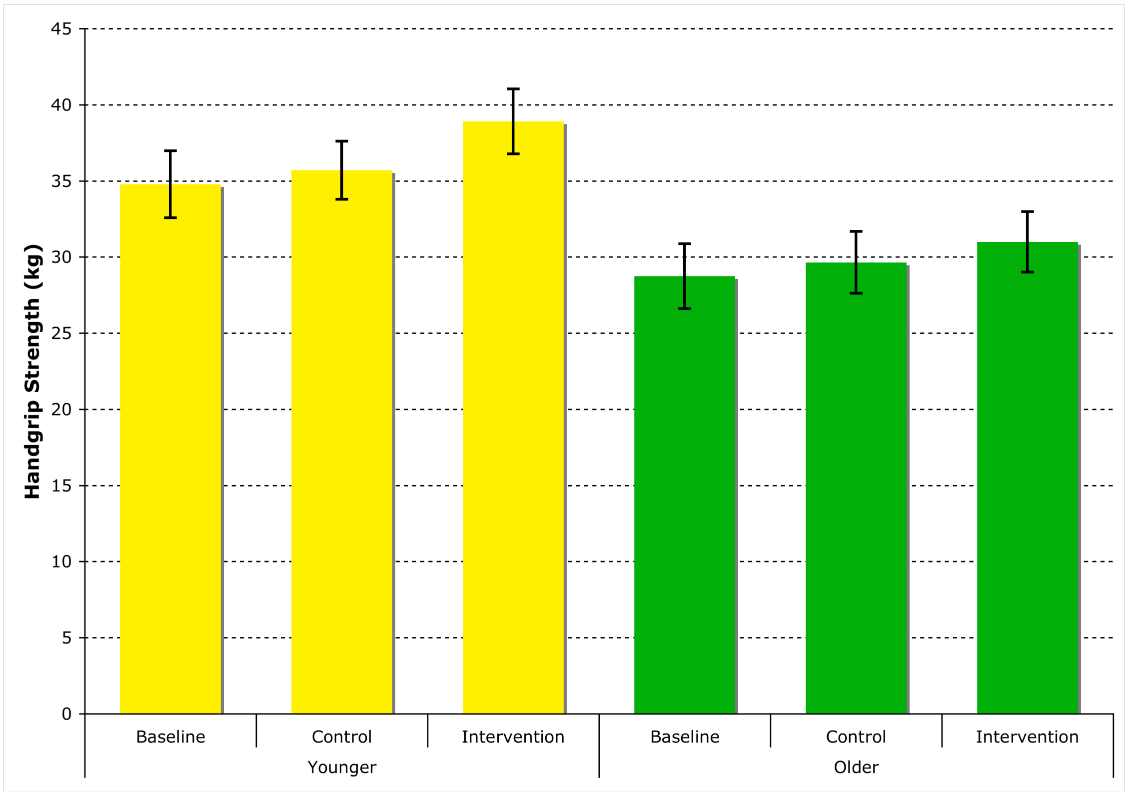
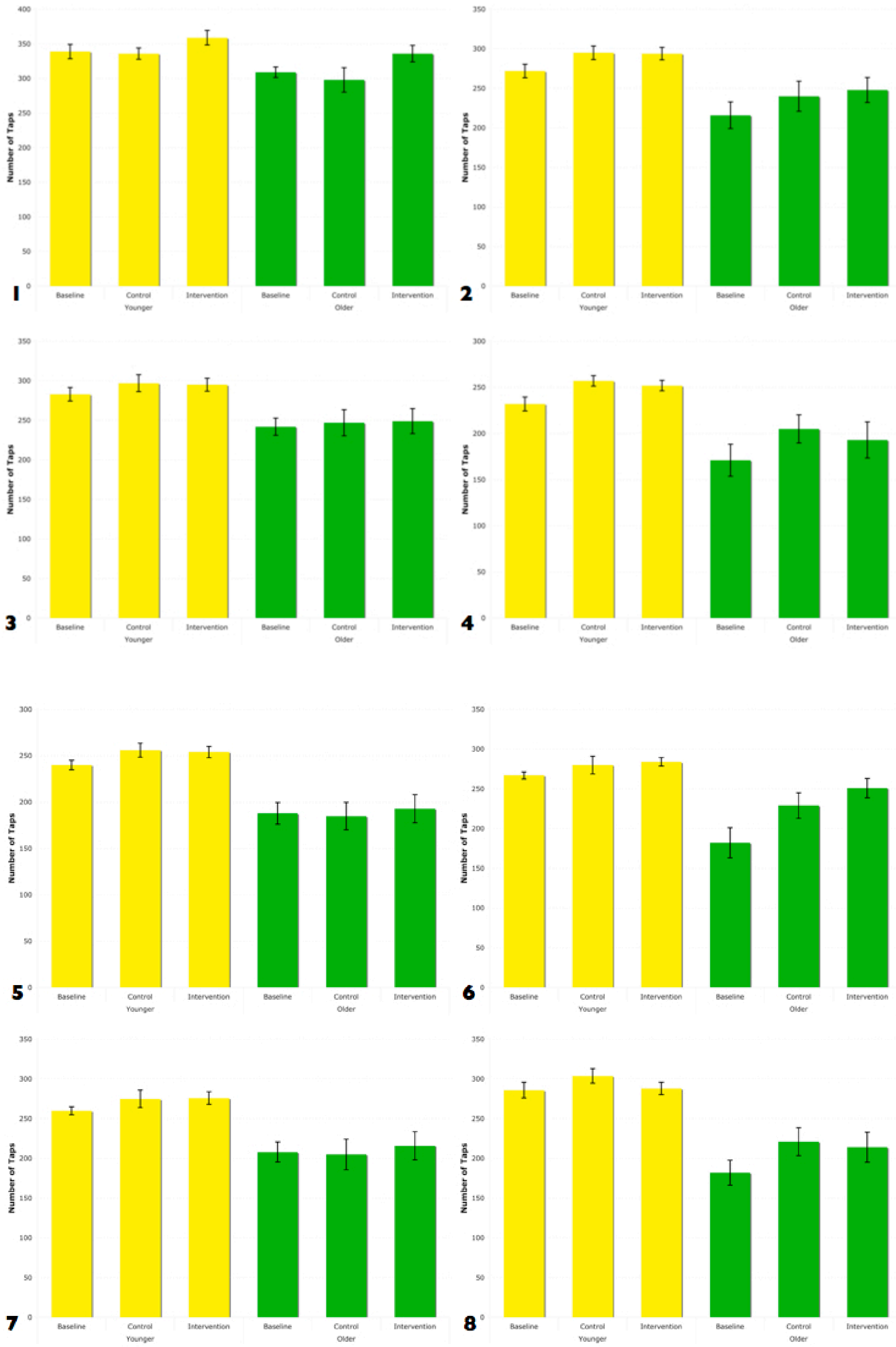


Figure 6.5: The number of button taps measured (Mean ± Standard Error) for younger and older aged adults at baseline, after the hand exercise and control exercise conditions for each of the tapping tasks 1-8. Bars charts are labelled (1-8) respectively.



6.5 DISCUSSION

Based on the finding that hand-grip strength and tapping speed dexterity were related in Chapter 5, the aim of the present study was to test whether improvements in hand-grip strength would improve tapping speed dexterity irrespective of the participant age. From the data already collected in this thesis and the literature, we expected to find that the older aged adult group would have a weaker hand-grip strength compared to younger aged adult group and that the older aged adult group would have slower tapping dexterity compared to the younger aged adult group. From the literature presented in the introduction to this chapter, we also expected that a hand-grip strength exercise would increase hand-grip strength for both the younger and older aged adult groups. Related to the findings in Chapter 5, we finally hypothesised that increased hand-grip strength would lead to improved movement speed of the hand (i.e., tapping dexterity).

The data were generally consistent with these hypotheses. For the first hypothesis, analysis of hand-grip strength showed that older aged adults were significantly weaker than younger aged adults. The data presented on button tapping confirmed our second hypothesis in that older aged adults showed significantly slower movement speed compared to younger aged adults, with the older aged adults producing less taps per minute in all button tap sequences compared to the young adults. The third hypothesis that the exercise condition would improve strength irrespective of age was also correct. These data show that hand grip strength increased for both younger aged and older aged adults (by 8% and 12% respectively) when using the same foam ball squeezing exercise. Furthermore, there were no interactions between the exercise condition and age group suggesting that the strength gain was equal for both groups. This finding is consistent with existing literature showing that young and older aged adults can equally increase strength after exercise training (Frontera et al., 1988; Hakkinen et al.,1998; Harridge et al., 1999; Tracy et al., 1999; Scaglioni et al., 2002).

The final and critical hypothesis for the present investigation was that increased hand-grip strength would lead to improved tapping dexterity. The data however only supported this hypothesis for the single button tapping task. This showed significantly improved tapping dexterity following the exercise compared to control condition. However, the exercise condition did not show any significant improvements on tapping dexterity for the other seven tasks measured. While condition effects were evident for double and triple button dexterity tapping tasks in which buttons were aligned along the coronal plane, none of these tapping tasks showed significantly different responses from the baseline and control conditions. That is, the strength training condition alone did not improve tapping dexterity for these measures.

The finding that significantly improved tapping dexterity was only observed in the single button task, but not the other dexterity tapping tasks might suggest that the findings from Chapter 5 were not correct. That is, we reported that strength accounted for more variance than age on aiming and tapping movement tasks (though both were significant), and from that concluded that strength was an important contributor to the increased age and reduced dexterity relationship. In the data presented here, we isolated the strength variable and showed that we were able to increase the strength of participants irrespective of their age. Therefore, if strength really were an important contributor to the increased age and reduced dexterity relationship, we would expect that increased strength at any age would cause increased dexterity. Counter to this expectation, the data here largely didn't support the relationship. Despite significant increased hand-grip strength for both age groups, seven of the eight dexterity measures showed no increase in performance following the exercise compared to control condition. This data suggests that strength was not an important factor that interacted with the increased age and reduced dexterity relationship, as the relationship remained despite the increased strength.

A possible reason for the largely null effect from the exercise condition might be due to the importance of adaptation specificity relative to the resistance training exercise. As stated by Rutherford et al. (1986) (see also Carroll et al., 2001), strength improvements gained from resistance training can only be anticipated in circumstances where the specific muscle activation patterns reinforced in training match those required in the functional task. It could be argued that the hand muscles used in the single button dexterity tapping task closely match those of ball squeezing and so the exercise condition specifically improved single button tapping. On the other hand, it is more difficult to justify that the exercise condition would improve movements that involved muscles of the upper arm and shoulder, such as in the double, triple and five button dexterity tapping tasks. Therefore, it could be that the effects of exercise condition were not detected on seven of the eight dexterity tasks as the specific muscles used in the task were not actually strengthened. In order to test this point, future studies should consider training other upper limb muscles in the arm or shoulder and measure their relative effects on movement. If the latter proposal is correct and that strength improvements need to be specific, it should be possible to show that hand strength improvements specifically improve single button tapping dexterity whereas for example shoulder strengthening might improve dexterity tapping tasks across coronal plane buttons (e.g. left button, right button, left button etc.).

With regard to the single button dexterity tapping task (matched to the tapping task used in Chapter 5), the data presented here did support the final hypothesis in that increased hand-grip strength lead to improved tapping dexterity. To our knowledge, this is the first study to show that improvements in hand-grip strength are associated with increased hand movement dexterity following a short two-week strength resistance training exercise. Such a finding has important implications for physical exercise interventions with both aged or injured adults in community and clinical environments that have reduced strength (compared to young or healthy adults). In the hand exercise intervention used here, improvements in strength and dexterity occurred from an exercise that was undertaken in the individual's own home environment, on a daily basis and self monitored. Therefore, the hand exercise intervention presents a relatively cheap option for improving dexterity function, though more testing is needed to understand whether a variety of exercises of various muscles would be better. It would also be interesting to identify if the effects of increased hand-grip strength and increased movement speed following longer training periods, and whether there is an optimal time course for the greatest improvement. For older adults, it would also be important to measure how long the strength improvements maintain dexterity and what minimum ongoing level of resistance training is necessary to maintain well functioning dexterity.

In conclusion, the current study suggests that improvements in hand-grip strength as a result of a hand exercise intervention lead to improved dexterity irrespective of age. Although this statement is only supported for the single button tapping following appropriate hand-grip exercise, suggesting that this conclusion should be consider with caution since it is clear that much more data are needed to fully support the idea that strength improvements can improve the relationship between increased age and reduced dexterity. We suggest that further clarification is needed through future empirical research.

CHAPTER 7 - GENERAL DISCUSSION

The experiments presented within this thesis consistently replicated the literature presented in Chapter 1 in that we found that increased age was related to decreased movement dexterity performance. In addition, the thesis also presented data that tested two further relationships and measured the relative impact that these had on dexterity. These relationships were between increased age and reduced selective attention (or inhibition) and between increased age and reduced strength. In both cases, we demonstrated that the apparent effect of age on movement dexterity might not be correct, and instead may be an effect of differences in other factors (i.e., selective attention and strength). While these data are preliminary steps in an attempt to have a more detailed understanding of the effects of age on dexterity, they are nevertheless important and provide a basis from which we suggest further experimentation is needed.

In this chapter, I have separated the main discussion into three sections. The first discusses the screening study presented in Chapter 2. In this, we reported findings about the relative effects of age on movement dexterity, hand grip strength, sense of touch and selective attention, and discussed the implications of these findings with respect to understanding how the dexterity movements of older aged adults are influenced. The studies provided a foundation for further empirical studies contained within the rest of the thesis. The second and third sections of the main discussion then present the relative impact that selective attention (Chapters 3 and 4) and strength (Chapters 5 and 6) had on the age and dexterity relationship. At the end of the chapter, I present some potentially interesting future avenues of research that could follow-up the thesis.

7.1 Effects of Age, Sense of Touch, Strength, and Selective Attention on Dexterity.

In Chapter 2 we set out to replicate existing literature showing a relationship between increased age and reduced dexterity, and in addition wanted to test possible other relationships between age and hand grip strength, sense of touch and selective attention that might have an impact on dexterity. The basic relationship was demonstrated, with significant effects of age on both fine and gross dexterity movement performance (Purdue Pegboard and Box and Block tests). This showed that with increased average age, there was decreased average dexterity performance. The post-hoc analyses showed compatible, although slightly different results for fine and gross dexterity movements. For fine dexterity, the older-aged adult participant group were slower overall than both the middle- and younger-aged adult groups, while for gross dexterity assessment, both the older- and middle-aged adult groups were significantly slower than the younger-aged adult group. In addition, a hand dominance effect was shown for both fine and gross dexterity, in that the dominant hand outperformed the non-dominant hand. Together, these findings replicate existing literature (see for example: Bennett & Castiello, 1994; Desrosiers et al., 1994; Desrosiers 1995; Desrosiers et al., 1999; Falconer et al., 1991; Mathiowetz et al., 1985; Shiffman, 1992).

Analyses of the relationships between age and sense of touch, hand grip strength and selective attention were also significant. The data showed that sense of touch was significantly reduced in the older compared to younger and middle aged adults (replicating Desrosiers et al., Gilles & Wing, 2003; Van Nes et al., 2008), hand grip strength showed that older aged adults were weaker than middle aged, who were in turn weaker than younger aged adults (replicating Bassie and Harries, 1993; Desrosiers et al., 1995 a, b, 1999; Kallman, Plato & Tobin, 1990; Mathiowetz et al.,1985; Ranganathan et al., 2001) and selective attention showed in general that the older aged adults were slower than the younger aged adults (replicating Perianez et al., 2007; Tombaugh, 2004).

From these findings, we suggested that it was possible that any of the factors: sense of touch, hand grip strength and selective attention might actually confound or mediate the relationship between age and dexterity. However, the relative effects of hand-dominance within some of these relationships lead us to believe that sense of touch was perhaps less important than hand grip strength. This was based on the finding that the age and dexterity relationship showed a hand dominance effect with the dominant hand having faster dexterity than the non-dominant hand. A similar hand dominance effect was observed for hand grip strength, meaning that the stronger dominant hand might be faster compared to the non-dominant hand. However, analysis of sense of touch showed no hand dominance effect. Therefore, it seemed to us unlikely that sense of touch confounded the age and dexterity relationship, as if it did, there should not have been a hand dominance effect in the age and dexterity relationship. Although the factor of selective attention and it's impact on age and dexterity was not tested for hand dominance, we considered that it was of interest as no other studies in the literature had considered the impact of attention on action in ageing.

On the basis of this rationale, the data from Chapter 2 defined two areas of interest that was pursued in the PhD research. Firstly, the effect of selective attention ability on movement dexterity was tested in order to understand whether older aged adults showed reduced dexterity as they were slower to visually select the object that they intend to move or interact with. Secondly, the effect of hand grip strength on movement dexterity was tested in order to understand whether older aged adults showed reduced dexterity because they were weaker than younger aged adults.

7.2 The Effects of Selective Attention and Age on Dexterity Movement.

In Chapter 3, we developed a simple movement response task based on the Box and Block Test in which we were able to vary stimuli complexity. The test was designed such that the blocks were presented and moved to set positions on a table so that every participant made the same actions over the same distance. Therefore the time to make the actual actions could be measured using an accurate motion tracking system and accurate comparisons made. From the obtained data, we determined the relative differences between action types (e.g., selection, reach and grasp of the target object vs. transfer the target object to a new location vs. return the hand to the end position) so that we could determine whether selection (i.e. object to reach to and grasp) was the only component of movement slowed with age.

In the study, it was hypothesised that movements would generally be slower with increased age, and that movements that contained a selection component (i.e., selection, reach and grasp of the target object or transfer the target object to a new location respectively) might be slower than actions that did not have a selection component (i.e. return the hand to the end position).. The data were somewhat consistent with these hypotheses. Surprisingly the overall movement time showed no significant age group effect. However, mean total reach time did show a significant age effect, in that the older aged adults were significantly slower than the younger and middle aged adult groups. As expected, mean total return time showed no effects of age. Further investigation of the age effect on reach time revealed a significant age group effect for actions to objects 2, 3, 4 and 5, but not to object 1. This showed that the older-aged adult group had slower movements during the reach movement compared to young and middle-aged adult groups. We suggested from these findings that the slower movements corresponded to the selection difficulty with increased age as reported in

Chapter 2 for the Trail Making Tests (A and B). That is, when selection was required to be made online, movements were slowed to objects 2,3,4 and 5 while movements could be pre-planned for object 1 prior to the task.

It was also hypothesised that if selective attention ability was important to dexterity, with increased age, participants would become even slower when responding to complex stimuli configurations as selection was of greater complexity. While the data showed a significant effect of stimuli complexity for the overall time taken in the task, there was however no effect of stimuli complexity on reach time to the object. Although this last finding was at odds with our hypothesis, the data overall provided clear evidence that the age effect on dexterity could be in part be explained by selection difficulty that also increases with age. When selection was required for an action, the movements in that phase were particularly slowed.

In Chapter 4, we sought to further clarify the findings of impaired selective attention as suggested from data report in Chapters 2 and 3. To do this, a common measure of visual search selective attention was used (Watson & Humphreys, 1997). By measuring the ability of older aged adults to select and process visual stimuli from an array of distractors, it was possible to identify whether older aged adults can use visual search stimuli as successfully as younger aged adults. Since it follows that if attention or inhibition ability was reduced with increased age, this would in turn create an increased demand on attention resources that would cause older aged participants to respond slower to accommodate their reduced ability. Therefore, the purpose of the Chapter 4 was to investigate the effects of ageing on selective attention, speed of visual search and the benefit of preview. It was hypothesised that older aged adults would be slower to select visual stimuli, especially with preview items due to impairments in selective and inhibitory attention processes compared to normally functioning younger-aged adults.

The data were in support of the hypothesis in that it showed that older adult participants were slower overall and demonstrated a slowed search rate in both the simple search and preview search conditions for all visual display sizes. The finding that search was slowed through the search displays in older adults was coherent with previous research (Folk & Lincourt, 1996; Plude & Doussard-Roosevelt, 1989; Watson & Maylor, 2002). Comparisons between the search rates in the preview and simple search conditions demonstrated that while younger aged adults were able to inhibit preview distractor items effectively, older aged adults were not able to do so. This finding was also supported by the response data, which showed that the older aged adults made more time-out errors than the younger aged adults, especially when the visual search display size was greater than 16 items. Therefore, these data support the hypotheses that older aged adults are slower to select visual stimuli, and that visual marking of preview stimuli appears to become completely ineffective in large display stimuli (>16 items).

From the data presented and discussed in Chapters 2, 3 and 4, we suggest that the finding of older aged adults being particularly slower than younger aged adults on reach, selection and grasp actions to objects 2, 3, 4 and 5 was similar to the finding that older aged adults were slower in visual search and unable to effective use the preview condition. That is, it appears that the older aged adults had reduced attention capacity and as a result of this, selective attention ability was reduced which both impacted upon the speed of selective attention behaviour and on dexterity of movements that required selective attention components.

7.3 The Effects of Age and Strength on Dexterity.

On the basis of the data reported in Chapter 2 that showed similar relationships between age and dexterity and between age and strength, and similar effects of hand dominance within each, Chapters 5 and 6 investigated the relative relationship between age, strength and dexterity. In Chapter 5, we investigated the relationship between age, strength and movement dexterity for 107 adults aged between 18 and 93 years of age on four measures of dexterity. It was hypothesised that the data would replicate existing findings in the literature that show relationships between age and strength, and age and movement dexterity, and furthermore, that the presumed relationship between strength and movement dexterity would also be supported. Using multiple linear regression models, the data showed findings that clearly supported the hypotheses, showing significant relationships between increased age and decreased strength, increased age and reduced movement dexterity and decreased strength and reduced movement dexterity (replicating Desrosiers et al., 1994; 1995; 1999; Michimata et al., 2008; Smith et al., 1999; Williams et al., 1990).

Further analyses of the relationships revealed that the variance for steadiness and line tracking dexterity measures were explained by age more than strength, while the aiming and tapping dexterity measures were explained by strength more than age. In addition one interaction in regression for steadiness dexterity showed that strength only explained variance for mean and younger aged adults, whereas older aged adults showed that strength did not explain the variance. From these data, it was suggested that the dependent measures of steadiness and line tracking differ from aiming and tapping. Movements involving steadiness and line tracking represent an ability to maintain a certain arm-hand position with as little change as possible over a period of time. Any errors in this type of movement might more likely be caused by impairments in the use of visual feedback or eye-hand co-ordination, or may be affected by tremor, all of which are likely to be independent of the strength factor. For aiming and tapping dexterity, the tasks more likely involve selecting a target for action and then co-ordinating the muscles involved in the movement as fast as possible. Therefore, strength of the muscle would be related to the ability to rapidly activate the muscle in these tasks.

In Chapter 6, we followed up the findings of Chapter 5 by isolating the strength variable and attempting show that increased strength ought to lead to increased tapping speed dexterity irrespective of the participant age. The data replicated Chapter 5 by showing that the older aged adults had a significantly weaker hand grip than younger aged adults, and that older aged adults were significantly slower in all dexterity tapping tasks than younger aged adults. Of interest to the main aim of the study, the data also showed that increased hand grip strength through specific hand muscle exercise significantly improved tapping dexterity for the single button tapping task. Therefore, the findings were consistent with our expectations and supported existing literature reporting strength and function improvement in aged adults (Frontera et al., 1988; Hakkinen et al.,1998; Harridge et al., 1999; Tracy et al., 1999; Scaglioni et al., 2002).

In summary, Chapters 5 and 6 showed that strength was an important factor in the age and dexterity relationship. Although these data represent a first step, the findings are somewhat intuitive. That is, with reduced exercise or activity, strength reduction with age is accepted. However, until now, the impact that this reduced strength has on upper-limb function has not been understood. These data are important as they show that strength and dexterity are related, independent of age, and furthermore, show that older and younger aged adults can improve strength (and dexterity) to the same degree.

7.4 Limitations

Whilst the data present within this thesis have potentially important implications for current and future research, there were a numbers of limitations within the thesis that should be acknowledged and considered to provide context to the presented data.

First, in retrospect, the recruitment of participants in chapters 2, 3, 4 and 6, would have benefit from an across the age range recruitment approach as used and report in chapter 5 of this thesis rather than a groups approach. Whilst categorising participants by age groups provides a simple and time effective method to ensure successful data collection and analysis for this thesis, such an approach may also mask some interesting age related information or be influenced by confounds that co-factor with age and differ for the selected participant groups. A better approach would been to have a large participant base from across the age span as used in chapter 5, such an approach is likely to provide a wealth of information and be more informative about the nature of age associated changes in dependent, covariant and the possible confounding variables. The drawback to such an approach is that its time consuming to recruit and test such a large number of participants, a task that is not necessarily achievable within a 3 year PhD.

Second, the level of habitual physical activity undertaken by all participants is likely to be a potential confound or mediator to the data present within this thesis. Whilst it was considered important to glean an understanding about the level of physical activity undertaken by all participants using specific questions within a self report medical history questionnaire (see Appendix 1). The data reported was considered to be inaccurate and omit from further analysis within the thesis and any future reporting. The data was omit since it was identified through follow up verbal discussions with participants that older aged adults complete this part of the questionnaire more comprehensively than younger aged participants, specifically by taking account of all walking and movement that they did on a daily basis. In comparison, younger aged adults typically only report the purposeful sports or physical activity in which they participate (for example, swimming for leisure, football, rugby, hockey etc.) and ignored their daily habitual activity, such as walking or cycling to university that often accumulate to one or more hours of physical activity per day. In future research, it is recommended that an accurate report of habitual physical activity is achieved for all participants as those whom are regularly more active are likely to be stronger and more physically active.

Third, its important to acknowledge that the Trail Making Test used within this thesis as a method to assess selective attention has a limitations. The Trail Making Tests A and B are said to measure attention, visual searching, mental processing and the ability to mentally control simultaneous stimulus patterns, and as such is a test preferentially used for testing executive function rather than selective attention. In retrospect, it would have been better to undertake basic examinations of attentional processes using tests of spatial attention as described by Posner (1980) in which a spatial cue is provided such as a momentary brightening of a stimuli and the speed of visual response measured, or feature/object visual search as originally described by Treisman (1982), or the d2 Test of Attention (Brickenkamp and Zillmer, 1998) that is said to measure processing, rule compliance and quality performance and provide a neuropsychological estimate of individual attention and concentration performance. Additionally, it would have been useful to have information for simple response and simple motor planning investigations (e.g. simple and choice reaction time tasks, or simple sequence planning and motor actions tasks) to investigate the participants conformity to Hick's and Fitt's laws, (Hick, 1952; Fitt's, 1954, respectively). Obtaining such basic behavioural information for all assessed participants should be done to get a better insight about the influence that these components have upon dexterity movements to establish a much better understanding.

7.5 Suggestions for Future Investigations.

From the data presented in this thesis, we consistently demonstrated that increased age was associated with reduced dexterity, as reported in the literature. However, we demonstrated that increased age was associated with reduced selective attention ability and strength, and that both factors could explain the apparent relationship between age and dexterity. There are a number of further experiments that could be carried out to further explore the effects of ageing on dexterity.

One very interesting avenue of research would be to further explore the effects of exercise on the age and movement dexterity relationship. It was clear from Chapter 6 that exercising the specific muscle used for tapping dexterity both increased the strength of the muscle and more importantly, increased dexterity irrespective of age. In the discussion of Chapter 6, we suggested that further experimentation should consider strengthening other muscles and measuring resultant improvements in different types of dexterity task. For example, strengthening the shoulder muscle might improve actions that use a shoulder movement such as moving an object from the left to right (e.g., in the Box and Block Task). In a similar vain, it might be that exercising cognition or more specifically, selective attention, might result in increased attention capacity that results in faster selection processes, better use of inhibition (for example in preview search) and faster dexterity in actions that have a selection component. If we can demonstrate through these experiments that exercise reverses the observed effects of ageing on dexterity, then we would be able to say that ageing itself has no impact on dexterity and that instead the apparent effects are purely caused by confounding factors.

Another avenue of research that could be carried out on the basis of the data here would be to try and combine the effects and measure the relative impact that each has on dexterity. The aim of the experiment would be to demonstrate that age, selective attention and strength all impact on dexterity, but perhaps aim to show that the factors could be independent of one another. For example, in the modified Box and Block Test used in Chapter 3, impairments in selective attention would show reduced dexterity on the reach action phase directed to the object (especially if more than five objects were used in the task), whereas reduced shoulder strength would show reduced dexterity in the transfer of the object from one side to the other side. Independent exercises to either selective attention or shoulder strength should only impact on the specific associated dexterity component, and as such demonstrate the relative independence that the factors have on the overall task. The relative use of this would be to demonstrate that although the relationship between age and dexterity is multi-faceted, understanding the important underlying variables contributing to the effects are important, especially if they can be isolated and improved through exercise.

7.6 Conclusion.

With each day that passes our chronological age increases, we become older, and yet the changes that occur with increased age within our movements go unnoticed. Our bodies adapt to these changes in order to allow us to continually perform daily tasks that rely on dexterous movements, visual selective attention search and strength, albeit, slower than when we were of a younger age.

The experiments reported here have identified that a number of changes take place with increasing age. Movement dexterity decreases, object selection and grasp during continual 'online' movements become slower, visual search capabilities get slower and less efficient, and hand grip strength becomes weaker. It also appears that if we challenge our body to do more, it will quickly adapt and provide us with greater ability to perform dexterity movements increasing our capability, almost as if reversing the effects of time (or age). Therefore the key to unlocking the effects of increasing age may be that we simply need to challenge ourselves to do more than we choose in our daily life, since it appears that if we do not use our cognitive and physical capabilities, with increased age, we will simply lose these abilities.

Hopefully in the future, the study of ageing will more widely investigate the other associated independent variables that confound with the effect of age on dexterity. While many changes occur with increased age, it appears that not all changes are a foregone conclusion and rather can be maintained or improved with novel thinking and a little effort.

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CONTENTS OF APPENDIX

Appendix 1: Assessment Health Questionnaire

The purpose of this questionnaire is for us to understand your medical / physical history and any lifestyle choices / illness that may influence the research study findings. You have the freedom refuse to answer any question, but you should answer all questions as honest and as accurate as you can. All of the completed information contained within the questionnaire will be kept confidential.

Full Name	
Date of Birth	
Gender	Male Female
Height	
Body mass (kg)	
Contact Address	
Email Address	
Emergency Contact (if applicable)	

Living Status (circle or complete the appropriate response)				
Single	With Partner	With Friend	Other ______________________	
Marital Status (circle or complete appropriate response)				
Single	Married	Divorced	Widowed	
Other (include Details)				

General State of Health					
Excellent	Very Good	Good	Fair	Poor	Very Poor

Health Information					
General Level of Activity (per week) in Hours.					
< 1	**1-2**	**2-5**	**5-10**	**10-20**	**20+**
Circle or complete the typical types of exercise that you carry out					
Walking	Cycling	Jogging	Swimming	Gardening	Bowling
Other					

How many units of alcohol do you drink per week on average? (1 unit = ½ pint of beer or one glass of wine/spirit)	
How many occasions have you been too ill to attend work / or complete your daily activities (e.g., shopping, meetings etc…) over the last 3 months?	
List any current health problems:	None
1	
2	
3	
4	
5	

List Any current medication that you are taking	None
1	
2	
3	

4	
5	

Have you had any major surgery / hospitalisations	None
1	
2	
3	
4	
5	

List any dietary restrictions or allergies that you have	None
1	
2	
3	
4	
5	

Employment History

What were your previous Jobs? Were there are special skills required or developed?
(e.g. Typist, logic programmer, machine engineer, brick layer, tailor)

Hobbies History What were your hobbies? Were there any special skills required or developed?

Further Comments (P.T.O.)

I certify that I have reviewed the foregoing information supplied by me and that it is true and complete to the best of my knowledge. I authorise Jason Martin to hold this information confidentially for record and information purposes only. I am aware that I can have a complete copy of this transcript on request at any time should I so wish.

Signature	Date (dd/mm/yy)

Appendix 2: Arthritis Screening Questionnaire

The aim of the questionnaire is to provide an indication of whether there are any signs of Arthritis. There are no correct answers. Please answer each question honestly.

Please circle your answers.

Name ____

Date ____

Date of Birth __________________________________

1) Have you been diagnosed with Arthritis?
Yes No

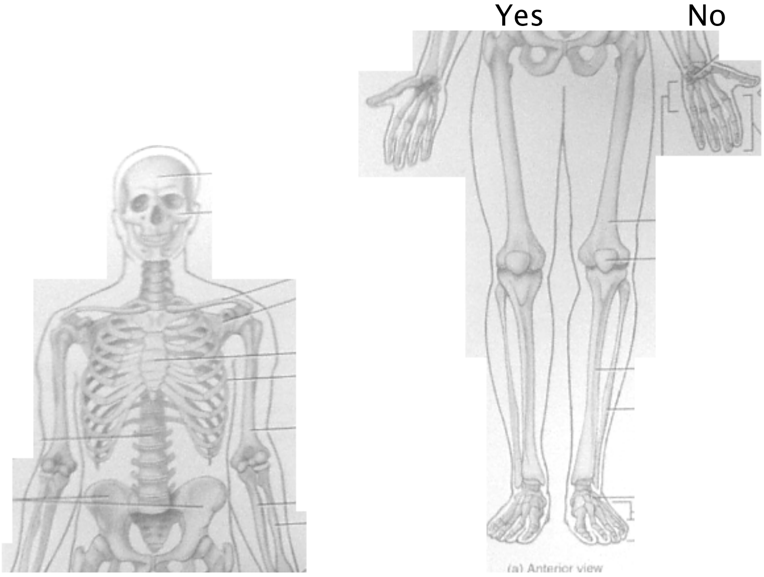
2) Do you feel persistent pain in one or more of your joints?
Yes No

3) Do you feel pain in one or more joints that worsens with movement or activity?
Yes No

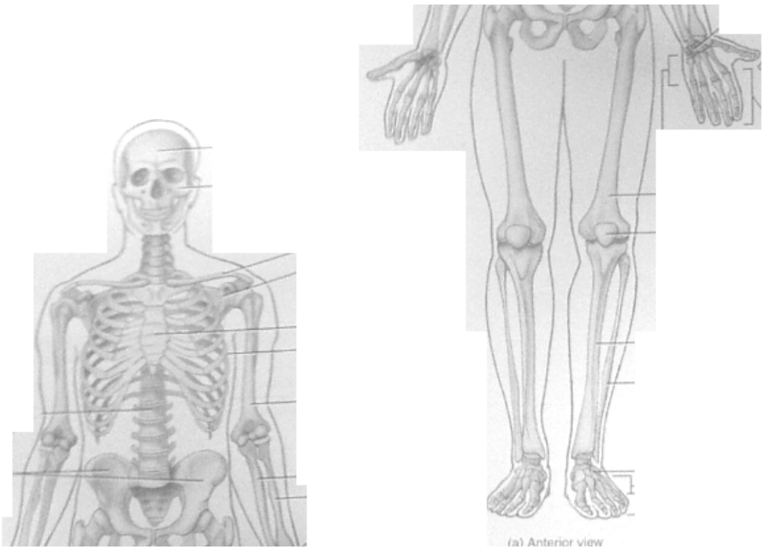
4) Do you feel stiffness in your joints in the morning?
Yes No

5) Is it possible that you injured yourself recently at work or playing sports? Yes No

6) Does one or more of your joints appear swollen?
Yes No



7) Does one or more of your joints appear red or feel warm to the touch? Yes No



8) Have you noticed a change in the range of motion of any of your joints?
Yes No

9) Have you noticed any deformity in your hands or feet?

Yes No

10) Do you experience fatigue beyond what you would consider normal?
Yes No

11) Did you fall recently?

Yes No

12) Do you experience low-grade fevers?

Yes No

13) Do you have x-ray evidence of joint damage?

Yes No Have not had x-rays

14) Are any of your joint tender to the touch?

Yes No

15) Is your joint pain symmetric (for example, on the same joint on both sides of the body) or is it asymmetric?

Symmetric Asymmetric

16) Do you have symptoms of psoriasis as well as symptoms associated with arthritis?

Yes No

17) Do you have generalised, widespread muscular pain?

Yes No

18) Do you get pain relief from anti-inflammatory medications (i.e. aspririn, ibuprofen, naprosyn etc.)?

Yes No

19) Does applying heat or cold to your joints relieve your pain?

Yes No

20) Do other members of your family have arthritis?

Yes No

Further Comments

Appendix 3: Edinburgh Handedness Inventory

Name__________________________

ID___________

When:	Which hand do you prefer?			Do you ever use the other hand?	
Writing	L	R	Either	Yes	No
Drawing	L	R	Either	Yes	No
Throwing	L	R	Either	Yes	No
Using Scissors	L	R	Either	Yes	No
Using a Toothbrush	L	R	Either	Yes	No
Using a Knife (without a fork)	L	R	Either	Yes	No
Using a Spoon	L	R	Either	Yes	No
Using a Broom (Upper Hand)	L	R	Either	Yes	No
Striking a Match	L	R	Either	Yes	No
Opening a Box (lid)	L	R	Either	Yes	No

Comments

Appendix 4: Mini Mental State Examination

Name of Participant ____ Age ______________________

Name of Examiner ____ Years of School Completed___.

Approach the patent with respect and encouragement.
Ask: Do you have any trouble with your memory? Yes No Date of Examination _______ ______________

May I ask you some questions about your memory? Yes No

SCORE ITEM

5 ( ) TIME ORIENTATION
Ask:
What is the year________________(1) Season____________________________(1)
Month of the year_______________(1) Date_______________________(1)
Day of the week________________(1)?

5 ( ) PLACE ORIENTATION
Ask:
Where are we now? What is the county____________________(1) City________(1)
Part of the city ______________________(1) building____________________________(1)
Floor of the building___________________________________(1)

3 ( ) REGISTRATION OF THREE WORDS
Say: Listen carefully. I am going to say three words. You say them back after I stop.
Ready? Here they are… PONY (wait 1 second). QUARTER(wait 1 second). ORANGE (wait one second). What were those words?
__________________________ (1)
__________________________ (1)
__________________________ (1)
Give 1 Point for each correct answer, then repeat them until the patient learns all three.

5 ( ) SERIAL 7s AS A TEST OF ATTENTION AND CALCULATION
Ask: Subtract 7 from 100 and continue to subtract 7 from each subsequent remainder until I tell you to stop. What is 100 take away 7?__________________________(1)

Say:
Keep Going__________________________(1)___________________________(1)
_____________________________________(1)___________________________(1)

3 ( ) RECALL OF THREE WORDS
Ask:
What were those three words I asked you to remember?
Give 1 point for each correct answer ____________________________(1).
______________________________(1). ___________________________________(1).

2 ( ) NAMING
Ask:
What is this? (show pencil) _____________________(1).
What is this? (show watch) _____________________ (1).

1 ( ) REPETITION
Say:
Now I am going to ask you to repeat what I say: Ready? No ifs, and, or buts.
Now you say that
____(1).

3 ( ) COMPREHENSION
Say:
Listen carefully because I am going to ask you to do something:

Take this paper in your left hand (1) fold it in half (1) and put it on the floor (1)

1 ( ) READING
Say:
Please read the following and do what it says, but do not say it aloud. (1)

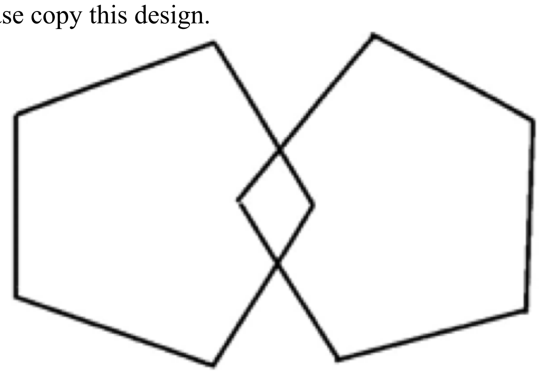
Close your eyes

1 ( ) WRITING
Say:
Please write a sentence. If patient does not respond say: Write about the weather (1)

____

____

1 ( ) DRAWING
Say: Please copy this design.



TOTAL SCORE ____________

(Assess level of consciousness along a continuum)

Alert Drowsy Stupor Coma

	Yes	No	Deterioration from previous level of functioning	Yes	No	FUNCTION By PROXY Please record date when the person was last able to perform the following tasks. Ask caregiver if patient independently handles	Yes	No	Date
Cooperative									
Depressed			Family history of Dementia						
Anxious			Head Trauma			Money/Bills			
Poor Vision			Stroke			Medication			
Poor Hearing			Alcohol Abuse			Transportation			
			Thyroid Disease			Telephone			
Native Language									