Examining the Role of Cardiovascular and Cognitive Fitness in Goal-directed Aiming Across the Lifespan

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EXAMINING THE ROLE OF CARDIOVASCULAR AND COGNITIVE FITNESS IN GOAL DIRECTED AIMING ACROSS THE LIFESPAN

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy of Human Factors and Cognitive Psychology
in the Department of Psychology
in the College of Sciences
at the University of Central Florida
Orlando, Florida

Summer Term
2017

Major Professor: Janan A. Smither

ABSTRACT

Older adults experience more difficulties completing goal directed movements than younger adults. The reasons for this have not been completely elucidated within the research literature; however, it is thought that age related movement differences are due to at least one of three possible reasons. The current study investigated the influence of these three hypotheses: (1) biomechanical changes (limbs, joints, or muscles), (2) sensory feedback processing ability, or (3) differences in overall movement strategy on movement kinematics. Additionally, physical activity is known to improve both physical and cognitive functioning and staying cognitively active may also attenuate age-related declines in cognitive ability; thus the current study also examined the impact of physical and mental fitness on movement performance across the lifespan. Both active and sedentary young and old adults completed different experimental conditions to determine how biomechanical ability, sensory processing ability, and individual differences impact different kinematic aspects of movement performance. Participants completed two different Fitts' pointing tasks where difficulty was manipulated by either increasing biomechanical effort and/or amount of feedback processing needed to complete each movement. Results indicated that distance impacted movement more than width for all participants indicated by a greater ID-MT slope. While increasing age was associated with an increases slope, the larger finding was that age increased the overall time. Thus, it was concluded that distance and width constraints are processed by similar processes regardless of age, but these processes slow with age. Cardiovascular fitness attenuated declines in the distance condition while mental fitness attenuated those in the width condition. Further supporting a theory of differential movement constraints.

ACKNOWLEDGMENTS

I would like to thank those that contributed to my success during my doctoral career. Without all your help the completion of this project would have been but a mere possibility. First, to Jessica Michaelis who shared an office with me over the past eight years and has always provided me with thoughtful comments and encouragement when needed. Next, to Fernando Montalvo, Melissa Dabydeen, Victoria Pineda, Baotran Ho, and Daniela Zapata-Ocampo for helping me collect data, schedule participants, and assist with the research. Finally, I would like my committee for all of their guidance. Dr. Janan Smither for being a thoughtful mentor who guided my research during my graduate career and Dr. Mouloua for being a co-mentor along the way. Dr. Stafford for providing valuable guidance and support. Lastly, I would like to thank Dr. Daniel McConnell for being supportive of all my research and providing valuable advice during my course of study.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
BFI	Big Five Inventory
BDNF	Brain-Derived Neurotrophic Factor
BMI	Body Mass Index
CDC	Centers for Disease Control
CE	Constant Error
CEPT	Constant Error of the Primary Movement Phase
CEMT	Constant Error at the End of the Movement
D	Distance
DSSQ-S	Dundee Stress State Questionnaire
EXT	Extracted File
FoB	Flock of Birds
HPF	High Physical Fitness
ID	Index of Difficulty
LPF	Low Physical Fitness
VO2 MAX	Maximal Oxygen Consumption
MET	Metabolic Equivalent Units
MoCA	Montreal Cognitive Assessment
MC	Movement Constraint
MT	Movement Time
PA	Peak Acceleration

PAR-Q+	Physical Activity Readiness Questionnaire
PD	Peak Deceleration
PPT	Proprioceptive Pointing Task
PropPT	Proportion of Time Spent in the Primary Movement Phase
PropST	Proportion of Time Spent in the Secondary Movement Phase
PT	Time Spent in the Primary Movement Phase
PV	Peak Velocity
ST	Time Spent in the Secondary Movement Phase
TF	Time Function Filtered File
tPA	Time to Peak Acceleration
tPV	Time to Peak Velocity
UFOV	Useful Field of View
VE	Variable Error
VEPT	Variable Error of the Primary Movement Phase
VEMT	Variable Error at the End of the Movement
W	Width
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

Perceiving and acting is fundamental to human interaction with the world. This involves goal directed actions that are both purposeful and voluntary and include simple activities such as flipping a switch, pressing a button, turning on the television, opening a door. These activities constitute to our day-to-day interactions with the environment, yet we trivialize the amount of effort it takes to perform them as accurately and efficiently as we do. Complex coordination between bodily systems is required to perform these movements efficiently. Feedback from both vision and proprioception must be combined along with the specific recruitment of muscles and joints in a feedback loop that uses both streams of information to reach the intended object of the movement. Because the frequency at which people engage in these movements is innumerable, it is important to understand the underlying factors that affect efficient performance of purposeful movements. In fact, reaching or pointing movement time is taken as a measure of the efficiency of the human information processing system (Fitts & Peterson, 1964; Mackenzie, 1992; Poletti et al., 2015).

Older adults move more slowly than younger adults (Bohannon, 1996; Welford, 1981) and take much longer to complete goal directed hand movements (Bakaev, 2008). This suggests that as people age they become less efficient at interacting with their environment. While this is thought to be a side effect of the aging process, the reasons behind this phenomenon have not been completely explained yet.

Fitts' law stats that the time it takes to complete a goal-directed movement (MT) is a combination of two types of movement constraints: (1) the distance to be moved by the effector (e.g. arm, hand) and (2) the size of the object or target (classically called width). This idea is a key part of MT prediction in Fitts' law and is called the index of difficulty (ID). ID increases as either distance increases or the target becomes smaller. Fitts' law therefore, does not make specific predictions about either the distance or the target size, but about the ratio between distance and size. However, this combined approach is unable to disentangle the effect of either parameter independent from the other. Separating these movement constraints allows one to examine the mechanisms underlying age-related increases in MT.

By examining the distance parameter, movement declines can be explained as a decrease in physical adaptability. In other words, the central and peripheral nervous systems are less efficient at directing movement of the limbs and processing sensory feedback imparted from the environment through the peripheral nervous system (Sleimen-Malkoun, Temprado, & Berton, 2013). This view is supported by a research literature that has chronicled the effects of aging on the human body (e.g. Bjorklund & Bee, 2008; Salthouse, 2009). These age related declines include both physical and cognitive changes. Physical changes include loss in strength and flexibility, including sarcopenia, osteopenia, and arthritis (Bjorklund & Bee, 2008; Covinsky, 2006). This is the effector constraint hypothesis. If this hypothesis is correct, scaling the movement distance would have a greater impact that decreasing the target size. By examining the size parameter separately, declines in movement performance are seen as a loss of cognitive adaptability. In other words, the aging process leads to brain related changes that are associated with decreased processing speed, working memory capacity, sensory processing efficiency (Salthouse, 2009), and also introduce additional error and variability (often called noise) into the nervous system that interfere with the ability to successfully interact with the world as well as increase movement time (Newell, Deutsch, Sosnoff, & Mayer-Kress, 2006). Thus, instead of physical declines cognitive declines interfere with online feedback corrections that are required to be accurate at smaller target sizes. This is the task constraint hypothesis and this second hypothesis states that it is the brain declines associated with aging that decline performance. One study investigated these claims further by comparing both younger and older adults in three movement conditions: (1) speeded (as quickly as possible without accuracy), (2) accurate (as accurately as possible while speed was secondary) and (3) both speeded and accurate as a control (Van Halewyck, Lavrysen, Levin, Boisgontier, Elliott, & Helsen, 2015). This study tested various hypotheses. For example, if older adults were affected by physical and physiological limitations they may not be able to complete movements as quickly as younger participants in the speeded condition, and they may also take longer to be as accurate as possible during the accuracy condition. This study found, however, that older adults experienced no impairments during the speeded condition when compared to younger adults. Additionally, older adults did not increase their overall movement times going from the control to the accuracy condition. Older adults did move more slowly when directly compared to younger adults; they took longer to verify that their movement was inside the target and showed a lower peak movement velocity. Van Halewyck et al. (2015) concluded that there were two potential explanations for their findings. Either older adult participants were slower due to decreased efficiency in feedback processing mechanisms that limited their physical movement speed and their ability to verify their movement had ended, or older adults were more error averse and strived to move more carefully during their movements. This latter idea may imply that aging differences are not due to physiological or cognitive limitations, but are the results of a play it safe strategy instead. However, it is critical to note that both of these explanations discount the biomechanical aspect of the task. However, the researchers held distance constant and limited the range of motion of the movement effector. Thus only a small wrist deflection was required to move the cursor to the target. Also, the speeded condition was completed under a limited set of distances. Combined, these limitations may obfuscate contributions of the biomechanical system (joints, muscles, touch receptors, etc.). Another set of studies (Poletti et al., 2015; Temprado, Sleiman-Malkoun, Lemaire, Rey-Robert, Retornaz, & Berton, 2013; Sleimen-Malkoun, Temprado, Huys, Jirsa, & Berton, 2012) found that the distance the participant was required to move during each trial increased movement time to a greater degree than target size which was manipulated in the Van Halewyck study. Both of these findings together suggest that there may be three potential factors that affect movement performance in older adults: biomechanical, cognitive, and strategic. In order to understand factors that underlie movement across the lifespan all three must be examined.

However, these three factors are not the only ones posited to account for movement differences between age groups. It is important to consider functional age instead of only chronological age as an indicator of health and wellbeing (Sharkey, 1987). While health and cognitive declines occur due to chronological age, individual differences in fitness level can drastically moderate their effects leading to individuals who may be older chronologically, but younger functionally. The connection between physical and cognitive health has been well-known for a while. For example, according to Xenophon (n.d.), Socrates stated:

"Because our city does not practice military training in public, that is no reason for neglecting it in private, but rather a reason for making it a foremost care. For be you assured that there is no contest of any sort, nor any transaction, in which you will be the worse off for being well prepared in the body; and in fact there is nothing which men do for which the body is not a help. In every demand, therefore, which can be laid upon the body it is much better that it should be in the best condition; since, even where you might imagine the claims upon the body to be slightest —in the act of reasoning —who does not know the terrible stumbles which are made through being out of health? It suffices to say that forgetfulness, and despondency, and moroseness, and madness take occasion often of ill-health to visit the intellectual faculties so severely as to expel all knowledge from the brain" (XII, para. 2).

This quote illustrates the findings of modern research that physical fitness improves cognition. In the literature, physical activity and exercise has been shown to significantly improve health, fitness, and cognitive functioning and may even reverse age related cognitive declines (Colcombe et al., 2004). An additional line of research has argued that as older adults become more physically active and exercise more, aging effects may be attenuated. If this hypothesis is correct it would directly impact these findings. Numerous studies have found evidence that may support this hypothesis. Increased physical activity such as engagement in exercise programs for older adults has previously been shown to improve cognitive health (Hillman, Snook, & Jerome, 2003; Hopkins et al., 2012) such as neurogenesis in the executive functioning and feedback processing centers of the brain (Edwards et al., 2005; Vance et al., 2007; Voelcker-Rehage, Godde, & Staudinger, 2011). Two recent studies attempted to investigate the role of activity as a potential moderator of age-related declines in movement efficiency (Van Halewyck et al., 2014; Van Halewyck et al., 2015); however, these studies did not tease apart biomechanical, cognitive, or strategic differences and used very different methodological approaches. One study, used lower values of ID (3.4 & 4.4) and manipulated vision of the target. The second, used a more difficult ID value of 6.2 and used a simpler version of the aiming task. Differences in task design and ID may have led to their mixed results. One final more recent paper, using a more comprehensive measure of physical activity and a more physically involved aiming task found moderate benefits of physical activity on aiming performance (Boisgontier, Serbruyns, & Swinnen, 2017). A lack of understanding of fitness' impact is a clear deficiency in the literature.

Thus the primary objective of the current work is to further science by increasing our knowledge and understanding of the factors that underlie age-related changes in movement performance. The proposed work achieved this goal by carefully investigating how the four identified factors (efficiency of the biomechanical and cognitive systems, strategic carefulness, and physical fitness) alter movement performance across the lifespan.

The results of the current study are expected to provide data critical to the understanding of how aging and fitness interact during movement execution. This knowledge will also provide essential insights in several related areas. First, because completing goal directed movements are an essential part of interacting with our environment, it is expected that the current study will further the science by increasing our knowledge of the factors important for successful interactions as we age and the cognitive mechanisms underlying them. For example, aging is related to an increased risk of injury related falls (e.g. Hue et al., 2007; Riva et al., 2013). By better understanding the role of both the biomechanical and cognitive systems during movement execution, we may be better able explain reasons for age-related declines in other areas as well.

Secondly, the results from the study are also expected to have several implications to practice and the design of technology. Because Fitts' law makes specific predictions regarding movement time and performance efficiency several studies have expanded this to examine performance with tangible interface devices. Devices that minimize the ID-MT slope allow users to interact with a computer more easily than those that require longer MTs. Thus, Fitts' law has traditionally been used to describe how individuals interact with computers and technology (MacKenzie, 1992) especially using mice (Card, English, & Burr, 1978; Thompson et al., 2007), joysticks (Card, English, & Burr, 1978), trackpads (MacKenzie, 1992), and touch screens (Albinsson & Zhai, 2003). Although older adults generally have more difficulty using technology (Czaja et al., 2006), which may lead them to be more resistant or hesitant to embrace it **(**Röcker, Ziefle, & Holzinger 2014; Ziefle & Bay 2005), today, more individuals than ever are using technology and computer systems including older adults. For example, internet usage among older adults (ages 65+) has increased 150% from 13% in 2009 to 34% in 2011 (Zickuhr & Madden, 2012). This is only expected to increase based on studies surveying interest in technology across age groups (Mitzner et al., 2010). Because Fitts' law has been shown to generalize to the ease of use of computer input devices and technology (MacKenzie, 1992), the results of the current study will provide data regarding critical factors that may interfere with successful technology use. This will enable designers to create better designs targeted to specific issues faced by users.

CHAPTER TWO: LITERATURE REVIEW

Information Processing Theory

Fitts' law stemmed from a much older theory called information processing theory. This theory was first described by Shannon and Weaver (1949). Their work was developed to describe the mathematical basis of human communication with an emphasis on how information is transmitted across wired telephone lines. As information travels along a communication channel it must overcome noise as it passes through from a point of origin to an end point. During the development of Fitts' law this idea became a metaphor for the biological processes of transmitting a particular pattern of action potentials from the brain to the muscles in order to perform a goal directed movement. Thus, it is important to briefly review this theory before moving on to Fitts' law.

In Information Processing Theory, Shannon and Weaver denoted how information is processed through a system. The authors described three levels of communication failure: Level A, Level B, and Level C. Level A failures are errors of transmission accuracy, Level B failures are errors of semantics and meaning (e.g. translation between source and receiver), and Level C failures are errors of the effectiveness of the received communication. In an electronic system, an analog message such as a set of instructions must be converted to electronic signals and encoded along a communication channel and then reassembled at the receiving end of the message. Shannon and Weaver explained that computers send information in a binary format: a value of "0" is interpreted if no current is received, as opposed to a value of "1" if electrical current is received. Thus the amount of information transmitted is described by a logarithm to the base 2 (number of choices possible) and is called a bit with the amount of information being sent across a channel as bits per second (bandwidth), a measure of channel capacity. Finally, Shannon and Weaver described the concept of noise to signal ratio of the communication channel. Noise introduces error and thus increases the amount of uncertainty present in the message. For example, information may be removed or extraneous information may be added during transmission. Thus the true capacity of the channel is only the usable information in bits per second that may be different from its theoretical maximum rate in a noisy system. For example, it is often the case that wired internet connections are faster than wireless connections. Holding all else constant, the process of transmitting a wireless signal means that it must compete with other signals in the environment that may cause interference causing it to degrade. Communication systems use lines of cable or radio waves to transmit information, whereas the human body uses synaptic connections. However, noise can impact information transmission both in the central and peripheral nervous systems similarly. Thus, this is an apt analogy to describe the transmission of neural signals and has been the basis of early work on motor behavior (e.g. Fitts, 1954).

Fitts' Law

Built on the previous work of Shannon and Weaver, Fitts' law is one of the few psychological laws. This law shows purposeful human movements have similar processing limitations as communication systems. Information processing theory designates a discrete channel processing capacity and that capacity is degraded by the amount of noise present in the system. Fitts' work described how this theoretical framework applied, in a biological context, to how individuals interacted with their environment; thus, the relationship predicting the movement time

(MT) for purposeful behavior is termed Fitts' law. Processing capacity is limited by two spatial constraints, the movement distance (D) and target width (W). MT is known to increase as the ratio between these constraints increases. Fitts' law describes human psychomotor behavior as a tradeoff between the speed and accuracy of the movement, a phenomenon first studied in detail by Woodworth (1899). During purposeful movement people adopt a strategy to maximize movement efficiency that produces a movement that is maximized for speed as well as accuracy (Thompson, et al., 2007). This concept is important to Fitts' law as movements that are too slow do not reveal the information processing capacity of the communication channel and movements that are too quick lose accuracy. This relationship is defined by the equation: $MT = a + b\,log_2\left(\frac{2D}{W}\right)$; where MT represents total movement time, a and b are constants that describe the line slope and intercept. D is movement distance (called amplitude in the original formulae; Fitts & Peterson, 1964), and W is target width. The $log_2\left(\frac{2D}{W}\right)$ portion of the relationship describes the spatial constraints of distance and target size and is described as the index of difficulty (ID) measured in bits. ID describes the difficulty that the movement poses on the human motor system (Fitts, 1954). Calculating the ratio between ID and MT $\left(\frac{ID}{MT}\right)$ provides a measure of the channel capacity measured in bits/sec.

Movement Phases

Prior to the work of Fitts or Shannon, Woodworth (1899) provided evidence that people make purposeful movements in two distinct phases: a ballistic open loop movement that guides movement close to a target, then a second corrective movement phase that aligns the movement with sensory feedback to increase accuracy by "homing in" on the target location (Elliott, Helsen, & Chua, 2001). Measuring the time of acceleration (initiation to peak velocity) is one way to capture the primary phase while measuring the deceleration (time from peak velocity to termination) captures the secondary control phase. This definition is often seen in classic research such as Woodworth (1899). Another more common approach based on the stochastic optimized-submovement model of human movement (Meyer, Abrams, Kornblum, Wright, & Smith, 1988) defines the primary movement phase as the time from movement onset through deceleration until a zero crossing occurs in the acceleration graph; thus the secondary phase is defined as a phase of re-accelerations that occur after peak velocity (Figure 1). Since this later method provides a more distinct measure of the onset of feedback-driven corrective sub-movements, we adopted this approach in the current work.

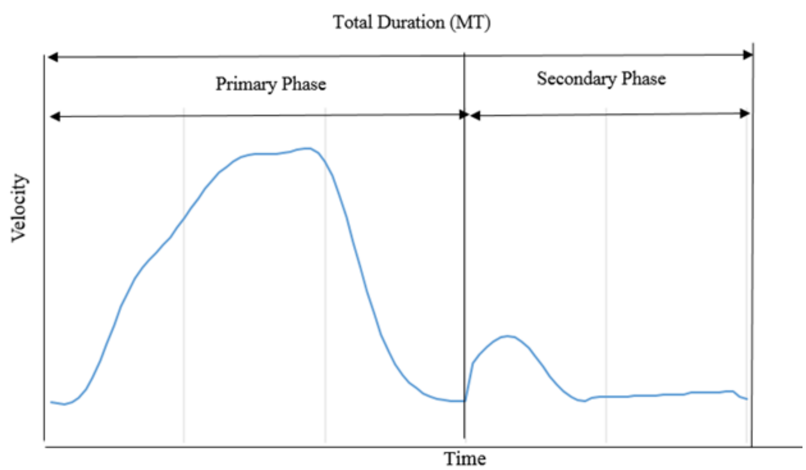


Figure 1. Example Velocity Profile for a Difficult Goal-Directed Movement.

Further, the time required to make such movements, or total movement time (*MT*), includes time spent during both the primary and secondary movement phases. Analyses of this data have found several useful kinematic markers underlying movement efficiency. Movements at lower IDs are symmetrical and completed entirely in the primary phase, but difficult movements place additional accuracy constraints on the movement elongating the secondary phase (Bootsma, Boulard, Fernandez, & Mottet, 2002). Changes to distance increase MT by extending both primary and secondary phases by constraining the effector; while changes to width extend the secondary phase alone placing additional constraints on the cognitive sensory feedback processing centers due to the nature of the task (called task constraints). Figure 1 shows a sample kinematic profile of a movement that is decomposed into the primary and secondary phases.

Sources of Variability within the Human Nervous System

Shannon and Weaver (1949) discussed the effect of noise on the degradation of transmitted information. The biological mechanism for movement control is the propagation of action potentials across neurons, which differs greatly from transmitting packets of data across a network. However, this previous work provides a useful analogy to describe the limiting factors and processing capability of the human nervous system (Fitts, 1954). Likewise, it is thought that sources of noise or variability within the human body contribute to movement errors and the difficulty of a movement. At larger movement distances and target widths the biological systems have to complete more work, increasing variability. This noise can manifest as neuromotor noise (a source of biomechanical variability) such as variability in the location of movement of termination (Elliot et al., 2001). Additionally, sensory feedback processing abilities and executive functioning may also introduce variability in the time it takes to perform corrective sub-movements during the secondary movement phase.

Movement Constraints

Three factors are responsible for movement: the individual, the task, and the environment. All of these factors constrain movement in some way (Shumway-Cook & Woollacott, 2001). Within the individual, processes including perception and cognition are essential for accurate purposeful movement. One specific issue has been called the “degree of freedom problem,” which includes the vast effort needed to coordinate and control all of the various muscles and joints of the human body during movement control (Bernstein, 1967).

Fitts’ law reduces *MT* to two general factors: the movement distance and the target width. Movement distance incorporates the effort required by the effector to carry out the movement along with variability included in the motor system, while the target width portion of the equation incorporates the effort required by the cognitive and sensory processes for precise movement accuracy. While changes to both the distance and target width increase the ID and thus movement time, Fernandez and Bootsma (2004) found that changing one or the other affected the movement kinematics differently. Movements farther away are more effortful and place constraints on the biomechanical system of the human body. These are called effector constraints. Effector constraints tend to scale the overall movement time while preserving the symmetries of the movement. Examples of effector constraints are movement distance, limb, muscle, joint recruitment, direction of force required, and others that modify the movement amplitude affecting the primary sub-movement of the task or scaling the overall movement. This effect occurs because the peak velocity of the movement trajectory increases with distance as faster movements are used to cover farther distances (Thompson & McConnell, Slocum, & Bohan, 2007).

On the other hand, task constraints affect the movement profile in a separate manner. For example, decreasing target size increases the proportion of total movement time spent in the secondary phase of the movement due to the increased visual-motor precision control required (Bootsma, Fernandez, & Mottet, 2004). Thus, the asymmetries produced by difficult task constraints are limited to the secondary movement phase and appear as a series of re-accelerations or small velocity peaks that occur at the end of the movement. When such precision is required, people may move more carefully as indicated by a slower peak velocity in the primary phase which further leads to a loss of symmetry (e.g. Langolf, Chaffin, & Foulke, 1976). Undershooting the target is more advantageous than overshooting the target, as overshooting its location requires more biomechanical effort (Van Halewyck et al., 2015).

Role of Vision and Proprioception to arm movements

While feedback based corrections occur during the secondary phase of the movement, sensory information is processed throughout the entire movement (Elliot et al., 2001). This underscores the importance of these cognitive processes in movement control. This task may not require extensive conscious awareness; however, locating one's hand in space requires complex coordination between the body's visual and proprioceptive systems. Sensory feedback regarding the seen position (vision) and the felt position (proprioception) of the body are integrated to create an awareness of our limb position in space with visual information being more precise for discriminations made laterally across the body, and proprioceptive information being more precise locating hand position using depth cues (i.e. positions located nearer or farther way from the body; van Beers, Wolpert, & Haggard, 2002). Therefore, both vision and proprioception are important forms of sensory feedback in movement control.

Vision

Visual input enhances accuracy of reaching movements primarily during the second phase; however, when movements are small and quick enough, sighted, and sightless movements have similar error rates which is attributed to a larger proportion of the movement spent in the primary phase (Keele & Posner, 1968; Woodworth, 1899). More recent studies have also shown visual input is useful during movement planning such as visual feedback of the hands starting position (Desmurget, Pelisson, Rossetti, & Prablanc, 1998; Elliot & Allard, 1985; Elliot et al., 2001). Movement accuracy can also be reduced when visual feedback is absent or distorted (Bagesteiro et al. 2006; Holmes & Spence, 2005; Rossetti et al. 1995).

Disorders of the “where pathway” can lead to individuals neglecting body parts or location in their visual field which also impairs their ability to navigate their environment as they often favor one side over the other (Zillmer & Spiers, 2001). Further these disorders can lead to apperceptive agnosias such as Balint’s syndrome leading to visual-spatial difficulties. This condition was first discovered by Balint (1909) and further expanded upon by Holmes (1918) and Holmes and Horrax (1919) which found that dorsal pathway damage led to spatial disorientation and profound errors pointing to objects in space and difficulties focusing attention on a single object at a time and integrating visual and spatial information (e.g. spatial navigation) and fixating on objects in space. Robertson, Treisman, Friedman-Hill, & Grabowecky (1997) investigated one such case (RM) due to successive strokes. As a part of his condition RM suffered optic ataxia meaning he could not reach to objects and was unable to draw or mark at specific spatial locations or use visual cues such as occlusion or depth. While these difficulties were especially pronounced, RM did not suffer from any damage to his primary visual pathways shown by having 20/15 visual acuity, normal color vision, and contrast sensitivity.

Another case study with optic ataxia (AT) was investigated by Milner, Paulignan, Dijkerman, Michel, & Jeannerod (2003). AT presented with similar bilateral parietal damage as RM. Milner et al. (2003) had AT perform a reaching task to a series of lighted targets across various spatial positions. AT was able to complete easy pointing tasks, but was unable to complete more difficult ones without significant difficulties. Additionally, when pointing was delayed, AT's performance was markedly improved. These findings suggested that while visual feedback integration with motor behavior was impaired by damage to the posterior parietal cortex another, albeit slower, pathway may also be involved with visual-motor feedback integration. This alternative pathway is thought to be more inferior and more temporally located within the parietal lobe (Milner & Goodale, 1995; Milner et al., 2003); therefore it may be the ventral visual pathway. In fact Milner et al. (2003) suggest that the ventral pathway may be responsible for the broad ballistic movement completed in the primary movement phase whereas the dorsal pathway is specifically involved with the corrective feedback processing experienced during the secondary movement phase. Therefore, in AT, the temporal lobes functionally compensated for the PPC damage.

Proprioception

Proprioception is the ability to localize one's own body position in space across both static limb position and dynamic limb position (kinethesis; Gandevia, Refshauge, & Collins, 2002). As individuals age, sensitivity to proprioceptive feedback regarding limb position in space decreases (Adamo, Alexander, & Brown, 2009). This finding has been assessed using both ipsilateral and contralateral tests of static ability. Both tests involve blindfolding the participant, but test types differ with task type. First, ipsilateral ability is assessed by moving a limb to a target location then returning to a standardized start position. The individual then uses the same limb and places it on the specified target location. Contralateral assessments however, involve an experimenter positioning a limb in a specific spatial location and the individuals has to use the limb on their opposite side to match that position (Goble, Coxon, Wenderoth, Van-Ipse, & Swinnen, 2009). Several studies have also tested dynamic proprioception by measuring one's sensitivity to the movement of their limbs. One study found that older adults required larger movements to detect motion than did younger adults (Kokmen et al., 1978).

Studies examining motor movements of both non-human primates and human participants with normal vision but non-functioning proprioceptive ability show impairments when completing dexterous coordinated hand movements. These studies indicate that compromised sensory feedback from proprioceptive systems limits crucial information about preliminary limb position that aids motor coordination (Sarlenga & Sainburg, 2009). Proprioceptive feedback is also useful during the secondary movement phase as it provides important positional updates allowing for enhanced corrections to be made during movement (Sainburg et al., 1995). Overall, individuals without proprioception can make limb movements; however, they have deficits when completing complex or repetitive behaviors due to the loss of sensory feedback (Rothwell et al., 1982).

The impact of aging on health and cognition

The aging process is associated with many changes that may decrease physical and mental health. One change to the physical body is decreased bone mass due to calcium loss that makes bones more fragile. Moderate bone density loss, osteopenia, is a risk factor for injury (Bjorklund & Bee, 2008). Additionally, aging is associated with a progressive reduction in the size and mass of muscle fibers called sarcopenia. This includes declines in proprioception such as sensitivity to limb position in space (Camicioli, Panzer, & Kaye, 1997; Mion et al., 1989). Another physical change is that the artery walls become thicker due to a loss of elasticity that increases blood pressure and may be a risk factor for cardiovascular diseases (Bjorklund & Bee, 2008). This loss of elasticity also decreases one's VO_2 Max capacity impacting cardiovascular fitness. Further, both stamina and balance decline with age as a result of cardiovascular, muscular, and bone density changes (Bjorklund & Bee, 2008). Many cognitive changes also occur due to the aging process. Fluid intelligence or the type of intelligence that requires individuals to adapt to new circumstances such as tests of cognitive abilities declines as people age. Studies also show declines in working memory recall and speed of processing tasks (Bjorklund & Bee, 2008). One study found while older adult vocabulary and crossword puzzle performance increased (measures of crystalized intelligence), performance declined in several fluid intelligence tasks such as recall accuracy, speed of recall, and reasoning performance (Salthouse, 2009). Further, the literature has shown declines in both bottom-up and top-down attention processes in older adults using visual search tasks (Madden, 2009). One meta-analysis investigated reasons for such declines and suggested that these results were mainly due to resource limitations as they were largest for divided attention as opposed to selective attention tasks (Verhaegen & Cerella, 2002).

Living a sedentary lifestyle

Increased rates of sitting and inactivity can negatively affect health and increase the impact that age-related physical and cognitive declines have on an individual's well-being. The literature often identifies different activity levels as sedentariness, light, moderate, and vigorous. One study defined sedentariness as a lack of regular physical activity (e.g. failing to meet the CDC recommendations; Lowry, Wechsler, Galuska, Fulton, & Kann, 2002). While, another study used a more precise definition of expending 2,000 Kcal or fewer per week from Physical Activity (Paffenbarger, Hyde, Wing, & Hsieh, 1986). More recent research refined the definition of sedentariness as only engaging in activities that do not increase energy expenditure substantially above resting. The Sedentary Behavior Research network (2012) stated that sedentary behaviors include sleeping, eating, sitting, lying down, engaging in seated-entertainment (e.g. watching TV), driving, reading, or any activity expending fewer than 1.5 metabolic equivalent units (METs). Light activity, on the other hand, involves expenditure between 1.6 – 2.9 METs (e.g. walking, cooking, and washing dishes). MET is the energy cost of resting quietly, which is measured using oxygen uptake as $3.5\ mL{\cdot}kg^{-1}{\cdot}min^{-1}$ (Pate, O'Neill, & Lobelo, 2008). Measuring sedentary activity in this manner allows one to discuss percentage of the day being sedentary, engaged in light, moderate, or vigorous activity. Using this definition of sedentary behavior, one study found that 50% sedentariness led to adverse health outcomes including mortality (Katzmarzyk, Church, Craig, Bouchard, 2009). Another study defined sedentariness using a similar definition as any time spent engaging in behaviors with energy expenditures of fewer than 1.5 METs, while light activity was 1.5-3.0 METs, moderate to vigorous activity was any activity greater than 3.0 METs (Madden, Ashe, Lockhart, & Chase, 2014). A Meta-analysis examining physical activity levels in older adults identified cut offs for each activity level (Gorman et al., 2013). Sedentary individuals typically spend at least 68% of the day inactive. This would occur if an individual completed the equivalent of light activity for 8 hours of the day and spent the remainder of the day at rest, or while completing seated activity.

Movement Performance across the Lifespan

Previous work has examined the Fitts' law relationship between younger and older adults. Results from many studies have shown that as people age movement time increases proportionally with age (e.g. Goggin & Meeuwsen, 1992; Stelmach, Amrhein, & Goggin, 1988), and that it may take older adults twice as long to complete the cognitive processes required to complete a movement (Bakaev, 2008). Kinematic analyses of older adults' movement data indicate the ID-MT relationship held and both primary and secondary movement phases were elongated (Goggin & Meeuwsen, 1992). Additionally older adults had steeper movement time by ID slopes than younger adults showing that differences in movement time become more pronounced at more difficult movements (Poletti et al., 2015).

However, the reason why this occurs is less understood. Currently, three competing hypotheses exist: the effector constraint hypothesis posits that aging declines in physical and cardiovascular health increase biomechanical stress in the body and constrain the effector system (Poletti et al., 2015). The task constraint hypothesis posits that, instead, cognitive declines impair visual and proprioceptive feedback processing ability (Camicioli, Panzer, & Kaye, 1997; Owsley & McGwin, 2004; Van Halewyck et al., 2015; Welford, 1981) placing additional stress on the cognitive system. Lastly, the strategic differences hypothesis states that differences in behavioral carefulness account for increased MT (Bakaev, 2008; Van Halewyck et al., 2015).

The effector and task constraint hypotheses explain movement declines among older adults as having different underlying mechanisms. A movement to a small but close target as compared to a large but farther away target with the same ID been seen as the same under Fitts' law although the effort required to perform them differ greatly. The target at a farther distance may involve the movement of the entire arm and shoulder (many joints and muscles), whereas the target that is closer may require only a slight movement of the finger. On the other hand, the target with a large width would be easy to maneuver inside of, but the smaller width may be much more challenging and require additional cognitive effort. The effector constraint hypothesis would proclaim that older adults would have markedly increased MT in the condition with the longest distance, whereas the task constraint hypothesis would posit that the most difficult movement would be the one with the smallest target width. The strategic difference hypothesis may posit similar results to the traditional Fitts' law hypothesis that in conditions with greater IDs, regardless of source, older adults will slow down due to increased carefulness.

Movement Strategy

The most widely accepted model of personality in the literature is the five-factor model (FFM) which consist of five personality traits (1) neuroticism or emotional instability, (2) extraversion, (3) agreeableness, (4) openness also called intellect, and (5) Conscientiousness (McCrae & Costa, 2013). Several of these factors may affect how cautious or risky people may are. Additionally, younger and older adults vary in terms of personality which may led to differences in strategy between age groups. Older adults are more agreeable and conscientious than younger adults (McCrae et al., 1999).

Longitudinal studies further indicate that conscientiousness increases with age (e.g. Robins, Fraley, Roberts, & Trzesniewski, 2001; Roberts & Mroczek, 2008). As people age it is behaviorally adaptive to be more conscientious. Being more detailed, careful, and risk averse leads to healthier behaviors and consequentially increases longevity (Bogg & Roberts, 2004). Therefore, employing a slower movement strategy to maximize accuracy may be part of a shift in conscientiousness instead of physiological limitations of the biomechanical system. In this interpretation the large differences between verification times of younger and older adults would be seen as differences due to conscientiousness – older adults spend significantly more time because they are more detailed instead of experiencing physiological limitations.

This leads to the third hypothesis (i.e. the strategic difference hypothesis) which predicts that older adults move more slowly as a way to maximize accuracy at the cost of speed. Other studies support this hypothesis. In one study, while older adults were twice as slow they were also twice as accurate as younger adults suggesting they moved slower to maximize accuracy (Bakaev, 2008). These findings were also consistent with classic studies. For example, Salthouse

(1979) argued that older participants consistently ranked accuracy over speed when spatial accuracy was a task requirement; thus employing a conservative movement strategy (Goggin & Meeuwsen, 1992). Recent research examined older adults' movement strategies in more detail. A cautious movement strategy may be more adaptive because moving more slowly may be less fatiguing and potentially less stressful to the biomechanical system (Van Halewyck et al., 2015). Thus, utilizing a cautious strategy may be an attempt to minimize the stress on the cognitive and motor systems. Therefore, older adults may be more error aversive because of processing limitations. In this view hypothesis 3 is a side effect of hypotheses 1 and 2. Therefore more research is needed to determine if these hypotheses are separable.

Further other personality differences in addition to conscientiousness may impact performance as well. Neuroticism has been associated with greater processing in the limbic system when exposed to novel stimuli and higher levels of cortisol release linking it to greater likeliness of stress and decreased ability to deal with stressful stimuli (DeYoung, 2002). Therefore, individuals with greater neuroticism may be more impacted by movement constraints at greater values of ID and adopt a more careful strategy to compensate for this.

Finally, impulsiveness may also impact movement performance. Impulsiveness has been defined as a tendency to make rapid or unplanned reactions to both internal and external stimuli (Stanford et al., 2009). Therefore, more impulsive individuals may be less likely to plan their movements efficiently leading to less efficient primary phases and more time spent in the secondary phase to correct these errors. One of the most well-known measures of impulsiveness is the Barratt impulsiveness scale which measures impulsiveness in motor, planning, and attentional behavior (Barratt, 1959). Individuals who report low impulsivity on the motor and planning scales may be more likely to adopt a careful movement strategy.

Physical Fitness

Physical activity, exercise, and physical fitness are three correlated but distinct terms. First, physical activity is defined by any movements of the body via skeletal muscles expending energy; secondly, exercise which is often described in both duration and intensity is any physical activity that is planned, structured, repetitive, and purposeful. Finally, fitness is the ability to carry out tasks (physical activities) without fatigue as measured by health-related metrics such as maximal oxygen uptake (VO_2 Max), body mass index, muscular strength, endurance, and flexibility, as well as skill-related metrics such as agility, balance, coordination, speed, power, and reaction time (Caspersen, Powell, & Christenson, 1985). Fitness is thought to be a resultant from repeated and sustained exercise more so than more general physical activity. A meta-analysis incorporating over 10,000 physical activity, fitness, and health papers reported that increases in regular exercise leads to increases in physical fitness and overall health (Blair, Cheng, & Holder, 2001). Currently, the World Health Organization (WHO) recommends that adults should engage in a minimum of 150 minutes of moderate-intensity aerobic physical activity and 75 minutes of vigorous-intensity activity per week to produce health benefits (WHO, n.d.). These guidelines are also recommended by a variety of other organizations such as the Center for Disease Control (CDC) in the U.S. (CDC, 2008). Everyday physical activities are additive, meaning the recommended amount of exercise can be accumulated by completing frequent shorter duration physical activities (Pate, 1995). This recommendation is also advised by the CDC (2014) which stated that activity can be broken into 10-minute blocks or shorter exercises completed throughout the day.

The impact of physical exercise on physical and cognitive health

The benefits of physical exercise are well known and have been replicated in a long-standing interdisciplinary body of research (Fentem, 1994). The benefits of physical exercise include reduced mortality rates and rates of cardiovascular disease (Dubbert, 2002), lower risk of developing diabetes or respiratory diseases (Smith, Shipley, Batty, Morris, & Marmot, 2000), reduced heart attack and stroke risk (Fentem, 1994), as well as lower musculoskeletal disorders risk (Proper et al., 2003). Active older adults were also more sensitive to passive movements of their upper limbs than sedentary older adults indicating they were better at processing proprioceptive feedback from the upper limbs (Wright, Adamo, & Brown, 2011). This finding was also replicated during training studies that provided physical activity training (Xu, Hong, & Chan, 2004) and was used to explain a fitness advantage for older adults in a pointing task (Van Halewyck et al., 2014).

Regular exercise also makes one more efficient at managing the effects of stress (Dubbert, 2002). A more recent study replicated these findings. Individuals rated lower anxiety and greater positive affect on days they exercised than on non-exercise days (Hopkins, Davis, Vantieghem, Whalen, & Bucci, 2012).

Exercise also has widespread cognitive benefits. Intervention program studies have shown consistent findings of cognitive improvements. These programs are divided into either acute, single session, or chronic, regular exercise, programs. Positive findings were shown for both rat and human exercise studies. Animal studies have shown increased spatial learning in water maze tasks (Liu et al., 2008), increased object recognition (O'Callaghan, Ohle, & Kelley, 2007), increased learning and memory performance (Ang, Dawe, Wong, Moochhala, & Ng, 2006) to name a few benefits after both short term and longer (12-week) aerobic exercise programs. Human studies show similar results. One study showed that acute exercise (30-minutes of treadmill running) could increase performance on an Eriksen flanker task (Hillman, Snook, & Jerome, 2003). Another study showed that results on a novel vocabulary task were optimized in an acute intense exercise condition over lower intensity and a relaxation condition (Winter et al., 2007), indicating that cognitive performance may be dependent on duration and intensity of the exercise. Additionally, longer-term exercise programs have additional benefits to cognitive functioning. Results of a 4-week exercise program showed improved performance on a novel object recognition task over control or acute conditions, but performance was best if participants exercised earlier in the day prior to testing (Hopkins et al., 2012). Visual attention, the process of identifying salient objects in the visual field while ignoring irrelevant information, is both one aspect thought to become diminished later in life and also improved with increased exercise (Owsley & McGwin, 2004). One study found that after 12 months of increased physical activity during a walking program, older adult participants demonstrated increased processing in visual-spatial processing areas that correlated with increased performance on visual search and flanker tests (Voelcker-Rehage, Godde, & Staudinger, 2011). These findings may indicate that increased exercise was associated with the ability to process visual feedback more efficiently and improved visual-spatial attention processes along with executive functioning among older adults. Highly physically active older adults also outperform sedentary individuals on visual memory, trail-making tests and the ability to recall previously presented visual stimuli (Vance et al., 2007). Finally, increased exercise both in duration and intensity was associated with increased performance in processing visual information presented in individuals' peripheral vision (Roth, Goode, Clay, & Ball, 2003). All together this evidence suggests that more physically fit individuals' process visual information and feedback more effectively than less active individuals.

Why does physical exercise improve health and cognition?

Increased physical activity including aerobic exercise is hard work for the body. In order to meet the needs of this increased exertion, breathing rate increases to allow for more oxygen intake. In fact, breathing rate may increase 15 times during intense exercise in order to increase the body's aerobic respiration rate which is the process used to convert oxygen into energy (Adenosine triphosphate often called ATP), which is in turn used by the skeletal muscles to perform the physical activity of exercise (Reece et al., 2011). One measure of fitness is one's VO_2 Max rate also called aerobic capacity or the maximum amount of oxygen the body can use during intense exercise. VO_2 Max rate improves with regular exercise to increase endurance and overall fitness (Kirk-Sanchez, & McGough, 2014). Next, in order to support increased physical activity, the sympathetic nervous system increases heart rate to pump blood more quickly to the muscles. With regular exercise, the body becomes more efficient at this process by increasing the number of blood vessels which over time decreases blood pressure and increases the efficiency of the heart to pump blood also called cardiac output (Kirk-Sanchez, & McGough, 2014). Previous studies also show that regular exercise increases brain gray matter volume in both the prefrontal cortex and hippocampus (Erickson, Leckie, & Weinstein, 2014), increases neurogenesis, blood vessels in the cortex, and brain-derived neurotrophic factor (BDNF; e.g. Lista & Sorrentino, 2010). Increased BDNF levels assist with the formation of long-term memories and supports neurogenesis (Erickson, Hillman & Kramer, 2015). Levels of BDNF are also decreased in age-related diseases such as Parkinson's disease and Alzheimer's (Nagahara & Tuszynski, 2011). Clinically increasing BDNF prevents cell death, improves memory, and supports axonal regeneration (Nagahara & Tuszynski, 2011), which further supports its role as a neuro protectant.

Physical fitness moderates age related declines

Physical activity and exercise significantly improve health, fitness, and cognitive functioning and may even reverse age related cognitive declines (Colcombe et al., 2004). Greater fitness may lead to older adults of the same chronological age to perform similarly to younger adults. Therefore, showing a difference in functional age. More fit older adults have been found to exhibit better executive functioning, spatial ability, and speed of processing performance as compared to older less fit adults (Kramer, Erickson, & Columbe, 2006). Another study indicated that a 6-month exercise program showed increased white matter volume in the hippocampus and caudate nucleus which is related to improvements in spatial memory (Erickson et al., 2010). A 12-month training program using resistance and balance exercises indicated increased executive functioning as well as greater adherence to an increased physical activity lifestyle after the program ended. Colcombe and colleagues (2006) found starting an exercise program increased older adults' brain volume in both white and grey matter regions after only six months. Additionally, exercise has been linked to a 2% increase in hippocampal volume (Erikson et al. 2011). This finding is important because the hippocampus has been linked to memory, and as such, plays a crucial role in our daily lives (Squire, 1992). An 8-year longitudinal study found that physical activity by older adults reduced age related cognitive declines as compared with inactive older adults. Additionally even small amounts of physical activity insulated participants against negative aging declines (Chu, Chu, Fox, Chen, & Ku, 2014).

Physical fitness is an Important Factor for Movement Performance

Research has only begun to uncover all of the health benefits that engagement in a physically active lifestyle may bring. The next section considers the research both on physical activity and age related findings. Following this, was hypothesized that physical activity may attenuate declines in movement efficiency in older adults.

Mental Fitness

Another perspective on enhancing cognitive ability with older adult populations is a focus to improve individuals' mental fitness. First, physical and mental fitness are connected. Lack of physical activity has been shown to covary with reduced cognitive functioning including earlier onset of dementia (Conroy, Golden, Jeffares, O'Neill, & McGee, 2010). This also supported the findings from Barnes et al. (2013) in which staying active was the largest predictor of cognitive health. In this way physical activity may be the most effective activity to support mental fitness. This may be due to the physical and neurological benefits of exercise, but another potential reason may be the increases in mental engagement and interaction also gained with exercise.

Among younger adults boredom is associated with poorer academic outcomes while those who practiced more efficient cognitive strategies, and may be more mentally fit, experienced boredom less often (Tze, Daniels, & Klassen, 2015). This indicates that staying busy with activities may improve fitness as well, but which activities are effective is less well known. Results from Wilson et al. (2007) that found social support and activity reduced the onset of dementia among older adults. Being social and connecting with other therefore may be important due to increased mental engagement.

However, another research literature has suggested that similar to physical fitness, participation in certain repetitive and sustained activities are believed to promote increased health and cognitive functioning; thus, these activities act as exercises for the mind and are thought to provide many of the same benefits as physical exercise to an extent. Mental fitness can be described as “a use it or lose it theory” where proponents of this view argue that activities that require cognitive effort and thought stimulate the brain and increase mental fitness (Kanthamalee & Spipankaew, 2013). Reading, writing, playing card or board games, musical instruments, completing crossword puzzles, Sudoku, participating in intellectual discussions, or other social interactions were all suggested as potential ways to increase mental fitness (Fernandez, Goldberg, & Michelon, 2013). Randomized controlled studies have indicated that participating in dual *n*-back training can improve working memory, executive functioning abilities (Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013), and even increase fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008).

While these empirical results indicate that specific and intense cognitive training may enhance mental fitness, what about the activities suggested above that individuals may realistically engage in? Is there empirical evidence to support the idea that engagement in certain daily activities may boost cognitive functioning and health? The frequency in which an individual engages in cognitive and social activities significantly decreased the risk of developing dementia in one study (Wilson, Scherr, Schneider, Tang, & Bennett, 2007). Research with younger adults and children have found avid readers performed better on scholastic and memory testing than non-readers (Stanovich, 1993). Playing a musical instrument have both been indicated to improve memory and spatial skills (Rausher, Shaw, & Ky, 1993). Undergoing musical training, was found to improve fluid intelligence and was posited to be due to similarity of skills shared between the specific musical instrument training and intelligence testing (e.g. fine dexterity, working memory). For example, individuals who learned the keyboard resisted distraction far better than individuals who took singing lessons (Schellenberg, 2005). Overall, a synthesis of the research on mental fitness supports the idea that a wide variety of activities are important for supporting cognitive health. Additionally, those activities should be ones that are novel, challenging, social, and require both creativity and physical effort to maximize mental fitness (Kuszewski, 2011). A large scale randomized controlled study (Barnes et al., 2013) found active controls were similar in terms of cognitive improvements and concluded that staying active is the most important characteristic to reducing cognitive decline.

Why does mental exercise improve cognition?

One mechanism through which mental exercise is thought to work is by stimulating increased blood flow to specific cortical regions of the brain by engaging in contemplative behavior. Over time this increased neural activity is believed to promote overall increases in vasculari-zation improving cognitive functioning (Xiong & Doraiswamy, 2009). Another perspective is called the glucocorticoid cascade hypothesis (Sapolsky, Krey, & McEwen, 1986). This hypothe-sis states that hippocampal volume declines with age and is increasingly susceptible to additional declines (or damage) in response to physiological stressors (McEwen, 1999). Glucocorticoid steroids are one type of molecule released in response to repeated exposure to stress. These ster-oids are also thought to bind to receptors in the hippocampus leading to premature cell death by moderating the update of glucose and oxygen (see McEwen & Sapolsky, 1995), which may propagate in a feed-forward manner. This hypothesis then may explain cognitive declines that we associate with the normal aging process (McEwen, 1999). One study followed older adult indi-viduals over 4 years and showed that these steroids both increased over time and greater levels were associated with greater cognitive declines at the end of the study period (Lupien et al., 1998). This relationship is also thought to be moderated by individual differences that regulate the amount of steroids that are released following a stressful event (McEwen, 1999; McEwen & Sapolsky, 1995). While these researchers were talking about genetic and biological differences, it is well known that some people are more resilient to stress than others. Mental fitness or resili-ency may be one non-genetic individual difference that provides protection against stress. In one study, participants either meditated before or after exposure to stress. Individuals who meditated prior to the stress had a similar physiological response to the stress task except they did not pro-duce as much stress-related steroids and had greater working memory following the stressor (Mohan, Sharma, & Bijlani, 2011). This suggests that activities that would be supportive of greater mental fitness would also be ones that show this pre-post interaction in stress hormones.

Whether or not other activities such as conversing with a friend at a dinner party, attending a scientific lecture, learning a new skill, or completing the weekly crossword can attenuate the stress response is less well-known, but this relationship can be examined indirectly in the current study.

Current Research and Hypotheses

Figure 2 shows the hypothesized model to be tested in the current study. In all analyses, regression was used to determine how well each independent variable predicts each of our dependent variables derived from the kinematic data. In each analysis it is expected that there will be a significant effect of age on the movement performance following prior research and that this difference will be more pronounced at greater values of ID. Specifically, there will be a significant effect of ID on movement kinematics and that age will interact with ID so that older adults will show a steeper slope across all pointing movements where both speed and accuracy are required according to Fitts' law. However, it is still unclear what the predictors will be of this decline in movement performance and what daily activities may attenuate this aging effect.

The proposed experiment has three goals. The first goal (1) is to investigate the unique contributions of effector and task constraints to movement performance (e.g. separating distance & width) in both younger and older adults. The second goal (2) is to examine the impact fitness has on movement performance. It is expected that fitness will moderate age-related declines in kinematic performance. Finally, the third goal (3) is to investigate differences in movement performance based on potential strategic differences due to individual differences amongst groups.

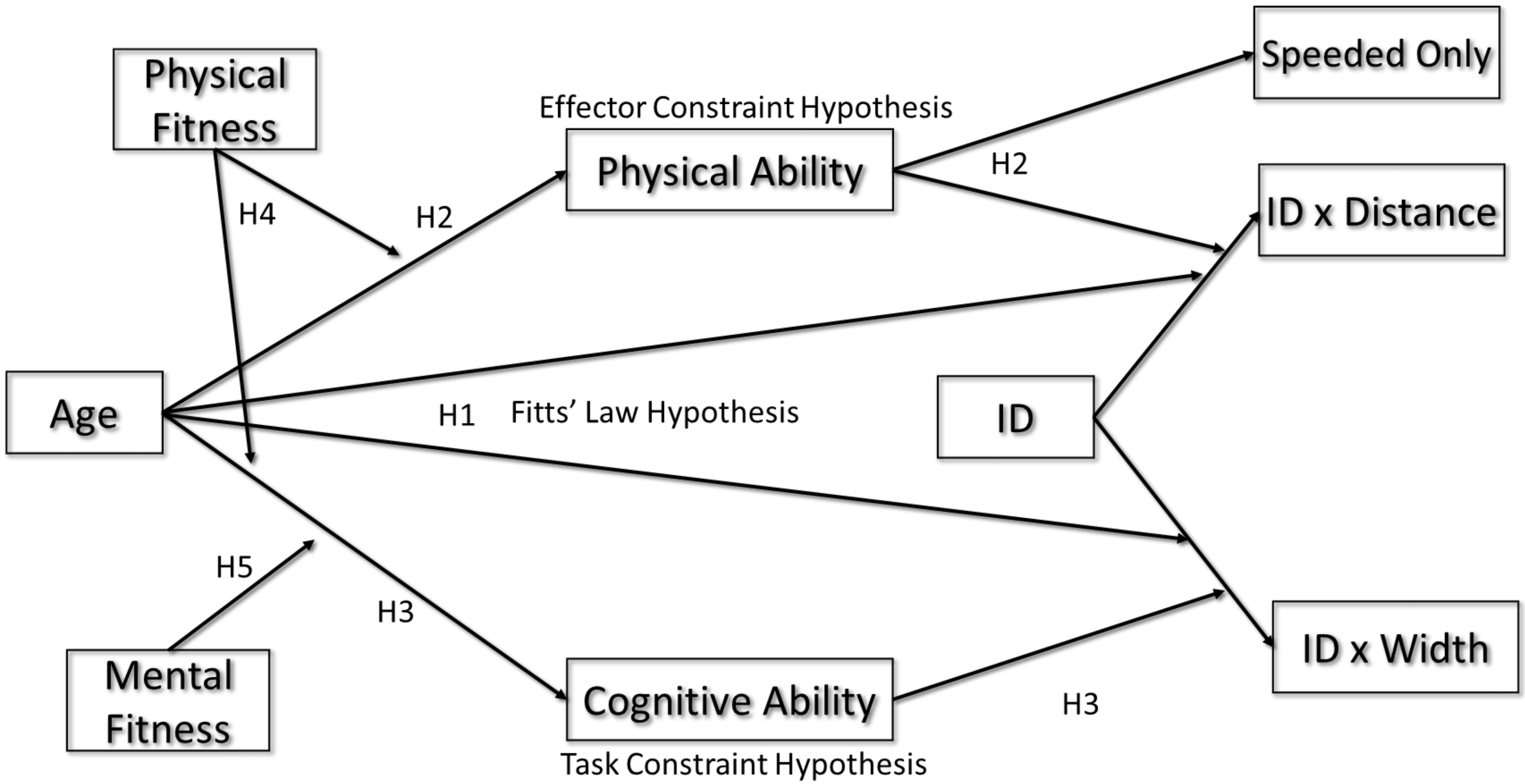


Figure 2. Overview of the Hypothesized Model Tested in the Current Study

Objective 1

To achieve the first goal, three hypotheses will be investigated: (1) the Fitts' Law Hypothesis, (2) the Effector Constraint Hypothesis, and (3) the Task Constraint Hypothesis. To tease these hypotheses apart participants will complete several tasks: (1) the UFOV to measure visual processing efficiency, (2) a proprioceptive pointing task, (3), a speeded only movement task where participants will have to move quickly without accuracy, and (4-5) two Fitts' pointing where individuals will be required to make both speeded and accurate movements to a target. One block will manipulate ID based on physical effort to test the effector constraint hypothesis, while the other will manipulate ID based on feedback processing requirements to test the task constraint hypothesis.

Fitts' Law Hypothesis (H1)

The Fitts' law hypothesis states that ID alone, and not specific types of movement constraints, will be the predictor of movement time (MT), accuracy, and kinematic efficiency. If this hypothesis is correct, it is predicted that MT will increase while accuracy and kinematic efficiency will decrease as ID increases (H1). In other words movements will become more difficult at greater ID and that will drive declines in performance. It is also expected that this relationship will also explain the declines in movement performance for older as compared to younger adults shown in other studies. We would also expect that there would be no significant differences in movement performance between the conditions designed to maximize effector or task constraints because ID is held constant.

Effector Constraint Hypothesis (H2)

The effector constraint hypothesis states that physical aspects of the movement explain differences in movement performance between younger and older adults (H2). If this hypothesis is correct, we would predict that older adults would not be able to make speeded movements as well as younger adults can especially at greater ID (H2a). Therefore, it is predicted that older adults will have longer movement times during the speeded condition. They may show declines on other kinematic markers as well. For example, not be able to produce as strong of an initial motor impulse as younger adults as indicated by smaller peak velocity and acceleration amplitude. Additionally, it is predicted that older adults will perform worse on the movement task where ID is manipulated by distance rather than width (H2b) because older adults will not be able to adapt to these physical demands as well as younger adults. Therefore, increasing age will be associated with steeper ID-MT slopes and a greater proportion of time spend in the secondary movement phase in the distance condition. It is also expected that an interaction between movement constraint types will be found so that while steeper slopes will be found in the distance condition, this will not occur when ID is only manipulated by width. Thus, age will have a greater impact in the distance condition than the width condition.

Task Constraint Hypothesis (H3)

The final hypothesis to be tested for objective 1 is the task constraint hypothesis. This hypothesis posits that it is the feedback processing requirements that cause difficulties for older adults and not difficulties with the biomechanical system (H3). If this explanation is correct, then we would expect that older adults would not be significantly different in their ability to make speeded movements when compared to younger adults. Next, it is predicted that older adults would have greater ID-MT slopes and spend longer in the secondary phases, indicating worse performance than younger adults, in the condition where ID is manipulated by width than when ID is manipulated by movement distance (H3a). This will occur because the older adults will be less able to adapt to the feedback processing demands of the task. Next, it is hypothesized that while performance on the UFOV and PPT will predict performance in both the distance and width conditions, these measures will be better predictors of movement performance in the width condition (H3b) because these measures are thought to be measures of feedback processing and greater feedback processing resources are needed in this condition.

Objective 2

To achieve the second goal both physical fitness will be measured and individuals' fitness and activity level will be used to predict movement performance. It is hypothesized that greater fitness will attenuate aging related declines in movement performance (H_4). More fit individuals are expected to have a flatter movement slope than less fit individuals because they will have a greater spare capacity to meet increased demands as the index of difficulty increases.

Physical Fitness Hypotheses (H4)

Based on previous research cardiovascular fitness is predicted to be a significant moderator of age related declines in movement performance (H4). There are three ways in which this benefit may be manifested. Fitness may improve effector efficiency (H_{4a}), cognitive feedback processing ability (H_{4b}), or both indicating a generalized benefit of fitness (H_{4c}). If physical fitness improves effector efficiency we would expect that older adults who have higher cardiovascular fitness scores will have faster movement times during both the speeded movement task and faster movement times with greater accuracy in the movement condition where ID is manipulated by distance but not in the condition where ID is manipulated by width. Specifically, it is expected that participants will make more efficient movements during the primary phase (closer to the target and less of a need to utilize secondary movements). This effect should be greater as age increases leading to an age × cardiovascular fitness interaction.

If instead physical fitness improves movement efficiency because it enhances cognitive ability, we would expect to see faster movement times and greater movement accuracy for all participants who are more fit when ID is manipulated by width than when it is manipulated by distance or during the speeded movement condition. It is expected due to age-related declines fitness will have a greater impact as age increases leading to an age × fitness interaction.

While younger adults may experience a ceiling effect on UFOV scores, older adults with greater fitness will detect changes at a lower display time on the UFOV than less fit older adults and that UFOV score will be a significant predictor of movement time and performance leading an interaction between age and fitness. This would show an indirect or mediated effect. Fitness improves visual processing efficiency which then improves movement performance. It is also hypothesized that individuals with greater fitness would be more efficient and complete movements with a lower proportion of the movement spent in the secondary phase (lower PropST). This would indicate more accuracy sensory feedback integration. This effect is hypothesized to be more evident for older adults leading to an age × fitness interaction. To support the third possibility it is expected that physical fitness will improve performance on all experimental tasks. Thus, widespread benefits of cardiovascular fitness will be seen. It is also hypothesized that these benefits would be greater for older adults due to their reduced physical and cognitive ability leading to an age × fitness interaction.

Mental Fitness Hypotheses (H5)

It is expected that greater mental fitness will improve cognitive feedback processing ability but not effector ability (H5); thus, it is hypothesized that older adults who are more mentally active will have decreased movement times and greater accuracy during the movement conditions when ID is manipulated by width but not during the condition where ID is manipulated by distance alone (H_{5a}). It is also expected that older adults who are more mentally fit will outperform less mentally fit individuals' on the UFOV (H_{5b}) by detecting and localizing objects at a lower display time. However, hypotheses regarding proprioceptive processing efficiency are more complicated. On one hand, this improved cognitive ability due to mental fitness may carry over to proprioception. Thus, individuals who stay mentally active will outperform less fit individuals (H_{5c}). On the other hand, it may be that proprioception improves though peripheral receptors and thus would not improve with greater levels of mental fitness. The unique combination of conditions presented in the current study does allow us to tease these effects apart somewhat. If individuals show improved performance when ID is manipulated by W and show greater proprioceptive ability, but not greater biomechanical ability we can theorize that central feedback mechanisms are responsible for these effects and thus mental fitness may improve this ability. On the other hand, if we see improvements when ID is manipulated by D and the biomechanical assessment, but not when ID is manipulated by W and the visual processing task then more peripheral mechanisms are responsible. Further analyses of kinematic markers during the movements and proprioceptive task may shed light on these two theories. It is not expected that mentally fit individuals would perform better during the biomechanical assessment. It is expected that improvement gains from mental fitness would be more beneficial to older adults than younger due to cognitive declines in this group leading to an age × fitness interaction. Finally, since mental fitness is thought to improve sensory processing mechanisms it may also enhance improvement gained from physical fitness. In this way physical and mental fitness may interact and these individuals will have the lowest movement times of any other condition (H_{5d}).

Objective 3

The third goal is to examine the veracity of the strategic hypothesis that states older adults who are more error averse and careful will perform movements more slowly than individuals who are less careful (H_6). To test this hypothesis, individual differences in personality will be assessed and these ratings will be used to predict movement time differences amongst the participant groups.

Strategic Differences Hypothesis (H6)

The strategic differences hypothesis is often confounded with age related declines because these differences in strategy may be due to limitations in ability. It is hypothesized that if moving more slowly is not due to processing limitations but due to being more careful, then greater conscientiousness, less motor and planning impulsivity and less neuroticism will lead to decreased movement time and increased movement performance than age alone (H_{6a}) or UFOV and PPT performance (H_{6b}). It is also expected that we would see a general decrease in movement time and an increase in accuracy across both of the speed + accuracy conditions (width and distance), but not the speeded movement task (H_{6c}). Finally, it is expected that individuals with more error adverse personality traits will report they prioritized accuracy over speed during the speeded + accuracy conditions but not the speeded movement task. And this decrease in movement time will be associated with an increase in self-reported performance (H_{6d}).

CHAPTER THREE: METHODOLOGY

Participants

One-hundred and ninety eight participants were recruited for this study. Of these, 9 were removed due to not meeting screening requirements or technical difficulties. The final sample consisted of 189 participants (73 men; 116 women) between the ages of 18 – 86 (*M* = 47.37, *SD* = 23.36, *Mdn* = 52) years old who completed all experimental tasks. Student participants were recruited using the university's online participant recruitment tool (Sona Systems) and received course credit for their participation. Non-student participants were recruited from both the university (such as the Learning Institute for Elders at UCF) and the surrounding metropolitan area and received $10/hour for their participation.

To be included in the study participants were required to report to be right-handed, in good health, have normal/corrected-to-normal visual acuity (20/40+), no evidence of cognitive impairment such as dementia, and have no other visual or self-reported impairments of their sensorimotor systems. Visual acuity was tested using a Snellen eye chart. Evidence of no cognitive impairment was defined as both reporting no cognitive declines and scoring a 24 or higher on the Montreal Cognitive Assessment Test (MoCA; Nasreddine et al., 2005). Being in good health was defined as reporting no difficulties on the Physical Activity Readiness Questionnaire (PAR-Q+; Warburton, Jamnik, Bredin, & Gledhill, 2014) indicating they are healthy enough to engage in exercise without a physician's permission reporting never being diagnosed with any health conditions that could impact their motor or cognitive abilities (e.g. Parkinson's disease), and have a

BMI between 15 – 45 (outside that range may indicate a medical condition). Table 1 shows the demographic variables broken down by age groups.

Table 1. Mean, Standard Deviation, and 95% CI for Demographic Variables For Each Age-Group.

Variable	Younger (*n*=83, 36 men, 47 women)		Middle Age (*n*=39, 8 men, 31 women)		Younger-Old (*n*=46, 19 men, 27 women)		Older-Old (*n*=21, 10 men, 11 women)	
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
Age	22.97 (5.46)	[21.80, 24.14]	55.53 (6.41)	[53.52, 57.55]	70.30 (2.64)	[69.53, 71.06]	79.52 (3.69)	[77.94, 81.10]
BMI	25.45 (5.17)	[24.35, 26.55]	28.77 (6.64)	[26.68, 30.85]	27.04 (4.87)	[25.64, 28.45]	26.1 (4.52)	[24.16, 28.03]
Fitness Score	13.60 (2.38)	[13.09, 14.11]	9.50 (3.02)	[8.55, 10.45]	9.29 (2.06)	[8.69, 9.89]	8.10 (2.40)	[7.07, 9.13]
Openness	3.55 (0.57)	[3.43, 3.67]	3.76 (0.47)	[3.61, 3.91]	3.90 (0.54)	[3.74, 4.06]	3.82 (0.50)	[3.60, 4.03]
Conscientious-ness	3.83 (0.62)	[3.69, 3.95]	4.14 (0.54)	[3.97, 4.31]	4.09 (0.58)	[3.92, 4.25]	4.19 (0.61)	[3.92, 4.45]
Extraversion	3.16 (0.82)	[2.98, 3.34]	3.48 (0.85)	[3.21, 3.75]	3.48 (0.80)	[3.25, 3.71]	3.33 (0.56)	[3.09, 3.57]
Agreeableness	3.87 (0.66)	[3.73, 4.01]	4.04 (0.65)	[3.83, 4.24]	4.14 (0.49)	[4.00, 4.28]	4.15 (0.48)	[3.94, 4.36]
Neuroticism	2.72 (0.87)	[2.53, 2.90]	2.40 (0.89)	[2.12, 2.68]	2.14 (0.65)	[1.95, 2.33]	1.91 (0.52)	[1.68, 2.13]
Motor Impul-sivity	2.81 (0.92)	[2.61, 3.00]	2.30 (0.83)	[2.04, 2.56]	2.27 (0.71)	[2.07, 2.48]	2.35 (0.82)	[1.99, 2.70]
Planning Im-pulsivity	2.13 (0.71)	[1.97, 2.27]	1.93 (0.63)	[1.73, 2.13]	1.82 (0.43)	[1.69, 1.94]	1.86 (0.55)	[1.62, 2.10]
Attention im-pulsivity	2.79 (0.59)	[2.66, 2.91]	2.44 (0.50)	[2.28, 2.59]	2.53 (0.48)	[2.40, 2.67]	2.22 (0.57)	[1.98, 2.47]

Note. CI = confidence interval. Age groups: Younger (18-39), Middle Age (40-64), Younger-Old (65-74), & Older-Old (75-86). Older adults are broken into younger-old and older-old for easy of comparison within the older adult group. All data were analyzed continuously. Largest age gap was 4 years.

Apparatus/Materials

An OPTEC 5500P vision screener was used for vision screening. The Montreal Cognitive Assessment (MoCA; Smith, Gildeh, & Holmes, 2007) was used to indicate normal mental functioning. The Useful Field of View assessment (e.g. Edwards et al., 2005) measured speed of visual processing ability. Physical fitness was measured using a self-report of hours/week and intensity of engaging in physical activities, and a non-exercise cardiovascular fitness test (Jurca et al., 2005). Participants completed a Fitts' law pointing tasks using a Wacom Intuos XL digitizing tablet and pen stylus with the standard pen nib. NeuroScript MovAlyzeR software was used to present each stimulus and to perform initial filtering of the kinematic data. Kinematic was further coded in MATLAB using a custom script. The 2015 version of the PAR-Q+ survey was given to participants along with demographics as a screening measure. The PAR-Q+ questionnaire is a validated survey that assesses individuals' readiness to engage in physical activity and includes questions to screen for a wide variety of health conditions that would impede biomechanical or cognitive.

The Big Five Inventory (BFI; John, Naumann & Soto, 2008) was used to assess individuals personality traits across the big 5 domains. Another measure, the revised Barratt Impulsiveness scale (Patton, Stanford, & Barratt, 1995) is a common valid and reliable method to measure carefulness. This scale is a brief measure scored on a 5-point Likert scale (anchored between low – rarely to high – always) and measures three types of impulsiveness: motor, planning, and attention. This scale has been shown to correlate with behavioral carefulness and processing ability in the prefrontal cortex, an area thought to regulate behavioral planning (Spinella, 2007).

Mental fitness was measured as a composite of responses on a brief survey that asked how often participants engaged in activities thought to keep individuals mentally active (e.g., read books, play a music instrument). The mental fitness scale was scored in a 7-point Likert type scale (1 = seldom, 7 Everyday). Participants also had the option of selecting "0" to indicate they have not engaged in the activity at all over the past year. A shortened, 30-question version of the Dundee Stress State Questionnaire (DSSQ-S; Matthews, Joyner, Gilliland, Huggins, & Falconer, 1999; Matthews, Emo, & Funke, 2005) was used to assess how three aspects of stress: task engagement, distress, and worry changed as a result of completing the study. Potentially, older adults or those with less fitness may be less engaged or experience more distress which may confound study results. This measure helped control for these issues.

Kinematic Data

The kinematic data consisted of several important markers that access the temporal, accuracy, and efficiency aspects of the movement. Completing a goal-directed pointing movement is subject to the speed/accuracy tradeoff. This means a participants could have made a fast movement at the cost of accuracy or have slowed down in order to be more accurate.

First, temporal measures include overall movement time (MT), movement time spent in the primary phase (PT) and secondary phase (ST). MT was calculated as the total time interval (in seconds) between the first and last samples while the stylus is in motion. Time spent in PT was the time interval of MT from the start of the movement until a zero-crossing occurred in the acceleration graph. Time spent in ST was the time interval from the end of the PT to the end of the movement.

For each target, participants were directed to end their movement at the target center. Measures of accuracy examine deviations between participants' endpoint and the location of the target. The first measure of accuracy included the constant error (CE) at the end of the movement. CE provides information regarding the amount that participants undershot (indicated by a negative CE) or overshot (indicated by a positive CE) the target and is calculated as the sum of the differences between the actual endpoint of the movement and the center of the target divided by the number of trials (in cm). In the current study we divided CE into the overall error at the end of the movement (CeMT) and the CE at the end of the primary movement phase (CePT) to determine the target error (undershoot or overshoot). We also used an additional accuracy measure which was variable error (VE). VE measures movement precision and is sensitive to errors due to moving inconsistently across trials. For example, VE is larger for participants who end in a different location on every trials as compared to people who move consistently. VE is defined as the sum of the root mean squared deviations in the movement endpoint. In the current study we divided VE into the overall error at the end of the movement (VeMT) and the error at the end of the primary phase (VePT) which measures errors due to a lack of consistency.

Measures of kinematic efficiency included peak acceleration (PA), peak deceleration (PD), peak velocity (PV), time to peak acceleration (TPA), time to peak deceleration (TPDA), time to peak velocity (TPV), as well as the proportion of the movement spent in the primary (PropPT) or secondary (PropST) movement phase. Calculations of velocity and acceleration were made on the filtered movement data files in MovAlyzeR (specific processing details are described in the results section). Values are reported in cm/s and cm/s^2 respectively. Additionally, we measured the average axial pressure (z) of the stylus in tablet units (maximum pressure = 2048) on the tablet during the movement (pen pressure) as recorded by MovAlyzeR.

Proprioceptive Pointing Task (PPT)

A proprioceptive pointing task (PPT) measured individuals' proprioceptive sensitivity. Participants sat in a chair at a table placed 73.50 cm above the floor. In front of them on the table a rectangular foam board with a height of 15 cm, a length of 91.44 cm and a width of 40.64 cm was placed. On upon the table, five markers (one start location and four targets) were centered on the foam board from right to left. One marker was a start position for the right hand placed 15.24 cm from the right edge of the board. The four other markers defined target locations placed at an irregular pattern approximately 5cm, 13cm, 16.5cm, and 23cm from the start location. These markers were raised so they could be felt without vision underneath the foam board. Participants wore a Flock of Birds (FoB) movement sensor mounted on a finger splint on their right index finger. The FoB sensor recorded the x, y, & z coordinates of the right finder tip at the end of each trial. Coordinates of each target location were identified before each participant arrived by the experimenter placing the sensor on top of each location and recording their x, y, & z coordinates. The task setup is shown in Figure 3. The participant was blindfolded during the task and on each trial the experimenter placed the participant's left index finger on one of the target markers located underneath the board palmar side up. The experimenter placed the participant's right index finger on the start location. Upon hearing a go signal the participant was instructed, in a single movement, to move their right index finger to where they felt their left index finger to be so that they would perfectly overlap. Participants were also instructed not to reposition their hand after they placed it down on the table. Pointing error for each point was derived by taking the average location of three repetitions for each point and calculating the root mean squared error between the movement endpoint and the actual target location.

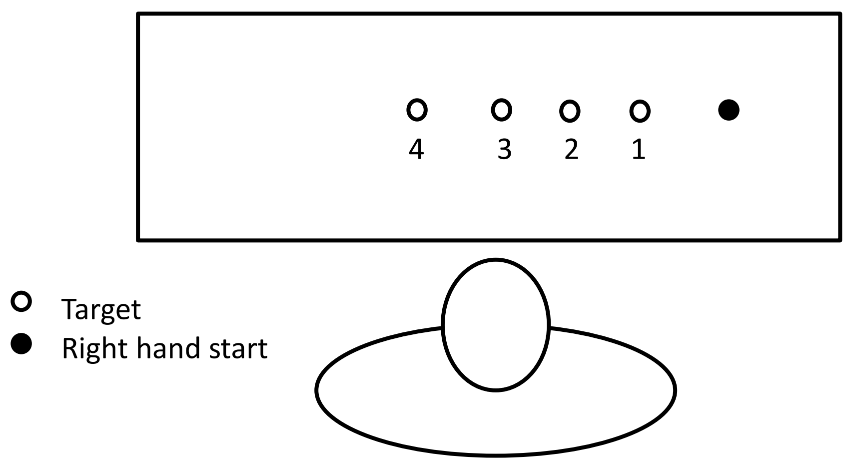


Figure 3. Proprioceptive Pointing Task Setup.

Useful Field of View

The term Useful Field of View (UFOV) was coined by Ball Beard, Roenker, Miller, & Griggs (1998) as the amount of information that can be processed within one eye fixation. A larger UFOV indicates a greater visual information processing capacity. The UFOV assessment measures several visual metrics. First it measures speed of visual processing of central vision (processing speed), second, it measures response time and accuracy to visual information presented in the periphery (selective attention), and finally, it measures visual response time and accuracy to peripheral visual stimuli with the presence of distractors (divided attention). This task requires additional cognitive effort that examines the speed of executive functioning and response inhibition during visual processing (Ball et al., 1998; Wood, 2014). UFOV has previously been predictive of older adults' performance in everyday tasks such as successful computer use and driving ability (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Oswald, McAbee, Redick, & Hambrick, 2014). UFOV procedure includes presenting a circular array around a central fixation point containing a reference stimulus box. Participants are required to focus on the central point while a target or distractor stimulus is displayed at one of 8 potential target locations: 0°, 45°, 90°, 135°, 180°, 225°, 270°, & 315° that are presented briefly (13 – 500 milliseconds). Finally, the divided attention task fills the display with distractors and participants must ignore the irrelevant stimuli. All stimuli presentations are followed by a brief mask and participants must select the location at which the reference stimuli was presented. It is important to note that for UFOV scores lower ones are better as they represent the time the stimuli were displayed on screen in milliseconds. For example, a score of 50ms would indicate that that participant took 50 ms to process the stimuli and respond during that block of trials.

Design

This experiment had five within-subject tasks: the UFOV, the PPT, and three experimental pointing tasks. The first pointing task was a speeded movement task where accuracy did not matter while the second and third pointing tasks required both speed and accuracy. This study had several between-subjects variables with the variables of primary interest being age and cardiovascular fitness. During the study we also measured personality, and engagement in specific activities of physical and mental fitness.

Speeded Movement Task

First, a speeded Fitts' law condition similar to Van Halewyck et al. (2015) was used to tease apart participants' ability to physically make speeded movements ruling out limitations in the biomechanical systems. During these movements target width were not manipulated and movements did not have an accuracy requirement. Participants were required to instead move the stylus along the tablet to cross a 1px vertical line drawn at the target distance as quickly as possible and to lift up as soon as they have crossed the line. All target lines were presented in a random order. The distances used were be the same as the main experiment and thus will be described below. In this condition participants were be told not to pay attention to end point accuracy and instead to make movements overshooting the target as quickly as they can.

Speed + Accuracy Task

In the second and third pointing tasks, participants were required to move as quickly and as accurately as they can to move to a variety of targets. Unlike the speeded movement task movements were made to a circle and required participants to be both speed and accurate. Participants completed two versions of this task which were counterbalanced. In one condition movement difficulty was manipulated by the distance participants were required to move while in the other condition difficulty was manipulated by the size of the target while the other constraint was held constant.

Distance and Width

Within-subjects factors: 5 values of ID were created (held constant between conditions); in one condition, ID variations were achieved via manipulations of D holding W constant (Distance condition) and in the other condition, ID variations were achieved holding D constant and manipulating W (Width condition; Table 2). Individuals completed one block of each condition, counterbalanced. Each block included 15 repetitions of each of the 5 IDs (75 trials in a random order). The speeded movement task used the same distances as the distance condition.

Table 2. Distances, Widths, and ID Values for the Goal-Directed Pointing Task.

ID manipulated by W			ID manipulated by D		
D	W	ID	D	W	ID
16	4	3	32	0.5	7
16	2	4	16	0.5	6
16	1	5	8	0.5	5
16	0.5	6	4	0.5	4
16	0.25	7	2	0.5	3

Note: D = movement distance, W = target width, & ID calculated using the Fitts (1954) formulation. Distances and widths are in cm. Speeded task followed the same distances as the distance condition.

Age

The first between-subject factor was age. This continuous variable was be measured using a demographic assessment included in a prescreening.

Cardiovascular Fitness

The second between-subject factor was physical fitness level. This was measured using a non-exercise based cardiovascular fitness level assessment, which combines self-report information with an individuals' Body Mass Index and resting heart rate to determine a fitness level based on metabolic equivalent units (Jurca, 2005). Physically inactive individuals who spend on average 60% of the day completing activities such as sleeping, eating, sitting, laying down, engaging in seated-entertainment (e.g. watching TV), driving, or seated desk work and no regular exercise (Gorman et al., 2013; Madden, Ashe, Lockhart, & Chase, 2014) will score lower on this scale. Active individuals will meet or exceed the United States guidelines for physical activity of 150 minutes of moderate physical activity per week (CDC, 2014) or its equivalent will score higher on this measure.

Procedure

All participants were treated according to American Psychological Association (APA)'s ethical guidelines and according to the declaration of Helsinki. After informed consent, participants completed a vision screening. Older adult participants (over age 50) were also be administered the MoCA. All participants completed a health prescreening with the PAR-Q+. All participants completed the study tasks in the same order with the exception of the speed + accuracy condition which were counter balanced. Half of the participants completed the distance condition first while the other half completed the width condition first.

Following the prescreening, a 5-minute resting heartrate measurement was taken while participants were sitting quietly. Participants then completed the DSSQ-S pre-questionnaire (based on how they felt at the moment) and completed a cardiovascular fitness assessment. The fitness assessment required participants to first stand in front of a height meter placed on the wall to measure their height. Next, participants stood on an Omron body composition scale to measure their weight in order to calculate their BMI. Measurements of BMI, and resting heart rate along with self-reported questions were used as a non-exercise based measure of fitness (Jurca et al., 2005).

Following this, participants completed the UFOV, the PPT, the speeded movement task, and the two speeded and accurate movement tasks. After each pointing task participants completed a two question survey that asked them to rate their movement strategy tradeoff between speed and accuracy (from only speeded to only accurate) and a self-rating of their performance (from complete failure to perfect). A short break was given between each task and as needed. Before participants' completed each task they were be instructed on how to complete it and were given a brief practice session until they demonstrated they understood the task. Each pointing task was self-paced with participants pressing a button each time they were ready to start a movement. Within each of the three pointing tasks the order of each condition for trial was randomized. Participants then completed a post-study DSSQ-S, demographics, physical and mental fitness surveys, and personality questionnaires.

CHAPTER FOUR: RESULTS

Processing of Kinematic Data

Kinematic data were obtained from both time filtered (TF) and Extracted (EXT) data files in MovAlyzeR. TF files contain the X, Y values of the cursor taken at each sample during the movement that have been filtered. A 10 Hz Butterworth low pass filter with a sharpness of 1.75 was used to smooth the data. The trailing pen lift was also removed. EXT files contained summarized data extracted from each movement including movement reaction time and the duration of each movement phase that resulted from a sub-movement analysis that separated overall MT into PT and ST. The end of the PT was determined by a zero crossing in the velocity profile.

A custom script was written in MATLAB that combined the data from each TF file with the response time data from the EXT file to calculate all kinematic markers used in the current study. This script also performed error checking on each trial. For the speeded movement condition, trials were removed if they were outside of $\pm$ 2.5 SDs above or below the mean, had a movement duration of less than 100 ms, or had a movement duration of more than 10,000 ms. For both of the speeded + accuracy conditions trials were removed if they were outside of $\pm$ 2.5 SDs above or below the mean, had a movement duration of less than 200 ms, or had a movement duration of more than 10,000 ms. A separate criterion was used for speeded conditions because they lacked accuracy requirements which would lead to a faster reaction time. Overall less than 5% of trials were removed from each condition.

Unless stated otherwise, all statistical tests were conducted in SPSS v.23. Variables were checked for assumptions of normality prior to data analysis. While age and fitness were normal, UFOV, proprioceptive error, and the kinematic variables were significantly skewed and kurtotic. Therefore, the analysis was conducted on the log transformed values. For sequential regression analyses a criteria of p_{in} of .05 and p_{out} of .06 were used. Due to the large sample size of trials (*n* = 945) in each regression models were only considered significant if they have an adjusted R^2 greater than .10 to prevent type I error. Significant group differences were assessed by examining the *t*-test and comparing the 95% CI for each independent variable. For all figures error bars are 95% CI of the mean.

Self-Reported Task Assessments

Prior to analyzing the experimental tasks a backwards multiple regression was conducted on each of the three subscales of the DSSQ-S. Participants were given a pre-study version before they completed experimental tasks and another immediately following the conclusion of those tasks. It was thought that the amount of engagement, distress, or worry experienced by participants may be impacted by their age, fitness, or a combination of the two shedding additional light on age-related declines. However, no differences were found.

Additionally, after each block participants were asked to rate their strategy from completely speeded to completely accurate and rate their performance on that block of trials. Another set of regression analyses were conducted on these variables using age, fitness and the age × fitness interaction as predictors. Ratings on all scales ranged between 0 and 100. No differences were found for any of the conditions. The strategy variable was also used as a manipulation check to ensure everyone understood the instructions. After collapsing across age and fitness participants employed an approach that was biased toward speed in the speeded condition (*M* =

39.92, 95% CI: [36.37; 43.47]), while in both the distance (*M* = 61.81, 95% CI: [59.14; 64.49]) and width (*M* = 65.15, 95% CI: [59.63; 70.69]) conditions participants took an approach balanced between speed and accuracy. After examining the self-reported success results, participants in the speeded condition rated their success (*M* = 34.24, 95% CI: [31.56; 36.94]) lower than the distance (*M* = 41.95, 95% CI: [38.79; 45.10]) or width conditions (*M* = 40.95, 95% CI: [38.00; 43.89]). No differences were found due to overlapping confidence intervals for self-reported success. It is noted that all success ratings were less than the mid-point of the scale. Because of this a one-sample *t*-test was conducted to determine if these ratings were significantly less than the midpoint value of 50. Success ratings for all conditions were significantly lower than the scale midpoint suggesting all participants found each of the pointing tasks equally difficult. Test values for each test were: $t(188) = -11.56$, $p < .001$ for the speeded condition, $t(188) = -5.04$, $p < .001$ for the distance condition, and $t(188) = -6.06$, $p < .001$ for width condition.

Explanations for these results are that either there were no differences based on age and fitness or that individuals were equal in their inability to self-access their affective states and performance in the current study. Therefore, these variables were dropped from consideration in other regression models.

Fitts' Law Hypothesis (H1)

To test the hypothesis that ID instead of the type of movement constraints will impact goal-directed movement performance, a hierarchical backwards multiple regression analysis was conducted using index of difficulty (ID), movement constraint (MC; distance = 0 or width = 1), and the interaction between ID and MC on each of the kinematic variables. The analysis revealed a significant effect of ID for movement time (MT), proportion of movement spent in the secondary phase (PropST), constant error at the end of the primary phase (CEPT) and end of the movement (CEMT), variable error at the end of the primary phase (VEPT) and at the end of the movement (VEMT). A main effect for MC or a MC × ID interaction was found for seven of the kinematic variables: MT, PropST, CEPT, VEMT, and tPV providing evidence against the Fitts' Law Hypothesis (Table 3 & Table 4).

Table 3. Correlations between ID, Movement constraint type (MC) and Kinematic Variables.

#	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	ID	—											
2	MC	0	—										
3	MT	.35**	-.32**	—									
4	PropST	.27**	-.50**	.64**	—								
5	CEPT	.34**	.06*	.10**	-0.04	—							
6	CEMT	.45**	-0.01	.26**	.11**	.97**	—						
7	VEPT	.58**	-0.02	.48**	.33**	.39**	.55**	—					
8	PV	.43**	.39**	-.32**	-.26**	.44**	.44**	.38**	—				
9	tPV	.19**	-0.01	.50**	-0.04	.14**	.20**	.24**	-.080**	—			
10	tPA	-0.02	-.15**	.24**	-.10**	0.03	.08	-0.006	-.13**	.76**	—		
11	PA	.21**	.24**	-.51**	-.28**	.24**	.20**	.21**	.80**	-.38**	-.26**	—	
12	PD	.11**	.18**	-.54**	-.37**	.22**	.15**	.11**	.76**	-.19**	-0.03	.89**	—

Note: *p<.05, **p<.001, Movement Constraint coded distance = 0 and width = 1. MC = Movement Constraint Type, MT = Movement Time, PropST = Proportion of ST, ST = Time in Secondary Phase, CEPT = Constant Error at the End of PT, CEMT = Constant Error at the End of the Movement, VEPT = Variable Error at the End of PT, VEMT = Variable Error at the End of the Movement, PV = Peak Velocity, tPV = Time to PV, PA = Peak Acceleration, PD = Peak Deceleration, tPA = Time to Peak Acceleration.

Table 4. Distance and Width Condition Regression Results Using ID and MC as Predictors.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	20.08	<.001	.25	.012				223.91	3, 1886	<.001	.26	.26
Index of Difficulty (ID)	19.06	<.001	.045	.002	.53	.35	.38					
Move Constraint (MC)	4.24	<.001	.074	.017	.30	-.32	.08					
ID × MC	-9.05	<.001	-.30	.003	-.68	-.26	-.18					
Proportion ST (PropST)												
Overall Model	38.99	<.001	.15	.004				453.08	2, 1887	<.001	.32	.32
ID	14.44	<.001	.01	.001	.27	.27	.27					
MC	-26.41	<.001	-.05	.002	-.50	-.50	-.50					
Constant Error (CE) PT												
Overall Model	-19.29	<.001	-16.48	.85				130.40	2, 1887	<.001	.12	.12
ID	15.94	<.001	2.53	.16	.34	.34	.34					
MC	2.57	.01	1.16	.45	.06	.06	.06					
Constant Error (CE) MT												
Overall Model	-21.00	<.001	-19.45	.93				472.15	1, 1888	<.001	.20	.20
ID	21.73	<.001	3.87	.18	.45	.45	.45					
Variable Error (VE) PT												
Overall Model	3.07	.002	.047	.015				953.23	1, 1888	<.001	.34	.34
ID	30.87	<.001	.09	.003	.58	.58	.58					
Peak Velocity (PV)												
Overall Model	44.18	<.001	.86	.019				469.99	2, 1887	<.001	.33	.33
ID	22.59	<.001	.08	.004	.43	.43	.43					
MC	20.73	<.001	.21	.01	.39	.39	.39					
Time to Peak Velocity (tPV)												
Overall Model	n.s.											
Time to Peak Acceleration (tPA)												
Overall Model	n.s.											
Peak Acceleration (PA)												
Overall Model	n.s.											
Peak Deceleration (PD)												
Overall Model	n.s.											

Note: Only the final model for each dependent variable is shown. ID = Index of Difficulty, MC = Movement Constraint Type.

Specifically for movement time, an interaction was found between MC and ID. This interaction indicated for all participants at easier ID values there were no differences in movement time due to movement constraints. However, as ID increased distance led to a greater increase in MT than did width (Figure 4). Next, main effects of ID and MC were found for PropST. This indicated that participants spent a longer time in the ST phase as ID increased and for movements made in the distance condition (Figure 5).

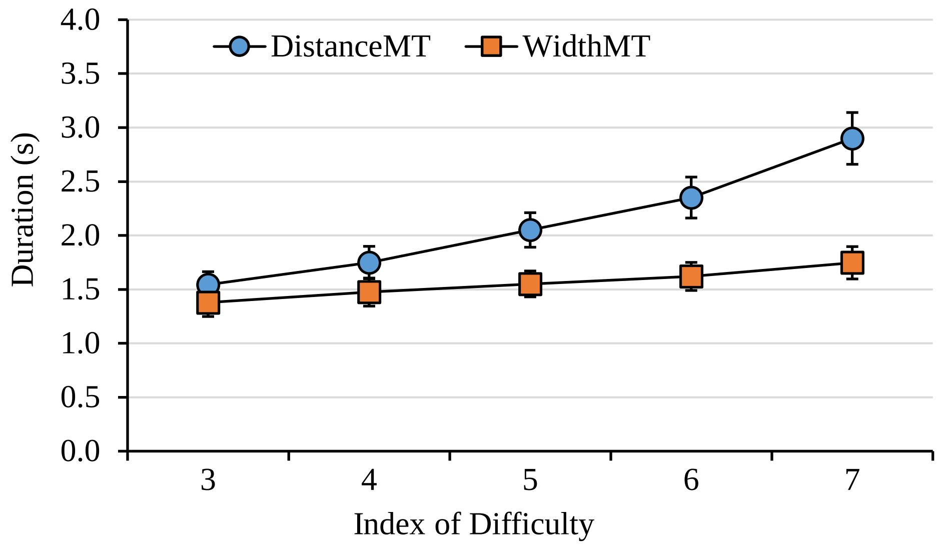


Figure 4. Movement Time (MT) Across ID for Distance and Width Conditions.

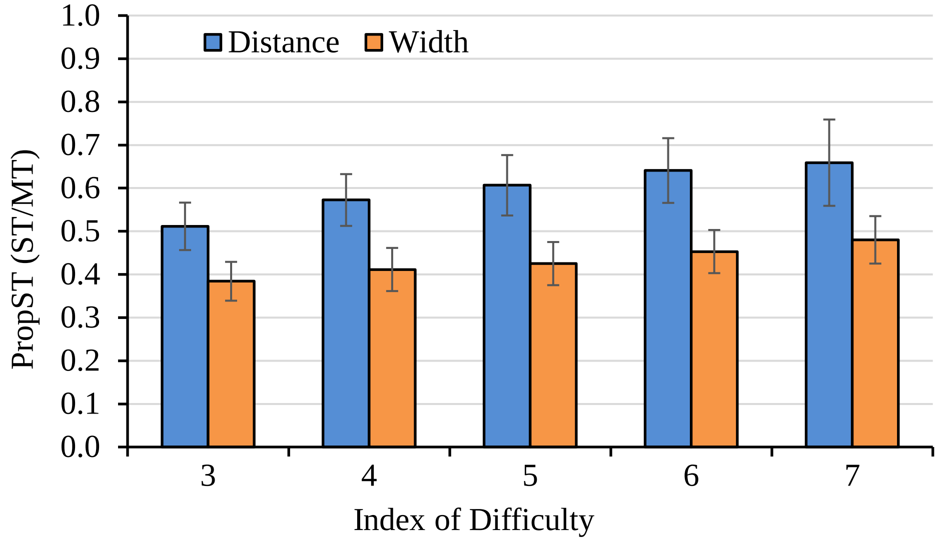


Figure 5. Proportion of ST (PropST) for Distance and Width Conditions.

In terms of constant error (CE), main effects of ID and MC were found for CE at the end of the primary movement phase (CEPT), while only a main effect of ID was found for CE at the end of the movement (CEMT). Distance increased CEPT greater than width. In the Distance condition participants were more likely to undershoot a target as long as ID was less than 5 as indicated by the negative CE values. At ID values greater than 5 participants' were more likely to overshoot the target as indicated by the shift from negative to positive CE values. Participants were slightly more likely to undershoot a target as ID increased in the width condition (Figure 5). This likely occurred because distance was held constant in the width condition. However, as ID increased participants stopped sooner leading to a shorter distance traversed. His occurred although the target circle was smaller which would allow them to get closer to the center. This finding indicated that the greater accuracy requirements decreased the time spent in the primary phase allowing for an increased accuracy phase.

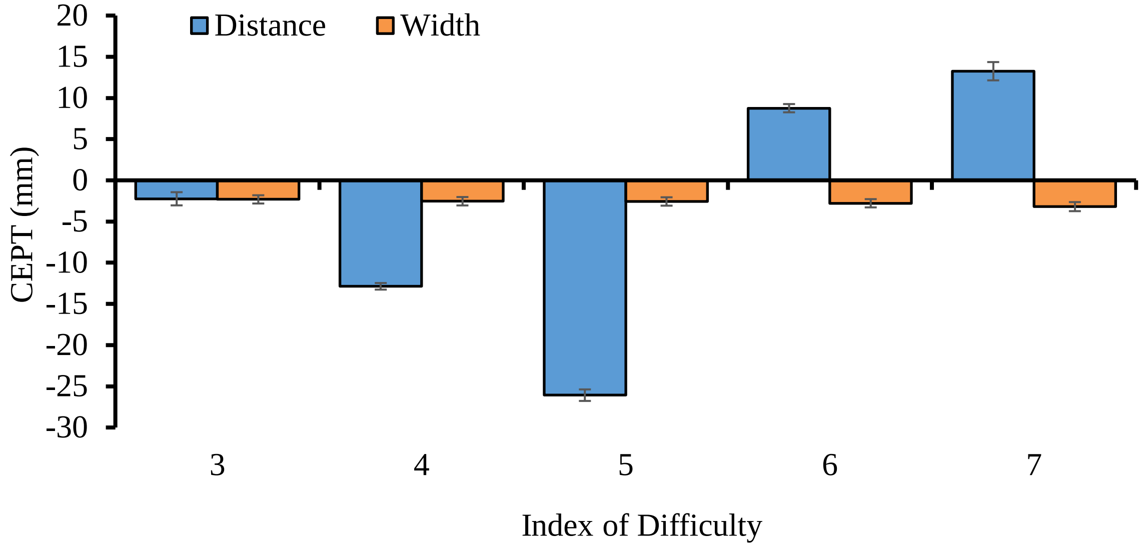


Figure 6. Constant Error at the end of the primary movement phase (CEPT) for Distance and Width Conditions

Movements in the width condition had a greater peak velocity (PV) than in the distance condition. PV was also more consistent across ID in the width condition because of the constant distance. In the distance condition PV scaled with the distance traveled consistent with prior research on motor control and effector constraints. For every increase in ID by 1 the PV approximately doubled with the exception of movements with an ID value of 7. This could have indicated these movements were close to reaching maximum efficiency of the motor system. It took more physical effort to move a longer distance. To minimize movement time participants planned a more forceful motor impulse meaning they moved more quickly to account for the increased distance, but participants could only scale the movement so much before reaching the limits of the human motor system. For an ID value of 6, PV for both the distance and width conditions were similar as expected because both movements shared the same distance and width parameters (Figure 7).

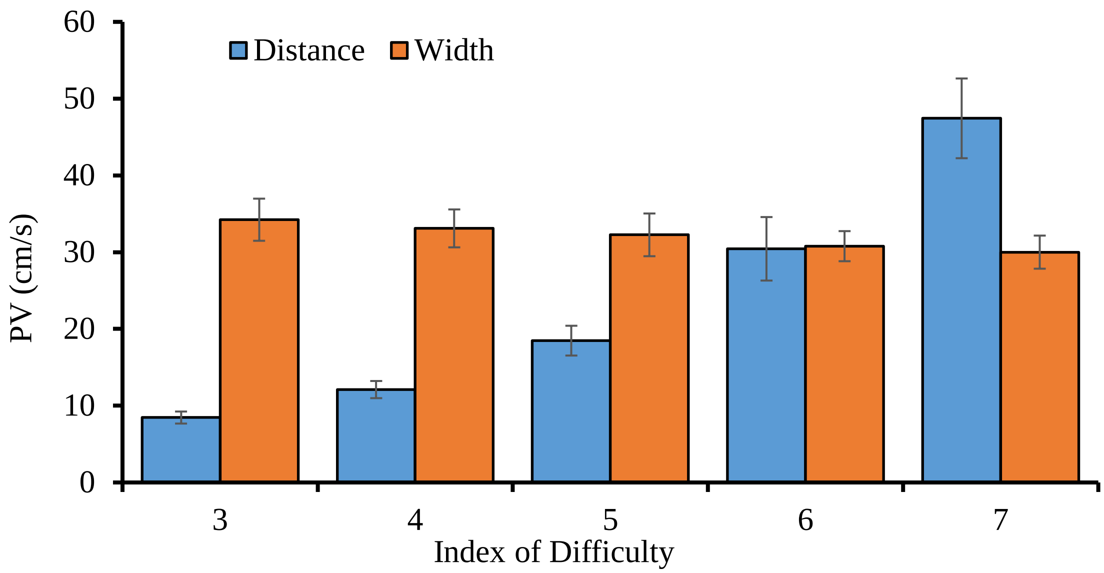


Figure 7. Peak Velocity (PV) for Distance and Width Conditions.

Analyses of Age and Fitness

Next, the effects of Age and Fitness were examined separately for each movement condition. Movement strategy may impact individuals' ability to make speeded and accurate movements and may make it more difficult to test the physical and cognitive constraint hypotheses to control for the effects of personality, an analysis which examined which personality traits varied with age and fitness in the current study so that these variables could be controlled for in future analyses.

Personality

Age, fitness and the age × fitness interaction were used as independent variables in the analysis and a regression was conducted for each of the five factor personality model variables (Conscientiousness, Agreeableness, Neuroticism, Openness, & Extraversion) and the three traits of the Barrett Impulsivity Scale (Motor, Planning, & Attentional Impulsivity). Significant inter-correlations, Age and fitness effects were found for each of the personality variables (Table 5 & Table 6). Because all the personality variables showed significant findings, they all were used in the following regression analyses.

Table 5. Correlations between Personality Variables.

#	Variable	1	2	3	4	5	6	7	8
1	Conscientiousness	—							
2	Agreeableness	.51**	—						
3	Neuroticism	-.40**	-.42**	—					
4	Openness	.20**	.23**	-.16*	—				
5	Extraversion	.26**	.23**	-.28**	.27**	—			
6	Motor Impulsivity	-.45**	-.25**	.33**	-.11	.01	—		
7	Planning Impulsivity	-.56**	-.33**	.22**	-.25**	-.20**	.50**	—	
8	Attentional Impulsivity	-.37**	-.29**	.28**	-.10	.03	.38**	.26**	—

Note: **p*<.05, ***p*<.001.

Table 6. Personality, Age, and Fitness Regression Results.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Conscientiousness												
Overall Model	20.78	<.001	36.15	1.74				6.20	2, 186	.002	.06	.05
Fitness	-1.99	.048	-.24	.18	-.14	-.17	-.14					
Age × Fitness	2.63	.009	.005	.002	.19	.21	.19					
Agreeableness												
Overall Model	21.09	<.001	36.98	1.75				5.19	2, 186	.006	.05	.04
Fitness	-2.17	.03	-.26	.12	-.16	-.18	-.16					
Age × Fitness	2.09	.04	.004	.002	.15	.17	.15					
Neuroticism												
Overall Model	8.58	<.001	42.53	4.96				15.17	3, 185	<.001	.20	.18
Age	-4.40	<.001	-.36	.08	-.38	-.37	-.29					
Fitness	-3.63	<.001	-1.34	.37	-.66	-.12	-.24					
Age × Fitness	2.66	<.001	.02	.007	.56	-.33	.18					
Openness												
Overall Model	33.27	<.001	33.41	1.00				16.07	1, 187	<.001	.08	.07
Age × Fitness	4.01	<.001	.008	.002	.28	.28	.28					
Extraversion												
Overall Model	22.96	<.001	24.41	1.06				5.19	1, 187	.024	.30	.20
Age	2.28	<.001	.05	.02	.16	.16	.16					
Motor Impulsivity												
Overall Model	9.50	<.001	12.90	1.36				10.27	2, 186	<.001	.10	.10
Fitness	2.27	.03	.21	.09	.16	.19	.16					
Age × Fitness	-3.60	<.001	-.006	.002	-.25	-.27	-.25					
Planning Impulsivity												
Overall Model	19.83	<.001	11.47	.58				8.38	1, 187	.004	.04	.04
Age × Fitness	-2.90	.004	-.003	.001	-.21	-.21	-.21					
Attentional impulsivity												
Overall Model	32.26	<.001	14.67	.46				17.52	1, 187	<.001		.09
Age	-4.19	<.001	-.04	.009	-.29	-.29	-.29					

To test the effects age and physical fitness on goal-directed movement performance a separate backwards hierarchical multiple regression analysis was conducted on each of the three movement conditions (speeded, distance and width). To control for potential strategic differences due to differences in personality we conducted each analysis in two separate steps. Each kinematic variable was tested in a separate multiple regression model. In the first step we entered both the Five Factor Model personality and Barrett Impulsivity traits as control variables. In the second step, we entered the independent variables of interest: ID, age, fitness, and their associated interaction terms so that the second analysis would account for differences in personality that might vary due to age or fitness.

Speeded Only Condition

As a function of distance, significant main effects were found on eight dependent variables: MT, CEPT, CEMT, PV, tPV, tPA, and PA. Significant main effects for age were found on seven dependent variables: MT, PropST, VEPT, PV, tPV, PA, and PD. Significant age × distance interactions were found for MT, PropST, CEPT, and VEPT. Significant main effects for fitness were found on two dependent variables: VEPT and PA. Significant age × fitness interactions were found for VEPT and PA. No three-way interactions between distance, age, and fitness were found in the speeded only condition. Table 7 contains the results from the regression analyses. In terms of the unique variance accounted for by an individual variable (sr^2), age and distance had the largest impact on MT. Age and distance also accounted for a significant proportion of unique variance for PropST, CEPT, CEMT, PV, tPV, tPA, and PD. The effects for fitness were limited and small in this condition, but affected kinematic components scaled to the primary phase of the movement. This was likely due to the low amount of time spent in the secondary phase.

Table 7. Speeded Condition Regression Results.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	6.37	<.001	.16	.025				111.74	6, 938	<.001	.42	.41
Agreeableness	2.71	.007	.001	.001	.08	.14	.07					
Conscientiousness	-3.49	.001	-.002	.001	-.11	.08	-.09					
Motor Impulsivity	-4.50	<.001	-.003	.001	-.13	-.22	-.11					
Age	8.23	<.001	.001	.001	.32	.42	.21					
Distance	6.13	<.001	.003	.001	.35	.47	.15					
Distance × Age	2.43	.015	.001	.001	.15	.59	.06					
Proportion ST (PropST)												
Overall Model	5.61	<.001	.018	.003				84.71	2, 942	<.001	.15	.15
Age	8.83	<.001	.001	.001	.30	.37	.27					
Distance × Age	4.60	<.001	.001	.001	.15	.29	.14					
Constant Error (CE) PT												
Overall Model	-19.11	<.001	-10.63	.56				521.23	2, 942	<.001	.53	.52
Distance	22.11	<.001	1.25	.06	.83	.72	.50					
Distance × Age	-3.71	<.001	-.004	.001	-.14	.53	-.08					
Constant Error (CE) MT												
Overall Model	-9.87	<.001	-9.05	.92				521.23	2, 942	<.001	.53	.52
Age	-2.26	.02	-.04	.02	-.05	-.05	-.05					
Distance	36.10	<.001	1.20	.03	.76	.76	.76					
Variable Error (VE) PT												
Overall Model	18.19	<.001	.61	.03				129.82	4, 640	<.001	.36	.36

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Age	-5.30	<.001	-.002	.001	-.22	-.01	-.14					
Fitness	-3.44	.001	-.007	.002	-.13	-.02	-.09					
Distance × Age	8.70	<.001	.001	.001	.40	.51	.23					
Distance × Fitness	6.59	<.001	.001	.001	.26	.52	.17					
Peak Velocity (PV)												
Overall Model	48.09	<.001	1.76	.04				135.32	4,940	<.001	.37	.36
Motor Impulsivity	3.95	<.001	.008	.002	.12	.20	.10					
Planning Impulsivity	-2.14	.03	-.006	.003	-.06	.08	-.06					
Age	-13.55	<.001	-.004	.001	-.37	-.39	-.35					
Distance	17.22	<.001	.012	.001	.45	.45	.45					
Time to Peak Velocity (tPV)												
Overall Model	3.79	<.001	.06	.015				74.07	6, 938	<.001	.32	.32
Extraversion	-.24	.016	-.001	.001	-.07	-.02	-.07					
Agreeableness	2.25	.03	.001	.001	.07	.11	.06					
Motor Impulsivity	-2.64	.009	-.001	.001	-.08	-.16	-.07					
Attention Impulsivity	2.17	.03	.001	.001	.07	-.07	-.06					
Age	9.26	<.001	.001	.001	.27	.28	.25					
Distance	17.73	<.001	.002	.001	.48	.48	.48					
Time to Peak Acceleration (tPA)												
Overall Model	1.51	.13	.02	.01				53.97	3, 944	<.001	.15	.14
Agreeableness	2.74	.006	.001	.001	.09	.13	.08					
Age	7.19	<.001	.001	.001	.22	.24	.22					
Distance	9.51	<.001	.001	.001	.29	.29	.29					

Peak Acceleration (PA)												
Overall Model	38.58	<.001	2.40	.062				57.35	6, 938	<.001	.27	.26
Neuroticism	-1.61	.11	-.002	.002	-.05	.13	-.05					
Motor Impulsivity	5.11	<.001	.013	.003	.17	.26	.14					
Planning Impulsivity	-2.48	.013	-.009	.004	-.08	.11	-.07					
Fitness	10.21	<.001	.30	.003	.30	.35	.29					
Age × Fitness	-10.67	<.001	-.001	.001	-.32	-.37	-.30					
Distance	4.57	<.001	.004	.001	.13	.13	.13					
Peak Deceleration (PD)												
Overall Model	23.39	<.001	2.71	0.12				86.79	4, 940	<.001	.27	.27
Conscientiousness	2.6	0.01	0.006	0.002	0.08	-0.09	0.07					
Motor Impulsivity	3.78	<.001	0.012	0.003	0.12	0.23	0.11					
Age	-16.06	<.001	-0.009	0.001	-0.47	-0.49	-0.45					
Distance	4.72	<.001	0.005	0.001	0.13	0.13	0.13					

Note: Only the final model for each variable is shown.

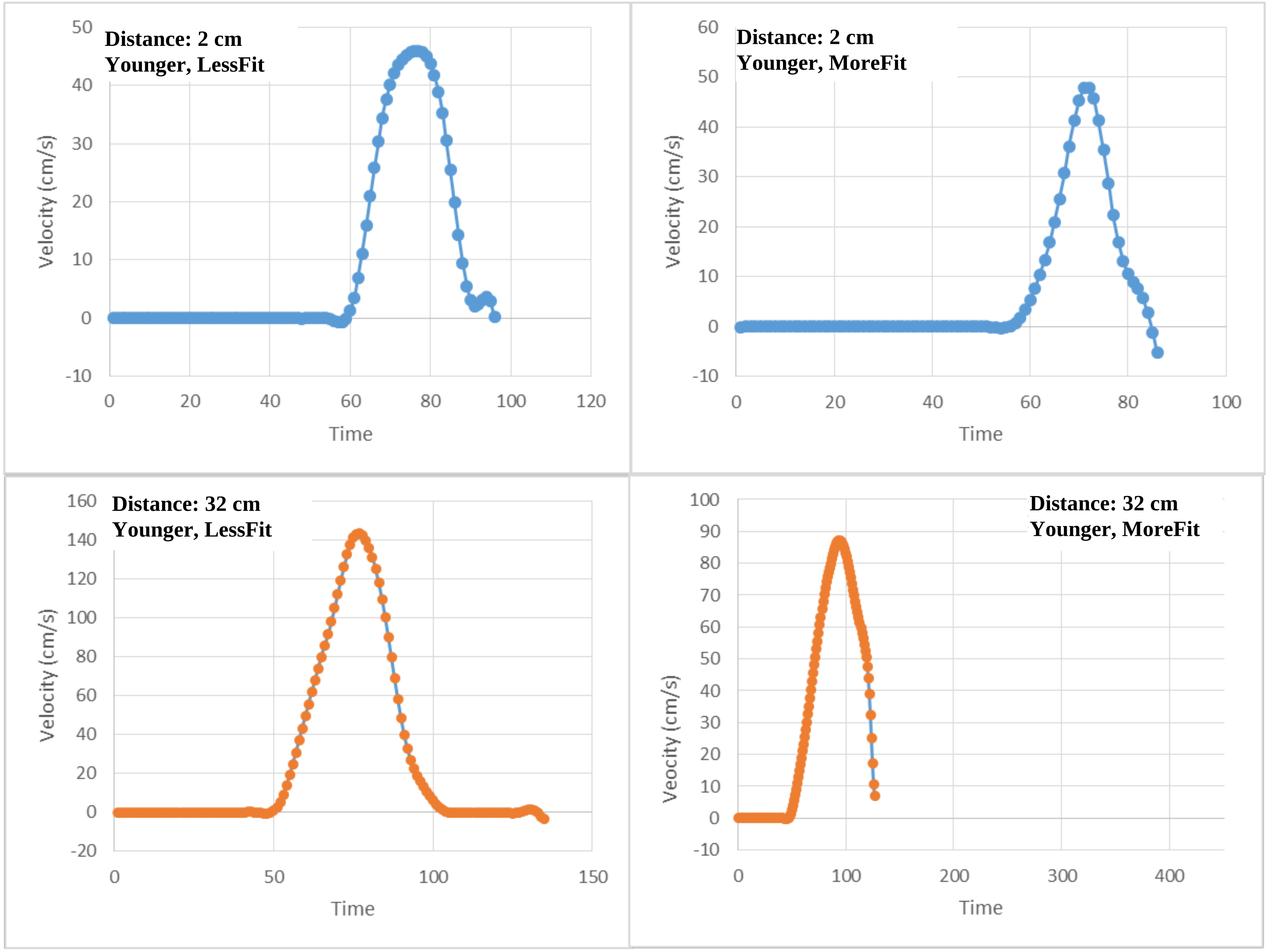


Figure 8. Speeded Condition Example Velocity Profiles for Younger LessFit and MoreFit Participants

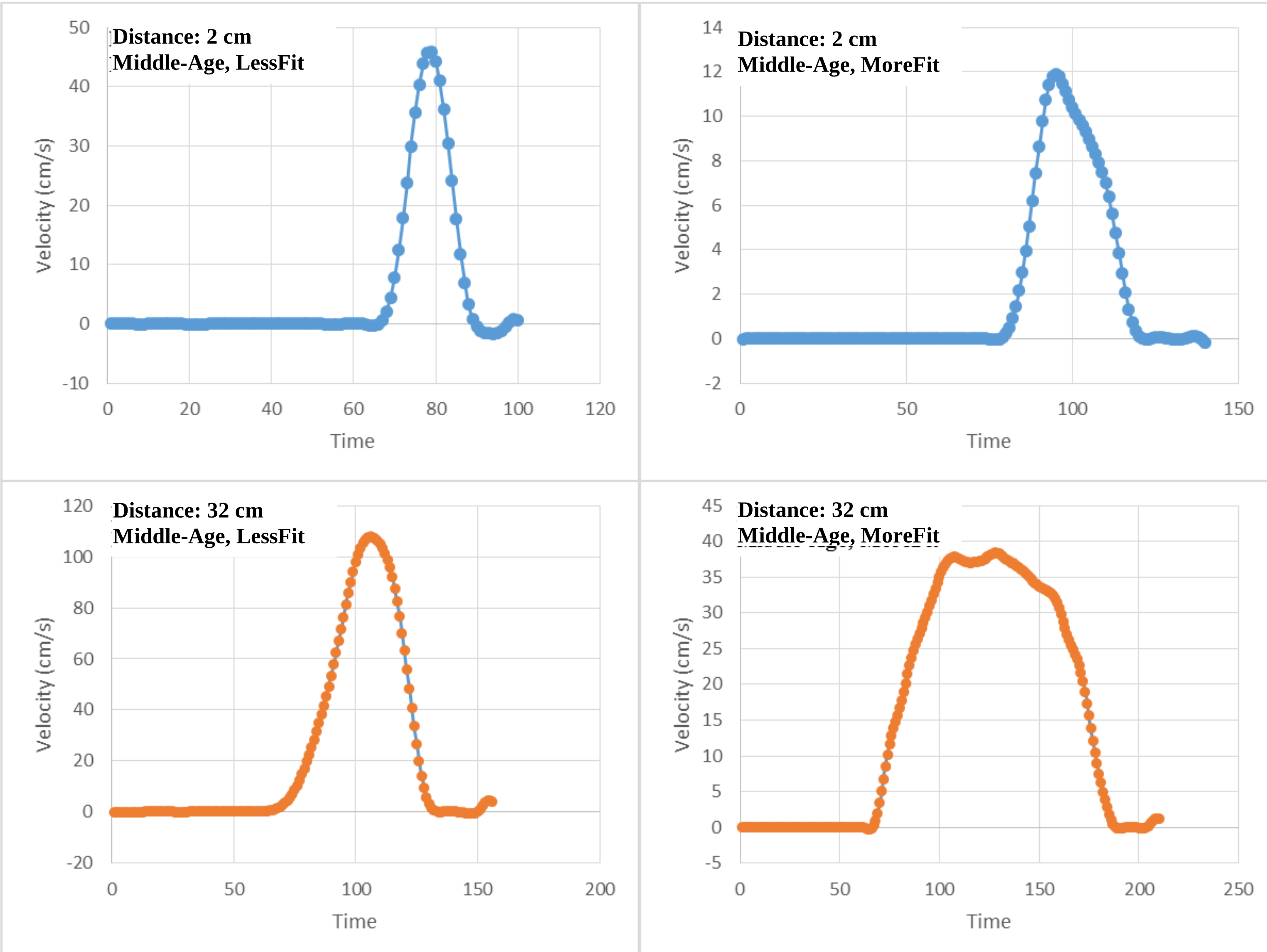


Figure 9. Speeded Condition Example Velocity Profiles for Middle-Age LessFit and MoreFit Participants.

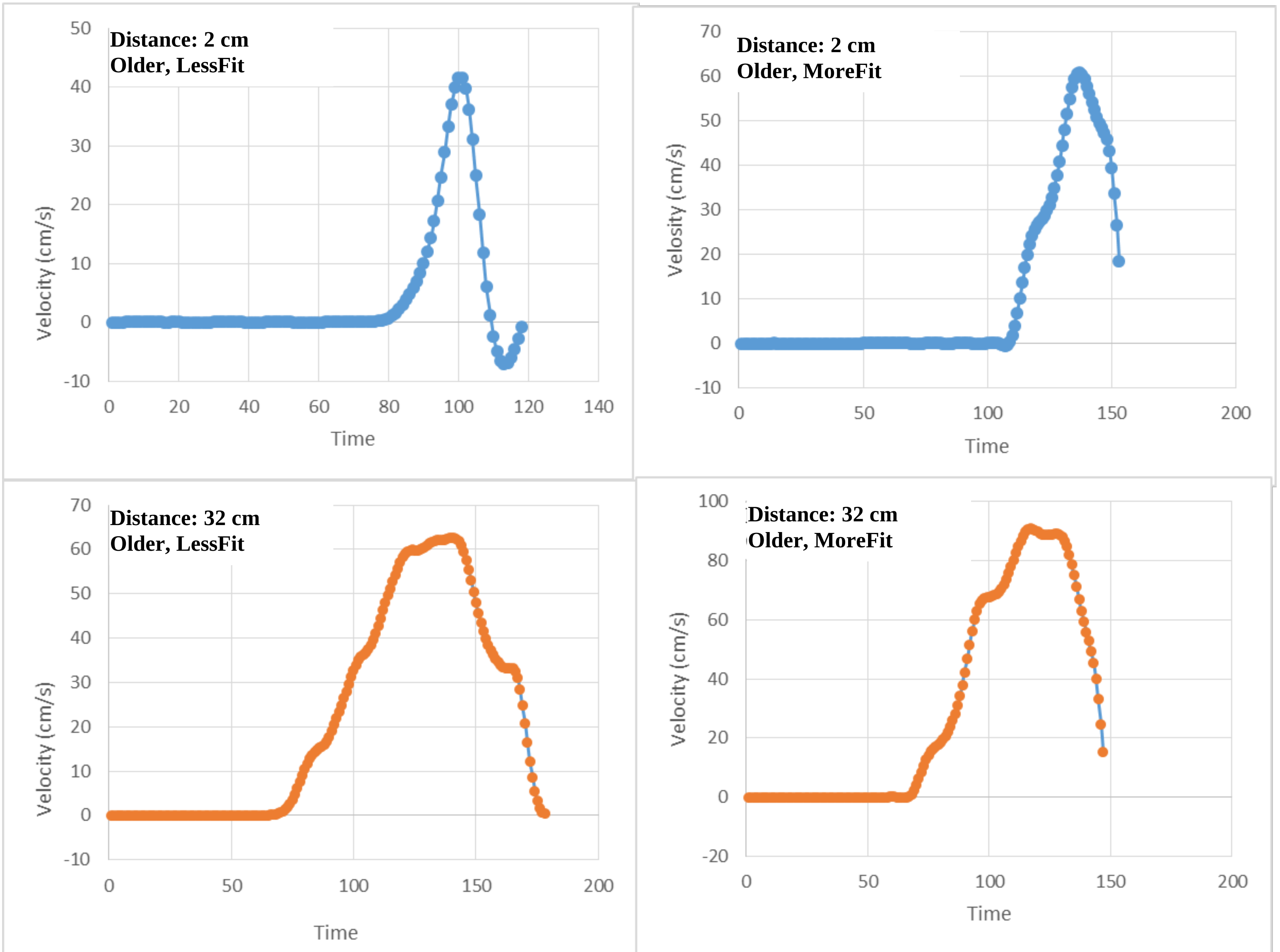


Figure 10. Speeded Condition Example Velocity Profiles for Older LessFit and MoreFit Participants.

The motor impulsivity scale was the personality variable with the largest effect across kinematic variables. Significant effects were found on MT in which greater impulsivity led to slower movement times. Small effects for motor impulsivity were found on velocity and acceleration so that greater impulsivity led to slightly increased peak acceleration and decreased time was needed to achieve peak velocity. In other words, greater motor impulsivity led to the generation of faster motor impulses, which may allowed more impulsive individuals to make speeded movements more quickly.

Example velocity profiles for a single movement for each fitness group (split by median split) are shown for younger adults in Figure 8, middle-age adults in Figure 9, and older adults in Figure 10 for both a 2cm distance (ID = 3) and a 32cm distance (ID = 7). ID of the corresponding distance condition is listed for ease of comparison with the distance condition. Older adults had significantly longer movement times than younger participants across all distances. However, older adults only showed significantly longer movement times than middle-age participants in at the 32 cm distance. Movement time increased with movement distance driven primarily by extending the primary movement phase. Younger adults were mostly able to finish each movement regardless of difficulty without a secondary phase as shown by their low PropST value. The longest distance, however, showed an increased secondary phase duration (Figure 11). This increase in PropST was due to older adults having more difficulty at the 32cm distance (Figure 12). Loss of symmetry can be seen in the example velocity profiles. The less fit older adults were more likely to show more jagged movement profiles due to late stage inflections in the velocity profile due to increased motor error. These inflections were unnecessary to complete the movement and may indicate biomechanical inefficiencies.

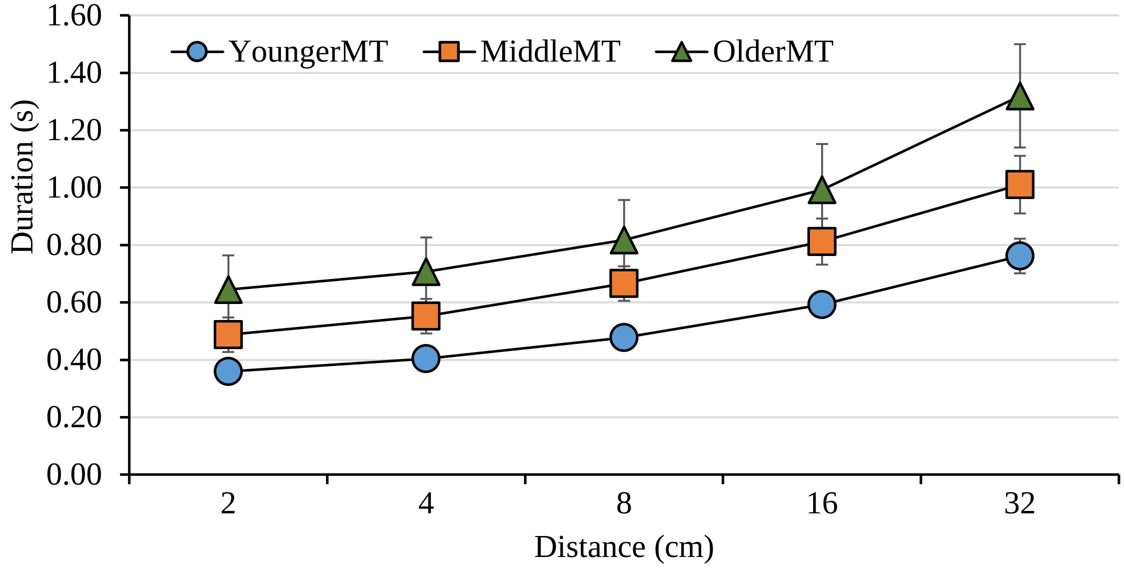


Figure 11. Speeded Condition MT for Each Age-Group and Distance.

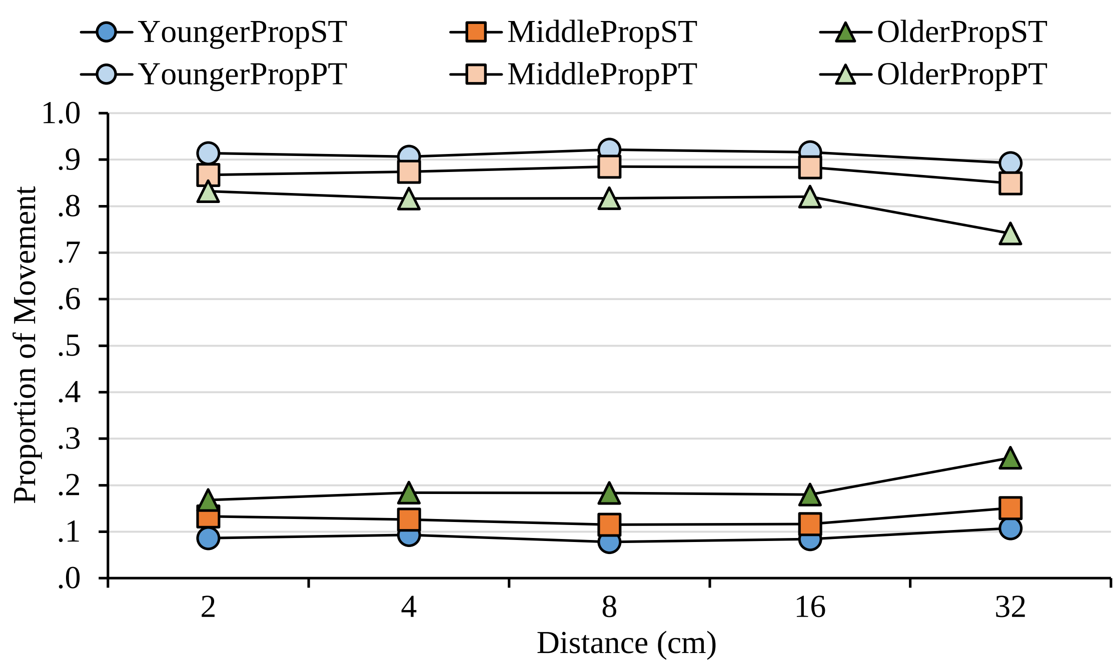


Figure 12. Speeded Condition Proportion of the primary (PropPT) and secondary (PropST) phases for Each Age-Group.

Movement end-point variability at the end of the primary phase increased as distance increased. Younger adults were more variable at shorter distances than middle-age or older adults. Older adults had greater variable error than younger adults at the longest distance (Figure 13).

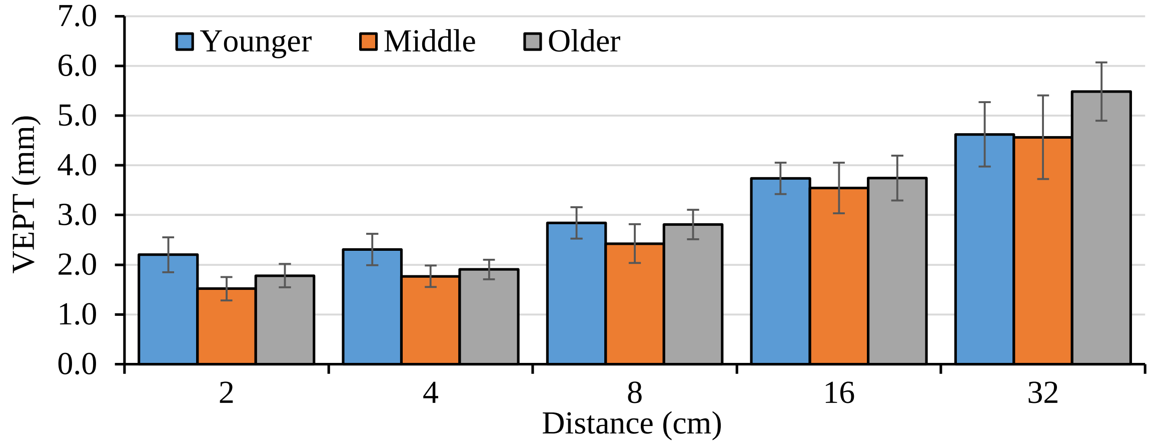


Figure 13. Speeded Condition Variable Error at the end of the primary phase (VEPT) for Each Age-Group and Distance.

An analysis of the Constant error at the end of the primary movement phase (CEPT) showed that for the easiest three distances: 2 cm, 4 cm, and 8 cm, participants were more likely to end the primary phase early and undershoot the target line. While for the longest distances: 16 cm and 32 cm participants were more likely to overshoot the target line. At the 2 cm distance, younger adults were more likely to undershoot the target than middle-age or older adults. However, across all ages CEPT was smallest for this condition indicating that everyone was successful at ending their primary phase close to the target (Figure 14). Because of the low PropST for younger and middle-age adults it may be the case that CEPT and CEMT are the same for movements where a secondary phase does not exist.

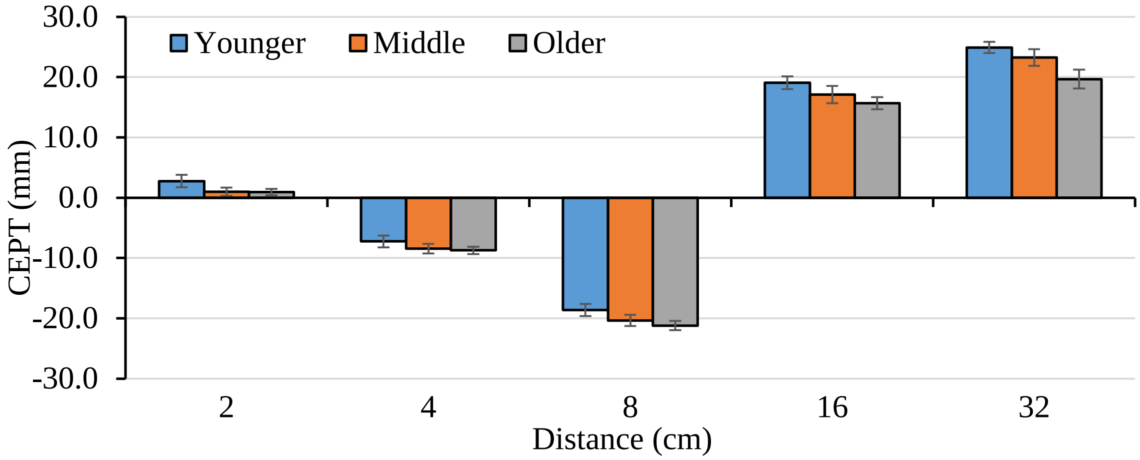


Figure 14. Speeded Condition Constant Error at the end of the primary phase (CEPT) for Each Age-Group and Distance.

There were two fitness by age interactions in the speeded condition. First, as people aged their peak acceleration (PA) decreased which indicated a decrease in motor output associated with age-related declines in physical health. However, greater cardiovascular fitness was able to attenuate these declines somewhat. More fit individuals showed greater PA than less fit individuals across the lifespan. While these differences were small for younger and middle-age adults, they significantly impacted older adult's performance. More fit older adults displayed significantly greater PA than less fit older adults or less fit middle-age adults and almost scoring as well as less fit younger adults (Figure 15). This increase in force was also associated with decreased time to peak acceleration (tPA). For tPA fitness did not have an impact on younger adults, but as more fit middle-age and older adults were able to achieve their greater acceleration faster than less fit individuals. Both of these provide evidence that greater fitness was associated with better motor performance (Figure 16).

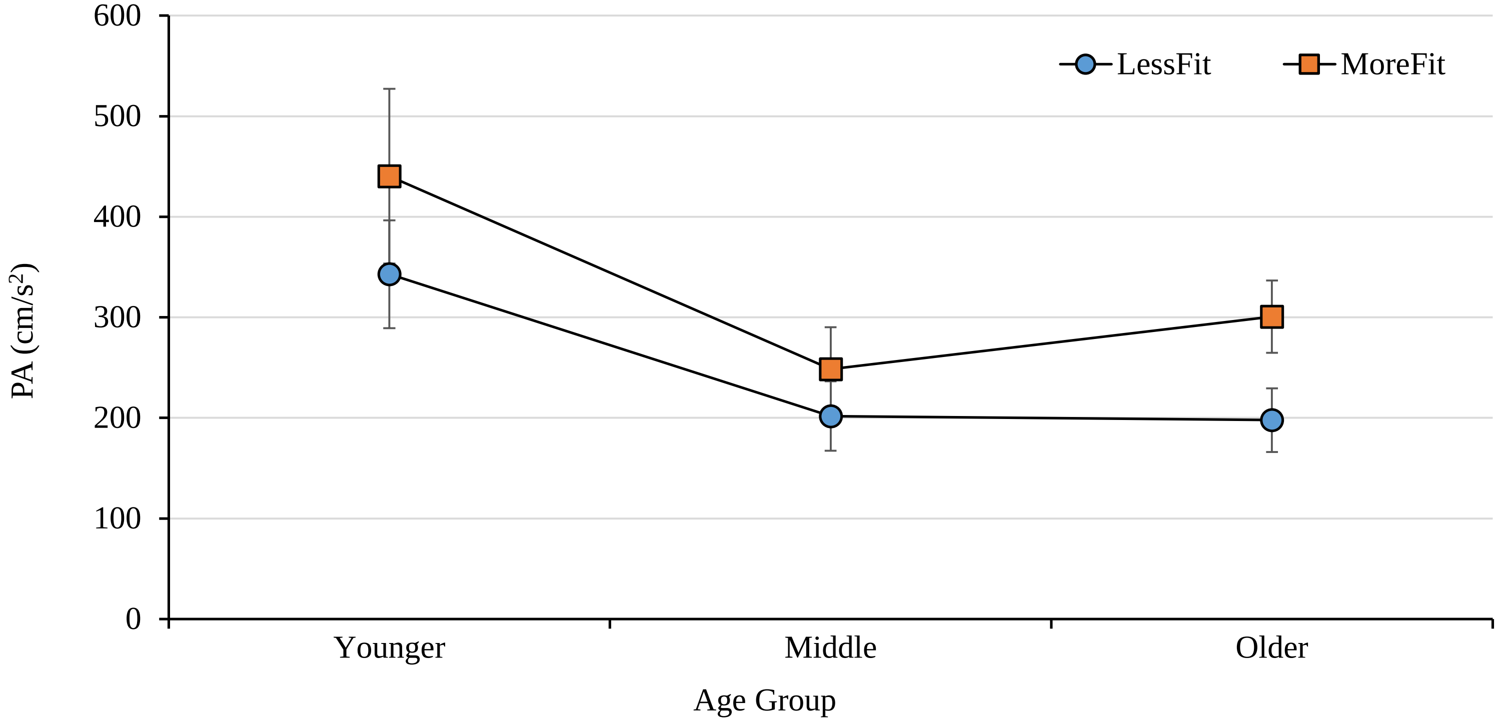


Figure 15. Speeded Condition Peak Acceleration (PA) For Each Age-Group Split by Median Fitness Score.

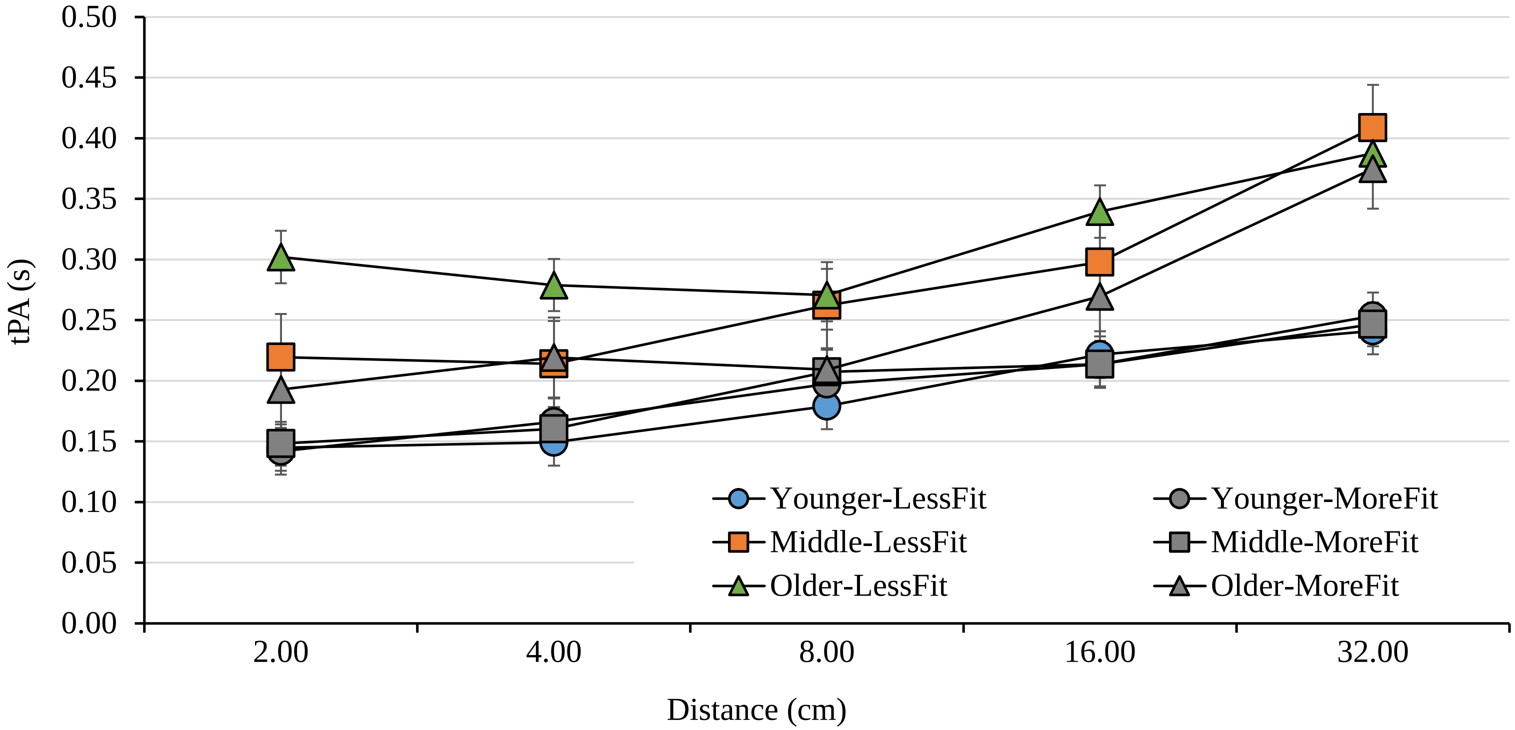


Figure 16. Speeded Condition Time to Peak Acceleration (tPA) Across Distance Condition Separated by Median Fitness Score and Age.

The second fitness effect found was a distance × fitness interaction for VEPT. Overall greater fitness reduced VEPT. Individuals above the median for fitness in their age group had an average VEPT of 2.43 (95% CI [2.10, 3.76]) and individuals scoring below the median for fitness had an average VEPT of 3.14 (95% CI [2.80, 3.48]). However, these differences were not large enough to be meaningfully interpreted as indicated by their overlapping confidence intervals.

Distance Condition

For ID, significant main effects were found on ten dependent variables: MT, PropST, CEPT, CEMT, VEPT, VEMT, PV, tPV, PA, and PD. Interaction effects between ID and age and ID and fitness were found for VEPT. Significant main effects for age were found for MT, tPV, and tPA. Significant fitness main effects were found for PropST, VEPT, PV, PA, and PD. Significant age × fitness interactions were found for PropST, VEPT, PV, PA, and PD. Finally, significant age × fitness × ID interactions were found for MT, PropST, and VEPT. Table 8 contains the regression results for each dependent variable.

Broader effects of personality were found in the distance condition. Several of the big five indicators: extraversion, agreeableness, and openness showed small but significant relationships on MT, PropST, tPV, tPA, and PD. The largest finding was the impact of extraversion and agreeableness had on tPV and tPA. While increased agreeableness increased tPV and tPA extraversion was associated with decreased tPV and tPA.

Similarly to the speeded condition motor impulsivity showed decreased time spent in the secondary phase. Motor impulsivity also led to increased tPA but not tPV. Unlike the speeded condition and potentially due to the accuracy requirements of the task greater effects were found for attentional and planning types of impulsivity. Specifically, greater attentional impulsivity led to greater MT, VEPT, decreased PV, increased tPV, tPA, and decreased peak acceleration. Greater planning impulsivity also increased MT, time spent in the secondary phase, and decreased time to peak acceleration. These results indicated that for distance constraints motor and attentional impulsivity led to issues in scaling the initial force impulse of the movement. Planning impulsivity led to greater difficulties with feedback processing evident by increased PropST.

Both time to peak velocity and acceleration increased with age. Middle-age adults were found to be the most variable, while younger adults showed significantly lower peak acceleration and deceleration values when compared to older adults (Figure 17).

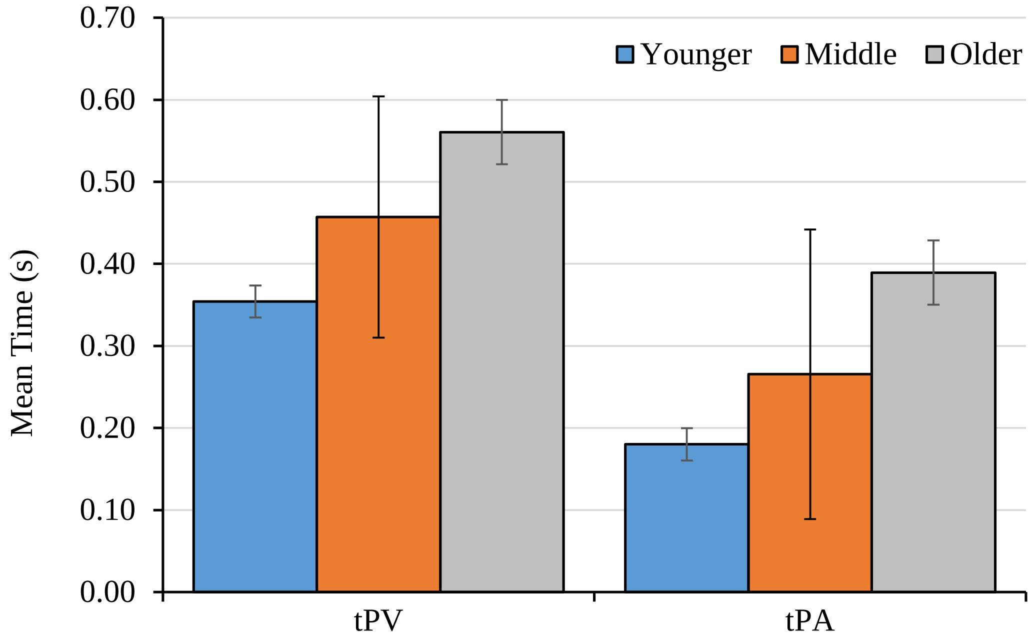


Figure 17. Distance Condition Mean Time to Peak Velocity (tPV) and time to Peak Acceleration (tPA) for Each Age-Group.

Table 8. Distance Condition Regression Results.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	.98	.33	.04	.04				147.80	7, 937	<.001	.49	.48
Agreeableness	2.56	.01	.002	.001	.07	.12	.06					
Openness	-2.34	.02	-.001	.001	-.06	-.08	-.06					
Planning Impulsivity	2.71	.007	.003	.001	.07	.03	.06					
Attention Impulsivity	2.81	.005	.003	.001	.07	.07	.07					
Age	19.98	<.001	.003	.001	.51	.47	.43					
ID	21.27	<.001	.045	.002	.50	.50	.45					
Age × Fitness × ID	-1.97	.049	.001	.001	-.42	-.37	-.13					
Proportion ST (PropST)												
Overall Model	6.37	<.001	.13	.021				23.50	9, 935	<.001	.18	.18
Extraversion	4.40	<.001	.001	.001	.14	07	.13					
Agreeableness	-2.2	.031	-.001	.001	-.07	-.06	-.06					
Openness	-2.3	.025	-.001	.001	-.07	-.05	-.07					
Motor Impulsivity	-2.8	.005	-.001	.001	-.10	-.009	-.08					
Planning Impulsivity	5.46	<.001	.003	.001	.2	.13	.16					
Fitness	-4.62	<.001	-.002	.001	-.14	-.12	-.14					
Age × Fitness	2.45	.014	.001	.001	.27	.06	-.07					
ID	6.30	<.001	.02	.002	.48	.34	.19					
Age × Fitness × ID	-1.96	.049	.001	.001	-.25	.22	-.06					
Constant Error (CE) PT												

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Overall Model	-20.19	<.001	-30.13	1.50				335.16	1, 943	<.001	.26	.26
ID	18.31	<.001	5.26	.29	.52	.52	.52					
Constant Error (CE) MT												
Overall Model	-24.31	<.001	-38.77	1.60				640.29	1,943	<.001	.40	.40
ID	25.30	<.001	7.77	.31	.64	.64	.64					
Variable Error (VE) PT												
Overall Model	-6.87	<.001	-0.37	.053				764.24	8, 936	<.001	.87	.87
Planning Impulsivity	2.60	.01	0.003	.001	.03	.03	.03					
Attention Impulsivity	2.16	.031	0.002	.001	.03	.02	.03					
Fitness	-2.42	.016	-0.008	.003	-.11	-.03	-.03					
Age × Fitness	2.03	.043	0.001	.001	.09	.04	.02					
ID	12.64	<.001	0.15	.012	.80	.93	.15					
ID × Age	2.84	.005	0.001	.001	.17	.49	.03					
ID × Fitness	2.99	.003	0.002	.001	.22	.61	.04					
Age × Fitness × ID	-2.61	.009	0.001	.001	-.18	.53	-.03					
Peak Velocity (PV)												
Overall Model	5.50	<.001	.30	.06				464.22	5, 938	<.001	.71	.71
Openness	2.89	.004	.003	.001	.05	-.01	.05					
Attention Impulsivity	-3.44	.001	-.007	.002	-.06	-.004	-.06					
Fitness	9.33	<.001	.015	.002	.17	.17	.16					
Age × Fitness	-8.00	<.001	.001	.001	-.15	-.14	-.14					
ID	46.48	<.001	.18	.004	.81	.81	.81					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Time to Peak Velocity (tPV)												
Overall Model	-.86	.40	-.02	.03				60.79	8, 936	<.001	.34	.34
Extraversion	-4.47	<.001	-.001	.001	-.13	-.01	-.12					
Agreeableness	4.61	<.001	.002	.001	.15	.15	.12					
Conscientiousness	-1.97	.049	-.001	.001	-.07	.06	-.05					
Planning Impulsivity	-2.78	.006	-.002	.001	-.09	-.13	-.07					
Attention Impulsivity	5.97	<.001	.004	.001	.18	.007	.16					
Age	9.23	<.001	.001	.001	.38	.40	.25					
ID	8.65	<.001	.016	.002	.32	.37	.23					
Time to Peak Acceleration (tPA)												
Overall Model	-1.10	.27	-.03	.026				37.06	6, 938	<.001	.19	.19
Extraversion	-4.79	<.001	-.002	.001	-15	-.01	-.14					
Agreeableness	3.65	<.001	.002	.001	.12	.15	.11					
Motor Impulsivity	3.31	<.001	.002	.001	.12	-.07	.10					
Planning Impulsivity	-4.13	<.001	-.004	.001	-.15	-.15	-.12					
Attention Impulsivity	4.53	<.001	.004	.001	.15	-.002	.13					
Age	13.07	<.001	.001	.001	.42	.37	.38					
Peak Acceleration (PA)												
Overall Model	17.08	<.001	1.45	.09				91.86	5, 939	<.001	.3	.33
Openness	3.67	<.001	.006	.002	.01	.004	.10					
Attention Impulsivity	-3.40	<.001	-.01	.003	-.09	-.003	-.09					
Fitness	8.54	<.001	.02	.003	.02	.24	.23					
Age × Fitness	-8.70	<.001	.001	.001	-.25	-.23	-.23					

ID	17.40	<.001	.10	.006	.47	.47	.47					
Peak Deceleration (PD)												
Overall Model	10.24	<.001	1.08	.11				39.78	6, 938	<.001	.20	.19
Extraversion	-1.90	.06	-.003	.002	-.06	-.04	-.06					
Agreeableness	3.09	.002	.006	.002	.10	.04	.09					
Openness	3.47	.001	.007	.002	.11	.03	.10					
Fitness	7.33	<.001	.02	.003	.22	.21	.21					
Age × Fitness	-5.43	<.001	.001	.001	-.17	-.16	-.16					
ID	11.93	<.001	.08	.007	.35	.35	.35					

Note: Only the final model for each variable is shown.

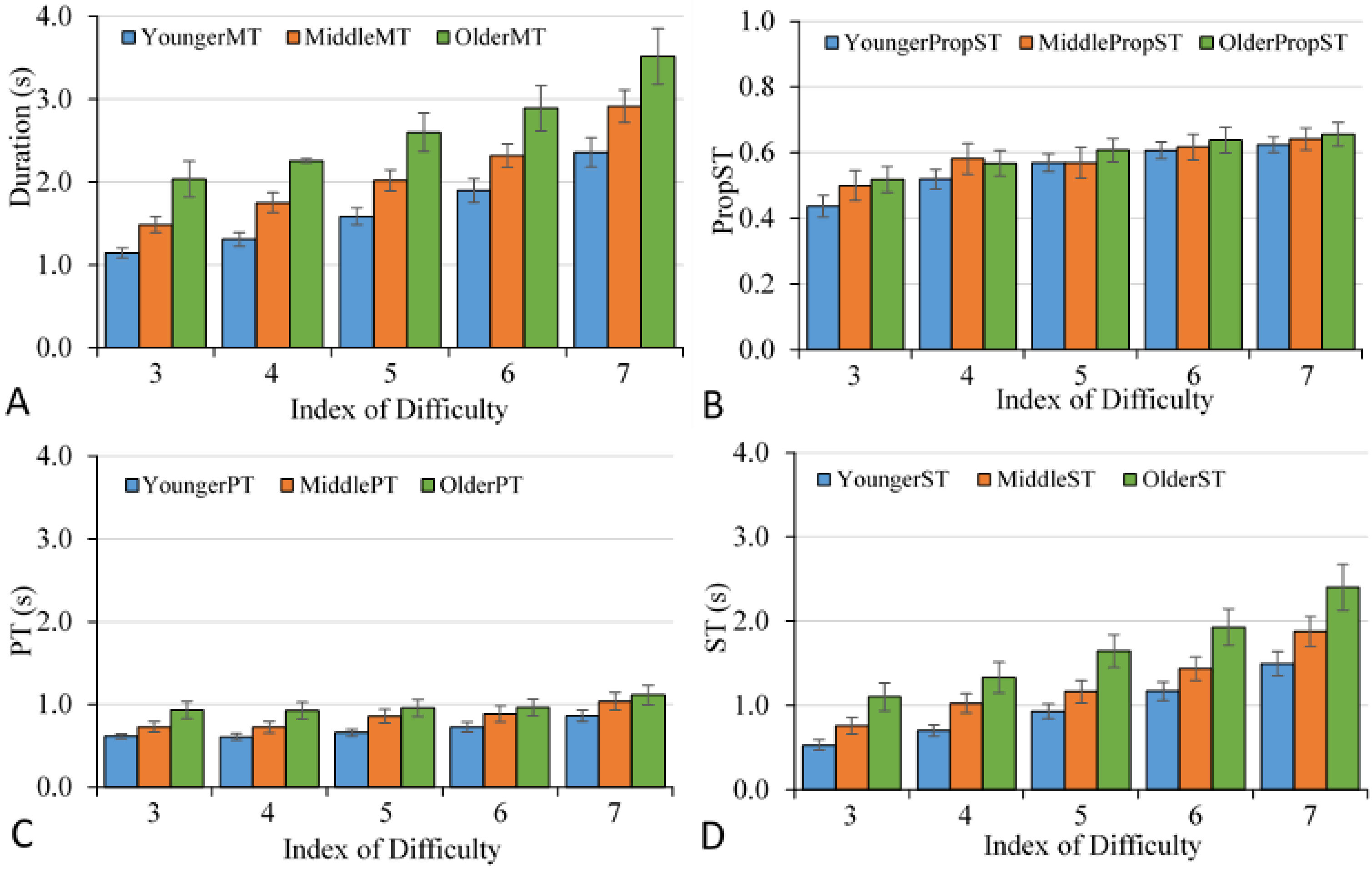


Figure 18. Distance Condition Movement time, PT, ST, and PropST.

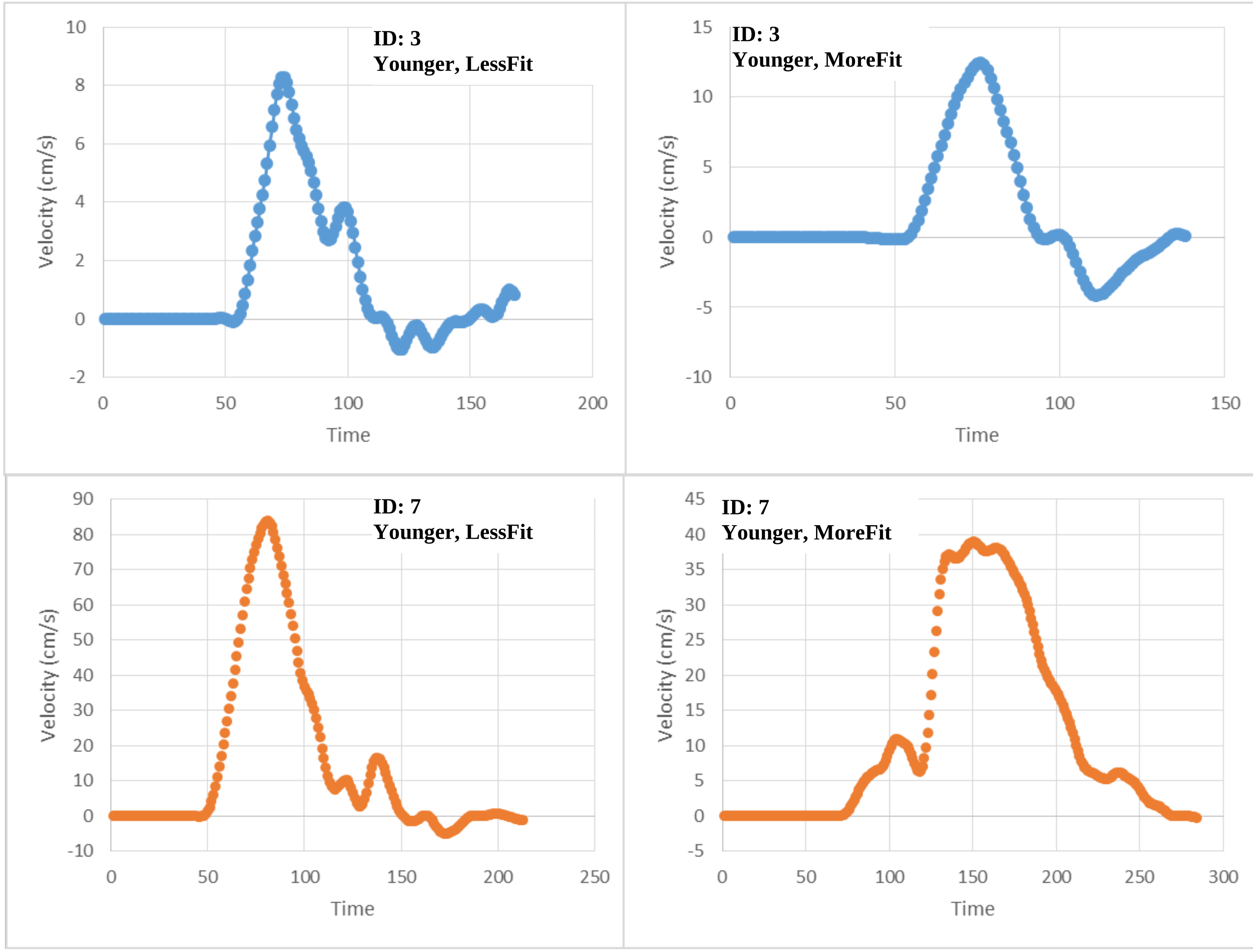


Figure 19. Distance Condition Example Velocity Profiles for Younger LessFit and MoreFit Participants.

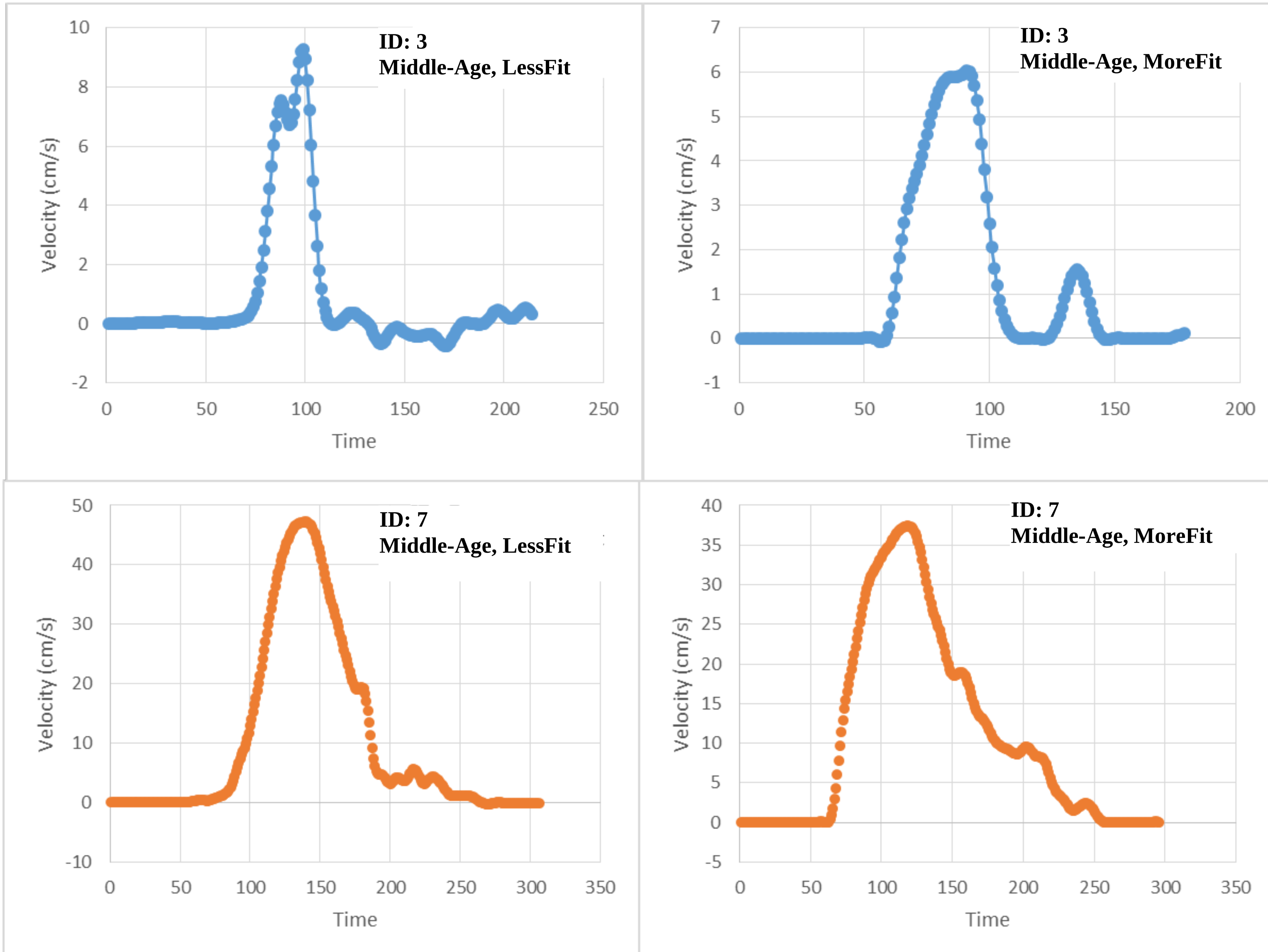


Figure 20. Distance Condition Example Velocity Profiles for Middle-Age LessFit and MoreFit Participants.

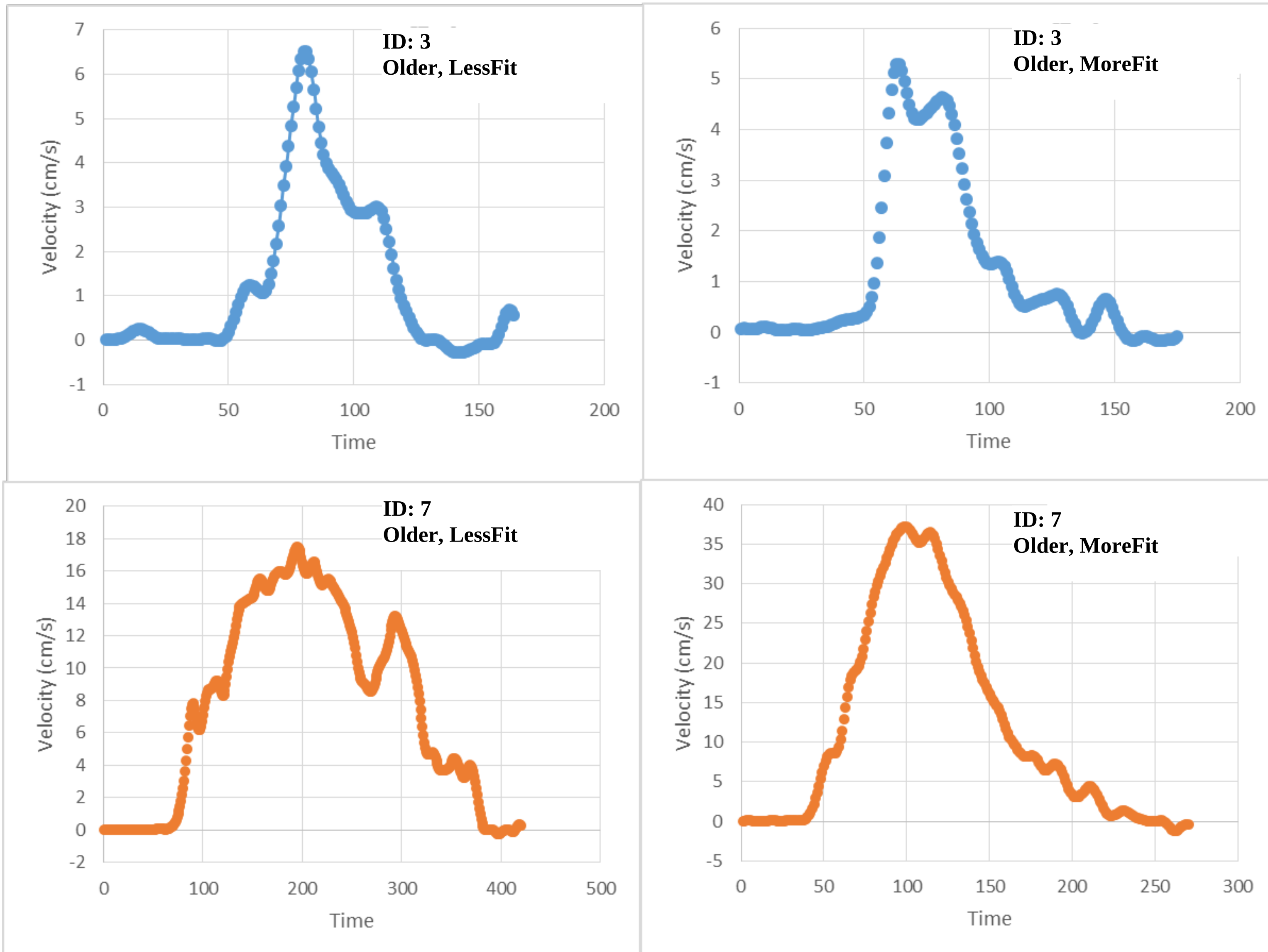


Figure 21. Distance Condition Example Velocity Profiles for Older LessFit and MoreFit Participants.

Increased age increased movement times across all ID values as shown in Figure 18a. Although this increase in MT is evident in both the primary (PT; Figure 18d) and secondary (ST; Figure 18d) phase, the groups were relatively similar in the proportion of ST (PropST; Figure 18b) indicating although group differences exist with age these differences are similar across age-groups. For example, in the distance condition the average movement time for an ID of 7 was 2.90 seconds while a movement with the same ID value in the width condition had an average MT of 1.74 leading to a large difference in MT.

Example velocity profiles for a single movement for each fitness group (split by median split) are shown for younger adults in Figure 19, middle-age adults in Figure 20, and older adults in Figure 21. Peak velocity, peak acceleration, and peak deceleration all showed a significant age × fitness interaction. For all three variables, no significant differences were found between younger and middle-age adults regardless of their fitness level. However, more fit older adults had greater peak velocity, acceleration or deceleration than less fit older adults (Figure 22, Figure 23, & Figure 24).

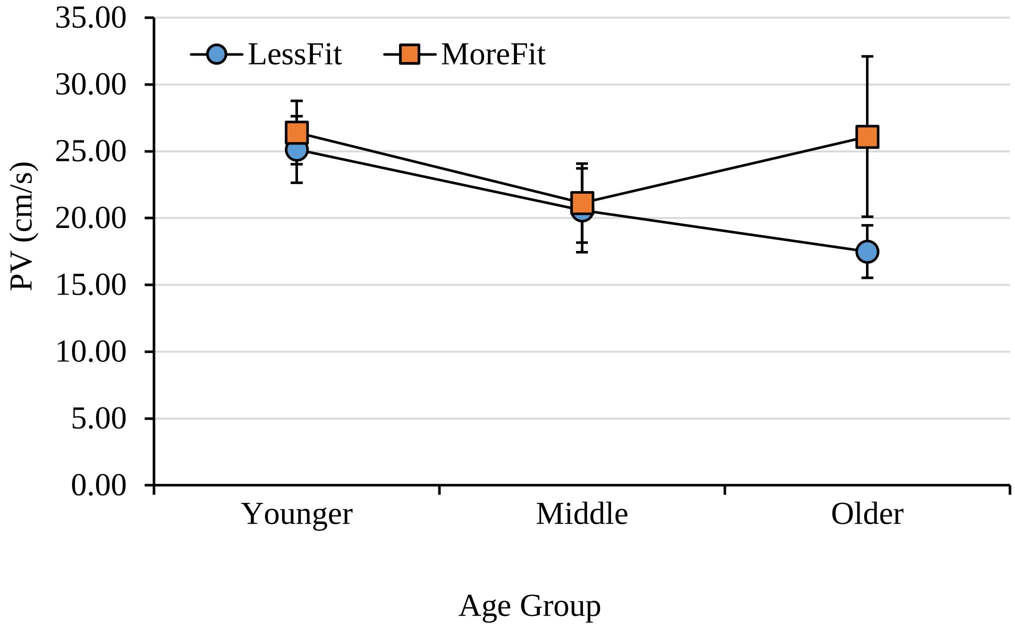


Figure 22. Distance Condition Time to Peak Velocity (PV) for each Age-Group Split by Median Cardiovascular Fitness Score.

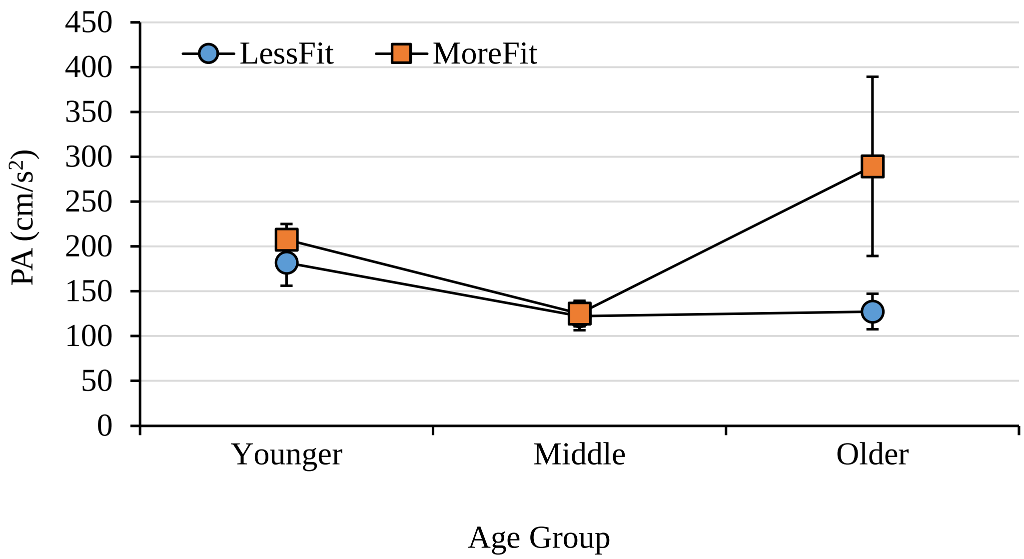


Figure 23. Distance Condition Time to Peak Acceleration (PA) for each Age-Group Split by Median Cardiovascular Fitness Score.

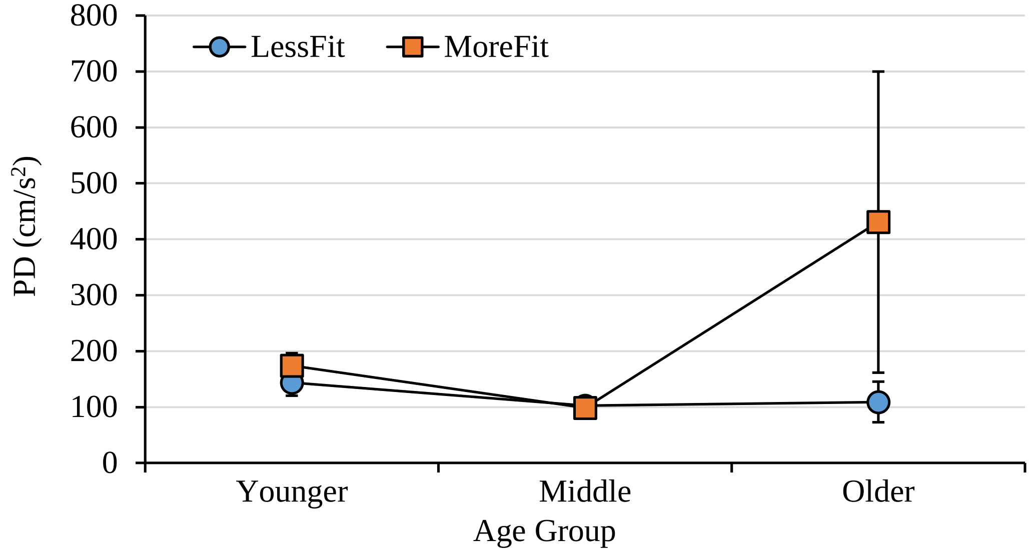


Figure 24. Distance Condition Peak Deceleration (PD) for each Age-Group Split by Cardiovascular Median Fitness Score.

Finally, significant age × fitness × ID interactions were found for MT. Movement time increased with the index of difficulty and younger adults completed movements across all levels of ID faster than middle-age or older adults. Additionally, while fitness did not affect movement time for younger or middle-age adults fitness was found to lead to significant differences in MT for older adults. Older adults in the LessFit group moved on average 0.31 seconds slower than older adults who were in the MoreFit group for movements with an ID of 3 and 0.41 seconds slower for movements at an ID of 7. As ID increased individuals across all ages spent more time in the secondary phase evidenced by increasing PropST. Middle-age and older adults who were less fit had a greater proportion of time spent in the primary phase for movements at an ID of 3 and 4 than younger adults or older adults who were more fit (Figure 25). Younger and middle-age groups across fitness score groups showed more overlap than the older adult participants which an inflection at the most difficult ID value. This led to a mean difference between older less fit and more fit groups of 0.41 seconds for an ID of 7 and a 0.40 difference for an ID of 6. A small age × fitness × ID interaction was also found for PropST. This effect was found because younger adults had lower PropST at easier ID's than the other age groups while all ages became more similar at more difficult ID values.

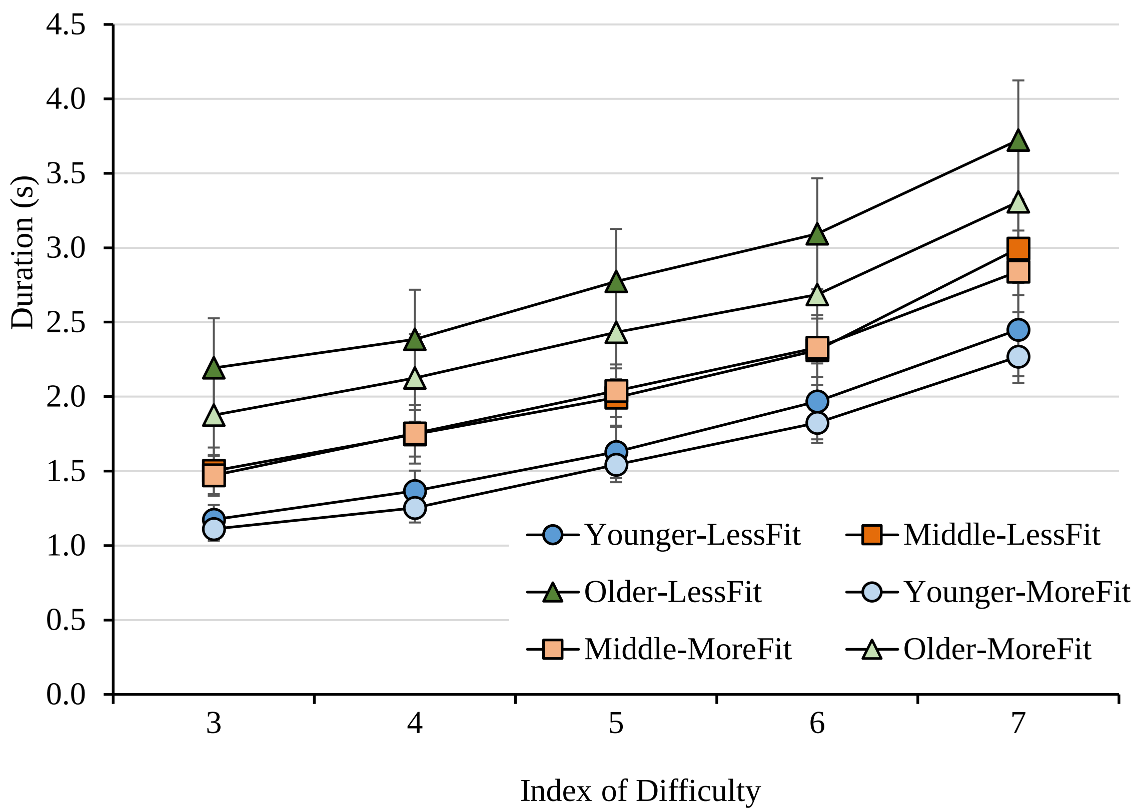


Figure 25. Distance Condition Movement Time (MT) for each Age-Group Split by Fitness Score.

Width Condition

A significant main effect for ID was only found for one variable, PropST, in the width condition. Significant main effects for age were only found on two dependent variables PropST and

PV. A significant main effect for fitness was only found for MT. The remaining effects were found as interaction effects. ID × age interactions were found for MT and PA. An interaction effect between ID × Fitness was found for MT, PV, and PA. MT and PropST both showed a significant three way interaction for age × fitness × ID (Table 9).

Personality also showed significant effects in the width condition. Greater endorsement of conscientiousness and openness traits was associated with lower MT while agreeableness was slightly associated with increased MT and PropST. Greater openness also was associated with a greater likelihood to end the primary phase closer to the target as shown by a positive effect on CEPT, but a decreased MT. Conscientiousness and openness was associated with greater times to peak acceleration. Unlike the distance condition greater motor impulsiveness was associated with greater PropST along with a negative relationship with CEPT indicated a greater likeliness to undershoot the target location in the primary phase. Attentional impulsivity also led to greater movement times, and decreased time to peak velocity and acceleration. Taken together these results may indicate a connection between motor impulsivity and online feedback control and a connection between attentional impulsivity and experiencing greater difficulties with accuracy constraints.

Increased age increased movement times in all condition as shown in Figure 26a. Although this increase in MT is evidence in both the primary (PT; Figure 26d) and secondary (ST; Figure 26d) phase, the groups were relatively similar in the proportion of ST (PropST) indicating although group differences exist with age these differences are similar across age-groups. Example velocity profiles for a single movement for each fitness group (split by median split) are shown for younger adults in Figure 27, middle-age adults in Figure 28, and older adults in Figure 29.

Table 9. Width Regression Results.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	7.18	<.001	.31	.04				41.94	9, 935	.001	.29	.28
Agreeableness	1.91	.06	.001	.001	.06	.08	.05					
Conscientiousness	-2.12	.04	-.001	.001	-.07	.02	-.06					
Openness	-3.53	<.001	-.002	.001	-.11	.04	-.10					
Attention Impulsivity	4.90	<.001	.005	.001	.15	.01	.14					
Fitness	-3.17	.002	-.007	.002	-.24	-.28	-.09					
Age × Fitness	4.93	<.001	.001	.001	.44	.3	.14					
ID × Age	3.86	<.001	.001	.001	.45	.48	.11					
ID × Fitness	3.45	.001	.001	.001	.28	-.05	.10					
Age × Fitness × ID	-2.24	.026	.001	.001	-.35	.42	-.06					
Proportion ST (PropST)												
Overall Model	1.65	.10	.028	.017				27.66	7, 937	<.001	.19	.18
Agreeableness	2.14	.03	.001	.001	.07	.08	.06					
Openness	-2.79	.005	-.001	.001	-.09	.005	-.08					
Motor Impulsiveness	4.62	<.001	.001	.001	.15	.04	.14					
Age	3.45	.001	.001	.001	.37	.26	.10					
Age × Fitness	2.02	.04	.001	.001	.27	.25	.06					
ID	3.28	.001	.01	.003	.33	.29	.10					
Age × Fitness × ID	-2.26	.02	.001	.001	-.29	.34	-.07					
Constant Error (CE) PT												
Overall Model	-2.99	.003	-1.84	.62				26.09	5, 939	<.001	.12	.12

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Motor Impulsiveness	-4.24	<.001	-.08	.02	-.15	-.25	-.14					
Planning Impulsiveness	2.54	.01	.06	.03	.09	.05	.08					
Openness	4.70	<.001	.06	.01	.15	.05	.15					
Age	-10.94	<.001	-.02	.003	.41	-.26	-.34					
ID × Fitness	-5.05	<.001	-.02	.003	.18	-.006	-.16					
Constant Error (CE) MT												
Overall Model	n.s.											
Variable Error (VE) PT												
Overall Model	n.s.											
Peak Velocity (PV)												
Overall Model	33.08	<.001	1.65	.05				52.11	4, 940	<.001	.18	.18
Openness	4.65	<.001	.005	.001	.14	.03	.14					
Attention Impulsivity	-4.25	<.001	-.008	.002	-.13	-.01	-.13					
Age	-13.99	<.001	-.004	.001	-.51	-.37	-.41					
ID × Fitness	-3.56	<.001	-.001	.001	-.12	-.10	-.11					
Time to Peak Velocity (tPV)												
Overall Model	n.s.											
Time to Peak Acceleration (tPA)												
Overall Model	n.s.											
Peak Acceleration (PA)												
Overall Model	17.83	<.001	2.02	.11				28.22	5, 939	<.001	.13	.12
Conscientiousness	2.25	.03	.004	.002	.08	.05	.07					
Openness	4.50	<.001	.008	.002	.15	.05	.14					

Attention Impulsivity	-3.54	<.001	-.01	.003	-.12	-.05	.11
Fitness	5.85	<.001	.02	.003	.18	.17	.18
Age × Fitness	-9.76	<.001	.001	.001	-.32	-.26	-.30
Peak Deacceleration (PD)							
Overall Model	n.s.						

Note: Only the results of the final model for each variable is shown.

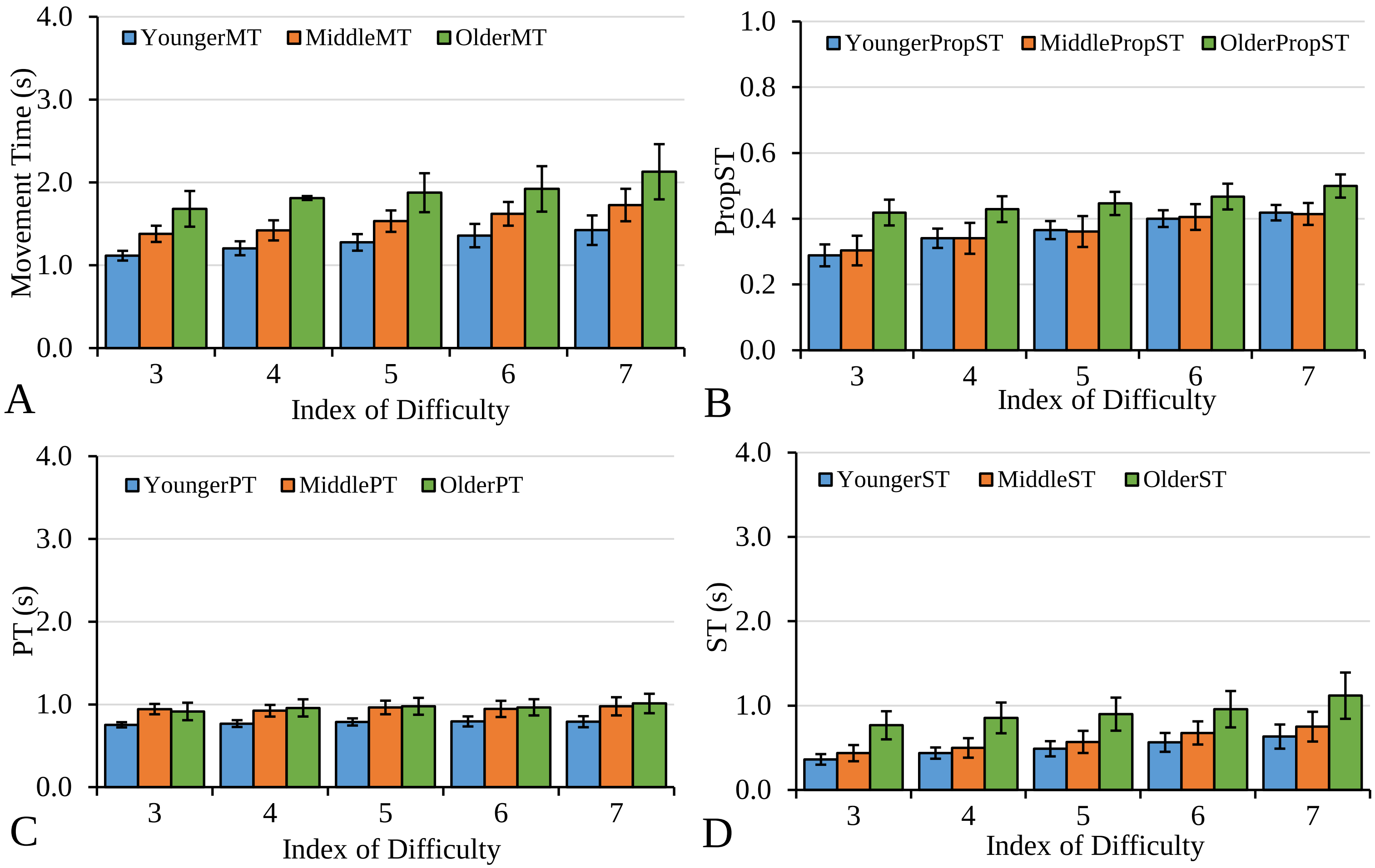


Figure 26. Movement time, PT, ST, and PropST for the Width Condition.

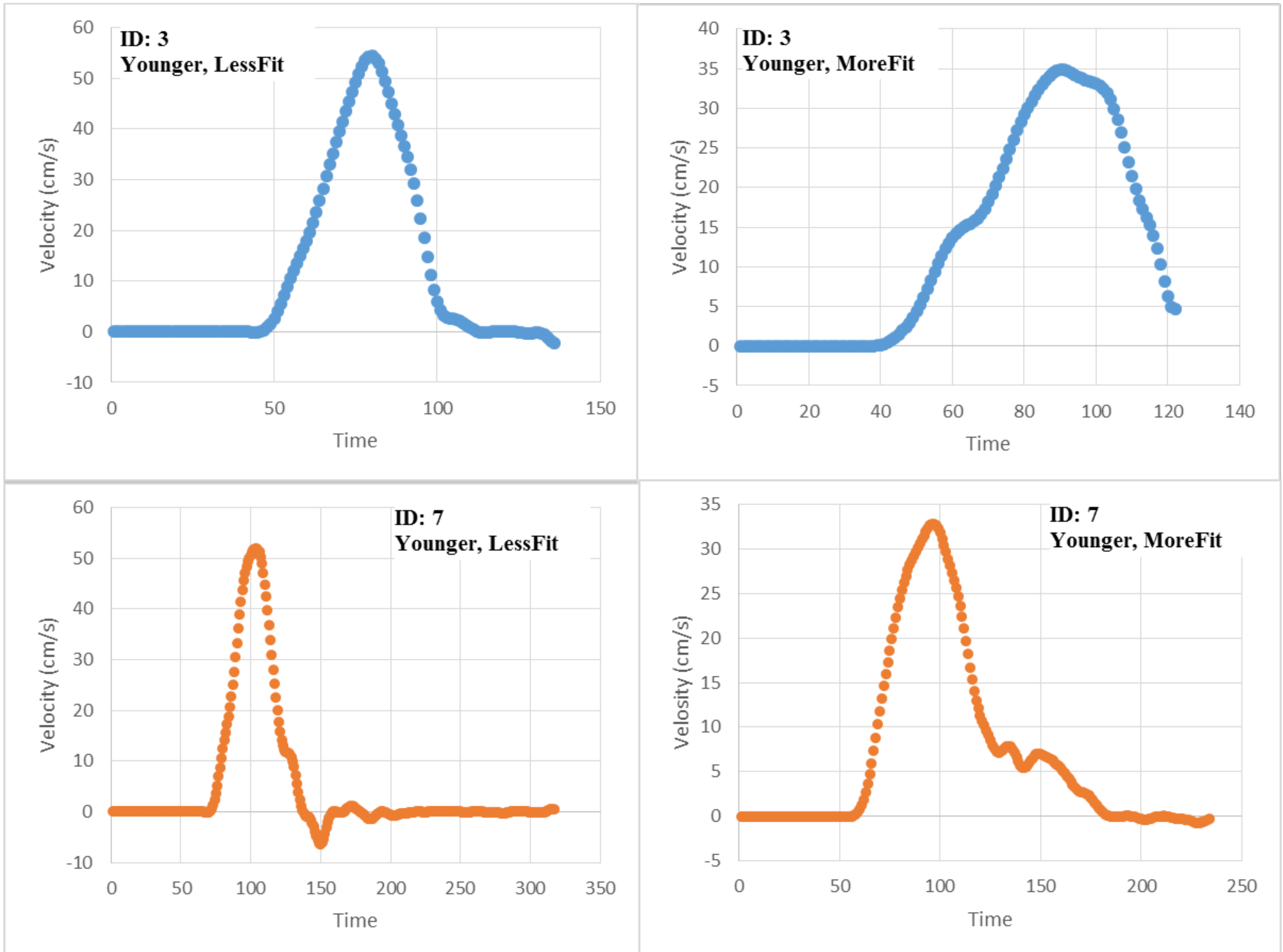


Figure 27. Width Condition Example Velocity Profiles for Younger LessFit and MoreFit Participants.

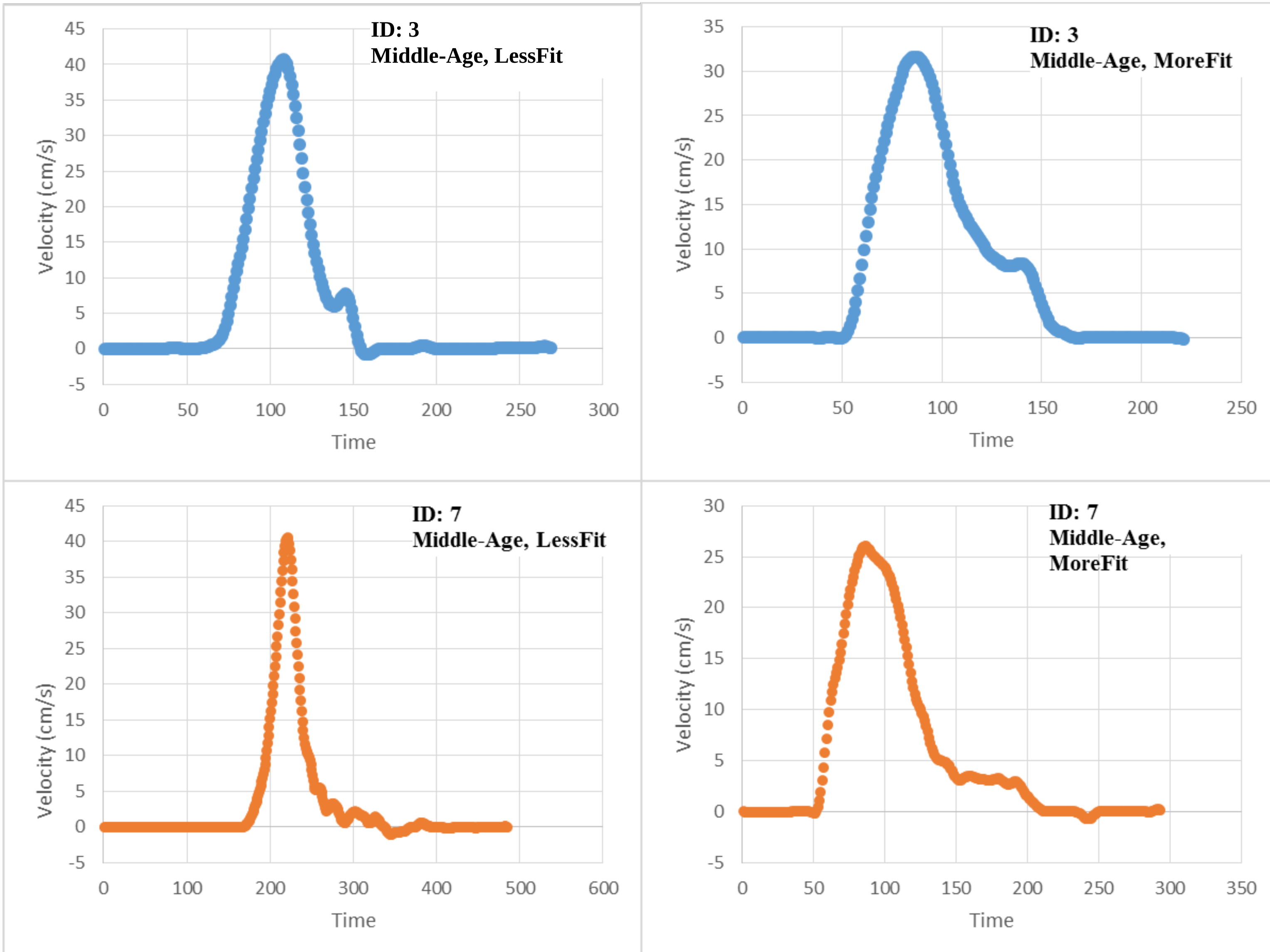


Figure 28. Width Condition Example Velocity Profiles for Middle-Age LessFit and MoreFit Participants.

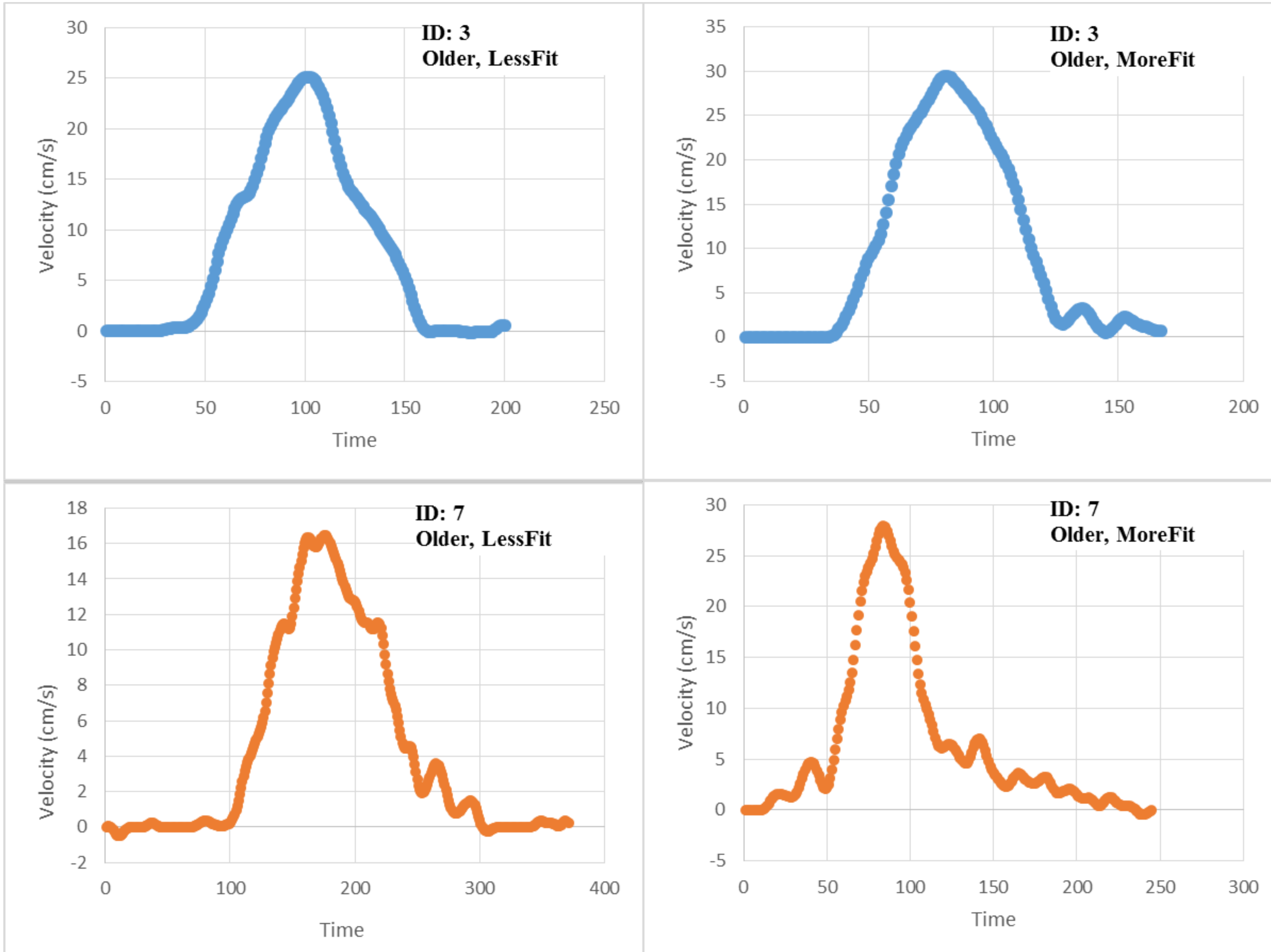


Figure 29. Example Velocity Profiles for Older LessFit and MoreFit Participants in the Width Condition.

Greater fitness led to greater time to peak velocity and peak acceleration, but this effect was larger for ID values lower than 5, explaining the ID × fitness interaction for PV (Figure 30) and PA (Figure 31). However, because error bars are overlapping these effects are small.

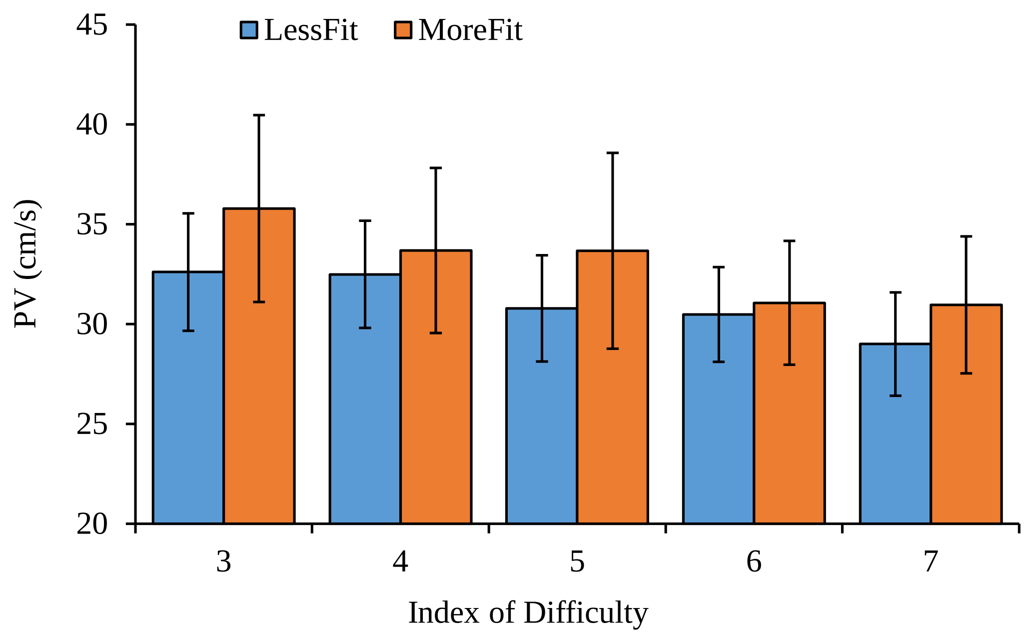


Figure 30. Width Condition Peak Velocity (PV) for each Age-Group Split by Median Fitness Score.

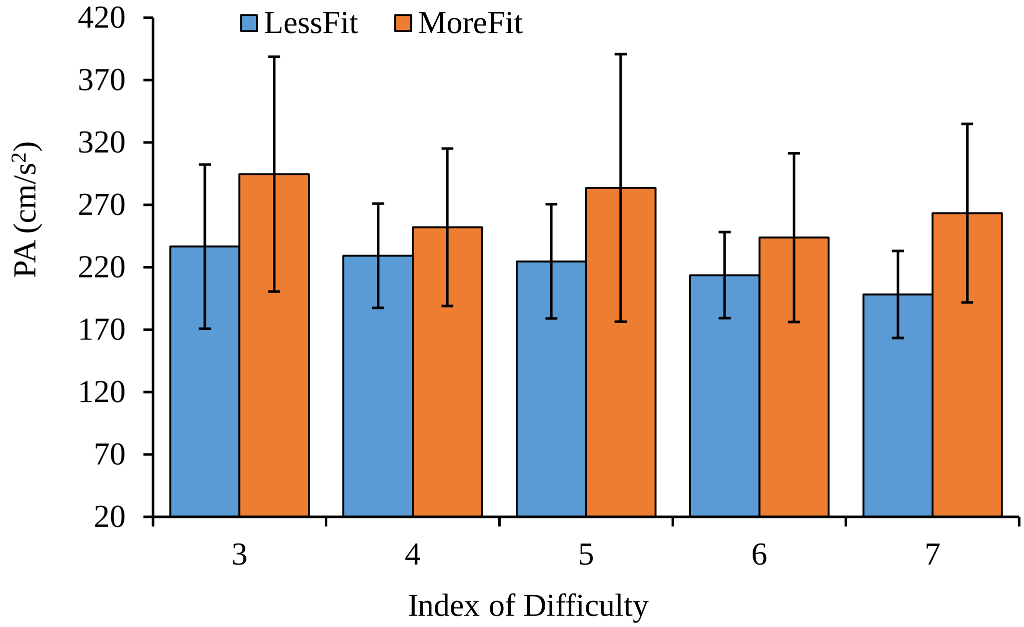


Figure 31. Width Condition Peak Acceleration (PA) for each Age-Group Split by Median Fitness Score.

Although, there was a significant ID × fitness × age interaction the confidence intervals for less fit and more fit individuals overlap for each age group at each ID indicating that these differences are small for the width condition. Nonetheless, older adults regardless of fitness displayed longer movement times when compared to middle-age or younger adults (Figure 32).

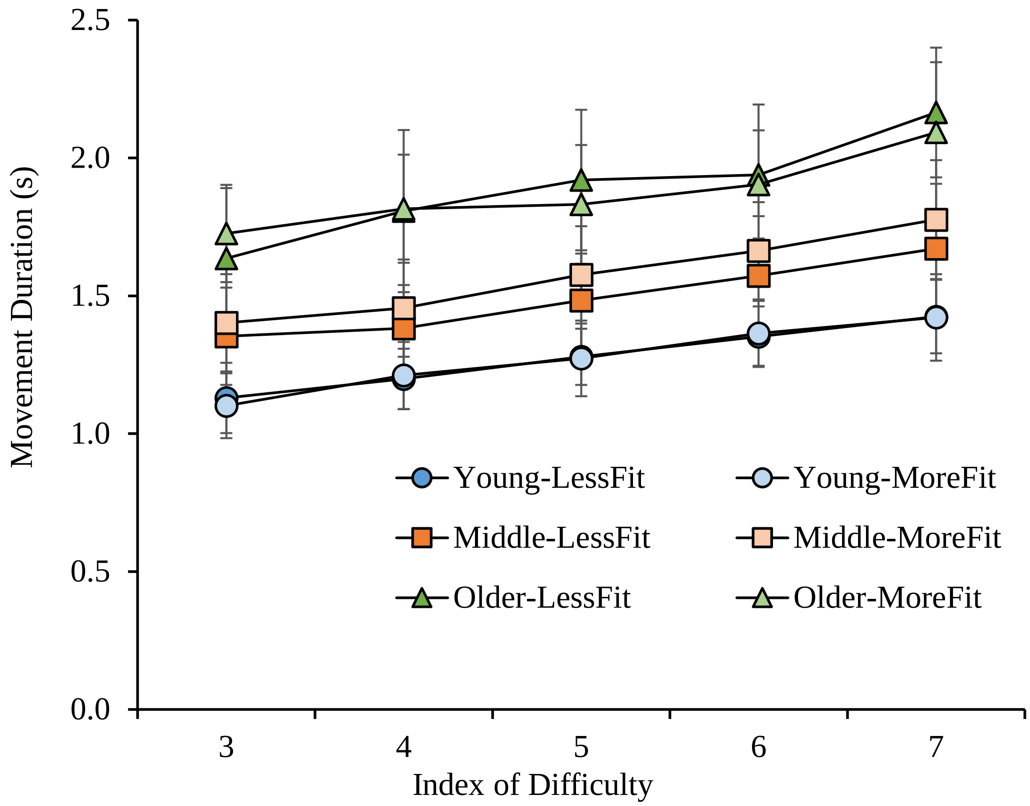


Figure 32. Width Condition Movement Time (MT) for each Age-Group Split by Median Fitness Score.

Similar to the findings for movement time the three way interaction between age, fitness, and ID is difficult to interpret because the confidence intervals across fitness group for each age and ID are overlapping. However, there is a significant age difference between younger and older adults. Older adults spend more of the movement in the secondary movement phase regardless of ID than younger adults do (Figure 33). A summary of the regression effects is shown in Table 10.

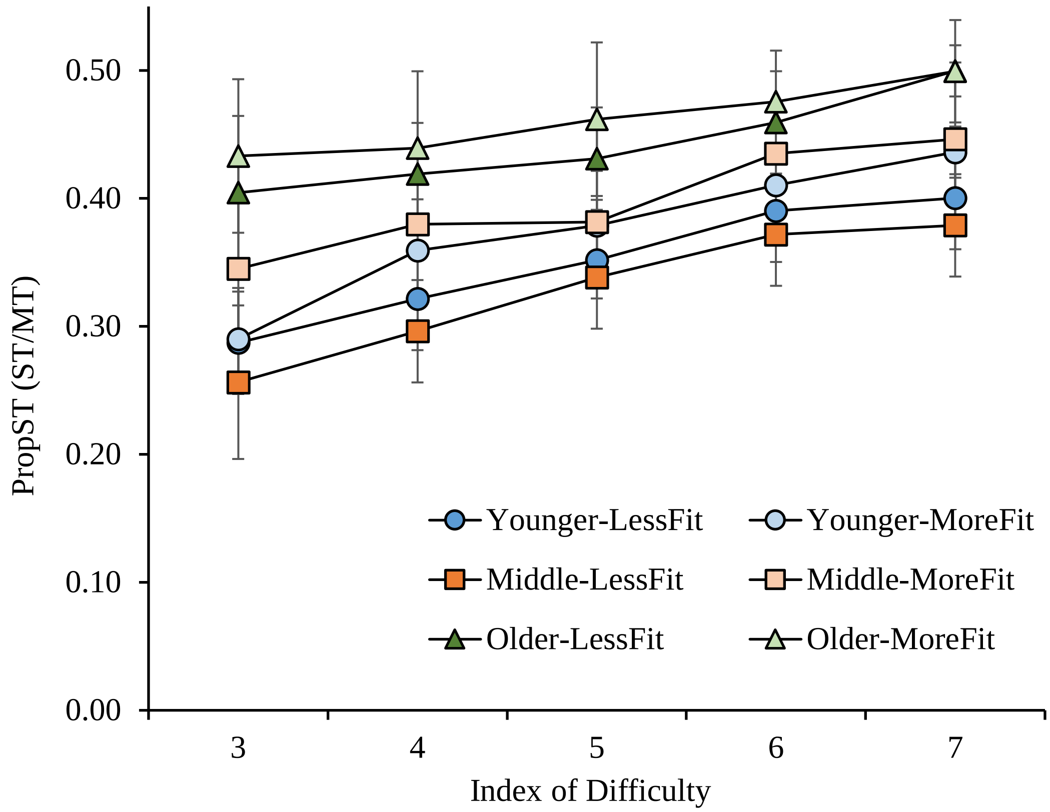


Figure 33. Width Condition PropST for each Age-Group Split by Median Fitness Score.

Table 10. Summary of Regression Results for Each Condition.

Variables	MT	PropST	CEPT	CEMT	VEPT	PV	tPV	tPA	PA	PD
Speeded Condition										
Distance (D)	Yes		Yes	Yes		Yes	Yes		Yes	Yes
Age	Yes	Yes			Yes	Yes	Yes			Yes
Fitness					Yes				Yes	
D × Age	Yes	Yes	Yes		Yes					
D × Fitness					Yes					
Age × Fitness									Yes	
D × Age × Fitness										
Distance Condition										
ID	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
Age	Yes						Yes	Yes		
Fitness		Yes			Yes	Yes			Yes	Yes
ID × Age					Yes					
ID × Fitness					Yes					
Age × Fitness		Yes			Yes	Yes			Yes	Yes
ID × Age × Fitness	Yes	Yes			Yes					
Width Condition										
ID		Yes								
Age		Yes				Yes				
Fitness	Yes									
ID × Age	Yes								Yes	
ID × Fitness	Yes					Yes			Yes	
Age × Fitness	Yes	Yes								
ID × Age × Fitness	Yes	Yes								

Age Differences between Distance and Width Conditions Compared

While both the distance and width conditions showed age related effects for MT and PropST these previous analyses do not directly allow for direct comparison between ID manipulations of distance and width. When compared directly, the distance manipulation led to a steeper ID-MT slope than the width manipulation for each age group. Age affected both the slope and the y-intercept. This indicated that while MT increased with age, MT increased more quickly across ID in the distance condition than in the width condition leading to a steeper ID-MT slope. For both distance and width, the ST phase accounted for increases in MT. The difference being that while PT decreased as ID increased in the distance condition PT was flat in the width condition. PropST was greater for all ID values in the distance condition for all age-groups. Movement time and time spent in the secondary movement phase for both the distance and width conditions are shown for younger adults in Figure 34, middle-age adults in Figure 35, and older adults in Figure 36. Finally, the proportion of time spent in the secondary phase (PropST) for each age group and condition is shown in Figure 37.

Additionally, it is important to note that the ID values were held constant in both the distance and width conditions therefore Fitts' law would predict the same MT in both conditions. Even in the case where the distance and width parameters were exactly the same (ID = 6) MT differed due to the block it was embedded in. This finding may indicate that people use different strategies when distance and width are manipulated in separate blocks. Another explanation is that moving to varying distances led to fatigue or increased noise which impaired movement efficiency.

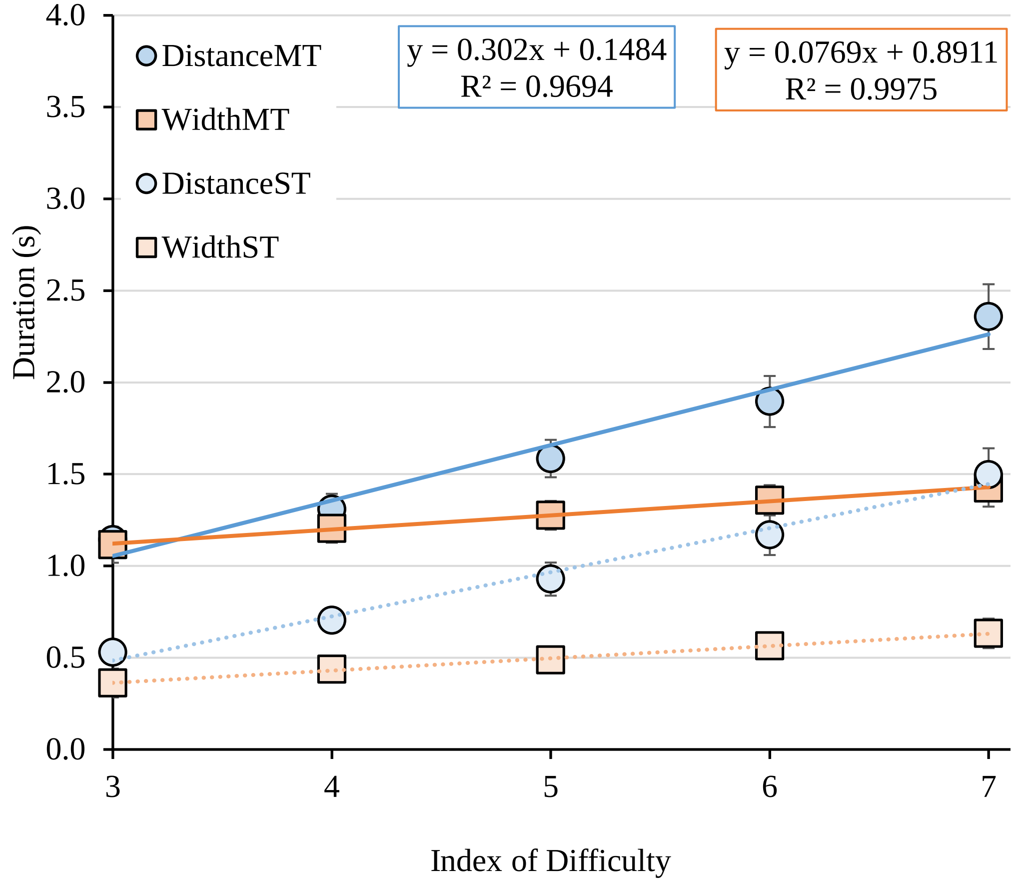


Figure 34. MT and ST for Younger Participants with Relevant Regression Equations.

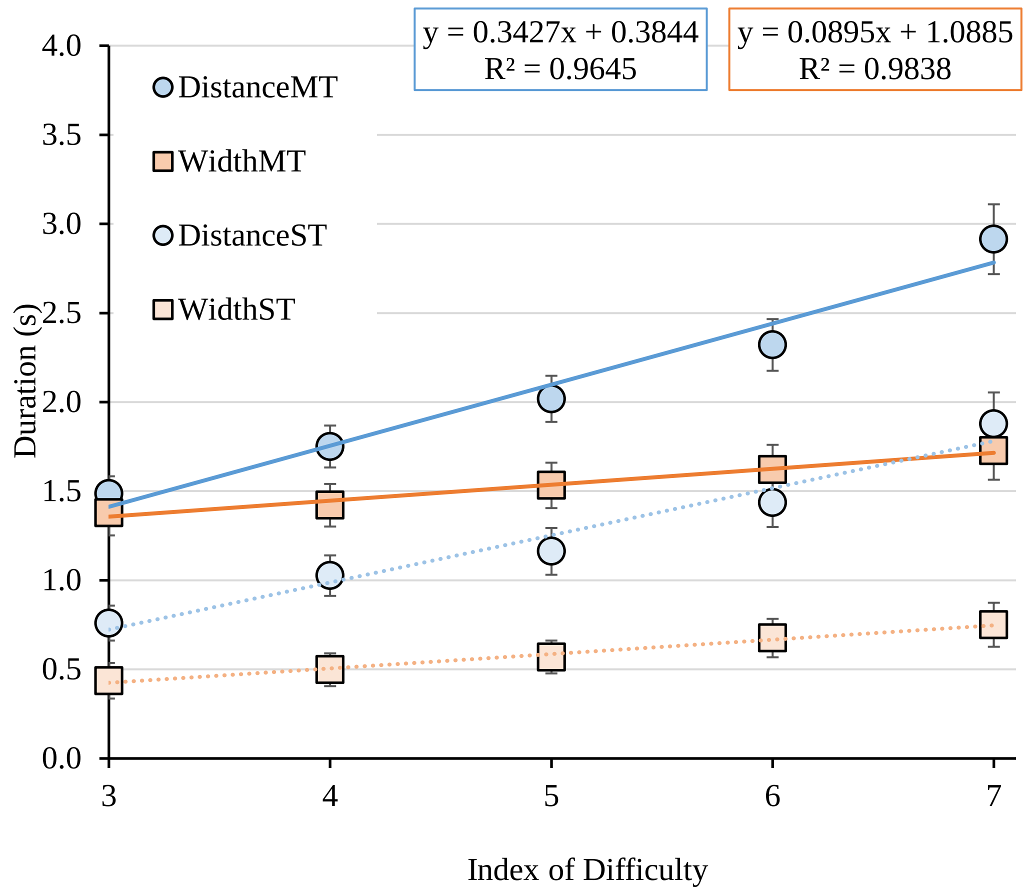


Figure 35. MT and ST for Middle-Age Participants with Relevant Regression Equations.

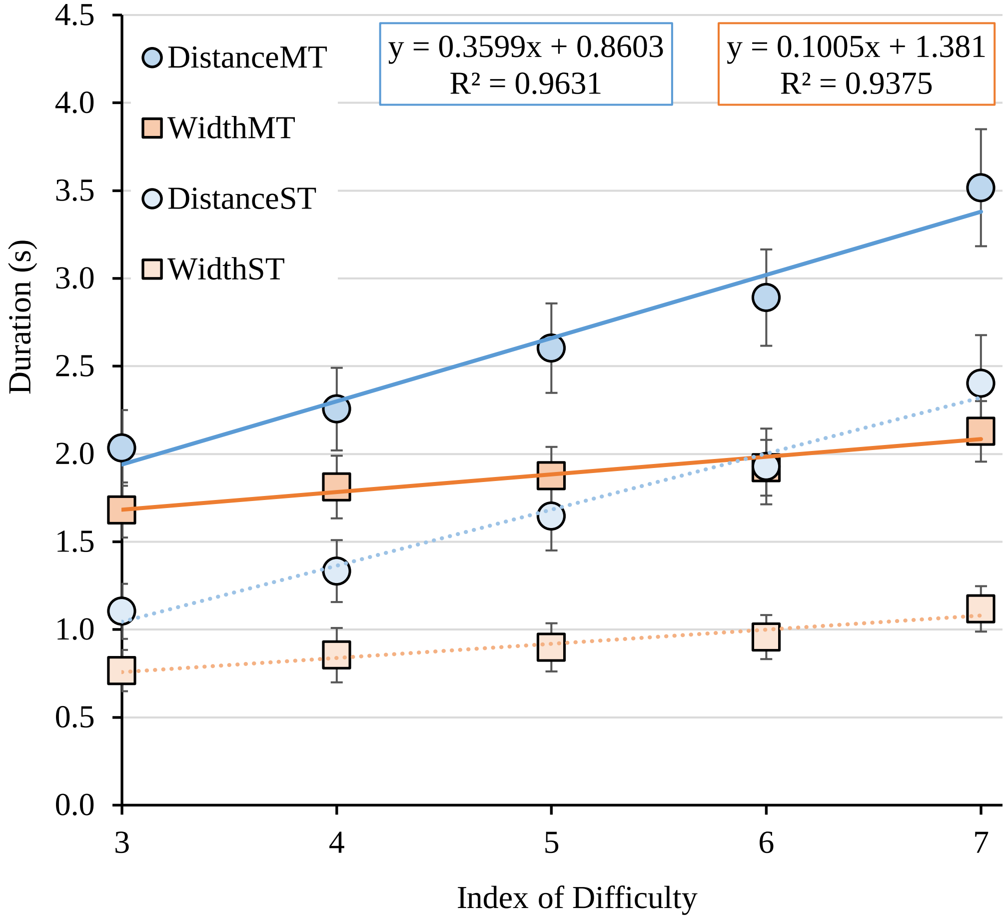


Figure 36. MT and ST for Older Participants with Relevant Regression Equations.

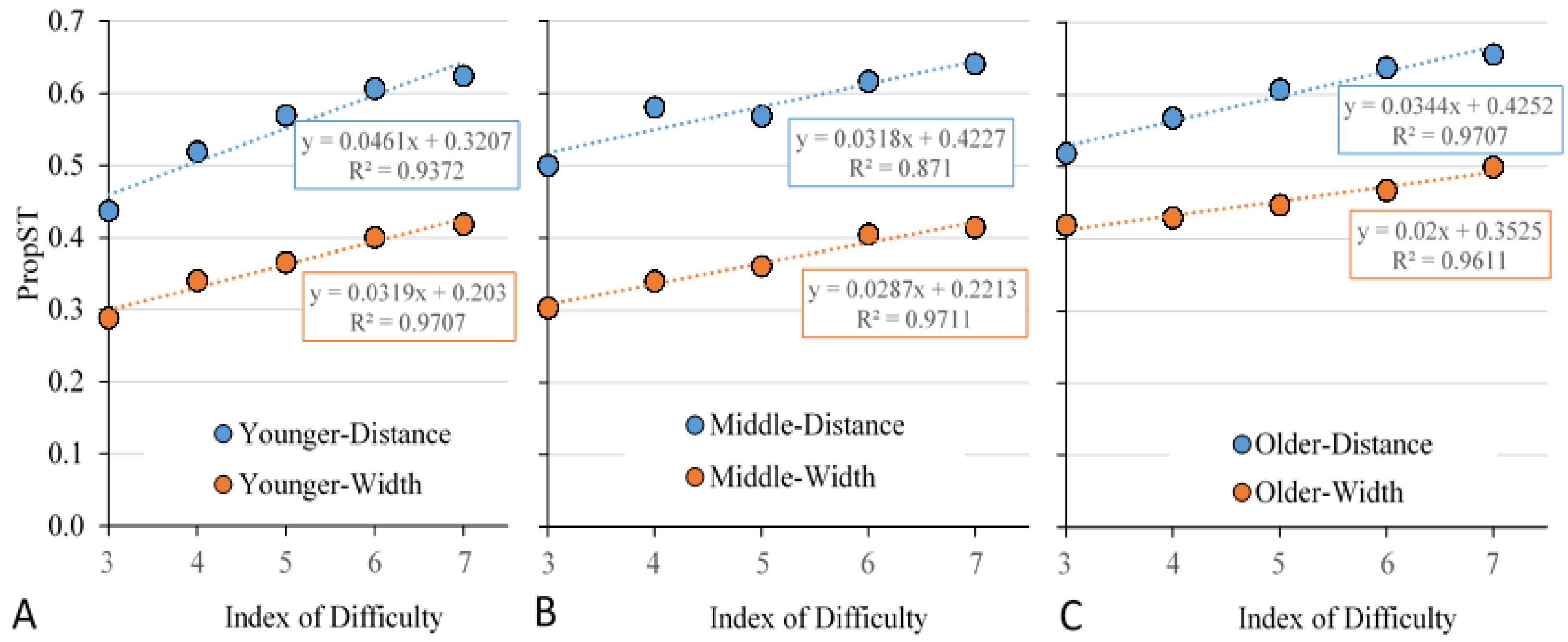


Figure 37. PropST for Distance and Width Conditions with Regression Equations for Younger (A), Middle-Age (B), and Older Adults (C).

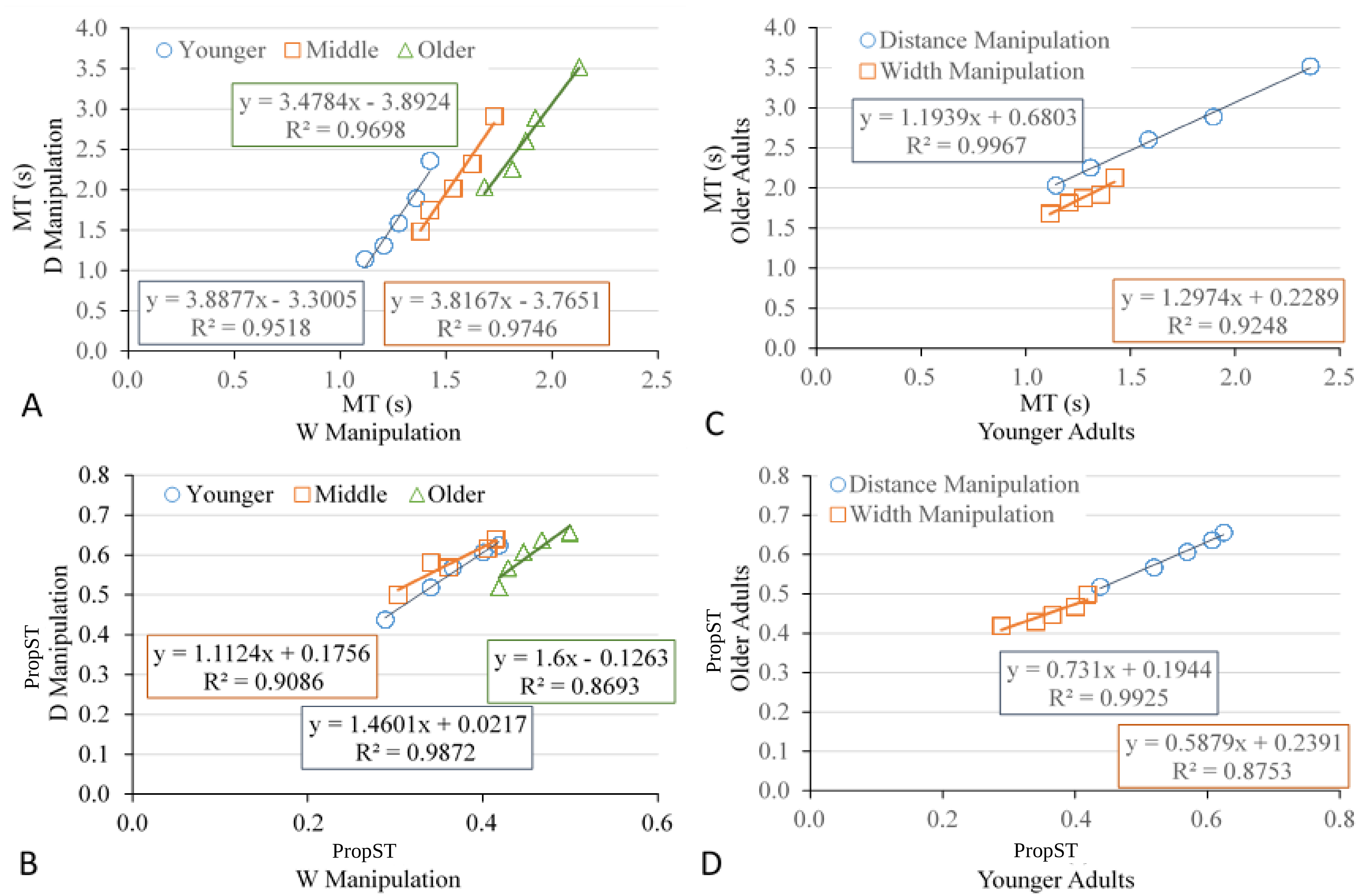


Figure 38. State Trace Plots Comparing Age-Groups for MT (A) and PropST (B) and Brinley Plots Comparing Age-Groups for MT (C) and PropST (D).

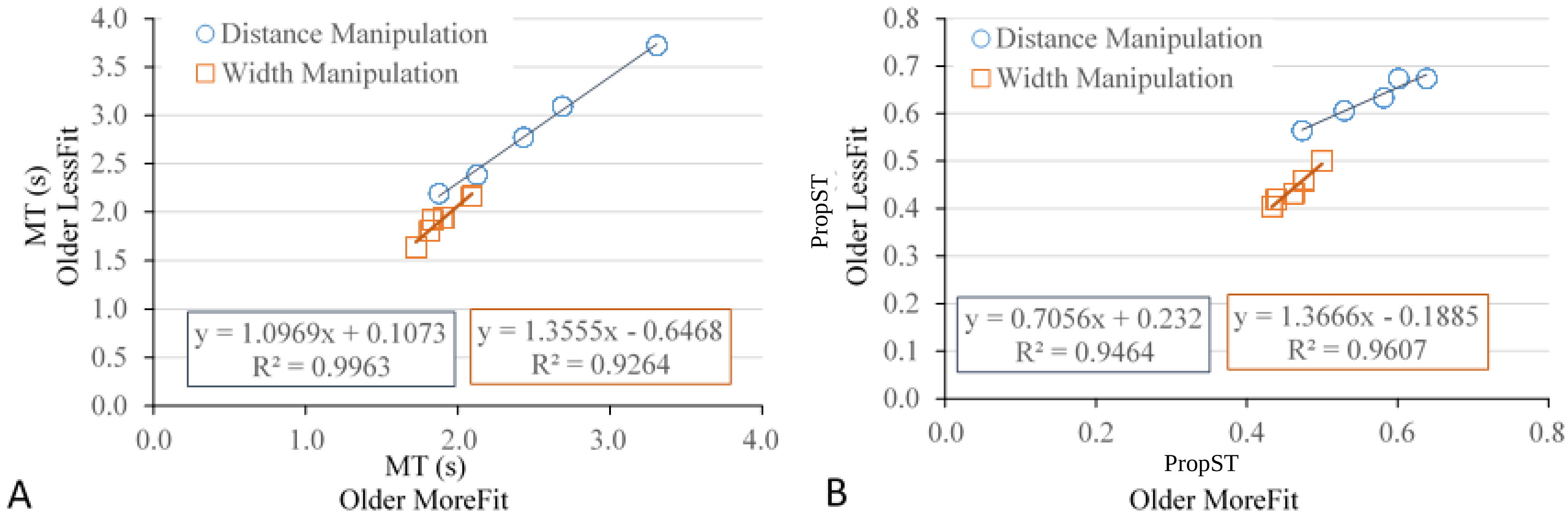


Figure 39. Distance and Width Binley Plots for MT (A) and PropST (B) Comparing Fitness Groups for Older Adults.

To further examine differences between younger, middle-age, and older adults between the distance and width conditions both state trace and Brinley plots were examined. These plots were designed to match Temprado et al. (2013) in order to represent the data from the current study in a similar manner to allow ease of comparison. First, plotting distance by width movement time (Figure 38a) and PropST (Figure 38b) for each age-group showed larger effects of distance across all age groups for MT. For PropST younger and middle-age adults showed a flatter slope which indicated that the width may have increased PropST more than distance. However older adults showed a much steeper slope indicating distance constraints affected PropST more for older adults than other age groups.

This analysis was followed up by examining the Brinley plots for older and younger adults. When these groups were compared it was shown that distance increased MT more greatly for older adults in the distance condition while MT in the width condition were similar for younger and older adults (Figure 38c). Examining the Brinley plot for PropST plotting younger by older adults for both distance and width conditions indicated PropST increased more greatly for older adults in the distance condition as compared to younger adults for both the distance or width conditions (Figure 38d).

Finally, Brinley plots comparing older adults by fitness group were examined for MT (Figure 39a) and PropST (Figure 39b). This analysis was designed to determine in which condition fitness was the most beneficial for older adults. This analysis revealed similar findings as the other analyses indicating a larger effect of distance over width. In other words, cardiovascular fitness was shown to be more beneficial in the distance condition.

Age and Fitness Effects for Proprioceptive Sensitivity and Useful Field of View

To determine if kinematic efficiency could be due to proprioceptive sensitivity error determined from the proprioceptive pointing task, a backwards multiple regression was conducted using age, fitness and the age × fitness interaction to predict error at each of the four points. No significant effects were found for any of the points.

Similarly another backwards regression analysis was conducted, with age, fitness, and age × fitness as independent variables, for each of the three Useful Field of View tests. Because UFOV scores were not normal the variables a logarithmic transformation was performed prior to analysis. No significant effects were found for the processing speed test. A significant effect of age was found for both selective attention and divided attention tests. No effects of fitness or an age × fitness interaction were found. Age was found to be a moderate to strong predictor of UFOV score for both the selective attention and divided attention tests but not the processing speed task. While fitness was shown to be significantly negatively correlated with UFOV score it was strongly correlated with age which may have led to it being a non-significant predictor in the regression models. Table 11 displays zero-order correlations between age, fitness and UFOV scores, while Table 12 displays the results from each regression model. Figures 40 and 41 respectively show the effects of age divided by fitness score for both the selective attention and divided attention UFOV tests. Because the PPT did not display and age and fitness effects and the UFOV divided attention test showed the greatest age effects, only the UFOV divided attention test was used in follow-analyses.

Table 11. Correlations between Age, Fitness, and Useful Field of View tests.

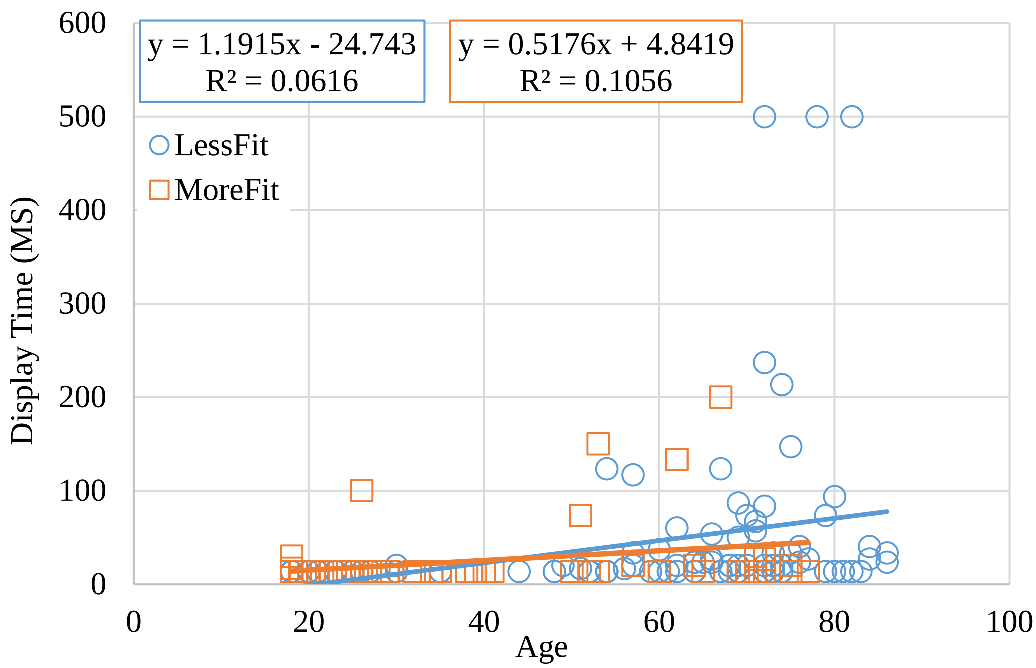
#	Variable	1	2	3	4	5
1	Age	—	-.51**	-.04	.35*	.52**
2	Fitness	-.68**	—	.07	-.12	-.46*
3	UFOV Processing Speed	.08	-.06	—	.25	-.007
4	UFOV Selective Attention	.30**	-.21**	.45**	—	.52**
5	UFOV Divided Attention	.59**	-.42**	.32**	.77**	—

Note: *p<.01, **p<.001. Lower diagonal are overall correlations and upper diagonal are correlations specifically for older adults (age ≥ 65)

Table 12. Regression Results for UFOV test scores comparing Age and Fitness.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
UFOV Processing Speed												
Overall Model	n.s.											
UFOV Selective Attention												
Overall Model	20.16	<.001	1.01	0.5				45.31	1, 187	<.001	.20	.19
Age	6.73	<.001	0.006	0.001	.44	.44	.44					
UFOV Divided Attention												
Overall Model	22.73	<.001	1.14	0.05				165.58	2, 186	<.001	0.47	0.47
Age	12.87	<.001	0.012	0.001	.69	.69	.69					

Note: Only the final model for each variable is shown. Note a higher UFOV score indicates less efficient processing.



Note: Lower number indicates better performance.

Figure 40. Useful Field of View **(**UFOV) Selective Attention Scores Displayed by Age and Fitness score.

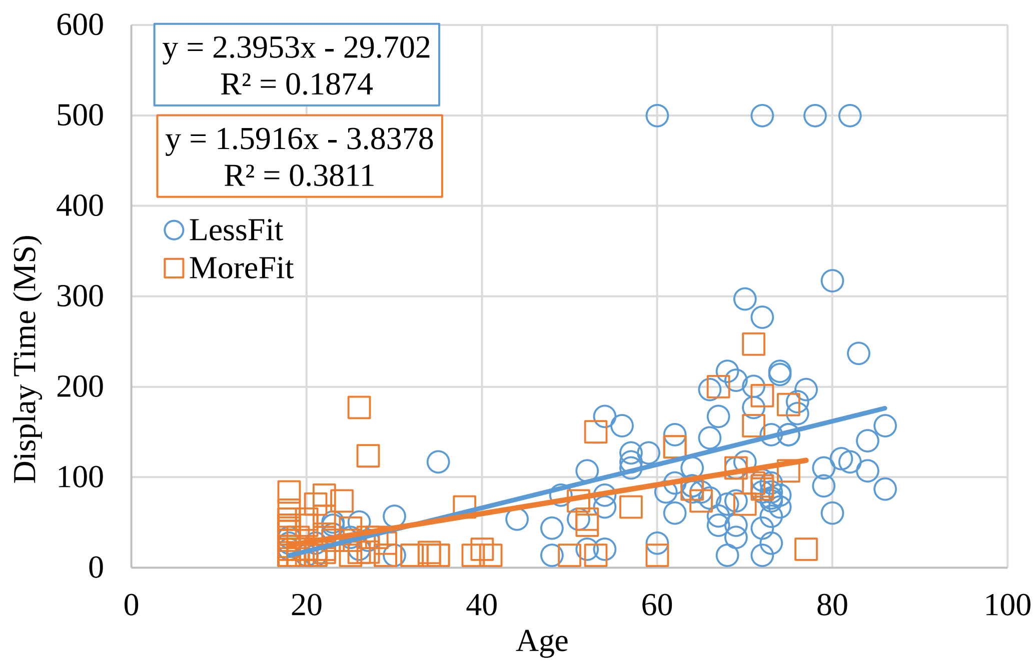


Figure 41. Useful Field of View (UFOV) Divided Attention Scores Displayed by Age and Fitness Score.

Impact of UFOV on movement performance.

Follow-up analyses were conducted on the UFOV divided attention test. First, kinematic performance was examined adding UFOV divided attention test scores to each of the regression models previously run for each task condition (speeded, distance, & width) for each kinematic variable. These new models were compared to the previous models to determine if the addition of UFOV increased the amount of variance accounted for in the model. Before examining these results, it is important to note that UFOV scores in the divided attention test represent the time needed for individuals to process the cluttered visual display. Therefore, lower scores indicate better performance.

Speeded Condition.

For the speeded task condition, significant main effects for UFOV and UFOV × fitness interactions were found for tPV, tPA, and PA. Significant UFOV × age interaction effects were found for MT and PV. Significant three way interactions between UFOV, fitness, and age were found for PropST, CEPT, VEPT, and tPV. Regression results for the addition of UFOV are shown in Table 13. The inclusion of UFOV into the model improved prediction for MT, tPV, and tPA more than other kinematic variables as evidenced by a change in adjusted R^2 (Table 14).

Table 13. Speeded Condition Regression Results with UFOV Added.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	7.68	<.001	0.19	.025				110.77	7, 937	<.001	.45	.45
Motor Impulsivity	-5.11	<.001	-.003	.001	-.14	-.22	-.12					
Agreeableness	2.89	.004	.001	.001	.08	.14	.07					
Conscientiousness	-.377	<.001	-.002	.001	-.12	.08	-.09					
Age	-3.38	.001	-.001	.001	-.29	.42	-.08					
Distance	6.33	<.001	.003	.001	.35	.47	.15					
Distance × Age	2.51	.012	.001	.001	.15	.59	.06					
UFOV × Age	7.85	<.001	.001	.001	.64	.45	.19					
Proportion ST (PropST)												
Overall Model	6.08	<.001	.02	.003				86.67	2, 942	<.001	.16	.15
Age	8.12	<.001	.001	.001	.28	.37	.24					
UFOV × Distance × Age	4.95	<.001	.001	.001	.17	.31	.15					
Constant Error (CE) PT												
Overall Model	-.19.10	<.001	-10.63	.56				520.55	2, 942	<.001	.53	.52
Distance	24.85	<.001	1.21	.05	.80	.72	.56					
UFOV × Distance × Age	-3.62	<.001	-.001	.001	-.12	.46	-.08					
Constant Error (CE) MT												
Overall Model	-9.87	<.001	-9.05	.92				654.19	2, 942	<.001	.58	.58
Age	-2.26	.02	-0.04	.02	-.05							
Distance	36.10	<.001	1.20	.03	.76							
Variable Error (VE) PT												
Overall Model	10.64	<.001	.70	.07				110.75	5, 939	<.001	.37	.37
UFOV	-2.64	.008	-.10	.04	-.22	.06	-.07					
Age × Fitness	-5.25	<.001	-.001	.001	-.73	-.03	-.14					
Distance × Age	10.20	<.001	.001	.001	.39	.51	.26					
Distance × Fitness	8.51	<.001	.001	.001	.30	.52	.22					
UFOV × Fitness × Age	4.00	<.001	.001	.001	.74	.01	.10					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Peak Velocity (PV)												
Overall Model	50.29	<.001	1.70	.03				136.10	4, 940	<.001	.37	.37
Motor Impulsivity	4.31	<.001	.009	.002	.13	.20	.11					
Non Planning Impulsivity	-2.06	.04	-.006	.003	-.06	.08	-.05					
Distance	17.24	<.001	.01	.001	.45	.45	.45					
UFOV × Age	-13.64	<.001	-.002	.001	-.37	-.39	-.35					
Time to Peak Velocity (tPV)												
Overall Model	1.60	.11	.04	.03				71.46	7, 937	<.001	.35	.34
Motor Impulsivity	-3.34	.001	-.001	.001	-.09	-.16	-.09					
Age	-2.59	.01	-.001	.001	-.29	.28	-.07					
Fitness	2.39	.02	.005	.002	.30	-.20	.06					
UFOV	4.34	.001	.06	.02	.46	.30	.11					
Distance	18.07	.001	.002	.001	.48	.48	.48					
UFOV × Fitness	-3.87	.001	-.006	.001	-.51	.03	-.10					
UFOV × Fitness × Age	3.90	.001	.001	.001	.43	.29	.10					
Time to Peak Acceleration (tPA)												
Overall Model	-2.00	.04	-.07	.04				23.42	10, 935	<.001	.20	.19
Attention Impulsivity	2.04	.001	.001	.001	.07	-.04	.06					
Agreeableness	2.19	<.001	.001	.001	.07	.13	.06					
Neuroticism	-2.92	<.001	-.001	.001	-.11	-.15	-.09					
Openness	-2.01	<.001	-.001	.001	-.06	.03	-.06					
Age	-3.07	<.001	-.001	.001	-.52	.24	-.09					
Fitness	3.17	.002	.007	.002	.44	-.17	.09					
UFOV	6.10	.02	.11	.02	.87	.29	.18					
Age × Fitness	3.63	<.001	.001	.001	.44	.19	.11					
Distance	9.81	<.001	.001	.01	.89	.29	.29					
UFOV × Fitness	-4.59	.002	-.007	.002	-.71	.05	-.13					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Peak Acceleration (PA)												
Overall Model	25.19	<.001	2.51	.10				59.07	6, 938	<.001	.27	.27
Motor Impulsivity	5.11	<.001	.01	.002	.16	.26	.14					
Conscientiousness	2.76	.006	.005	.002	.09	-.10	.08					
UFOV	-8.62	<.001	-.24	.03	-.28	-.37	-.24					
Age × Fitness	-8.45	<.001	.001	.001	-.28	-.37	-.24					
Distance	4.59	<.001	.004	.001	.13	.13	.13					
UFOV × Fitness	7.82	<.001	.02	.002	.24	.06	.22					
Peak Deacceleration (PD)												
Overall Model	23.39	<.001	2.71	.12				86.79	4, 940	<.001	.27	.27
Motor Impulsivity	3.78	<.001	.01	.003	.12	.23	.11					
Conscientiousness	2.60	.01	.006	.002	.08	-.09	.07					
Age	-16.06	<.001	-.009	.001	-.47	-.49	-.45					
Distance	4.72	<.001	.005	.001	.13	.13	.13					

Table 14. UFOV Summary Table for the Speeded Condition.

Variables	ΔF	ΔR^2	Δ adj. R^2
MT	-0.97	.03	.04
PropST	1.96	.01	0
CEPT	-0.68	0	0
CEMT	0	0	0
VEPT	-19.07	.01	.01
PV	0.78	0	.01
tPV	-2.61	.03	.02
tPA	-30.55	.05	.05
PA	1.72	0	.01
PD	0	0	0

Note: positive numbers indicate an advantage for including UFOV.

For movement time or time to peak velocity no differences were found between low and high UFOV scores for younger or middle-age adults. However older adults with higher UFOV scores had higher overall movement times (Figure 42) and a lower peak velocity (Figure 43). One potential reason could be that these individuals had more difficulties processing feedback during the movement leading to a slower and less forceful motor response. For PropST, although a three-way interaction was found overlapping confidence intervals indicated only a significant age × UFOV two-way interaction existed. Examining this effect in more detail yielded significant differences between low and high UFOV groups for both middle-age and older adults. Middle-age and older adults who had lower UFOV divided attention scores spent more of the time in the secondary movement phase than individuals with higher UFOV scores (Figure 44).

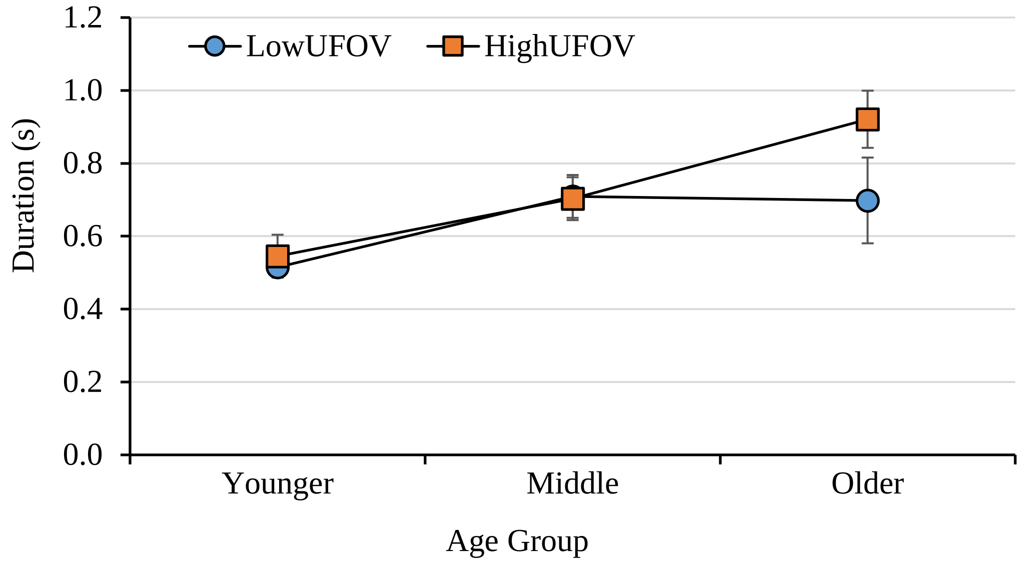


Figure 42. Speeded Condition Movement time (MT) for each Age-Group Split by UFOV Divided Attention Scores.

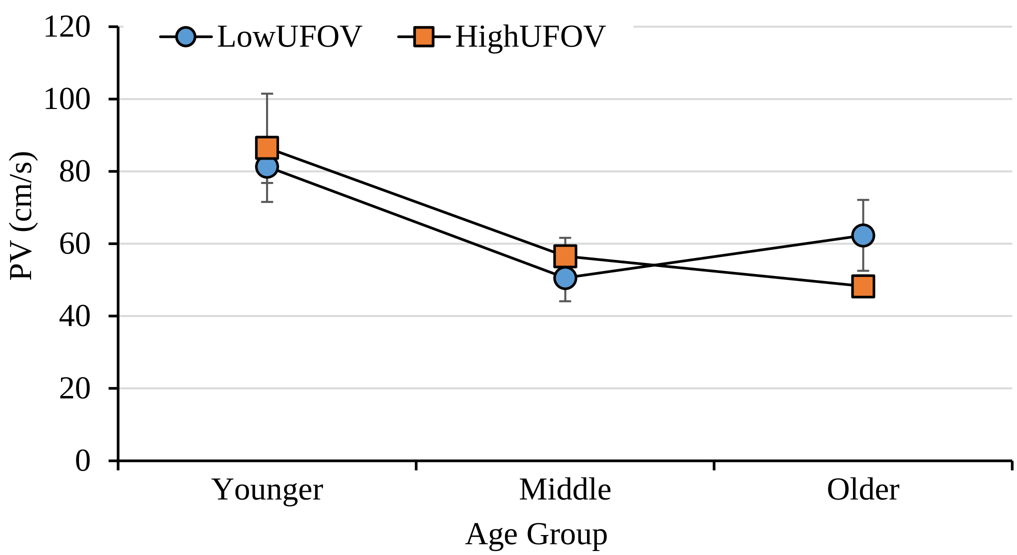


Figure 43. Speeded Condition Peak Velocity (PV) for each Age-Group Split by UFOV Divided Attention Scores.

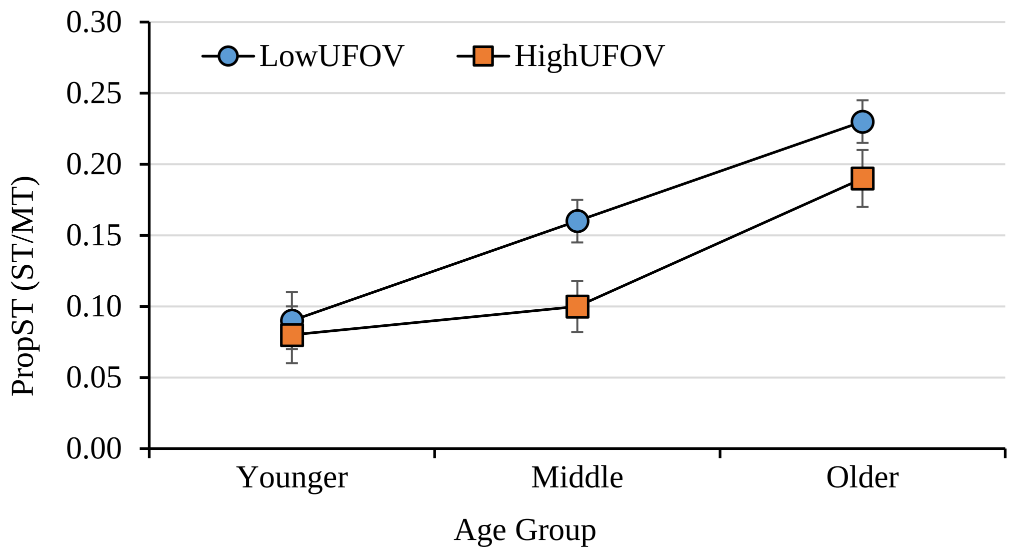


Figure 44. Speeded Condition PropST for each Age-Group Split by UFOV Divided Attention Scores.

Distance Condition.

In the distance condition, significant interaction effects between UFOV and age were found for MT, PropST, VEPT, tPV, and tPA. Significant UFOV × fitness interactions were found for MT, PA, and PD. Finally, significant three way UFOV × fitness × age interactions were found for MT, PV, PA, and PD (Table 15). The inclusion of UFOV into the model improved prediction for PA, PD, and PD as indicated by an increase in R^2 (Table 16).

Table 15. Distance Condition Regression Results with UFOV Added.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr²	*F*	*df*	*p*	R²	adj. R²
Movement Time (MT)												
Overall Model	3.57	<.001	.18	.05				91.54	10, 934	<.001	.50	.49
Attention Impulsivity	2.31	.02	.003	.001	.06	-.07	.05					
Agreeableness	2.95	.003	.002	.001	.08	.12	.07					
Conscientiousness	-2.85	.004	-.002	.001	-.08	.05	-.07					
Openness	-2.31	.02	-.001	.001	-.06	.08	-.05					
Fitness	-3.39	.001	-.01	.003	-.26	-.36	-.08					
ID	21.41	<.001	.05	.002	.50	.50	.50					
Age × Fitness	4.04	<.001	.001	.001	.46	.34	.09					
UFOV × Age	4.82	<.001	.001	.001	.51	.47	.11					
UFOV × Fitness	2.36	.02	.005	.002	.19	-.06	.06					
UFOV × Fitness × Age	-2.98	.003	.001	.001	-.59	.39	-.07					
Proportion ST (PropST)												
Overall Model	5.02	<.001	.12	.02				22.31	10, 934	<.001	.20	.19
Motor Impulsivity	-2.33	.02	-.001	.001	-.09	-.009	-.07					
Non-planning Impulsivity	5.35	<.001	.003	.001	.20	.13	.16					
Extraversion	3.18	.02	.001	.001	.11	.07	.09					
Agreeableness	-2.17	.03	-.001	.001	-.07	-.06	-.06					
Age	4.23	<.001	.002	.001	.85	.12	.12					
Fitness	-2.04	.04	-.003	.001	-.19	-.12	-.06					
ID × Fitness	3.97	<.001	.001	.001	.35	.16	.12					
Age × Fitness × ID	-2.33	.02	.001	.001	-.22	.22	-.07					
UFOV × ID	3.26	.001	.004	.001	.30	.29	.10					
UFOV × Age	-4.19	<.001	-.001	.001	-.70	.09	-.12					
Constant Error (CE) PT												
Overall Model	181.22	<.001	1.40	.008				377.30	3, 941	<.001	.55	.55
Agreeableness	-2.36	.02	.001	.001	-.05							
ID	-24.25	<.001	-.02	.001	-.61							

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
ID × Age	-7.98	<.001	-.001	.001	-.21							
Constant Error (CE) MT												
Overall Model	-24.31	<.001	-38.77	1.60				640.29	1, 943	<.001	.40	.40
ID	25.30	<.001	7.77	.31	.64	.64	.64					
Variable Error (VE) PT												
Overall Model	-23.86	-.43	.02					1240.93	5, 939	<.001	.87	.87
Non Planning Impulsivity	3.00	.003	.001	.04	.03	.04						
ID	49.43	.17	.003	.92	.93	.59						
ID × Fitness	2.82	.001	.001	.07	.61	.03						
Age × Fitness × ID	-2.80	.001	.001	-.07	.53	-.03						
UFOV × Age	5.66	.001	.001	.15	.07	.07						
Peak Velocity (PV)												
Overall Model	5.87	<.001	.32	.06				336.32	7, 937	<.001	.72	.71
Attention Impulsivity	-3.56	<.001	-.007	.002	-.07	-.004	-.06					
Openness	2.68	.007	.003	.001	.05	-01	.05					
Fitness	6.74	<.001	.01	.002	.14	.17	.12					
ID	18.03	<.001	.21	.01	.98	.81	.31					
Age × Fitness	-3.98	<.001	.001	.001	-.30	-.14	-.07					
UFOV × ID	-3.22	.001	-.02	.006	-.22	.51	-.06					
UFOV × Fitness × Age	2.36	.02	.001	.001	.23	-.16	.04					
Time to Peak Velocity (tPV)												
Overall Model	-0.40	.69	-.01	.03				66.74	8, 936	<.001	.36	.36
Non Planning Impulsivity	-2.94	.003	-.002	.001	-.09	-.13	-.08					
Attention Impulsivity	5.96	<.001	.004	.001	.18	.007	.16					
Extraversion	-4.46	<.001	-.001	.001	-.12	-.01	-.12					
Agreeableness	4.70	<.001	.002	.001	.15	.16	.12					
Conscientiousness	-2.14	.03	-.001	.001	-.08	.06	-.06					
ID	9.14	<.001	.02	.002	.32	.37	.24					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Age × Fitness × ID	2.01	.04	.001	.001	.09	.47	.05					
UFOV × Age	10.92	<.001	.001	.001	.40	.42	.29					
Time to Peak Acceleration (PA)												
Overall Model	-0.53	.60	-.01	.03				41.63	6, 938	<.001	.21	.21
Motor Impulsivity	3.11	.002	.002	.001	.11	-.07	.09					
Non Planning Impulsivity	-4.13	<.001	-.004	.001	-.15	-.15	-.12					
Attention Impulsivity	4.50	<.001	.004	.001	.15	-.002	.13					
Extraversion	-4.70	<.001	-.002	.001	-.15	-.01	-.14					
Agreeableness	3.67	<.001	.002	.001	.12	.15	.11					
UFOV × Age	14.04	<.001	.001	.001	.44	.40	.41					
Peak Acceleration (PA)												
Overall Model	17.24	<.001	1.47	-.09				66.95	7, 937	<.001	.33	.33
Attention Impulsivity	-3.43	.001	-.01	.003	-.10	-.003	-.09					
Openness	3.48	.001	.005	.002	.10	.004	.09					
Fitness	5.23	<.001	.04	.008	.45	.24	.14					
ID	17.44	<.001	.10	.006	.47	.47	.47					
Age × Fitness	-4.46	<.001	-.001	.001	-.53	-.23	-.12					
UFOV × Fitness	-2.60	.01	-.01	.005	-.22	.05	-.07					
UFOV × Fitness × Age	2.60	.01	.001	.001	.41	-.24	.07					
Peak Deacceleration (PD)												
Overall Model	9.99	<.001	1.24	.12				35.22	8, 936	<.001	.22	.21
Attention Impulsivity	-.21	.03	-.008	.004	-.07	-.01	-.06					
Agreeableness	2.15	.03	.004	.002	.07	.04	.06					
Openness	2.96	.003	.006	.002	.09	.03	.09					
Fitness	6.21	<.001	.06	.009	.57	.21	.18					
ID	12.02	<.001	.08	.007	.35	.35	.35					
Age × Fitness	-5.09	<.001	-.001	.001	-.66	-.16	-.15					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
UFOV × Fitness	-3.91	<.001	-.02	.006	-.36	.05	-.11					
UFOV × Fitness × Age	3.94	<.001	.001	.001	.69	-.17	.11					

Note: Only the final model for each variable is shown.

Table 16. UFOV Summary Table for the Distance Condition.

Variables	Δ*F*	ΔR^2	Δ adj. R^2
MT	-56.26	.01	.01
PropST	-1.19	.02	.01
CEPT	0	0	0
CEMT	0	0	0
VEPT	125.20	0	0
PV	-127.90	.01	0
tPV	5.95	.02	.02
tPA	4.57	.02	.02
PA	-24.91	.03	0
PD	-4.56	.02	.02

Similar to the speeded condition, greater UFOV scores led to increases in MT in the distance condition. However, instead of finding an age effect collapsed across ID, differences were not found between low and high older adults and overlapping confidence intervals between low and high groups for each age group do not suggest an age × UFOV effect. Instead individuals with greater UFOV scores took longer to make movements at all IDs than individuals with lower UFOV scores (Figure 45). Increases in MT for individuals with higher UFOV scores were due to increases in the proportion of time spent in the primary phase and not PropST.

Additionally, while no significant differences were found between low and high UFOV groups for younger or middle-age adults a significant effect of peak acceleration was found for older adults (Figure 46). Older adults in the high UFOV group had greater peak accelerations than older adults in the low UFOV condition.

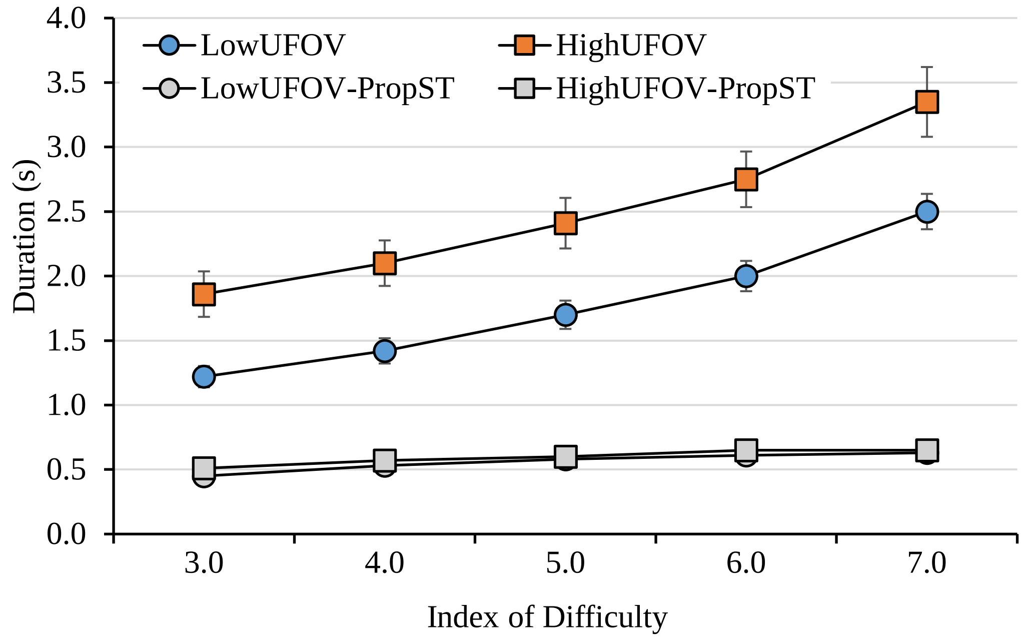


Figure 45. Distance Condition Movement time (MT) and PropST Split by UFOV Divided Attention Test Scores.

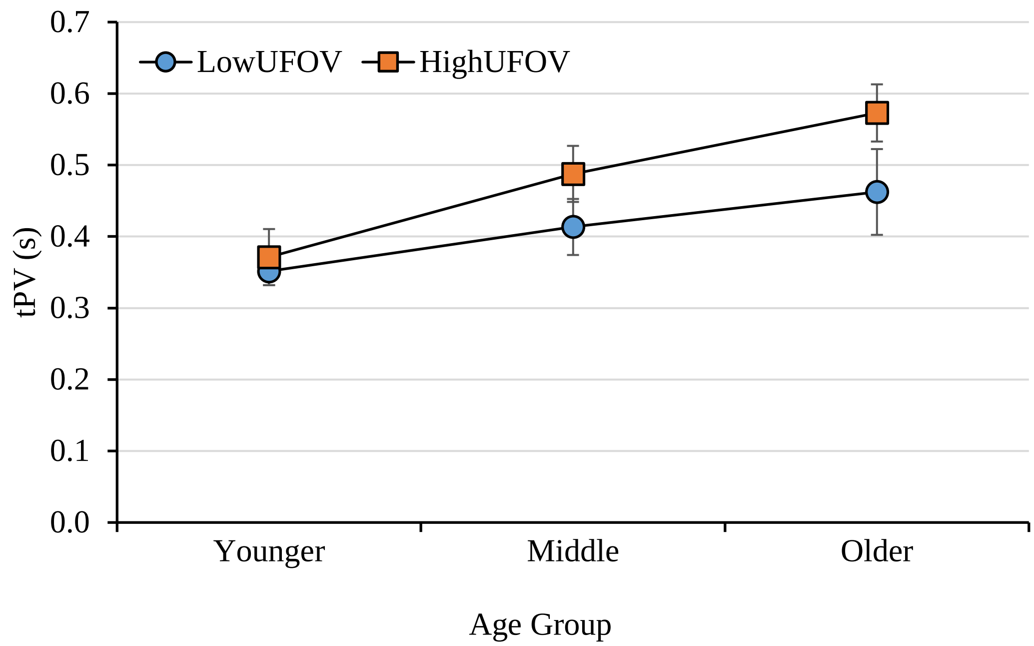


Figure 46. Distance Condition Time to Peak Velocity (tPV) for each Age-Group Split by UFOV Divided Attention Test Scores.

Width Condition.

In the width condition, significant main effects of UFOV were found for CEPT. UFOV × age interactions were found for MT, PropST, and PV. UFOV × ID interaction was found for MT, CEPT, PV. Finally, significant three way interactions for UFOV × fitness × age interactions were MT, PropST and PV (Table 17). The inclusion of UFOV into the model improved prediction for MT and CEPT as evidenced by a change in adj. R^2 of at least .02 (Table 18).

Table 17. Width Condition Regression Results with UFOV Added.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	6.84	<.001	.23	.03				50.71	8, 936	<.001	.30	.30
Attention Impulsivity	4.89	<.001	.005	.03	.15	.01	.13					
Agreeableness	2.06	.04	.001	.001	.07	.08	.06					
Conscientiousness	-2.20	.03	-.001	.001	-.07	.02	-.06					
Openness	-3.27	.001	-.002	.001	-.10	.04	-.09					
Age × Fitness	5.21	<.001	.001	.001	.43	.38	.14					
UFOV × ID	8.50	<.001	.009	.001	.29	.42	.23					
UFOV × Age	6.52	<.001	.001	.001	.40	.46	.18					
UFOV × Fitness × Age	-3.51	<.001	-.001	.001	-.40	.42	-.10					
Proportion ST (PropST)												
Overall Model	-.06	.95	-.002	.02				23.65	10, 934	<.001	.20	.19
Motor Impulsivity	4.60	<.001	.001	.001	.15	.04	.13					
Agreeableness	2.20	.03	.001	.001	.07	.08	.06					
Openness	-2.64	.009	-.001	.001	-.08	.005	-.08					
ID	3.69	<.001	.01	.003	.35	.29	.11					
UFOV	2.00	.04	.02	.01	.19	.24	.06					
Age × Fitness	3.41	.001	.001	.001	.60	.25	.10					
ID × Fitness	1.99	.04	.001	.001	.15	.13	.06					
Age × Fitness × ID	-2.29	.02	.001	.001	-.29	.34	-.07					
UFOV × Age	2.52	.01	.001	.001	.30	.27	.07					
UFOV × Fitness × Age	-2.00	.04	.001	.001	-.39	.28	-.06					
Constant Error (CE) PT												
Overall Model	2.04	.04	2.38	1.16				20.25	8, 936	<.001	.15	.14
Motor Impulsivity	-4.21	<.001	-.08	.02	-.15	-.03	-.13					
Non Planning Impulsivity	3.05	.002	.08	.03	.11	.05	.09					
Openness	4.65	<.001	.06	.01	.15	.05	.14					
Age	-5.93	<.001	-.03	.005	-.30	-.26	-.18					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Fitness	-4.40	<.001	-.38	.09	-.58	.12	-.13					
UFOV	-3.56	<.001	-2.13	.60	-.40	-.25	-.11					
UFOV × ID	-4.59	<.001	-.12	.03	-.18	-.26	-.14					
UFOV × Fitness	3.53	<.001	.17	.05	.42	-.07	.11					
Constant Error (CE) MT												
Overall Model	n.s.											
Variable Error (VE) PT												
Overall Model	n.s.											
Peak Velocity (PV)												
Overall Model	33.72	<.001	1.64	.05				38.02	6, 938	<.001	.20	.19
Attention Impulsivity	-4.16	<.001	-.008	.002	-.13	-.10	-.12					
Openness	4.60	<.001	.004	.001	.14	.03	.14					
Age × Fitness	-3.79	<.001	.001	.001	-.34	-.30	-.11					
UFOV × ID	-4.28	<.001	-.009	.002	-.16	-.29	-.13					
UFOV × Age	-6.25	<.001	-.001	.001	-.41	-.38	-.19					
UFOV × Fitness × Age	2.74	.006	.001	.001	.33	-.34	.08					
Time to Peak Velocity (tPV)												
Overall Model	n.s.											
Time to Peak Acceleration (tPA)												
Overall Model	n.s.											
Peak Acceleration (PA)												
Overall Model	17.83	<.001	2.02	.11				28.22	5, 939	<.001	.13	.12
Conscientiousness	2.25	.03	.004	.002	.08	.05	.07					
Openness	4.50	<.001	.008	.002	.15	.05	.14					
Attention Impulsivity	-3.54	<.001	-.01	.003	-.12	-.05	.11					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Fitness	5.85	<.001	.02	.003	.18	.17	.18					
Age × Fitness	-9.76	<.001	.001	.001	-.32	-.26	-.30					
Peak Deacceleration (PD)												
Overall Model												
Overall Model	13.60	<.001	1.55	.11				22.77	6, 938		.13	.12
Extraversion	-3.15	.002	-.006	.002	-.10	-.07	-.10					
Conscientiousness	3.99	<.001	.009	.002	.13	.05	.12					
Openness	5.02	<.001	.01	.002	.17	.06	.15					
Fitness	6.59	<.001	.03	.005	.29	.18	.20					
ID × Fitness	-3.21	.001	-.002	.001	-.14	.06	-.10					
Age × Fitness	-8.05	<.001	.001	.001	-.26	-.23	-.25					

Table 18. UFOV Summary Table for the Width Condition.

Variables	Δ*F*	ΔR^2	Δ adj. R^2
MT	8.77	.01	.02
PropST	-4.01	.01	.01
CEPT	-5.84	.03	.02
CEMT	0	0	0
VEPT	0	0	0
PV	-14.09	.02	.01
tPV	0	0	0
tPA	0	0	0
PA	0	0	0
PD	0	0	0

In the width condition, the same effect was found for UFOV scores as in the distance condition. Individuals in the high UFOV group had longer MTs than those in the lower UFOV group due to extended time spent in the primary movement phase and not PropST (Figure 47). Further, an age × UFOV × ID interaction was found for CEPT. Older adults with greater UFOV scores ended their primary phase further away from the target than any other age or UFOV group. This effect scaled with ID for older adults in the low UFOV group. No differences were found across ID for younger or middle-age adults regardless of UFOV group or older adults in the low UFOV group (Figure 48). This finding suggests that individuals with lower UFOV divided attention scores are able to process visual feedback of the target and their hand position better than older adults with worse UFOV scores. UFOV seemed to make an impact on CEPT only for older adults.

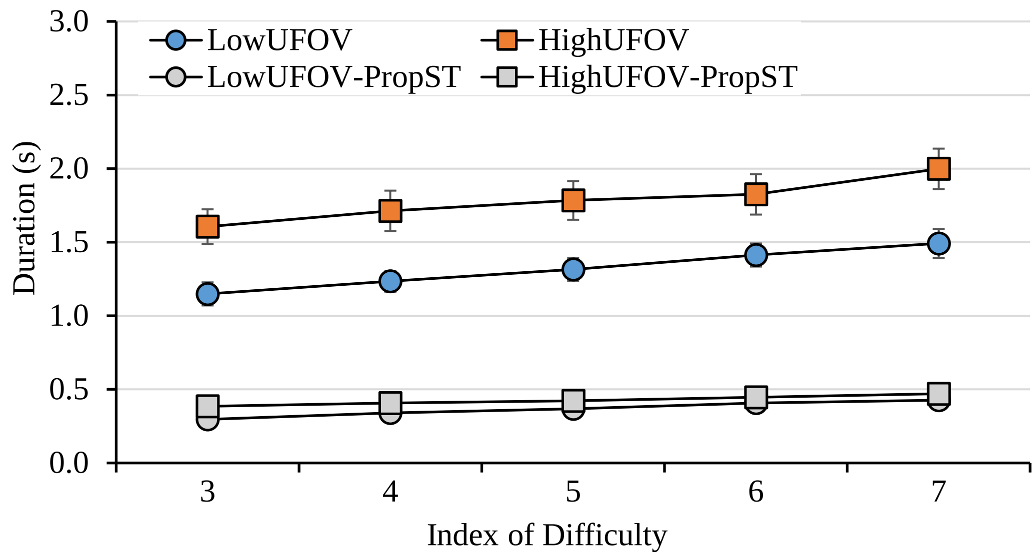


Figure 47. Width Condition Movement time (MT) and PropST Split by UFOV Divided Attention Test Scores.

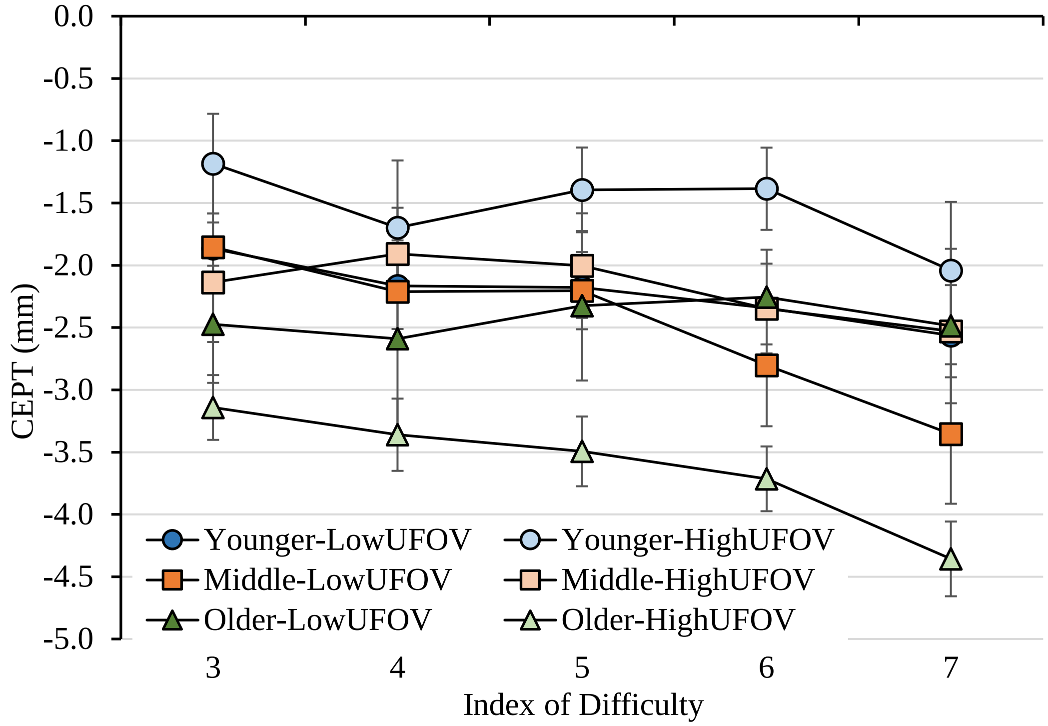


Figure 48. Width Condition CEPT Split by Age and UFOV Divided Attention Test Score.

Predictors of Fitness

To better understand the daily activities that predict cardiovascular fitness and may impact kinematic efficiency, a regression analysis was conducted. Self-reported physical activities and mental fitness activities were used as predictors of individuals' fitness score. Before completing the regression intercorrelations between physical (Table 19) and mental fitness (Table 20) activities were examined. In terms of physical activities time spent completing cardiovascular activities (e.g. walking & running), weight or resistance training, playing sports, and taking the stairs were all associated with greater fitness. On the other hand, taking a fitness class, yoga, or swimming were not associated with greater fitness in the current sample. While, this may indicate that these activities are not related to fitness lack of correlations could also be due to not specifically recruiting for participants who engaged in these specific activities. In terms of mental fitness activities, many of the activities that were hypothesized to improve cognitive health were negatively correlated with cardiovascular fitness. For example, greater education, time spend reading, completing puzzles, attending museums, or community events were all associated with lowered fitness. Conversely, learning a new skill and thinking deeply were weakly associated with greater fitness. These findings could be due to a limitation in recruitment for individuals who engaged in these activities across the age and fitness spectrum. Another reason for these findings could also be that mental fitness activities often lack physical movement and greater time engaging in these activities decreases the amount of time spent being physically active. Although, mental fitness activities mostly did not increase physical fitness these activities were more hypothesized to improve cognitive ability. Because no age or fitness effects were found for the proprioceptive pointing task and the UFOV divided attention scores showed the greatest age effect this score was also included with the mental fitness activities as a measure of cognitive ability. Greater education, attending classes, listening to music improved UFOV score. Listening to music was also found to be correlated with fitness and other physical activities. While greater education and lifetime learning was negatively associated with physical fitness these activities were associated with greater mental fitness. People may be more likely to listen to music while engaging in physical activities; thus, this finding may be related to physical activity instead of a specific effect of music listening itself. On the other hand, positive correlations were found for meditation, completing puzzles, visiting museums, and attending community events. These findings may be due to a limitation that this study did not specifically recruit for engagement in these activities.

The results of the regression between physical and mental fitness actives identified a combination of five activities that were able to predict 41% of the variance in cardiovascular fitness. Resistance or weight exercises, cardiovascular exercises, and taking the stairs were predictive of increased fitness while greater education and completing puzzles decreased fitness (Table 21). Based on these findings it seems activities that require movement or exercise are important for fitness.

In order to determine the daily activities that may improve mental fitness a backwards multiple regression was conducted on UFOV divided attention scores (Table 22). Self-reported physical activities and mental fitness activities were used as predictors of UFOV scores. The results of the regression analysis identified five activities that were able to predict 21% of the variance in UFOV scores. Individuals who engaged in Yoga, took the stairs more instead of the elevator, had more years of education, or experience playing a musical instrument showed lower UFOV scores. More experience visiting museums or attending plays increased UFOV scores. One potential reason could be due to the limitation that experience engaging in specific activities was not a specific recruitment criteria of the study. Another could be that attending a museum or watching a play is a passive activity while the others require effort and active participation. Overall it seems while physical activities may improve both physical and mental fitness, mental fitness activities only improved mental fitness.

Table 19. Correlations between Age, Fitness, and Self-reported Physical Activities.

#	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	Age	—											
2	Fitness	-.68**	—										
3	Seated Activity	-.09	-.007	—									
4	Hours of Sleep per Night	.17*	-.11	.001	—								
5	Upper Body Resistance	-.25**	.38**	-.15*	-.10	—							
6	Lower Body Resistance	-.31**	.37**	-.21**	-.10	.86**	—						
7	Cardiovascular Exercise	-.13	.37**	-.13	-.02	.46**	.44**	—					
8	Yoga	-.14	.004	.10	-.08	.17*	.15*	.10	—				
9	Taking a Fitness Class	.06	.07	.12	-.06	.20**	.23**	.22**	.35**	—			
10	Swimming	-.06	.06	.09	.05	.03	.07	.13**	.15*	.05	—		
11	Taking the Stairs	-.35**	.38**	.06	-.14	.24**	.20**	.18**	.17*	.009	.10	—	
12	Competitive Sports	-.29**	.36**	-.08	-.06	.27**	.31**	.20**	-.06	.01	.31**	.18*	—

Note: *p<.05, **p<.001.

Table 20. Correlations between Age, Fitness, UFOV and Mental Fitness Activities.

#	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Age	—																				
2	Fitness	-.69**	—																			
3	Years of Education	.66**	-.41**	—																		
4	Mindfulness or Meditation	.13	-.10	.10	—																	
5	Reading E-books	.28**	-.23**	.27**	.006	—																
6	Reading Paper Books	.07	-.01	.05	.20**	.004	—															
7	Playing a musical instrument	-.11	.09	-.07	.12	-.007	.15*	—														
8	Socializing	.03	.10	-.06	.19**	.04	.27**	.12	—													
9	Complete Cross-words or Puzzles	.35**	-.31**	.21**	.21**	.19*	.23**	.11	.003	—												
10	Playing Board Games	-.04	.01	-.03	.20**	-.02	.24**	.11	.21**	.38**	—											
11	Attending Talks or Classes	-.47**	.30**	-.31**	.08	.02	.37**	.14*	.19**	-.10	.21**	—										
12	Completing Brain-Games or Improve-ment Training	-.07	-.04	-.12	.20**	-.03	.05	.19*	-.09	.40**	.29**	.15*	—									
13	Writing	-.03	.04	-.04	.35**	-.06	.38**	.15*	.28**	.05	.21**	.29**	.21**	—								
14	Listening to Music	-.31	.22**	-.19**	.06	-.07	.15*	.27**	.28**	.003	.19**	.31**	.14	.29**	—							
15	Reading Scientific or non-fiction Mate-rial	.18**	-.03	.18**	.12**	.22**	.45**	.16*	.14	.15*	.24**	.18*	.03	.37**	.10	—						
16	Visiting Museums or Plays	.30**	-.13	.26**	.18*	.11	.35**	.19**	.11	.38**	.35**	.12	.26**	.30**	.14	.44**	—					
17	Using Non-domi-nant Hand	.003	-.02	-.07	.18*	.03	.16*	.11	.02	.08	.008	.12	.25**	.20**	.14	.26**	.12	—				
18	Trying to Learn a New Skill	-.11	.18*	-.12	.32**	.05	.20*	.24**	.12	.01	.25**	.38**	.21**	.32**	.19**	.32**	.28**	.32**	—			
19	Thinking Deeply	-.21**	.17*	-.13	.29**	-.03	.27*	.13	.22**	-.04	.19**	.33**	.12	.44**	.34**	.30**	.15*	.27**	.41**	—		
20	Attending Commu-nity Events	.46**	-.28**	.27**	.25**	.20**	.25**	.002	.30**	.30**	.16*	.02	.04	.23**	.06	.29**	.56**	.19**	.21**	.11	—	
21	UFOV Divided At-tention	.69**	-.53**	-.39**	.06	-.23**	.12	-.12	.02	.20**	-.05	-.25**	-.13	.06	-.27**	.12	.18*	.08	-.07	-.06	.33**	—

Note: *p<.05, **p<.001.

Table 21. Regression Results using Physical and Mental Fitness Activities to Predict Fitness.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Cardiovascular Fitness												
Overall Model	5.70	<.001	5.89	1.02				27.49	5, 183	<.001	.43	.41
Resistance or Weight training	2.41	.02	2.20	.88	.16	.38	.13					
Cardiovascular Exercises	2.20	.03	2.02	.90	.15	.38	.12					
Taking the Stairs	3.67	<.001	2.86	.77	.21	.38	.20					
Crosswords, Sudoku, or Logic Puzzles	-3.93	.003	-2.00	.52	-.22	-.31	-.21					
Education	-4.49	<.001	-.42	.10	-.25	-.41	-.24					

Table 22. Regression Results using Physical and Mental Fitness Activities to Predict UFOV Divided Attention Score.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
UFOV Divided Attention												
Overall Model	14	<.001	1.70	.12				11.20	5, 183	<.001	.23	.21
Yoga	-2.28	0.02	-.32	.14	-.15	-.12	-.15					
Taking the Stairs	-1.98	0.04	-.23	.12	-.13	-.23	-.13					
Playing a Musical Instrument	-2.11	0.04	-.22	.11	-.14	-.15	-.14					
Visiting Museums or Attending Plays	2.74	0.01	.30	.11	.20	.24	.18					
Years of Education	-4.16	<.001	-.06	.02	-.30	-.39	-.27					

Additional Analyses

Analyses that are related to the core research question but are not essential to the understanding of the relationship between age and fitness on kinematic performance are perused below.

Gender

Gender is an important individual difference. However, the current study was not able to recruit an equal amount of men (38.6%) and women (61.4%) to ensure an unbiased analysis of gender effects in the current study especially across age. These effects are examined to provide insights for future research. For all analyses Men are coded as 0 and women are coded as 1.

Speed Condition.

In the speed condition, the largest differences for gender were found for MT, PropST, and PD. Men increased at a greater rate than women for both variables. However, the results showed that the confidence intervals were overlapping indicating any differences that exist were small with low effect sizes. This aligned with estimates of sr^2 for gender. Thus, for this condition it is concluded that men and women do not significantly differ in their ability to produce a speeded movement. Table 23 shows the regression results for gender. Table 24 shows the summary of the model changes due to the addition to gender as a predictor. Figure 49 showed gender differences in MT and Figure 50 shows gender difference for PropST.

Table 23. Speeded Gender Regression Results.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	4.60	<.001	.12	.03				76.87	9, 935	<.001	.43	.42
Motor Impulsivity	-4.24	<.001	-.003	.001	-.12	-.22	-.11					
Agreeableness	2.73	.006	.001	.001	.08	.14	.07					
Conscientiousness	-2.56	.01	-.001	.001	-.08	.08	-.06					
Age	8.68	<.001	.002	.001	.43	.42	.22					
Gender	3.13	.002	.04	.01	.18	.-.57	.08					
Age × Gender	-4.00	<.001	-.001	.001	-.26	.12	-.10					
Distance × Age	6.34	<.001	.001	.001	.52	.59	.16					
Distance × Fitness	6.01	<.001	.001	.001	.32	.33	.15					
Distance × Fitness × Age	-2.85	.005	.001	.001	-.29	.55	-.07					
Proportion ST (PropST)												
Overall Model	5.80	<.001	.02	.003				66.83	3, 941	<.001	.18	.17
Age	10.29	<.001	.001	.001	.38	.37	.31					
Age × Gender	-5.15	<.001	.001	.001	-.17	.04	-.15					
Distance × Age	4.66	<.001	.001	.001	.15	.29	.14					
Constant Error (CE) PT												
Overall Model	-19.11	<.001	-10.63	.56				521.23	2, 942	<.001	.53	.52
Distance	22.11	<.001	1.25	.06	.83	.72	.50					
Distance × Age	-3.71	<.001	-.004	.001	-.14	.53	-.08					
Constant Error (CE) MT												
Overall Model	-9.87	<.001	-9.05	.92				654.19	2, 942	<.001	.58	.58
Age	-2.26	.02	-.04	.02	-.05	-.05	-.05					
Distance	36.10	<.001	1.20	.03	.76	.76	.76					
Variable Error (VE) PT												
Overall Model	20.89	<.001	.45	.02				67.98	8, 936	<.001	.37	.36
Motor Impulsivity	2.07	.04	.003	.001	.06	.03	.01					
Planning Impulsivity	-2.57	.01	-.005	.002	-.08	-.04	-.02					
Distance	8.45	.001	.009	.001	.51	.59	.32					
Age × Gender	2.18	.03	.001	.001	.17	-.03	-.07					
Gender × Fitness	3.57	.001	.007	.002	.19	-.02	-.02					
Gender × Distance	-2.12	.03	-.002	.001	-.11	.34	-.10					
Distance × Age	3.47	.001	.001	.001	.19	.51	.27					

Variables	t	p	B	$SE\ B$	β	Zero-order r	sr^2	F	df	p	R^2	adj. R^2
Age × Gender × Fitness	-3.52	<.001	.001	.001	-.33	-.05						
Peak Velocity (PV)												
Overall Model	42.40	<.001	1.80	.04				69.03	8, 936	<.001	.37	.37
Motor Impulsivity	3.93	<.001	.008	.002	.12	.20	.10					
Planning Impulsivity	-2.25	.025	-.006	.003	-.07	.08	-.06					
Age	-10.37	<.001	-.005	.001	-.43	-.39	-.27					
Gender	-2.47	.014	-.35	.14	-.60	.02	-.06					
Distance	17.27	<.001	.01	.001	.49	.49	.49					
Age × Gender	2.60	.009	.006	.002	.59	-.15	.07					
Gender × Fitness	2.21	.027	.03	.01	.47	.11	.06					
Age × Gender × Fitness	-2.22	.044	.001	.001	-.34	-.10	-.05					
Time to Peak Velocity (PV)												
Overall Model	3.74	<.001	.06	.016				45.25	10, 934	<.001	.33	.32
Motor Impulsivity	-2.47	.014	-.001	.001	-.08	-.16	-.07					
Attention Impulsivity	2.12	.034	.001	.001	.07	-.07	.06					
Extraversion	-2.34	.019	-.001	.001	-.07	-.02	-.06					
Agreeableness	2.07	.038	.001	.001	.06	.11	.06					
Age	6.23	<.001	.001	.001	.27	.28	.17					
Gender	2.04	.041	.06	.029	.52	-.01	.06					
Distance	17.75	<.001	.002	.001	.48	.48	.48					
Age × Gender	-2.33	.020	-.001	.001	-.55	.13	-.06					
Gender × Fitness	-2.29	.022	-.005	.002	-.51	-.08	-.06					
Age × Gender × Fitness	2.60	.010	.001	.001	.45	.09	.07					
Peak Deacceleration (PD)												
Overall Model	6.09	<.001	.12	.02				26.40	7, 937	<.001	.17	.16
Agreeableness	2.56	.011	.001	.001	.08	.13	.08					
Openness	-2.01	.045	.-.001	.001	-.06	.03	-.06					
Distance	9.59	<.001	.001	.001	.29	.29	.28					
Fitness	-5.09	<.001	-.004	.001	-.25	-.17	-.15					
Age × Gender	-3.97	<.001	-.001	.001	-.47	.09	-.12					
Gender × Fitness	-6.86	<.001	-.004	.001	-.35	-.10	-.21					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Peak Acceleration (PA)												
Overall Model	18.75	<.001	3.17	.17				43.97	8, 936	<.001	.28	.27
Motor Impulsivity	5.32	<.001	.014	.003	.18	.26	.15					
Planning Impulsivity	-2.53	<.001	-.009	.004	-.08	.11	-.06					
Age	-8.44	<.001	-.01	.001	-.67	-.47	-.23					
Gender	-4.43	<.001	-1.05	.25	-.93	-.03	-.09					
Distance	5.60	<.001	.004	.01	.13	.13	.13					
Fitness	-2.16	<.001	-.020	.009	-.19	.35	-.06					
Age × Gender	4.18	<.001	.012	.003	.45	-.22	.10					
Gender × Fitness	3.86	<.001	.07	.017	.47	.08	.08					
Peak Deacceleration (PD)												
Overall Model	23.39	<.001	2.71	0.12				86.79	4, 940	<.001	.27	.27
Conscientiousness	2.6	.01	.006	.002	0.08	-.09	.07					
Motor Impulsivity	3.78	<.001	.012	.003	0.12	.23	.11					
Age	-16.06	<.001	-.009	.001	-0.47	-.49	-.45					
Distance	4.72	<.001	.005	.001	0.13	.13	.13					

Note: only the final model for each variable is shown.

Table 24. Gender Summary Table for the Speeded Condition

Variables	ΔF	ΔR^2	Δ adj. R^2
MT	-34.87	0.01	0.01
PropST	-17.88	0.03	0.02
CEPT	0	0	0
CEMT	0	0	0
VEPT	-61.84	0.01	0
PV	-66.29	0	0.01
tPV	-28.82	0.01	0
tPA	-27.57	0.02	0.02
PA	-13.38	0.01	0.01
PD	0	0	0

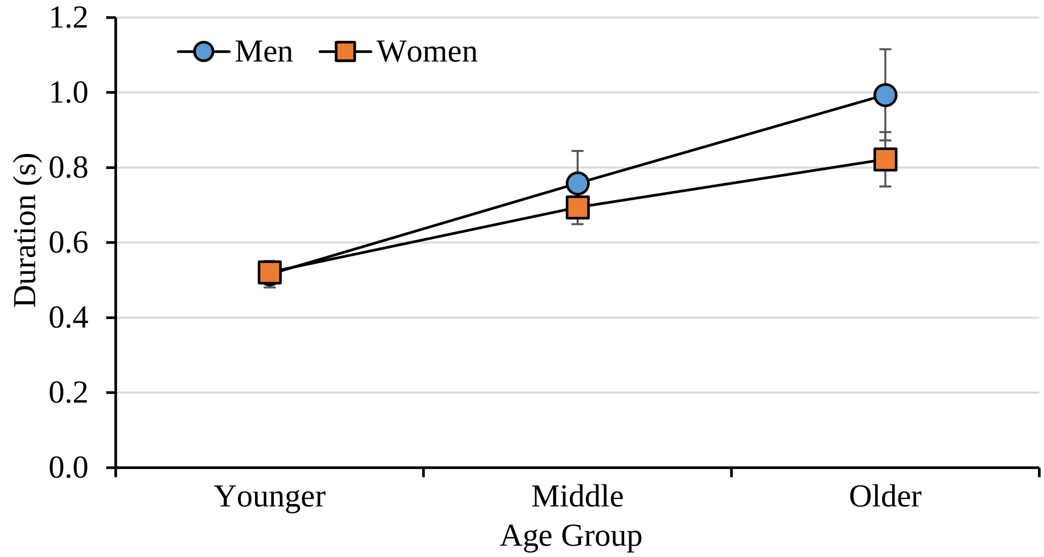


Figure 49. Speeded Condition Movement Time for Each Age-Group Split by Gender.

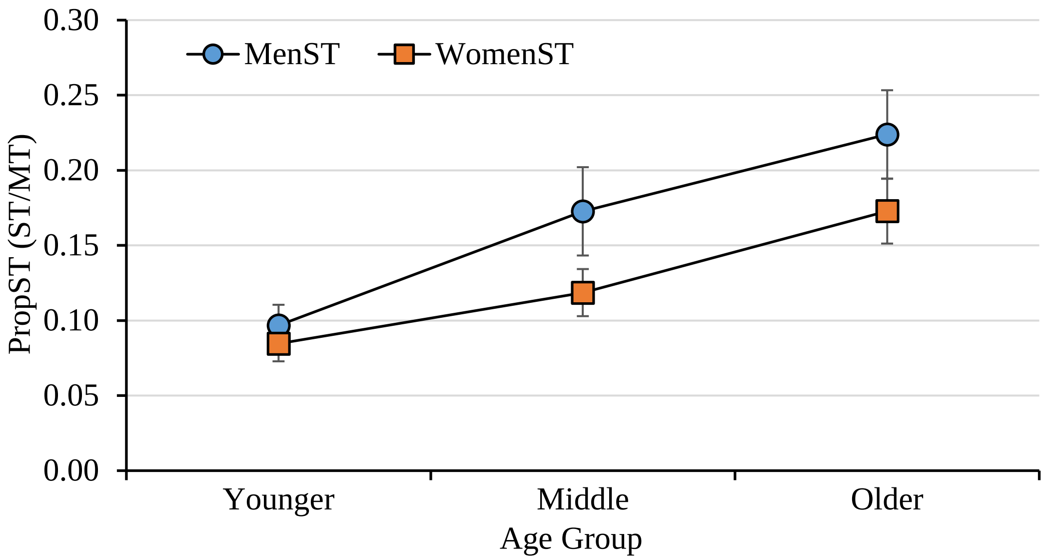


Figure 50. Speeded Condition PropST for Each Age-Group Split by Gender.

Distance Condition.

Similarly to the speeded condition effect sizes for gender were also small. The greatest increase in R^2 was for tPV and PD. The greatest estimate for sr^2 was for PD. At smaller ID values men and women showed similar accelerations and decelerations during their movements. However when were able to show greater tPV values at more difficult IDs. This effect was found to be small though due to overlapping confidence intervals. For PD at more difficult values of ID women showed a quicker time to decelerate while men had longer PD as ID increased. Table 25 shows regression results for the addition of gender. Table 26 shows the summary of the model changes due to the addition to gender as a predictor. Finally tPV values for men and women are shown in Figure 51 while PD values are shown in Figure 52.

Table 25. Distance Condition Gender Regression Results.

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	5.50	<.001	.39	.07				80.72	11, 933	<.001	.49	.48
Planning Impulsivity	2.23	.03	.003	.001	.07	-.03						
Attentional Impulsivity	2.10	.04	.002	.001	.06	-.07						
Agreeableness	2.77	.006	.002	.001	.08	.12						
Conscientiousness	-2.08	.04	-.002	.001	-.07	.05						
Openness	-2.08	.04	-.001	.001	-.05	.08						
Age	5.47	<.001	.002	.001	.35	.47						
Gender	-3.16	.002	-.12	.04	-.45	.06						
ID	20.68	<.001	.006	.001	.49	.49						
Fitness	-2.87	.004	-.008	.003	-.21	-.36						
Gender × Fitness	2.50	.012	.005	.002	.23	-.05						
Age × Gender × Fitness	3.58	<.001	.001	.001	.26	.22						
Proportion ST (PropST)												
Overall Model	10.70	<.001	.15	.01				24.00	7, 937	<.001	.15	.15
Motor Impulsivity	-2.90	.004	-.001	.001	-.10	-.009	-.09					
Planning Impulsivity	5.84	<.001	.003	.001	.22	.13	.18					
Extraversion	3.39	.001	.001	.001	.11	.07	.10					
Agreeableness	-2.15	.03	-.001	.001	-.07	-.06	-.07					
Age	5.34	<.001	.001	.001	.18	.12	.16					
Gender × ID	5.09	<.001	.001	.001	.17	.24	.15					
ID × Fitness	5.77	<.001	.001	.001	.20	.24	.17					
Constant Error (CE) PT												
Overall Model	-20.19	<.001	-30.13	1.50				335.16	1, 943	<.001	.26	.26
ID	18.31	<.001	5.26	.29	.52	.52	.52					

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Constant Error (CE) MT												
Overall Model	-24.31	<.001	-38.77	1.60				640.29	1, 943	<.001	.40	.40
ID	25.30	<.001	7.77	.31	.64	.64	.64					
Variable Error (VE) PT												
Overall Model	-18.65	<.001	-.49	.026				884.89	7, 937	<.001	.87	.87
Planning Impulsivity	2.74	.006	.003	.001	.034	.03	.03					
Attentional Impulsivity	2.01	.045	.002	.001	.025	.02	.02					
Age	5.67	<.001	.002	.001	.16	.05	.07					
ID	42.97	<.001	.18	.004	.93	.93	.51					
Gender × ID	-3.71	<.001	-.018	.005	-.18	.28	-.04					
Gender × ID × Fitness	3.08	.002	.001	.001	.14	.25	.04					
Age × Fitness × ID	-3.46	.001	.001	.001	-.11	.53	-.04					
Peak Velocity (PV)												
Overall Model	10.59	<.001	.58	.06				338.20	7, 937	<.001	.72	.71
Attentional Impulsivity	-3.98	<.001	-.008	.002	-.07	-.04	-.07					
Openness	2.31	<.001	.002	.001	.04	-.01	.04					
Age	-8.05	<.001	-.003	.001	-.22	-.21	-.14					
ID	34.63	<.001	.17	.005	.80	.81	.60					
Gender × ID	2.05	<.001	.02	.008	.15	.21	.04					
Gender × Fitness	-2.65	<.001	-.007	.003	-.12	-.01	-.05					
Age × Gender × ID	-2.24	<.001	.001	.001	-.11	.07	-.04					
Time to Peak Velocity (tPV)												
Overall Model	2.44	.02	.09	.04				57.06	9, 935	<.001	.36	.35
Attentional Impulsivity	6.06	<.001	.004	.001	.18	.007	.16					
Extraversion	-4.32	<.001	-.001	.001	-.12	-.01	-.11					
Agreeableness	4.13	<.001	.002	.001	.12	.15	.11					
Age	3.86	<.001	.001	.001	.27	.39	.10					

Gender	-3.56	<.001	-.05	.01	-.33	-.05	-.09					
ID	14.02	<.001	.002	.001	.37	.37	.37					
Fitness	-3.54	<.001	-.005	.002	-.26	-.26	-.09					
Age × Gender	-4.42	<.001	-.001	.001	-.42	.13	-.12					
Age × Gender × Fitness	5.39	<.001	.001	.001	.59	.11	.14					
Time to Peak Acceleration (tPA)												
Overall Model	-1.10	.27	-.03	.026				37.06	6, 938	<.001	.19	.19
Motor Impulsivity	-4.79	<.001	-.002	.001	-15	-.01	-.14					
Planning Impulsivity	3.65	<.001	.002	.001	.12	.15	.11					
Attentional Impulsivity	3.31	<.001	.002	.001	.12	-.07	.10					
Extraversion	-4.13	<.001	-.004	.001	-.15	-.15	-.12					
Agreeableness	4.53	<.001	.004	.001	.15	-.002	.13					
Age	13.07	<.001	.001	.001	.42	.37	.38					
Peak Acceleration (PA)												
Overall Model	27.01	<.001	2.19	.08				43.23	10, 934	<.001	.32	.31
Attentional Impulsivity	-3.55	<.001	-.01	.003	-.10	-.003	-.10					
Openness	3.10	.002	.005	.002	.09	.004	.08					
Age	-6.72	<.001	-.005	.001	-.36	-.29	-.18					
Gender	-2.61	.009	-.43	.17	-.67	-.010	-.07					
Age × Gender	3.30	.001	.008	.003	.78	-.22	.09					
Gender × Fitness	2.81	.005	.04	.01	.63	-.03	.08					
Gender × ID	2.50	.013	.004	.001	.12	.24	.07					
ID × Age	3.94	<.001	.001	.001	.20	.23	.11					
Age × Gender × Fitness	-4.42	<.001	-.001	.001	-.77	-.21	-.12					
ID × Fitness	4.57	<.001	.001	.001	.21	.46	.12					
Peak Deacceleration (PD)												
Overall Model	10.58	<.001	1.42	.13				37.30	7, 937	<.001	.22	.21

Attentional Impulsivity	-2.38	.02	-.009	.004	-.07	-.01	-.07
Agreeableness	2.47	.01	.005	.002	.08	.04	.07
Openness	2.70	.007	.005	.002	.08	.03	.08
Fitness	2.73	.006	.01	.004	.11	.21	.08
ID	12.03	<.001	.08	.007	.35	.35	.35
Age × Gender	-4.16	<.001	-.002	.001	-.17	-.22	-.12
Age × Fitness	-6.17	<.001	.001	.001	-.19	-.16	-.18

Table 26. Distance Condition Gender Regression Summary.

Variables	Δ*F*	ΔR^2	Δ adj. R^2
MT	-67.08	0	0
PropST	0.5	-0.03	-0.03
CEPT	0	0	0
CEMT	0	0	0
VEPT	120.65	0	0
PV	-126.02	0.01	0
tPV	-3.73	0.02	0.01
tPA	0	0	0
PA	-48.63	0.02	-0.02
PD	-2.48	0.02	0.02

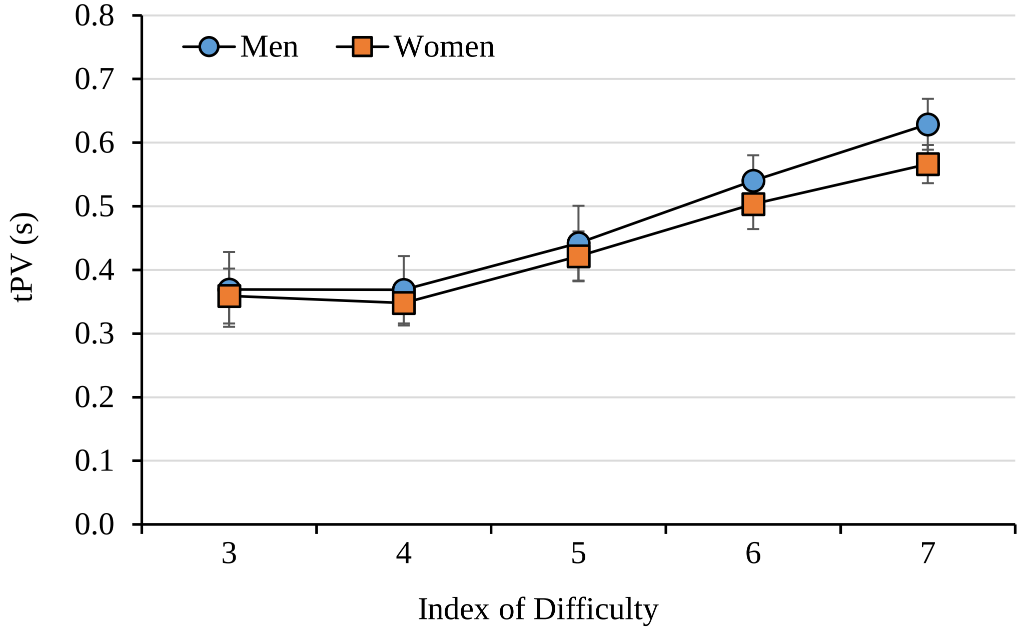


Figure 51. Distance Condition Time to Peak Velocity (tPV) Split by Gender for each ID Value.

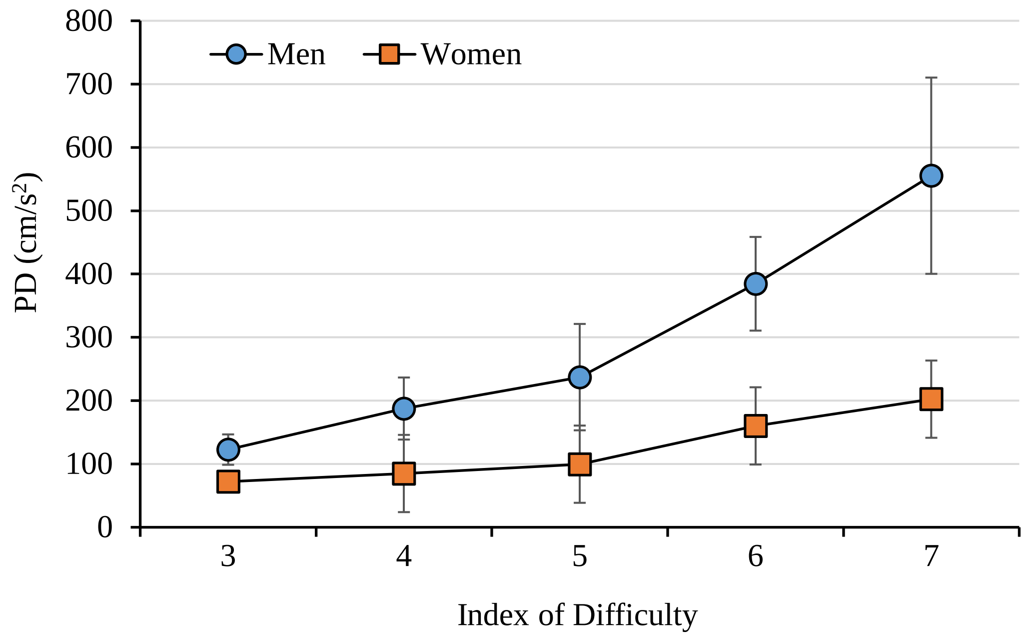


Figure 52. Distance Condition Peak Deceleration (PD) Values Split by Gender.

Width Condition.

Gender showed the greatest impact to kinematic performance in the width condition. Small to moderate estimates for sr^2 were found for several gender factors. Age × gender interactions were found for MT and PV, a gender × fitness interaction was found for PropST, and a gender × ID interaction was found for PA (Table 27). PropST and PA show the greatest increases in model R^2 due to the addition of gender (Table 28). For MT, older adults were the only group to show gender differences. Older women had longer MT than older men, but overlapping error bars indicated that these differences were small (Figure 53). These age differences for older adults were also shown with PropST indicating older women spent a longer time in the secondary movement phase than older men did. Taken together with the findings for MT the data may indicate differences in movement strategy for older men and women. However, the error bars for PropST were also overlapping indicating a small effect (Figure 54). Differences between genders were found for PropST once groups were split by a median split on cardiovascular fitness score. Less fit men spent longer in PropST than more fit men while, conversely, more fit women spent longer in PropST than less fit women leading to the gender × fitness interaction (Figure 55). Men showed greater time to peak acceleration than women for all ID values except for the ID value of 6 (Figure 56).

Table 27. Width Condition Gender Regression Results

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Movement Time (MT)												
Overall Model	7.14	<.001	.25	.04				50.01	8, 936	<.001	.30	.29
Attentional Impulsivity	4.79	<.001	.005	.001	.15	.01	.13					
Agreeableness	2.31	.021	.001	.001	.08	.08	.06					
Conscientiousness	-3.48	.001	-.002	.001	-.12	.02	-.10					
Openness	-2.82	.005	-.001	.001	-.08	.04	-.08					
ID	2.80	.005	.008	.003	.11	.22	.08					
Age × Gender	5.69	<.001	.001	.001	.21	.26	.16					
ID × Age	3.58	<.001	.001	.001	.22	.48	.10					
Age × Fitness	6.25	<.001	.001	.001	.30	.38	.17					
Proportion ST (PropST)												
Overall Model	-1.77	.077	-.04	.024				30.20	8, 936	<.001	.21	.20
Motor Impulsivity	4.33	<.001	.001	.001	.14	.04	.13					
Agreeableness	2.10	.036	.001	.001	.07	.08	.06					
Openness	-2.18	.03	-.001	.001	-.07	.005	-.06					
Age	6.99	<.001	.001	.001	.74	.26	.20					
Fitness	5.23	<.001	.005	.001	.39	-.10	.15					
ID	7.25	<.001	.012	.001	.41	.29	.21					
Gender × Fitness	4.50	<.001	.001	.002	.16	.001	.13					
Age × Fitness × ID	-2.46	.014	.001	.001	-.22	.34	-.07					
Constant Error (CE) PT												
Overall Model	-2.99	.003	-1.84	.62				26.09	5, 939	<.001	.12	.12
Motor Impulsiveness	-4.24	<.001	-.08	.02	-.15	-.25	-.14					
Planning Impulsivity	2.54	.01	.06	.03	.09	.05	.08					
Openness	4.70	<.001	.06	.01	.15	.05	.15					
Age	-10.94	<.001	-.04	.003	.41	-.26	-.34					
ID × Fitness	-5.05	<.001	-.02	.003	.18	-.006	-.16					
Constant Error (CE) MT												
Overall Model	n.s.											

Variables	*t*	*p*	*B*	*SE B*	*β*	Zero-order *r*	sr^2	*F*	*df*	*p*	R^2	adj. R^2
Peak Velocity (PV)												
Overall Model	25.56	<.001	1.54	.06				36.98	6, 938	<.001	.19	.19
Attentional Impulsivity	-3.46	.001	-.007	.002	-.11	-.01	-.10					
Conscientiousness	2.08	.038	.002	.001	.07	-.006	.06					
Openness	3.96	<.001	.004	.001	.12	.03	.12					
Age × Gender	-4.77	<.001	-.001	.001	-.17	-.22	-.14					
ID × Age	-4.94	<.001	.001	.001	-.22	-.36	-.15					
Age × Fitness	-5.51	<.001	.001	.001	-.23	-.30	-.16					
Time to Peak Velocity (tPV)												
Overall Model	n.s.											
Time to Peak Acceleration (PA)												
Overall Model	n.s.											
Peak Acceleration (PA)												
Overall Model	21.98	<.001	2.30	.11				27.05	6, 938	<.001	.15	.14
Attentional Impulsivity	-3.56	<.001	-.01	.003	-.12	-.05	-.11					
Conscientiousness	3.04	.002	.006	.0023	.10	.05	.09					
Openness	3.93	<.001	.007	.002	.13	.05	.12					
Gender × ID	-6.33	<.001	-.06	.009	-.49	-.07	-.19					
Age × Fitness	-11.26	<.001	-.001	.001	-.38	-.26	-.34					
Gender × ID × Fitness	4.22	<.001	.003	.001	.33	-.008	.13					
Peak Deacceleration (PD)												
Overall Model	15.33	<.001	2.13	.14				23.28	7, 937	<.001	16	15
Attentional Impulsivity	-2.22	<.001	-.01	.004	-.07	-.01	-.07					
Agreeableness	-2.02	<.001	-.005	.002	-.07	-.02	-.06					
Conscientiousness	4.53	<.001	.01	.003	.17	.05	.14					
Openness	3.79	<.001	.008	.002	.12	.06	.11					
Age × Gender	-3.25	<.001	-.002	.001	-.16	-.22	-.10					
Gender × ID	-2.68	<.001	-.02	.007	-.14	-.13	-.08					
Age × Fitness	-9.24	<.001	-.001	.001	-.34	-.23	-.28					

Table 28. Width Condition Gender Regression Summary Table

Variables	ΔF	ΔR^2	Δ adj. R^2
MT	8.07	0.01	0.01
PropST	2.54	0.02	0.02
CEPT	0	0	0
CEMT	0	0	0
VEPT	0	0	0
PV	-15.13	0.01	0.01
tPV	0	0	0
tPA	0	0	0
PA	-1.17	0.02	0.02
PD	-1.22	0	0

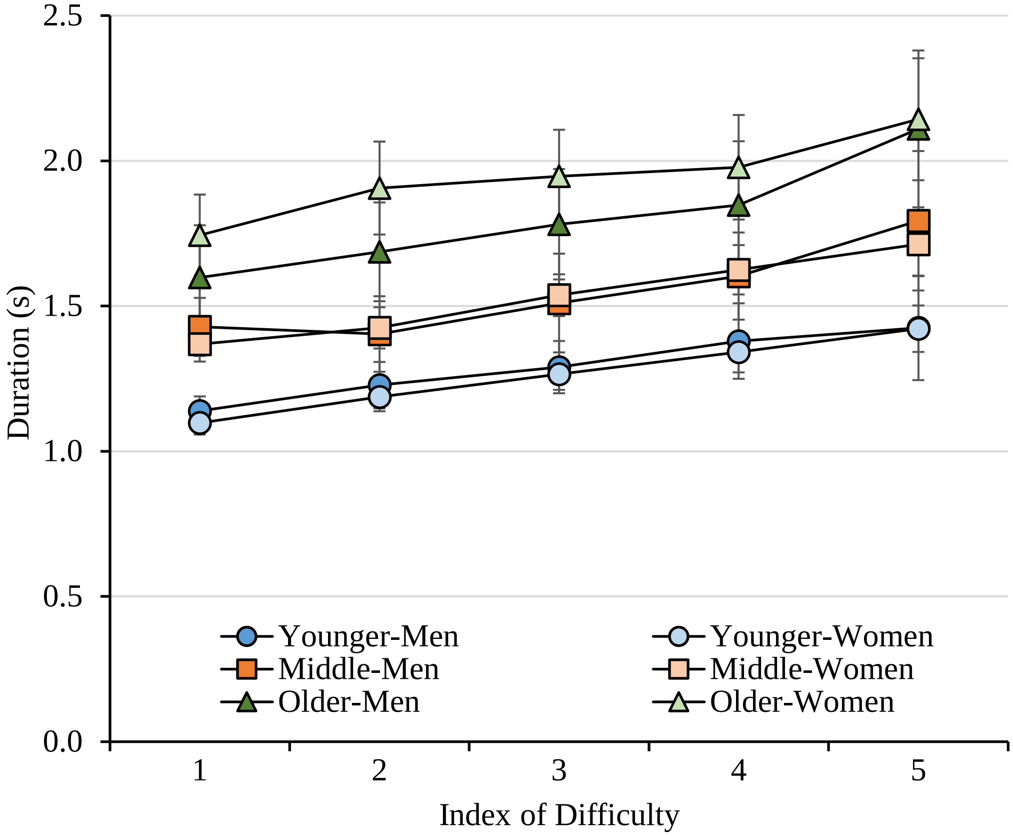


Figure 53. Width Condition MT Split by Age-Group and Gender.

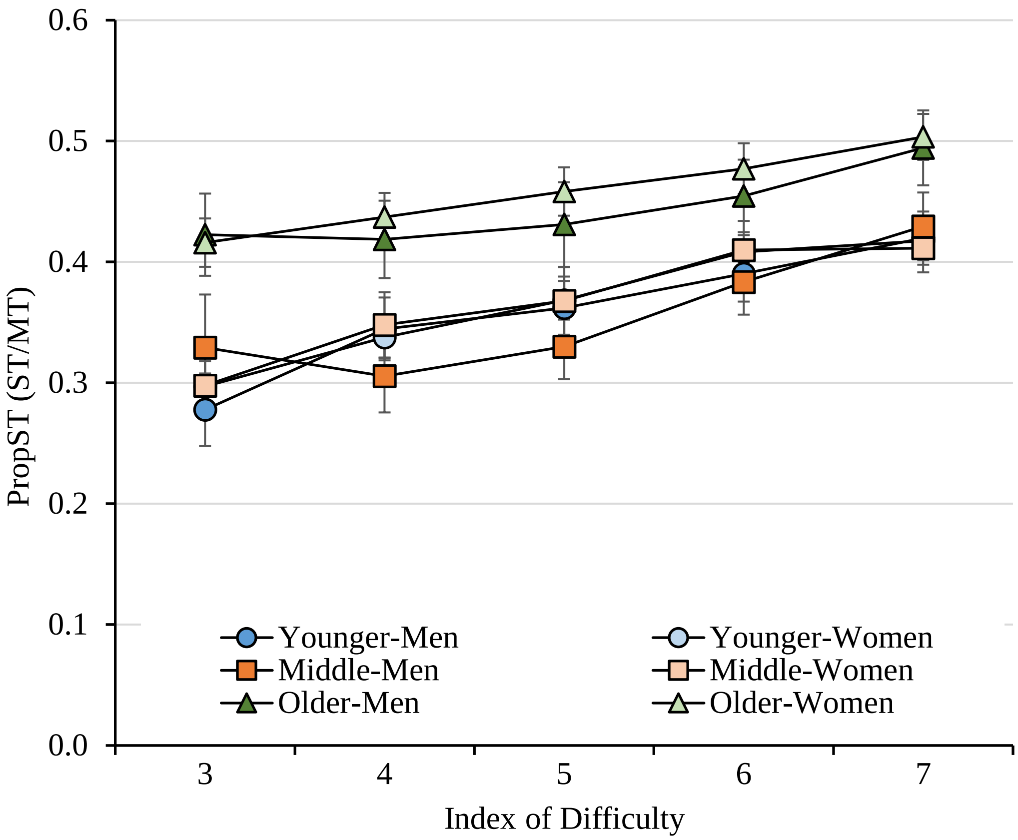
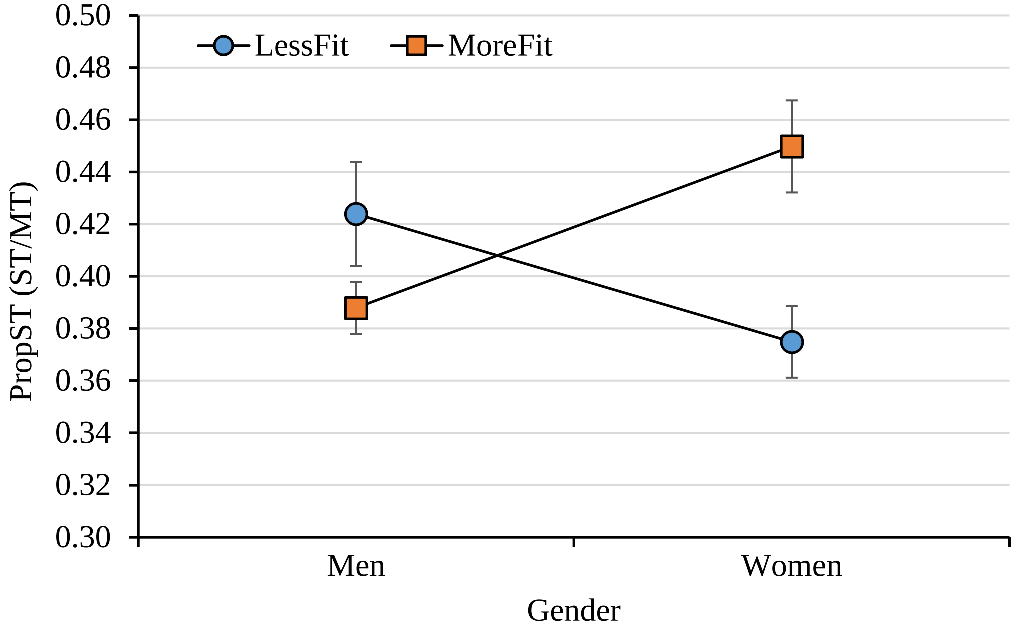


Figure 54. Width Condition PropST Split by Age-Group and Gender.



Note: Y-axis does not start at 0.

Figure 55. Width Condition PropST Split by Fitness and Gender.

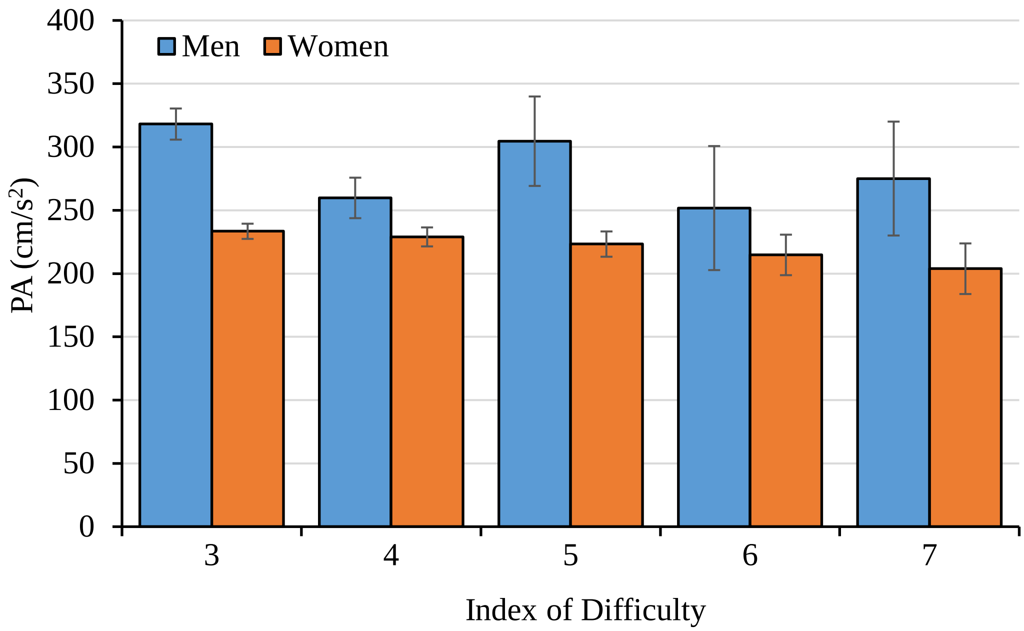


Figure 56. Peak Acceleration (PA) for each ID Split by Gender.

CHAPTER FIVE: CONCLUSIONS

Review of Study Goals and Hypotheses

As people age, they become slower and less adaptable to physical and cognitive performance demands. This leads to difficulties completing goal-directed pointing movements, especially at more difficult ID values. Studying these movements and uncovering the reasons why this occurs is important because these simple actions mediate our everyday experience. Thus, understanding how the aging process effects these movements can provide broad benefits. These include taking the first step in creating targeted interventions to attenuate sensorimotor decline improving older adults' functional independence and also developing testing methods for sensory and motor ailments. The specific goal of this dissertation was to examine the effects of movement constraints on goal-directed kinematic performance over the lifespan.

Several competing hypotheses have emerged in an effort to explain the mechanisms behind age-related declines in goal-directed movement performance. First, Fitts' law predicted that the index of difficulty (ID) would be the strongest predictor of movement time. Thus, both distance and width would affect movements similarly. The effector constraint hypotheses stated that movement time increases because older adults have difficulties due to inefficiencies of the motor system. Thus, distance would lead to more difficulty with age. Finally, the task constraint hypothesis, the rival of the effector constraint hypothesis, stated that target size and not distance taxes the sensory-visual feedback processing systems that are known to decline with age. Thus, as people age it is the width parameter instead of distance that drives aging-related declines. Performance in aiming tasks where ID was manipulated by Distance or Width was contrasted with a speeded only condition that examined people's physical ability to make fast speeded movements.

Another topic of interest was the role both cardiovascular and mental fitness may play in attenuating age-related performance declines. As Xenophon's quote of Socrates' underscored physical fitness may increase the body's resiliency to stress and other negative effects leading to improved cognition. Many people engage in many everyday activities with the intent that they will improve their physical and cognitive health, but little is known regarding how well these activities transfer to measurable increases in health and cognition. Finding activities that are associated with improved motor performance and cognition sets the stage for future studies to engage in in-depth testing and longitudinal intervention studies. Participants were asked how much time they spent engaging in common physical and mental fitness activities and these activities were used to predict non-exercise cardiovascular fitness scores and UFOV divided attention scores (as a measure of mental fitness). Both fitness measures were used as key predictors of performance.

Finally, this dissertation attempted to control for methodological limitations in other work that has examined the effect of physical activity on pointing movements. In these initial works participant physical motion was limited, only limited number of ID values were used, participants did not vary greatly in their physical activity scores between fitness groups, and this work did not separate movement constraints. This study, utilized a Wacom Intuos XL Tablet allowing distances up to 32cm to be used to overcome issues of a lack of physicality. It used five separate ID values were used, from ID = 3 to ID = 7), to overcome issues limitations of a lack of range in difficulty. Cardiovascular fitness equivalence scores were used to overcome a lack of variability in fitness, and finally the current dissertation used separate pointing tasks for distance and width while controlling for ID to identify which spatial parameter led to pointing performance declines.

Interpretation of Study Results

Analysis of Study Hypotheses

The Fitts' Law Hypothesis that ID and not the type of movement constraints (distance or width) were responsible for increases in movement time and decreases in efficiency, was not supported (H1). While ID was found to be associated with greater MT in both the distance and width condition and distance was associated with greater MT in the speeded only condition these changes were not equal across conditions. The distance constraint influenced the ID-MT slope more than in the width condition. PropST was also affected to a greater degree in the distance condition than in the width condition. The width constraint was associated with increasing PA to a greater degree than ID alone. In terms of the regression analyses, movement constraint type showed larger beta weights for PropST, and PV than ID alone.

Therefore, it must be concluded that movement performance was affected differently deepening how ID was manipulated. Overall increasing distance affected movement time more than decreasing the target size. This was especially true as difficulty increased. Movement times (MT) at ID values of 3 and 4 were similar between manipulations of distance and width. However, for ID values of five or greater distance manipulations led to greater increases in MT than manipulations of target size.

In terms of Age and fitness analyses of each of the conditions separately in order to examine the effector and task constraint hypotheses. First, older adults' ability to complete speeded movements as distance increased was tested. Even without any explicit target to constrain accuracy older adults moved more slowly and were more likely to make movements at larger IDs in two separate phases. One possibility for the finding that older adults were not able to make fast speeded movements could be a general speed of processing decline (Salthouse, 2009). However, it is noted that no differences were found with age on the UFOV speed of processing test which argues against a processing difference. This finding supported the effector constraint hypothesis (H2a) because distance was shown to degrade performance without specific processing speed declines. As distance increased a greater force was required to propel the effector. This led distance to significantly increase the peak acceleration required during each movement. Because these movements did not have any specific accuracy requirements their inability to make these movements as quickly as younger adults may be due to an inability to produce the same amount of initial motor force as younger participants, which would be consistent with previous work (Pratt, Chasteen, & Abrams, 1994; Walker, Philbin, & Fish, 1997). However, in the current study in the speeded task as age increased time to peak velocity decreased and peak acceleration and deceleration decreased indicating that older participants produced more force than younger participants, but they did so with less fine control over the timing of the force produced. Older adults were also most likely to engage a secondary phase by inserting a deceleration into their movement although one was not needed. These findings may suggest that older adults became fatigued at longer distances and needed a deceleration phase before reaccelerating to cross the line. Overall, the findings that older adults did not move as efficiently as younger adults in this condition.

The speeded condition was modeled on Van Halewyck et al. (2015). This study found MT between younger and older adults were similar when participants were instructed to move as quickly as possible without accuracy. Two differences between the current and this previous study may explain this finding. First, the task in the current study was more physically demanding and second the current task used several ID values which allowed for greater demands. Because the current study found that older adults had longer MT and PropST values especially at longer distances, the explanation that inefficiencies in pointing tasks are not due to declines in physical ability cannot be ruled out.

Next, differences for distance constraints were compared in terms of age and fitness in order to test the second part of the effector constraint hypothesis to be tested (H2b). This hypothesis was supported by the study data. Age significantly increased movement time in the distance condition. However, middle-aged adults did not differ from younger or older adults. Older adults, however, showed significantly greater peak acceleration and decelerations indicative of a decreased ability to scale the initial motor impulse to the appropriate distance. This finding was consistent with the speeded only condition. To control both PA and PD agonist and antagonist muscles have to work together in order to guide the effector to the target. Because of this the kinematic profile is affected by biomechanical properties (Dounskaia, Wisleder, & Johnson, 2005). Finding that older adults showed greater PA and PD indicated a decreased ability to coordinate these muscles while moving toward a target.

Overall MT increased with age and ID. Younger adults showed a lower PropST at easier ID values, but for more difficult ID values PropST did not differ across age for a given ID. Older adults showed greater PT than younger adults while middle-age adults did not differ from younger or older groups. For ST, older adults were significantly greater than younger or middle-age adults. ST increased more quickly with difficulty for older but not younger adults. In other words, older adults showed a slightly greater ID-MT slope than younger or middle-age adults. However, distance had a large effect on the movement for all age groups.

Next, the task constraint hypothesis was examined. Overall, this hypothesis was supported. When ID was manipulated by width rather than distance, MT increased with age similarly to the distance condition, but MT were shorter than when ID was manipulated by distance alone. MT for older adults was significantly greater than middle-age and younger groups across ID. For more difficult IDs however, MT confidence intervals did overlap between middle-age and older adults which may indicate that these groups did not significantly differ. For PT, younger adults showed a shorter time spent in the primary phase than middle-age or older adults for all ID values. However, for ST younger and middle-age adults showed overlapping confidence intervals across all IDs. Younger and middle-age adults also did not show statistically significant increases in PropST as ID increased. This suggests that width constraints were only a task constraint for older adults due to declines in sensory information processing. This finding supports the task constraint hypothesis because it shows performance for older adults declined more than younger adults in the width condition.

This difference between the width and distance conditions found for older adults supports previous studies on age-related neurological changes. For example, fMRI studies have found declines in sensory processing regions (e.g. posterior parietal and dorsal processing stream) occur more rapidly than in motor processing regions (Geerligs, Maurits, Renkenm, & Lorist, 2014;

2015; Vernooij et al., 2009; Ziegler et al., 2012). Thus, greater PropST in the older condition for width rather than distance supports these brain findings.

UFOV divided attention scores were found to be a significant predictor of kinematic performance. UFOV performance was more predictive of performance when ID was manipulated by width than distance, further adding support that as difficulty increases to a task constrained movement more online feedback control is needed. This finding supported the second part of the task constraint hypothesis (H3b). Lower UFOV scores indicate more efficient speed of processing, executive control, faster processing of information in ones periphery and found to impact many activities that older adults engage in everyday (e.g. Edwards et al., 2006). In the current study, more efficient visual processing evidenced by lower UFOV scores was associated with decreased movement time in all movement conditions for older adults. Additionally, similar findings to fitness were found for UFOV. Older adults with lower UFOV scores had greater PV in the speeded condition, lower peak acceleration in the distance condition, and were less likely to under shoot the target in the width condition. While limited research exists connecting UFOV scores to goal-directed motor performance and kinematics, applied research has linked better UFOV performance to fewer driving errors (Gamache, Hudon, Teasdale, & Simoneau, 2010; Hoggarth, Innes, Dalrymple-Alford, Severinsen, & Jones, 2010) which relies on efficient connections between sensory and motor systems. The current study extends this work by showing that UFOV performance can be predictive of motor performance. Although UFOV was associated with differences in motor performance no findings were found for the proprioceptive task contrary to the task constraint hypothesis. It was hypothesized that the integration of both proprioceptive and vision would be needed for successfully moving to smaller targets. Previous work on proprioceptive pointing indicates that proprioceptive information carries more weight when moving from left to right while vision is weighted more heavily for depth movements (van Beers, Haggard, & Wolpert, 2002). However, this was not found in this study.

Next, both of the objective 2 hypotheses were examined: (1) the physical fitness hypothesis (H4) and (2) the mental fitness hypothesis.

Only limited effects of cardiovascular fitness were found in the speeded condition. These differences were only found for older adults. More fit older adults took longer to achieve peak acceleration and were more constant in their movements which may indicate a greater level of movement control in this condition. Fit older adults showed PA values that were similar to less fit younger adults showing a strong attenuation in age-related changes in movement planning. One previous study associated motor declines with lowered fitness and greater mortality rates (Dumurgier et al., 2009). The current finding that cardiovascular fitness also extends to speeded movement performance may provide useful indicators of physical health.

Next, cardiovascular Fitness effects in the width condition were shown to be small and although several of the fitness interactions were significant overlapping confidence intervals provided evidence against a supportive fitness effect in this condition.

The greatest effects of cardiovascular fitness were found in the distance condition. Age was associated with decreased time to peak velocity and acceleration and age × fitness interactions showed significant differences related to fitness only for older adults. While less fit older adults showed decreased peak velocity and acceleration, but no significant differences in tPV or tPA were found across ID values. This suggests that while less fit older adults achieved the same peak movement amplitude timing they did so with force which may conserve energy. Additionally, it was found that lower fit older adults showed greater end-point variability indicating less control over the movement. This finding matches findings from the literature (e.g., Ketcham et al., 2002) which found that across ID older adults showed decreased PV without differences in tPV. This was the case when after separating the distance and width parameters. Greater cardiovascular fitness has previously been found to improve motor planning (Hillman, Weiss, Hagberg, & Hatfield, 2002). The current results support this idea because initial velocity and acceleration are planned before movement initiation and online feedback control occurs later in the movement. Older adults with greater cardiovascular fitness has longer time to peak velocities, time to peak acceleration, and deceleration than less fit older adults. The strategy of reaching peak velocity earlier in the movement may be inefficient and take more energy to sustain than a more controlled acceleration and deceleration toward the target. For overall movement time, less fit older adults showed greater movement times than more fit older adults which scaled with increasing ID. Although this difference was not statistically significant due to overlapping confidence intervals, it is suggestive of a potential fitness benefit that could be examined in a future study.

Next, participation in cardiovascular exercises such as walking, running, taking the stairs, and bicycling, strength training along with engagement in non-active activities were able to predict 41% of the variance in cardiovascular fitness score. This finding supports previous work showing increased physical activity may mediate physical health through improving cardiovascular fitness. Because greater fitness was associated with more efficient motor-planning ability in older adults' engagement in exercise may attenuate movement declines due to inefficient planning. Previous research has connected greater fitness mediated through greater engagement in cardiovascular activities with greater motor control. In one particular study of distance runners showed greater functional connectivity in both the frontoparietal and motor networks in young adults (Raichlen et al., 2016). This suggests a potential mechanism for greater fitness and physical activity to improve movements in the distance condition. This mechanism may also work in conjunction with local peripheral changes due to strength and resistance training. Bouchard & Janssen (2015) found that specific strength and resistance exercises were the best at preventing declines in muscle density such as sarcopenia in older adults. Many of the exercising participants in the current study did not only complete one specific type of exercise which was evident from the moderate correlations between activates. Thus, older adults with greater levels of fitness are likely to engage in cardiovascular activities to strengthen sensory and motor brain networks while complete strength activities that improve local muscle strength and coordination.

Greater physical fitness effects were observed in the distance condition rather than the speed or with conditions in the current study. While this may suggest fitness effects were limited to physical or motor health and not cognitive improvements there were significant moderate and positive correlations found between fitness, physical activities and UFOV scores. For example, taking the stairs showed a negative correlation with UFOV divided attention scores (r = -.23, p = .001) indicating it improved visual processing efficiency. Further, negative correlations (r = -.18, p = .013) were observed for strength training activities as well. This argues for a more global effect of fitness rather than one limited to physical health. One particular reason may be the limited effect width had on the movement even at an ID of 7. Larger effects on processing speed may be shown at greater ID values (i.e. smaller targets alone), those that combine both a large distance with smaller targets, or situations where cognitive resources are taxed allowing width effects to compete for other demands. The findings for the physical fitness hypothesis supported fitness improving effector efficiency (H4a) and partially supported fitness benefits for cognitive feedback efficacy (H4b). While fitness effects were not found directly on movement performance in the width condition. Indirect effects may have occurred mediated through UFOV score. Thus, it is concluded that generalized hypothesis (H4c) was partially supported.

While greater engagement in mental fitness activities led to decreased cardiovascular fitness they were associated with improved cognitive ability evidenced by decreased UFOV divided attention scores. In turn these activities may improve feedback processing ability which is valuable in movement control shown by significant UFOV effects. Overall, everyday physical activities that improve cardiovascular fitness also improved cognitive ability. However, unlike cardiovascular fitness staying mentally active may also improve aging trajectories as well.

It was found that increased education decreased UFOV score supporting a benefit for continuing education that may extend well beyond actual engagement of learning. This supports previous work on super-agers that found greater years of education were associated with attenuated brain related changes (Bott et al., 2017). Finding that visiting museums and plays decreased UFOV score may be due to the lack of mental activity involved in this activity. While this activity may be cognitively stimulating and culturally important it may not provide enough of a mental challenge to lead to quantitative differences.

Playing an instrument is interactive and potentially challenging. This finding supports previous research lining play with improved cognitive skills (Rausher, Shaw, & Ky, 1993; Schellenberg, 2005). Recent research with older adults showed musicians held better speed of processing and memory than non-musicians (Mansens, Deeg, & Comijs, 2017). The current study supports this view and extends this to improved UFOV divided attention performance.

Participation in yoga was also found to be a significant predictor of mental fitness. The finding that yoga supported improvements in UFOV but not cardiovascular fitness as well as that strength training and cardiovascular activities were less important to improving mental as opposed to cardiovascular health supports fitness selectivity. This idea is that fitness provides more specific and less generalized physical and neurological benefits (Smiley-Oyen, Lowry, Francois, Kohut, & Ekkekakis, 2008). The connection between playing a musical instrument, but not listening to music also supports the interactivity hypothesis of fitness. A meta-analysis of Yoga training has shown that its combination of dynamic and static movements supported specific improvements in visuospatial and proprioceptive integration while only mildly improved strength as compared to resistance exercises (Latham, Bennett, Stretton, & Anderson, 2004). Resistance and strength training show a different pattern. These studies indicate strength training improves muscle strength and endurance without improving visuospatial and proprioceptive integration (Gard, Noggle, Park, Vago, & Wilson, 2014). While our current study challenges the specificity of strength training somewhat, overlap could be due to the limitation that participants were not exercise specialists, but fitness generalists given moderate correlations between different types of activity. The finding that everyday mental fitness activities decreased UFOV divided attention scores and that these UFOV scores showed a greater impact on performance in the width condition rather than the distance condition provides some support for the mental fitness hypothesis

(H5). This hypothesis was not fully supported however, because no effects of the PPT were found on movement performance for any condition.

In summary, older adults were either not able to or not willing to generate speeded movements as quickly as younger or middle age adults in the speeded only condition especially at a distance of 32 cm. At the 32 cm distance older adults were the only group to being to show an inflection that indicated increased PropST. When participants were forced to be fast and accurate to movements constrained by distance, older adults showed greater movement times than when movements constrained by width. This increase was due to both increases in PT and ST. Participants of all ages showed steeper ID-MT and ID-PropST slopes for manipulations of distance than manipulations of width and overall larger values for MT and PropST (increased y-intercepts). Changes to movement efficiency were observed by changes in velocity, acceleration, and deceleration for older adults as they were less likely to control the fluidity of their movements. Taken together, movements to manipulations of distance were more difficult to make than movements to manipulations of width even at the same ID value because of the large effect distance had on the movement. Manipulations of width, extended movement asymmetry as ID increased primarily for older adults. Thus, width was only a task constraint for older adults. These findings are consistent with the idea that the distance parameter taxed physical ability while the width parameter was reliant on sensory information processing. Older adults showed declines in both distance and width manipulations suggesting issues of both physical and mental health affected movement execution.

Additionally, cardiovascular fitness mostly provided a benefit in the distance condition where it may have modulated participants' ability to modulate their motor impulses and plan each movement. The finding that fitness was beneficial in the distance condition, but not the speeded condition although both used the same distances may indicate fitness improved motor planning rather than the ability to produce a fast motor impulse. This finding was logical because physical activity and not mental activities were moderate predictors of cardiovascular fitness.

Effects of Personality

Overall the big five model showed small and limited effects on movement performance in the final model after age, fitness, and other variables were taken into account. This may be due to both overlapping correlations between the other personality variables (e.g. Table 5) or overlapping variance with the other predictors in the model specifically, age and fitness. This study found that as people aged conscientiousness and agreeableness increased while neuroticism decreased. This finding is consistent with previous literature (e.g. Allemand, Zimprich, & Hertzog, 2007). Additionally, personality has previously been found to correlate with engagement in exercise (Courneya & Hellsten, 1998; Yeung & Hemsley, 1997; Wilson, & Dishman, 2015) which also may explain the overlapping correlations found in the current study. Due to this at least some of the variance from personality was overlapping with age, fitness and the various interaction variables leading to decreased unique variance reported in each analysis.

Impulsivity scores on the other hand showed small to moderate effects which were consistently larger than the five factors traits across all goal-directed movement conditions. In the speeded condition without accuracy requirements the effects of impulsivity traits were small but associated with velocity and acceleration parameters indicating it affected the overall scaling of the movement. In the distance condition, larger effects of impulsivity were seen. Motor impulsivity again affected movement scaling, but attentional and planning impulsivity also shown an effect on movement consistency affecting variable error and increasing MT due to increasing PropST. Finally, in the width condition impulsivity affected the distance traveled in the primary phase and led to slower movements to smaller targets. Greater motor impulsivity has previously been linked to failures in response inhibition and motor control (Lage, Malloy-Diniz, Neves, Paiva de Moraês, & Correa, 2012). However, the effects of impulsivity on goal-directed kinematic performance has not garnered much attention in the literature. In fact, the current study may be the first one to examine the effects of the Barratt Impulsivity Scale on a Fitts pointing task across a while variety of ID values. Because of this, more research is needed to confirm these findings. However, accessing impulsivity may be a useful predictor of kinematic ability.

Finally results were examined in terms of the strategic difference hypothesis (H6). One criteria for supporting this hypothesis would be to show a general decrease with age on movement performance across both types of movement constraints, but not on the speeded condition. The rationale would be that older adults would follow instructions when no explicit target existed to show they could make speeded movements, but once they were required to be accurate they would move more slowly to indicate a general increased play it safe strategy.

Similarly to Van Halewyck et al. (2014) some evidence was found that less fit older adults displayed a play it safe strategy in the distance condition. When the ID-distance slopes were compared between the speeded and distance conditions it was found that less fit older adults displayed a much steeper slope than more fit older adults in the distance but not the speeded condition. Therefore although less fit older adults could make a fast arm movement without accuracy constraints they may have adopted this strategy of more carefulness. On the other hand, this finding could also be taken as a decreased in processing efficiency leading to this group experiencing greater difficulties processing the motor impulse to reach the target. This latter explanation may be more plausible taken with the lack of a self-reported change in strategy between fitness and age groups. The results also indicated that older adults moved more slowly in the speeded condition and did not show equivalent performance across each type of movement constraint. This leads to the conclusion that performance differences were more due to processing limitations rather than a general increase in carefulness with age.

Another potential method to examine and control for strategy related movement differences was to measure participants' personality using both the FFM traits and trait impulsiveness. While personality showed some effects, they were mostly small. The effects of the personality traits to be most hypothesized to lead to a more careful strategy, conscientiousness and neuroticism, were limited. Because of these findings the results do not support the strategic differences hypothesis.

Effects of Gender

The impact of gender were small in every condition. While gender accounted for significant effects in each model, in many cases, the addition of gender did not substantially improve R^2. In the speeded condition increases in R^2 were observed for PropST and tPA, but once those effects were examined overlapping confidence intervals led to the conclusion that these effects were too small to be meaningful. Although gender did not provide widespread improves to the predictive model, larger specific effects of gender were found in the distance and width conditions. In the distance condition, as distance increased, men displayed greater PD than women. Men may have more muscle strength allowing them to generate greater force. Finally in the width condition improved fitness led to decreases in PropST for men but not women and men showed greater peak acceleration across most ID values. The increased online feedback processing required in the width condition may have led more fit women to be more careful especially to move difficult movements. Women with greater fitness were found to be more likely to be conscientiousness which may support this finding.

Several studies in the literature have shown gender differences in pointing performance. One study showed women had slightly more shallow ID-MT slopes than men (Brogmus 1991). Conversely, another study found women showed longer MTs than men at larger ID values (Rhor, 2006). Differences in the results of these two studies and the current findings may be due to choice of ID values and task design. Rhor (2006) found that MT were increased for women at ID > 8 while the largest ID in the current study and in Brogmus was 7 which may affect these results. Also separating both distance and width may have affected our results especially if distance and width constraints interacted to further increase task difficulty.

Theoretical implications

The findings of this dissertation provide several important implications for goal-directed pointing, aging, and fitness research. First, while Fitts' law held for both manipulations of distance or width separately, when examined together the distance parameter was more important than the width parameter in determining movement time than ID alone. Thus, this study failed to support the Fitts' law hypothesis. The current study found support for both the effector and task hypotheses. While distance increases the ID-MT slope it increased this for all participants. Thus, it is concluded that while the distance parameter strongly impacts goal-directed movements it does not fully explain age-related declines in pointing performance. Distance was a strong factors in terms of increasing the y-intercept of each movement showing that as age increased movements involving distance also increased. This pattern was found in the speeded condition as well to a lesser degree. Taken together, age-related changes in physical ability does play a role in decreased kinematic performance. However, the finding that older adults were more impaired in the distance condition than the speeded condition in MT, time to peak velocity, acceleration, and deceleration suggests that impaired cognitive processes are also involved. Examples of potential processes are motor planning, distance estimation and force execution that may be reliant on motor regions in the brain.

It was found that manipulations of width were less efficient at increasing MT as ID increased leading to more shallow ID-MT slopes. The slopes of PropST as ID increased were also similar across age groups in the width condition. Age was associated with an increase in the y-intercept of the PropST-ID slope rather than an increase in slope itself. Increased PropST with age is consistent with the hypothesis that the secondary movement phase is associated with online sensory feedback processing that comes later in the movement and is impaired in older adults (Van Halewyck et al., 2015).

The separation of movement distance and target width have previously been hypothesized to be due to separate processes based on how they differentially effect movement trajectories (Temprado et al., 2013). Temprado et al. specifically found that slopes in the distance condition were steeper for both younger and older adults than those in the width condition. Leading them to conclude distance had a larger impact on movement than width. Time to peak velocity was steeper in the distance condition as well for both younger and older participants. Another study that manipulated ID by distance and size independently found that when ID was manipulated by distance older adults showed longer MT, and changes in tPV and PV. Finally older adults were more likely to undershoot the target (more negative CEPT) as distance increased. Whereas when ID was manipulated by width MT increased due to increased PropST (Ketcham et al., 2002). Another study showed decreased velocities when ID was manipulated by both distance and width. This study did not compare PropST between movement constraints (Haaland, Harrington, & Grice, 1993). Some of the findings may differ based on the specific values used in each study, but these findings support the current study that found distance and width affected the kinematic profile in different ways.

The current findings taken together previous research lead to the conclusion that manipulations of distance and width both impact separate, but related processes. Raising the idea of a theory of differential movement constraints. This idea is further supported with the dissociation between cardiovascular and mental fitness. Cardiovascular fitness was most impactful for effector constraints while UFOV was most impactful to task constraints. The connection between UFOV and effector constraints may be due to overlapping variance between fitness and UFOV score. Additionally, UFOV scores accounted for more variance in the width condition for MT, PropST, and CEPT which are more reliant on sensory and visual feedback integration and processing. In the distance condition UFOV scores accounted for more of the variance in peak velocity, acceleration, and decelerations which are the same markers affected by cardiovascular fitness. Therefore, the processing of effector and task movement constraints do not fundamentally change with age, but both become less efficient. Therefore, age-related kinematic declines are due to both effector and task constraints. Cardiovascular Fitness may peripherally improve motor control by strengthening muscles and flexibility and neutrally by increasing connectivity in the motor networks and other executive-attention, workload processing areas. Mental fitness may improve sensory and executive control areas leading to a better ability to program motor movements to larger distances and improve online feedback correction to smaller targets.

Theoretical Future Research

The results of the current study raise many theoretical questions that are appropriate for additional work described below.

Impact of Additional Effector and Task Constraints under Cognitive Load

First, it may be interesting to examine disassociations between distance and width movement constraints under increased cognitive load. The results indicated support for differential movement constraints. Therefore one hypothesis is that these differential constraints will reflect different patterns of cortical activation due to different brain areas. Increases in movement distance may tax motor regions while decreases in target size will instead tax the pre-frontal cortex (PFC), and Posterior Parietal cortex (PPC) areas. One way to tease this out is that amend the pointing task so that each constraint is compared with and without a task designed to differentially task cognitive resources to determine if they produce differential deficits in motor behavior. Finding a multitasking deficit in performance for one constraint type over the other will contribute to the development of a differential constraint theory of motor control.

Further, one study described a potential useful methodology for changing the impact effector and task constraints may place on bodily systems. Bohan, McConnell, Chaparro, and Thompson (2010) manipulated either the physical scale of the movement or the visual scale of the movement by using magnification and gain. This research has yet to be conducted with older adults or be assessed based on individual differences in fitness. Additionally, magnification is a common feature of many jobs (e.g., surgeons, electronic device makers, jewelers, scientists). Therefore, this is a much needed area of research that may shed light on both theoretical and practical concerns.

Delving Deeper into Fitness

The current study used a cross-sectional design using non-exercise based questionnaires to estimate users' cardiovascular fitness. While this methodology was useful in the current study, there are several limitations that come with its use. The survey developed by Jurca et al. (2005) strongly correlates with exercise testing and has been validated with older adults (McAuley et al., 2011), but it is not a direct measure of fitness. Shephard et al. (1968) described VO_2 Max has the international standard of reference for fitness and this idea persists to this day. The VO_2 Max metric describes the maximal intake of oxygen that occurs during exercise. Therefore, directly measuring this requires specialized equipment and may be stressful on participants. This is the reason why it was not used in the current study. Studies that do employ this standard find strong connections between fitness physical healthy and cognition (Kirk-Sanchez & McGough, 2014). Thus, one follow-up could be to test different ways to measure fitness on motor behavior.

Additionally, also due to the correlational nature of the current study moderate correlations were found across many of the physical and mental activities. Because of this it was difficult to isolate any single activity as the cause for a specific effect and instead discussed fitness as a broad concept. Thus another potential study would be to monitor fitness over a longer period of time using longitudinal methods. Therefore, individuals who initially have low fitness can be monitored as they become more fit and determine how this change directly impacts their motor performance.

Applying a Cognitive Neuroscience Approach to Develop a Better Model of Age-related Changes in Motor Behavior

Studies within the cognitive neuroscience literature have shown that age-related declines in simple motor behavior (e.g. finger tapping) are associated with functional patterns of bilateral activation in the prefrontal lobe (e.g. Cabeza, 2012) and motor cortex (Naccarato et al., 2006). Moreover, older adults have also been shown to recruit additional resources from both prefrontal and basal-ganglia areas to assist with movement control (Seidler et al., 2010). Activation patterns in these areas may be useful to explain behavioral performance on more complex motor tasks due to movement constraints. Additionally, changes in white matter integrity have been shown to be a strong predictor of normal age-related cognitive declines (Bennett & Madden, 2014). White matter serves a similar function as roads do allowing for neural activity to travel from different brain areas connecting different neural structures. Therefore, the structural connectivity of these paths may also be important areas to study. Adopting a neuroscience approach in aging is important as several brain-related changes may led to attempted or successful functional compensation that may reduce behavioral deficits.

Practical Implications

In addition to the theoretical implications the results of the current study can also inform how people use technology in their daily lives.

Informing Older Adult Technology Use

While older adults report favorable attitudes towards technology (Mitzner et al., 2010), older adults are less likely to use technology and experience more frequent issues learning how to use new technological systems leading to slower adoption rates and increased selectivity (Czaja et al., 2006; Olson, O'Brien, Rogers, & Charness, 2011). The results of the current study may provide insight into this issue. Fitts' law can inform how efficient computer input devices are by measuring how quickly people can perform pointing tasks (MacKenzie, 1992). This has been tested with mice (Card, English, & Burr, 1978; Thompson et al., 2007), joysticks (Card, English, & Burr, 1978), trackpads (MacKenzie, 1992), and touch screens (Albinsson & Zhai, 2003). The current study suggests that older adults may experience issues both pointing to a longer distance and to smaller targets. It was found that movements to longer distances affected movement parameters to a greater degree for everyone and that physical health and motor declines experienced as we age can exacerbate this difficulty. Due to this finding, older adults may experience greater difficulties with computer devices that have larger screens or high screen resolution that leads them to making longer movements. These difficulties can be further worsened by using small targets that tax older adults' feedback control processes. Future research should compare ID manipulated only by distance and width with more difficult IDs at longer distances with smaller targets to determine if the combination of movement constraints provide additive decreases in performance or if these constraints will interact. Additionally, physical and mental fitness may be useful predictors of technology use, acceptance, and issues experienced during learning based on the specific improvements found in this research. However, more research is needed to test this potential link with applied systems.

Testing for Physical or Cognitive Health Declines to Develop Targeted Interventions

By breaking apart both biomechanical and cognitive explanations of decreases movement efficiency increases, this study was able to inform the impact age-related changes have on how people interaction with their environment. Examining these age differences was the first step in creating targeted interventions to improve older adults' functional independence. This study found some support for both effector and task related hypotheses leading to the creation of a broader view that differential constraints affect movement in different ways. This view dovetailed with the results fitness. Cardiovascular and strength training activities improved motor health while staying cognitively active including performing physical activities that require increased motor and sensory processing demands. Because of this finding, cardiovascular fitness impacted movements under manipulations of distance while mental fitness impacted movements under manipulations of width. Future research including computational modeling and machine learning approaches could investigate if kinematic markers could be used as a measure of physical and cognitive health to predict performance on tests of dexterity, grip strength, working memory, spatial processing, and other physical and cognitive abilities. If so, then goal-directed pointing tasks may be useful clinical predictors of health. Further, if declines are found when ID is manipulated by distance cardiovascular and strength exercises may be prescribed. On the other hand, if declines are found instead when ID is manipulated by width then more cognitively stimulating activities may be used instead. However, for this to be possible much more research needs to be undertaken to support this idea. The findings of this study were merely the beginning of understanding role fitness and aging have in the perception and action cycle.

Implications for interacting in virtual reality

With the onset of the newest generation of virtual reality devices acting in computer generated environments has become more common. Virtual reality maybe the next generation of the computer experience as touch was for today's generation. Currently both the Oculus Rift and HTC Vive use gestural and hand controllers to allow individuals to point and grasp objects in the virtual world. Because of this trend, virtual reality may be a useful testbed for studying goal-directed movements, as the technology for natural interactions are currently being developed. Another reason is that experimenters can control the totality of the participant's user experience. This allows for precise control of the visual stimuli and the environment that has not previously been possible. One potential advantage of this is that experimenters can separate proprioceptive and visual cues (e.g., Deligiannidis, McConnell, & Vallee, 2009). In the current study, visual cues were weighted more than proprioceptive ones and no significant impact of the proprioceptive pointing task was found. In a virtual environment this might not be the case and large deviations from normality may negatively affect a user's experience in a virtual environment. In Deligiannidis et al. (2009) users were not conscious of small mismatches between their visual and proprioceptive senses, but these researchers did not test this in a realistic environment with a realistic virtual hand. The kinematics of pointing and grasping were also not measured to determine if this difference may have affected how individuals navigated through a virtual environment. As natural interaction methods become more common understanding how age-related declines affect reaching and grasping movements may help designers design natural interactions in virtual reality for users of all ages.

APPENDIX A: UCF IRB LETTER

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Michael A. Rupp**

Date: **April 18, 2016**

Dear Researcher:

On 04/18/2016, the IRB approved the following human participant research until 04/17/2017 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	The role of physical fitness in movement kinematics
Investigator:	Michael A Rupp
IRB Number:	SBE-16-12185
Funding Agency:	
Grant Title:	
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 04/17/2017, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Joanne Muratori

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Signature applied by Joanne Muratori on 04/18/2016 04:16:32 PM EDT

IRB Manager

APPENDIX B: BIG FIVE INVENTORY

Instructions: Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who *likes to spend time with others*? Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

1 Disagree strongly	2 Disagree a little	3 Neither agree nor disagree	4 Agree a little	5 Agree strongly

I see myself as someone who ..

1. ____ Is talkative
2. ____ Tends to find fault with others
3. ____ Does a thorough job
4. ____ Is depressed, blue
5. ____ Is original, comes up with new ideas
6. ____ Is reserved
7. ____ Is helpful and unselfish with others
8. ____ Can be somewhat careless
9. ____ Is relaxed, handles stress well
10. ____ Is curious about many different things
11. ____ Is full of energy
12. ____ Starts quarrels with others
13. ____ Is a reliable worker
14. ____ Can be tense
15. ____ Is ingenious, a deep thinker
16. ____ Generates a lot of enthusiasm
17. ____ Has a forgiving nature
18. ____ Tends to be disorganized
19. ____ Worries a lot
20. ____ Has an active imagination
21. ____ Tends to be quiet
22. ____ Is generally trusting
23. ____ Tends to be lazy
24. ____ Is emotionally stable, not easily upset
25. ____ Is inventive
26. ____ Has an assertive personality
27. ____ Can be cold and aloof
28. ____ Perseveres until the task is finished
29. ____ Can be moody
30. ____ Values artistic, aesthetic experiences
31. ____ Is sometimes shy, inhibited
32. ____ Is considerate and kind to almost everyone
33. ____ Does things efficiently
34. ____ Remains calm in tense situations
35. ____ Prefers work that is routine
36. ____ Is outgoing, sociable
37. ____ Is sometimes rude to others
38. ____ Makes plans and follows through with them
39. ____ Gets nervous easily
40. ____ Likes to reflect, play with ideas
41. ____ Has few artistic interests
42. ____ Likes to cooperate with others
43. ____ Is easily distracted
44. ____ Is sophisticated in art, music, or literature

Please check: Did you write a number in front of each statement?

APPENDIX C: BARRATT IMPULSIVITY SCALE

Abbreviated Barratt Impulsiveness scale

Instructions: Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who *likes to spend time with others*? Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

1 Disagree strongly	2 Disagree a little	3 Neither agree nor disagree	4 Agree a little	5 Agree strongly

I see myself as someone who ..

1. I don't "pay attention"
2. I am self-controlled
3. I concentrate easily
4. I am a careful thinker
5. I am a steady thinker
6. I do things without thinking
7. I say things without thinking
8. I act "on impulse"
9. I act on the spur of the moment
10. I plan tasks carefully
11. I plan trips well ahead of time
12. I plan for job security
13. I am future oriented

APPENDIX D: JURCA FITNESS SCALE

STEP 1

Physical activity score: Choose one activity category that best describes your usual pattern of daily physical activities, including activities related to house and family care, transportation, occupation, exercise and wellness, and leisure or recreational purposes.

	Score
Level 1: Inactive or little activity other than usual daily activities.	0.00
Level 2: Regularly (≥5 d/wk) participate in physical activities requiring low levels of exertion that result in slight increases in breathing and heart rate for at least **10 minutes** at a time.	0.32
Level 3: Participate in aerobic exercises such as brisk walking, jogging or running, cycling, swimming, or vigorous sports at a comfortable pace or other activities requiring similar levels of exertion for **20 to 60 minutes** per week.	1.06
Level 4: Participate in aerobic exercises such as brisk walking, jogging or running at a comfortable pace, or other activities requiring similar levels of exertion for **1 to 3 hours** per week.	1.76
Level 5: Participate in aerobic exercises such as brisk walking, jogging or running at a comfortable pace, or other activities requiring similar levels of exertion for **over 3 hours** per week.	3.03

STEP 2

Estimate MET level of cardiorespiratory fitness

Enter 0 for women or 1 for men	☐	x 2.77	=	☐
				minus
Enter **age** in years	☐	x 0.10	=	☐
				minus
Enter **body mass index**[a]	☐	x 0.17	=	☐
				minus
Enter **resting heart rate**	☐	x 0.03	=	☐
				plus
Enter **physical activity score** from step 1	☐	x 1.00	=	☐
				plus
Constant				18.07
				=
Estimated MET value				☐

Clinical relevance of selected maximal MET levels of cardiorespiratory fitness[b]

1 MET	Resting metabolic rate; sitting quietly in a chair
<3 METs	Severely limited functional capacity; a criteria for placement on a heart transplant list
3–5 METs	Poor prognosis in coronary patients; highly deconditioned individual
10 METs	Good prognosis in coronary patients on medical therapy; approximate maximal capacity expected in regularly active middle-aged men and women
13 METs	Excellent prognosis regardless of disease status
18 METs	Elite endurance athletes
20 METs	World-class athletes

Figure 1. Worksheet for estimating maximal MET levels of cardiorespiratory fitness from routinely collected clinical data. [a]Body mass index=(weight in lbs × 703)/(height in inches)^2 or (weight in kilograms)/(height in meters)^2. [b]Adapted from the American Heart Association.[45,46] MET, metabolic equivalent.

APPENDIX E: OVERALL PHYSICAL ACTIVITY SCALE

Consider an average or typical 7-day period (i.e. a week), how many hours per week (Hrs./wk.) do you engage in the following kinds of physical activity including exercise.

General Physical Activities

1. **Strenuous Cardiovascular Activity** [> 6.0 METs]

   _________Hrs./wk.

   (Your heart beats rapidly and you sweat: Aerobics, jogging/running, swimming)

2. **Moderate Cardiovascular Activity** [3.0 – 5.9 METs]

   _________Hrs./wk.

   (Your heart may beat faster than normal and you may sweat: Brisk walking, hiking, yoga, weight training)

3. **Mild Cardiovascular Activity** [1.6 – 2.9 METs]

   _________Hrs./wk.

   (More than minimal effort, but your heart beats about normal & you do not work up a sweat: Casual walking, stretching, table tennis)

4. **Seated Activity** [1 – 1.5 METs]

   _________Hrs./wk.

   (Minimal Effort: Sitting, working at a desk, driving, watching TV)

Specific Physical Activities

5. **Weight lifting**, **Resistance Training**, or similar?

   Overall: __________ Hrs./wk. **Lower Body: ___________**Hrs./wk. **Upper body: ___________**Hrs./wk.

6. **Body Weight Exercises**, **Yoga**, or similar?

   Overall: __________ Hrs./wk. **Lower Body: ___________**Hrs./wk. **Upper body: ___________**Hrs./wk.

7. **Cardiovascular Exercises**?

   Overall: __________ Hrs./wk. **Lower Body: ___________**Hrs./wk. **Upper body: ___________**Hrs./wk.

8. How often do you completed your physical activity outside?

Never (1) 2 3 4 5 6 **Always** (7)

9. How often do you engage in a physical activity long enough to work up a sweat?

Never (1) 2 3 4 5 6 **Several Times a Day** (7)

10. How many months have you been engaged in your current level of physical activity?
___________Mths.

11. How many hours do you sleep per night? ___________Hrs. Do you usually feel well rested? Yes No

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