Abstract

The Relationship between Visual Steadiness and Force Steadiness in Young and Old Adults

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Old adults exhibit a decrease in muscle force steadiness and visual capability compared to young adults. Many studies investigating force steadiness have used a visual target as the stimulus for modulating muscle force. Since vision is used in most investigations of muscle force control with age, reduced muscle force control in older adults might be partially related to or explained by altered visual capacity. The purpose of this study was to compare the relationships between eye movement, as a component of visual steadiness, and quadriceps muscle force steadiness in young and old adults during isometric quadriceps contractions of constant and varying forces. 19 healthy young adults (20.7±1.82yrs) and 18 healthy old adults (71.6±3.01yrs) participated in this study after providing written informed consent. Isometric quadriceps torque data were collected using an isokinetic dynamometer. Horizontal and vertical eye movement data were collected using an eye-tracking system. The tasks consisted of three vision only tasks, three vision and force tasks at a relative value of 40%MVC and three at an absolute value of 54Nm. There were no significant differences between age groups for force steadiness in the absolute condition (young 0.76±0.25Nm, old 0.84±0.29Nm; $p=0.19$). Contrary to our expectations, old

adults showed less force variability (0.79±0.36Nm) than young adults (1.16±0.44Nm) in the relative condition ($p<0.05$). The static vision-only condition did not show a significant difference between the two groups for the horizontal ($p=0.08$) or vertical ($p=0.28$) visual components. The remaining two vision-only conditions did not show a significant difference between young and old adults for the vertical vision component, $p=0.34$ and $p=0.47$, respectively. A significant difference was observed in the horizontal component for the two conditions. Old adults showed decreased horizontal visual steadiness compared to young ($p<0.05$). Correlations performed between visual steadiness and muscle force steadiness showed a statistically significant relationship for only one relative vision and force condition ($r=0.471$) and failed to show statistical significance for any of the remaining conditions using the following critical values for a two-tailed test at $p<0.05$: young adults ($df=17$) =0.456, old adults ($df=16$) =0.468. The absence of a statistically significant difference in force steadiness between young and old adults is indicative of an extremely healthy, mobile, and capable old adult subject pool. The only differences between the two groups were age and maximal strength (young 209±68.44Nm, old 145±51.5Nm). We were not able to identify any physiological relationship between muscle force steadiness and eye movement, as a component of visual steadiness. It is possible that the relationship between force steadiness and visual feedback identified in previous research is due to decrements in visual processing capabilities and not due to a decline in visual steadiness. Regardless, present data support observations that reduced muscle force steadiness with age may be due to reduced neuromuscular capacity and not visual capability.

The Relationship between Visual Steadiness and Force Steadiness in Young and Old Adults

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Chapter 1 - Introduction

The appropriate use of muscle force is fundamental in performing basic life activities such as walking, doing laundry, and eating. Most notably, reductions in the ability to control muscle force reduces our ability to successfully perform these and other activities. Older adults experience decreases in muscular strength, power, accuracy, and steadiness (Metter, 1997; Hortobágyi, 2001) and these changes affect their capacity to execute tasks with control and precision (Tracy & Enoka, 2001). Control and precision are needed during both variable force and constant force tasks. For example, movements such as walking and reaching for an object require variable force production, and activities such as holding a glass or balancing while standing upright require constant force production. Ultimately, inadequacies in muscle force control may pose safety risks to the older population; e.g. decreased muscle force steadiness has been linked to increased fall risk in older adults (Carville, Perry, Rutherford, Smith, & Newham 2007).

Reductions in muscle force steadiness with age can be partially attributed to the occurrence of skeletal muscle atrophy and subsequent motor unit remodeling in older adults. Motor unit remodeling can result in a decreased number of motor units and consequently, a larger number of fibers per individual motor unit (Brown and Hasser, 1996). These adapted motor units make it more challenging for older adults to modulate changes in muscle force and to generate the appropriate amount of muscle force during various activities of daily living (Galganski et al., 1993; Masakado et al., 1994).

In addition to reductions in force steadiness with age, there is also a decrease in visual capability. Older adults need more time to recognize and respond to visual targets compared to young adults (Owsley, 2010). This deficiency could be due in part to the delayed eye movement observed in older adults during visual tracking tasks (Sharpe & Zackon, 1987). Delayed eye movement is also thought to be a contributing factor to the difficulties older adults experience when attempting to synchronize eye movements with target movement, causing excess eye position errors as the eye tries to correct its focus on the target. The age-related increase in eye position errors contributes to decreased visual control and decreased accuracy during visual tracking tasks (Moschner and Baloh, 1994).

It is typical of studies investigating force steadiness to use some form of visual target as the stimulus for modulating muscle force, therefore it is necessary to take into account potential visual contributions to the decrease in force steadiness observed in older adults. However, the amount and type of visual feedback provided during a task may have an effect on age-related variations in force control. Older adults experience increases in force fluctuation during periods of high visual feedback compared to no visual feedback or low feedback conditions (Tracy, 2007; Ofori, 2010). This age-related effect could be indicative of the notion that older adults have a reduced capacity for tracking and processing visual information which leads to greater force fluctuations. Additionally, the decreased ability of older adults to process visual tracking information has been linked to mobility difficulties (Owsley and McGwin, 2004). Specifically, a decrease in occulomotor control has been associated with impaired postural control when standing (Glasauer et al. 2005; Paquette and Fung 2011) and longer time needed to complete common visual tasks (Owsley, McGwin, Sloane, Stalvey, & Wells, 2001).

Since visual capability declines with age and since vision is used in most investigations of muscle force control with age, reduced force control in older adults might be at least partially related to or explained by altered visual capacity. Further, aging impairs occulomotor abilities such as saccadic velocity and accuracy (Moschner and Baloh, 1994; Sharpe and Zackon, 1987) which may result in reduced visual steadiness, and these decreases in visual steadiness may at least partially contribute to the decreases in force steadiness observed in older adults. If a relationship between muscle force steadiness and visual capacity is identified, future visuomotor training opportunities can be investigated which could have a positive effect on muscle force control and ultimately, the quality of life for older populations.

Hypothesis

There are direct relationships between visual steadiness and muscle force steadiness in both young and old adults. This hypothesis implies that reduced muscle force steadiness in older adults can be at least partially explained by their reduced visual steadiness.

Purpose

The purpose of this study is to compare the relationships between eye movement, as a component of visual steadiness, and muscle force steadiness in young and old adults during isometric quadriceps contractions of constant and varying forces.

Delimitations

- Subjects were excluded if they had previous surgeries
- Subjects were excluded if they wore trifocals or had vision conditions such as blindness, glaucoma, or amblyopia
- Young adult subjects will be males and females between the ages of 18-25 years and old adult subjects will be males and females between the ages of 70-85 years.

- Isometric force steadiness measurements will be taken only from the right quadriceps muscle.
- All subjects will be healthy, mobile young and old adults with no previous history of any musculoskeletal or neuromuscular diseases.
- Eye tracking data will be measured only from the movements of the right eye.
- All interview information collected was assumed to be correct

Limitations

- The results are limited to the accuracy of the eyetracking and isokinetic measurement instruments.

Operational Definitions

- Force Steadiness – The measured fluctuation in isometric muscle force, as indicated by measures of variability (standard deviation and coefficient of variation).
- Visual Steadiness – The variation in horizontal and vertical eye movement behaviors, indicated by standard deviation and coefficient of variation.

Chapter 2 - Literature Review

The purpose of this study was to investigate and compare the relationships between eye movement, as a component of visual steadiness, and muscle force steadiness in young and old adults. This review of literature will focus on 1) The neuromuscular decline with age, 2) Visual declines associated with aging, and 3) The interactions between muscle force steadiness and vision.

Neuromuscular Decline with Age

Aging decreases muscular power, strength, accuracy, and steadiness in both men and women (Metter, 1997; Hortobágyi, 2001). Older adults display decreases in force accuracy and force steadiness at low to moderate submaximal levels similar to the level at which most daily tasks occur (Tracy & Enoka, 2001); the decline in force accuracy observed in older adults is not as pronounced as the decrease in force steadiness (Erim et al. 1999). This observation may indicate that although older adults are able to adapt force output to appropriate levels, the steadiness with which they do so is compromised. These age-related reductions in functional ability can have an inhibiting effect on movement speed and coordination (Morgan et al. 1994) which in turn may affect many activities of daily living such as walking or driving. For example, older adults display excess movement during drawing tasks leading to a characteristic jerky movement pattern and prolonged movement time (Morgan et al. 1994). In addition, decreased muscle force steadiness has been identified as a risk factor for falls in older adults (Carville, Perry, Rutherford, Smith & Newman 2007). In a comparison of older fallers with older non-fallers and young adults, older fallers exhibited decreased quadriceps steadiness during isometric and anisometric contractions, particularly during the eccentric phase (Carville et al. 2007). Even performance in daily functional activities such as standing from a seated position or climbing stairs has been associated with reduced isometric quadriceps steadiness in older adults (Seynnes et al. 2005).

Older adults experience greater fluctuations in muscle force compared to younger adults over a range of force levels (Tracy, 2001; Tracy et al., 2007). The majority of studies investigating muscle force steadiness in older adults have tested muscles of the upper limbs such as those of the hand or elbow. There is evidence supporting the notion that steadiness between muscle groups is variable (Tracy 2003). For example, there is a larger age-related difference in steadiness in the first dorsal interosseous muscle than knee extensor or elbow flexor muscles (Galganski et al. 1993; Tracy et al. 2003). Discrepancies in the literature also exist about the relationship between the type of contraction and steadiness of larger muscle groups such as the quadriceps. Some researchers have found that older adults are less steady than young adults during isometric contraction (Tracy and Enoka, 2002; Christou and Carlton, 2002) whereas others have not (Christou and Carlton, 2001; Hortobagyi et al., 2001). Looking solely at differences within old adults, many researchers have found greater variability in isometric quadriceps contractions compared to anisometric quadriceps contractions (Schiffman et al., 2001; Christou and Carlton, 2002) however, Tracy and Enoka (2002) did not. Other studies show inconsistencies in age-related steadiness during anisometric contraction (Christou et al., 2003) and eccentric compared to concentric contractions in older adults (Hortobágyi et al., 2001; Tracy and Enoka, 2001). Variation in findings of decreased steadiness in postural leg muscles such as the quadriceps may be a result of differences in testing methodology. For example, Krishnan, Allen, and Williams (2010) determined that quadriceps muscle force steadiness was significantly decreased over a range of target force levels when the knee was positioned at 90 degrees of flexion compared to 30 degrees of flexion. This is indicative of a possible relationship between muscle length and motor unit activation. Therefore, studies that used knee angles of 90 degrees or greater to assess quadriceps steadiness (Christou et al. 2001; Christou et al. 2002; Tracy & Enoka 2001; Tracy et al. 2003) may have interpreted higher force fluctuations as a direct result of the testing condition when in fact muscle length may have also contributed to the results.

Many factors contribute to the decrease in force steadiness with age including motor unit remodeling and reduced firing rate frequency (Burnett, Laidlaw, & Enoka, 2000; Erim, Beg, Burke, & Luca, 1999). The motor unit is a key functional element of the neuromuscular system and upon activation a net muscle force is exerted. When many motor units are activated simultaneously, the resulting force can vary in amplitude based on the contractile properties of the specific motor units (Galganski, Fuglevand, & Enoka,1993). When the contraction involves multiple muscles, the resulting force is primarily due to the activity between the muscles rather than the individual motor unit (Enoka et al., 2003). Older adults experience compromised motor unit function; with age motor units undergo structural remodeling, partially brought about by the atrophy of fast twitch muscle fibers seen with the onset of sarcopenia (Brown & Hasser, 1996). This structural remodeling is accompanied by a decline in the number of motor units and an increase in the number of fibers innervated per motor unit. The increased innervation ratio observed in older adults produces a higher twitch force compared to young adults at a similar recruitment threshold (Larsson et al., 1978; Masakado et al., 1994). Given that motor units modulate the production of muscle force, these modified motor units result in the reduced ability of older adults to control increases in varying levels of force and precise motion (Galganski et al., 1993; Masakado et al., 1994). Enoka et al. (2003) provided this observation as evidence that fluctuations upon initial motor unit firing are greater in older adults which is a contributing factor to the decreased steadiness seen at low to mid-range forces.

It is also thought that physical changes in the central nervous system contribute to the age-related decrease in motor function. One such change in the central nervous system is that older compared to younger adults have decreased brain volume due to the atrophy of gray and white brain matter (Jernigan et al. 2001). White matter has been associated with areas of the brain that control bi-manual coordination tasks such as tying one's shoes laces or eating with a knife and fork (Seidler et al. 2010). Additionally, changes in the gray matter result in deterioration of the motor cortex and somatosensory cortex which have been linked to the ability to modulate muscle force (Salat et al. 2004). Deficits in the primary motor cortex have been associated with an age-related decrease in performance on motor tasks such as responding appropriately to small changes in movement task complexity (Light and Spirduso 1990). Also, because the somatosensory cortex is involved in providing proprioceptive feedback, atrophy could be linked to increased fall risk and balance difficulties (Seidler et al. 2010). A decrease in proprioceptive function in older adults, as a result of deterioration of the somatosensory cortex with age, could potentially lead to a higher reliance on visual feedback cues when completing motor tasks.

Conventionally, muscle force steadiness is measured using visual feedback to guide a participants force output. Popular methodology utilizes either a continuous task, which involves a constant target force, or a discrete task that requires the subject to match a force-time target (Christou, Grossman, & Carlton, 2002). Cirillo, Todd, & Semmler (2011) found that older adults showed decreased force precision and accuracy during discrete visuomotor tracking tasks compared to young adults. The initial purpose of their study was to investigate the age related differences in corticomotor plasticity and motor learning changes following training with a complex visuomotor task. They found insignificant differences on these variables between the two groups. From this they suggested that “a decline in vision in older adults may contribute to decreased motor performance” (Cirillo et al. 2010). Given that it is typical of studies investigating force steadiness in young and old adults to use some form of visual target as the stimulus for modulating muscle force, it is necessary to take into account potential visual contributions to the decrease in force steadiness.

Visual Control with Aging

Vision is the primary means by which most humans perceive the ever-changing environment. Effective eye movements must be generated in order to view a scene and gather useful information on the surroundings, such as the presence of obstacles or change in ground slope. Effective eye movements may rely somewhat on the individual’s level of visual acuity, which relates to the clarity of vision and the ability to interpret detail within a scene. Older adults, in particular, experience a decline in visual acuity (Owsley 2010; Spear 1993); however, visual acuity can be returned to normal with corrective optometry and is therefore not thought of as a large contributor to the diminished overall visual function. It is more likely that the decrease in visual function with age is due to a decrease in visual control (Abel et al. 1983; Kosnik et al. 1986; Knox et al., 2005) which can affect eye movement accuracy when tracking a target and consequently, may instigate motor control deficits with aging (Paquette and Fung 2011; Chapman et al. 2006). Not surprisingly, an association has been found between eye movement behaviors and accurate stepping when walking suggesting that older adults at a high risk for falling look away from targets sooner than low-risk adults and display increased levels of variation and foot placement error compared to both young adults and low-risk older adults

(Chapman and Hollands 2006; Young, Wing, & Hollands 2011). It has even been suggested that a decline in the ability to visually process a scene and respond accordingly may result in an increased frequency of falls or injury (Chapman and Hollands 2006; Young, Wing, & Hollands 2011; Glasauer, Schneider, Jahn, Strupp, & Brandt 2005).

Visual control can be defined as the method by which we direct our gaze to a specific object or action within a scene, often referred to as visual tracking. Visual tracking usually involves both smooth pursuit and saccadic eye movements. Smooth pursuit tracking allows real time processing and involves visually following a slow moving object, such as a ball on a screen (Abernethy, 1988). Saccades occur during visual tracking when the eyes jump rapidly from one location to another but do not allow for real time processing (Turano, Geruschat, & Baker, 2002; Paquette and Fung 2011). Saccades occur about three times each second with durations ranging from 60-100ms (Turano, Geruschat, & Baker, 2002). These saccadic eye movements are punctuated by moments of active fixation that allow for processing (Munoz & Coe, 2011). When visual tasks are coupled with voluntary movement, saccadic eye movement is the dominant tracking method (Abernethy, 1988).

Some of the major age-related changes to the eyes include presbyopia, a decreased pupil size, and increased lens density and yellowing (Spear 1993). Presbyopia is a condition in which the eye loses its ability to focus due to decreased lens elasticity and reduced function of the ciliary muscles that help to change the shape of the lens. These changes may affect the mechanics of the eye and, in turn, visual function. Additionally, aging can result in the loss of neurons in the central nervous system (Sharpe and Sylvester 1978) and modifications in the neurotransmitter systems (Moschner & Baloh, 1994). Spear (1995) implied that much of the decline in vision seen with age cannot be attributed solely to optics, and that perhaps changes in the brain or retina such as a deficiency of neurons in the central visual pathways contribute to the decline. This notion is supported by research showing that low performance on tasks that test direction discrimination and speed discrimination may be a manifestation of the age-related effect on certain areas of the cortex (Britten, Shadlen, Newsome, & Movshon 1993; O'Connor, Margrain, & Freeman, 2010).

The neurological and physical changes to visual structures and systems seen in older adults effect occulomotor programming and control (Abel, Troost, & Dell'Osso 1983; Kolarik, Margrain, & Freeman 2010). Peak saccade velocities in older subjects are slower when compared to younger subjects (Moschner & Baloh, 1994). Saccade reaction times are also significantly longer in older adults than in young adults suggesting that older adults move their eyes more slowly when tracking an object (Abel et al. 1983). Additionally, older adults experience decreases in saccadic accuracy, specifically when tracking targets at distances further away from the center point of vision as measured by the amplitude of initial eye movement (Sharpe and Zackon, 1987). Aging increases the frequency of saccadic events and the increased frequency serves as evidence of diminished smooth pursuit function as a result of attempts to correct retinal errors (Sharpe and Slyvester 1978).

The objective of the smooth pursuit eye process is to visually focus on a moving target by synchronizing the movement of the eye with the moving target (Abernethy 1988). During smooth pursuit tracking, the age-related difference in eye movement velocity increases as target velocity increases, causing impairment in the visual abilities of older adults, especially when tracking fast moving targets (Sharpe and Sylvester, 1978l; Kolarik et al. 2010). Older adults experience a delay in the onset of smooth pursuit eye movements as well as delays during smooth pursuit tracking, causing reductions in eye movement accuracy (Moschner and Baloh, 1994; Spooner et al., 1980; Kolarik et al. 2010). This decline in the function of smooth pursuit eye movements results in a larger number of visual tracking errors as the eyes try to reposition on the target using saccades (Sharpe and Sylvester, 1978).

The deterioration in the saccade and smooth pursuit processes can be somewhat attributed to the atrophy of extraocular muscle fibers and their relative contributions to specific eye movements. Slow-twitch fibers are less affected by age (Kosnik, Fikre, & Sekulert 19869 and are primarily used during fixations (Scott and Collins, 1973). This notion is supported by the observation that both young and old adults exhibit similar amounts of visual steadiness during fixation tasks (Kosnik et al. 1986). Conversely, saccadic eye movements require the activation of both fast–twitch and slow-twitch fibers (Scott and Collins, 1973). Similar to other skeletal muscles, fast-twitch extraocular muscle fibers deteriorate with age (Kosnik et al. 1986). With this in mind, it would not be unreasonable to presume that the atrophy of extraocular fast twitch muscle fibers would result in motor unit remodeling and consequently, the reduced ability of older adults to control smooth pursuit eye movements with the same precision and accuracy of young adults (Kolarik et al. 2010). Accordingly, faster eye movements produced during pursuit tracking exhibit reduced speed discrimination and direction discrimination compared to eye movements produced during visual fixation (O'Connor, Margrain, & Freeman, 2010). Older adults also experience decreases in saccadic accuracy especially when tracking targets at distances further away from the center point of vision as measured by the amplitude of initial eye movement (Sharpe & Zackon, 1987). In addition, there is an age related decrease in the voluntary range of eye movement, particularly when the gaze is directed upward (Chamberlain, 1971). The interactions of these decreases in occulomotor control could cause a reduction in visual steadiness during a tracking task, especially one involving upward eye movements, or when initiating a movement in response to visual feedback (Paquette and Fung 2011).

Interactions between Force Steadiness and Vision

The ability to obtain and process visual feedback is essential to controlling muscle force fluctuations (Tracy et al. 2007; Ofori et al. 2010). As such, it has been suggested that age-related deficits in visuomotor processing partially contribute to the decrease in force steadiness observed in older adults (Sosnoff and Newell 2007, Sosnoff, 2006a; Tracy, 2007). Accordingly, the adverse effects of aging on vision seem to be exacerbated during balance and movement tasks, which could be indicative of deficits within the visual pathway (Paquette and Fung 2011). Similarly, eye movement has been found to evoke responses in motor control, specifically postural sway (Glasauer, Schneider, Jahn, Strupp, & Brandt 2005), this has large implications for the effect of vision, particularly declining vision with reduced occulomotor control, on force steadiness in large muscle groups.

The effect of visuomotor processing abilities on force steadiness has been previously analyzed through varied types of visual feedback. For example, some methods have required subjects to match force targets during both vision and no-vision conditions (Tracy 2007; Tracy et al. 2007; Welsh et al. 2007). Schiffman et al. (2002) applied this concept to bandwidth feedback in an attempt to decrease variability by reducing the number of corrections made by subjects. Bandwidth feedback provides a limited amount of visual feedback; only being displayed when the subject is outside of the bandwidth force rather than aiming for a traditional target. Ofori et al. (2010) alternated the type of tracking method between compensatory and pursuit visual displays used by the subject in matching target forces. Pursuit displays, which provide the subject with more complex visual feedback, were shown to be more difficult for older adults at low to mid-range force levels when compared to compensatory display types which provide less visual information (Ofori, Samson, & Sosnoff, 2010; Svendsen et al. 2011). The reduced ability of older adults to respond appropriately to increased amounts of visual feedback suggests a deficiency in their visual capacity.

Older adults are less able to use visual feedback to accurately maintain a steady force compared to young adults (Baweja et al. 2010; Ofori et al. 2010; Svendsen et al. 2011). These findings are in concurrence with research demonstrating that during tasks when visual feedback was not provided old adults exhibited increased muscle steadiness compared to tasks with visual feedback (Tracy et al., 2007; Welsh et al. 2007). For example, one study consisted of isometric knee extensor and elbow flexor contractions at 2.5, 30, and 65% MVC (Tracy et al. 2007). Force variability increased as the target force increased for both muscle groups in young and old adults. At low force levels older adults exhibited greater force fluctuations compared to young adults only during the vision condition; when visual feedback was not provided the age-related differences were not observed. These results suggest that vision is a potential contributor to the reduced muscle force steadiness observed in older adults. Tracy et al. (2007) concluded that visuomotor effects on force fluctuations should be taken into account when determining factors that may contribute to the decrease in force steadiness seen in older adults.

Visual feedback itself can vary based on the digital scaling of the information presented to the subject. By adjusting the number of pixels per unit isokinetic torque displayed on the screen, visual gain can be raised or lowered which acts to either increase or decrease the amplitude of force variability. This is often an unintentional result of differences in target force levels which can be controlled for by using an absolute target or by expressing gain relative to strength (Tracy et al. 2007). When the on-screen target is maintained in the same position, low target forces exhibit large amounts of gain and high target forces exhibit low amounts of visual gain (Tracy et al. 2007). Baweja et al. (2010) observed increased muscle force steadiness in response to higher visual gain levels. Conversely, Sosnoff and Newell (2006a) found no age-related differences in force variability at low visual scale levels, and others have observed higher force fluctuations in older adults during high visual scaling conditions (Tracy et al., 2007). One could postulate that the reduction in visual acuity observed in older adults would make it more difficult to extract visual information concerning force output. However, if vision were corrected to normal, as most study designs allow for, one would expect the age-related difference in visual acuity to decrease, thereby reducing or even negating any difference in steadiness produced as a result of visual acuity. In support of this notion, Sosnoff & Newell (2006a) concluded that visual acuity, when corrected to normal, did not affect task performance at any level of visual scale. These results suggest that although vision does affect muscle force steadiness, decreased steadiness is not a result of decreased visual acuity, but rather is the result of the decline of another component of visual processing and control.

Summary

Aging results in decreased muscle force steadiness, which has been shown to compromise functional ability during activities of daily living such as eating or doing laundry. Declines in muscle force steadiness could also present safety hazards for older adults such as an increased risk of falling and difficulties when balancing in an upright position. Furthermore, aging is associated with a decline in visual acuity and eye movement control. Older adults compared to young adults, exhibit an increase in eye movement errors when visually tracking a moving object. This discrepancy is thought to be caused by the reduced ability of older adults to match eye movement speed with target speed, resulting in excess eye movement in attempt to correct eye position.

There is a well-documented relationship between the presence of visual feedback and decreased force steadiness in both young and old adults. Older adults display a larger decrease in muscle force steadiness than young adults when using visual feedback to match a target force. Force steadiness is probably not affected by the age-related decline in visual acuity because with corrective optometry there is little to no difference in visual acuity between young and old adults. Therefore, an alternative explanation must exist for the decrease in muscle force steadiness observed in older adults when performing tasks in the presence of visual feedback. For this reason, when investigating the relationship between vision and muscle force steadiness, it is necessary to not only study visual capability in older adults simply by means of acuity but also by examining eye movement, as a component of visual steadiness.

Chapter 3 - Methodology

This study included an experiment to test the hypothesis that visual steadiness is a contributor to decreased torque steadiness, a surrogate for force steadiness, in old adults. This chapter describes the methods by which this hypothesis was tested. This chapter is divided into the following sections: 1) Subject characteristics and recruitment procedures 2) Equipment 3) Protocol 4) Data Analyses.

Subject Characteristics and Recruitment

Subjects were recruited using newspaper ads and through classroom announcements. Interested volunteers were advised to contact the Biomechanics Laboratory upon which they underwent a brief telephone interview to determine initial eligibility for the study. They were then scheduled for both visits to the laboratory. Table 1 shows average subject demographics. Twenty young and twenty old adults were recruited based on the following inclusion and exclusion criteria:

Exclusion Criteria:

- Any degenerative eye condition such as glaucoma, cataracts, or blindness
- Any eye orientation condition such as amblyopia or strabismus
- Current smoker or history of smoking
- Blood pressure > 160/90mm HG
- Previous injury or surgery on the right leg
- Cardiovascular disease, diabetes, or neurological disease
- BMI > $30 kg/m^2$

Inclusion Criteria:

- Healthy young and old adults that can perform several maximal and submaximal quadriceps contractions
- BMI < $30 kg/m^2$

Table 1 - Subject demographics

	n	Height (m)	Mass (kg)	Age (years)	BMI (kg/m^2)
Young	19 (9 male, 10 female)	1.73±0.08	74.2±14.4	20.7±1.82	24.7±3.20
Old	18 (9 male, 9 female)	1.71±0.09	73.4±10.39	71.6±3.01	25.1±2.50

Equipment

Isometric torque data were collected using an isokinetic dynamometer at a sampling frequency of 100 hz (HUMAC NORM, CSMi, Stoughton, MA). As muscle torque is directly proportional to muscle force, we will use the term muscle force to represent the Nm output measured by the HUMAC isokinetic dynamometer. Horizontal and vertical eye movement data were collected using a mobile eye-tracking system at a sampling frequency of 30 hz (Applied Science Laboratories, Bedford, MA). The mobile eye-tracking system included: Mobile eye XG software, a digital video cassette recorder (Sony Corp.) and eye-tracking glasses consisting of a pair of eyeglass frames with two digital resolution cameras mounted above the right eye, one that tracked the scene and one that tracked the eye. Visual targets were displayed on a 19 inch computer monitor (Dell, USA) using a custom made software program. Height and weight for all subjects was measured and recorded in meters and kilograms using a digital scale (Seca, Hanover, MD). The SF-36 (Ware, Kosinski, & Keller, 1994) and SPPB tests (Sayers et al. 2004) were administered to subjects to gauge functional ability.

Protocol

A pilot study was conducted to ensure feasibility of the study. Five young and six old adults were tested during the pilot study, the data from which supported our hypothesis and also aided in our ability to accurately collect data with the equipment. A modified protocol was used; the subject was only required to visit the lab one time. Our pilot data also provided us with an average MVC value that we used during our absolute tasks. The 54Nm absolute value was determined by gathering MVC values from 4 young and 4 old adults. We also used MVC data previously collected in the ECU biomechanics laboratory from 8 young and 8 old adults. 40% MVC values were calculated for the 12 individuals and were averaged together to obtain 54Nm.

Subjects were required to visit the lab twice within seven days, with the two visits being separated by at least one day. The first day assessed maximal quadriceps strength and served as a practice day for the subjects to acclimate to the protocol and equipment and allow for more accurate data collection on day two. On the second day, data were collected for all nine conditions. The first visit lasted approximately 1 hour and the second visit lasted approximately 45 minutes.

During the first visit, the subject signed the East Carolina University approved IRB informed consent form and had their height and weight measured. They also took the SF-36 (Ware, Kosinski, & Keller, 1994) and SPPB tests to confirm functional ability. Blood pressure was taken before any other procedures on both days as a preventative measure to assess the subject's physical health before completing multiple isometric force tasks. Maximal quadriceps force was assessed over three 5 second trials, allowing for 60 seconds of rest in between consecutive trials.

The three second window with the highest average, across all of the trials, was determined to be the maximal voluntary contraction (MVC). All remaining torque tasks were conducted at either 40% MVC or at an absolute value of 54Nm.

The eye-tracker glasses were placed on the subject's face, adjusted so that the three corneal reflections were as close to the center of the pupil as possible, and calibrated using a nine point calibration screen (Figure 1). The main overhead lights were turned off during calibration and for the remainder of the testing session. It was requested of the subjects that they wear contact lenses for corrective vision purposes rather than glasses when applicable. However, if necessary the eye tracker device was able to be calibrated with eye-glasses. The calibration process was repeated at the beginning of the testing session on day two, and if the glasses were moved or shifted on the subject's face at any point during either testing session.

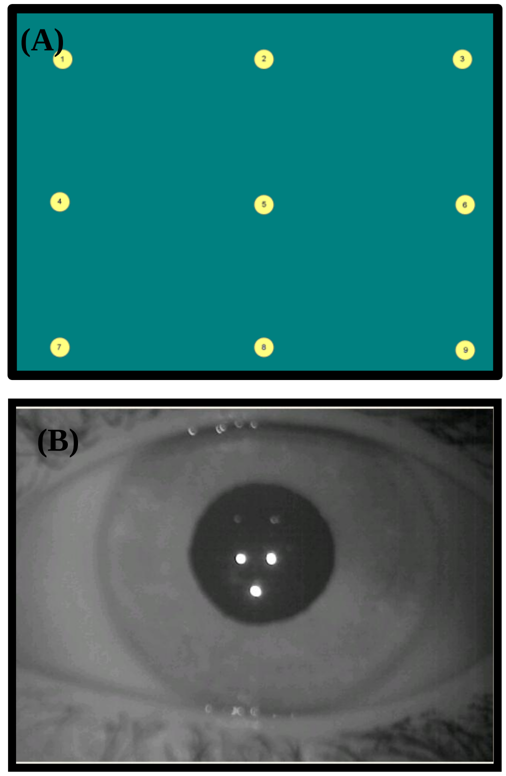

Figure 1: (A) Nine point calibration screen (B) Three corneal reflections.

The subject sat with their forehead approximately 130cm away from the computer monitor which sat 162cm above the floor. The subject sat in the isokinetic dynamometer chair with the back angle at approximately 90 degrees, and the right knee aligned with and parallel to the input shaft of the dynamometer. The right knee was held at a 60 degree angle throughout all tasks. The shin pad was placed on the lower portion of the leg at a comfortable position for the subject and a thigh strap immobilized the right thigh. The seat belt and shoulder stabilization belt were also utilized as an attempt to limit upper body movement during testing.

Data were collected over nine tasks, each task had three trials. The tasks consisted of: three vision only tasks, three vision and force tasks at a relative value of 40% MVC, and three vision and force tasks at an absolute value of 54Nm. The vision only conditions consisted of: a stationary target, the cursor moving across the middle of the blank screen, and the cursor moving across the middle of a screen on a horizontal white line. The force conditions, both relative and absolute, required the subject to bring the ball up to a horizontal line in the middle of the screen and maintain the force, and provide appropriate amounts of force to increase and decrease the ball on triangle and parabola shaped targets (Figure 2). The visual feedback in all force

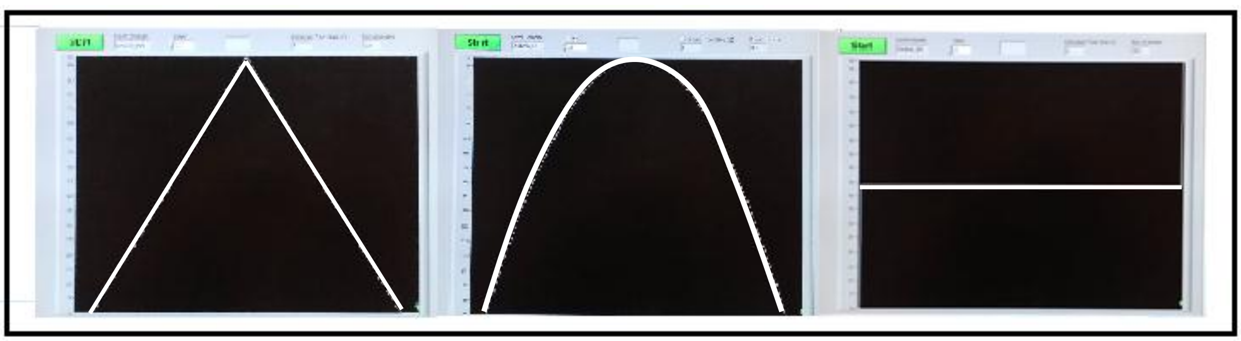

Figure 2: Target force conditions. From left to right: triangle, parabola, horizontal line.

conditions consisted of pursuit type feedback with a cursor in the form of a green ball moving in the vertical direction in response to force production. The ball moved horizontally at a single speed throughout all trials. Each individual task lasted 8 seconds. Both horizontal and vertical vision data and force data were collected for each trial individually.

Data Analyses

The eye tracker provided a continuous recording of eye position for each trial, as well as an indication to any possible disruptions that caused a loss of signal. The recording for each trial was initiated one second before the subject started the trial, as determined by the three second countdown at the beginning of the trial, and terminated one second after the subject finished the trial. In the event that the infrared beam producing the three corneal reflections on the subject's eye was disrupted, that section of the data was removed from the trial. Disruptions to the data recording could be a result of blinking, excessive squinting, or in some other way obstructing the path of the infrared light to the cornea.

Force data were collected from the isokinetic dynamometer for all force conditions. Horizontal and vertical eye movement data were collected from the eye-tracker. Following data collection, trials were entered into an excel spreadsheet for each subject. The middle 60% of each set of data was plotted on a line of best fit for all three trials (Figures 3a, 4a, and 5a). The middle 60% was used in an attempt to only analyze data collected when the subject was performing the intended task. For example, we did not wish to analyze the portion of the trial during which the subject was moving their eyes or the cursor to the target line. Measures of variance and central tendency were averaged over each condition. The horizontal and vertical vision data and force data were detrended before calculating measures of variance and central tendency for all conditions other than the stationary vision condition (Figures 3b, 4b, and 5b). Detrending was accomplished by subtracting the line of best fit from each point. We used standard deviation and coefficient of variation to quantify the amount of steadiness for the vision and force trials.

Statistical Analysis

We compared young and old adults on strength, visual steadiness, force steadiness, and selected visual parameters to determine any age-related differences using a simple t-test. A Pearson Product Moment Correlation analysis was also performed with each test condition individually to establish a relationship between visual steadiness and muscle force steadiness. The horizontal 40% MVC and horizontal 54Nm conditions were used to compare muscle force steadiness values that we obtained from our subject pool with the literature. The correlations performed on the triangle 40% MVC, triangle 54Nm, parabola 40% MVC, and parabola 54Nm conditions were used to analyze the relationships between vision and force data. The alpha level was set at $p < 0.05$ for all tests.

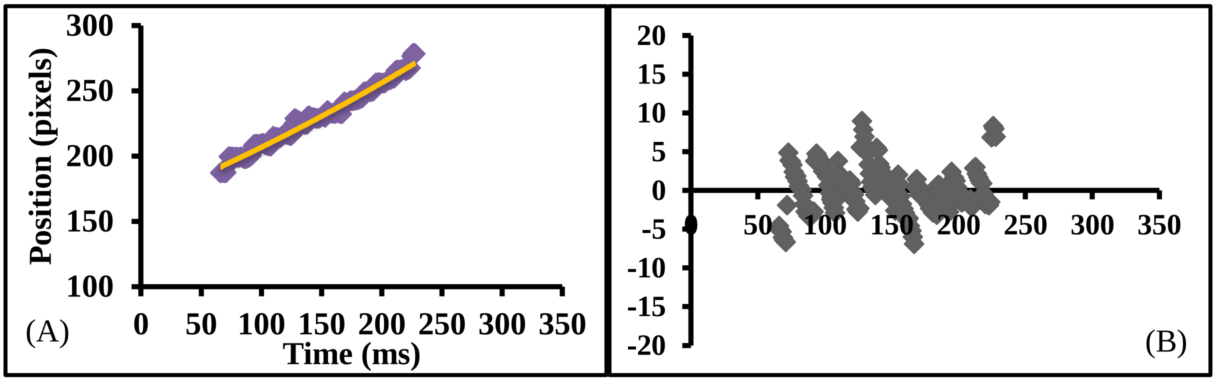

Figure 3: Representative horizontal vision data for a triangle task from one individual. (A) Middle 60% of data set (B) Detrended data from A

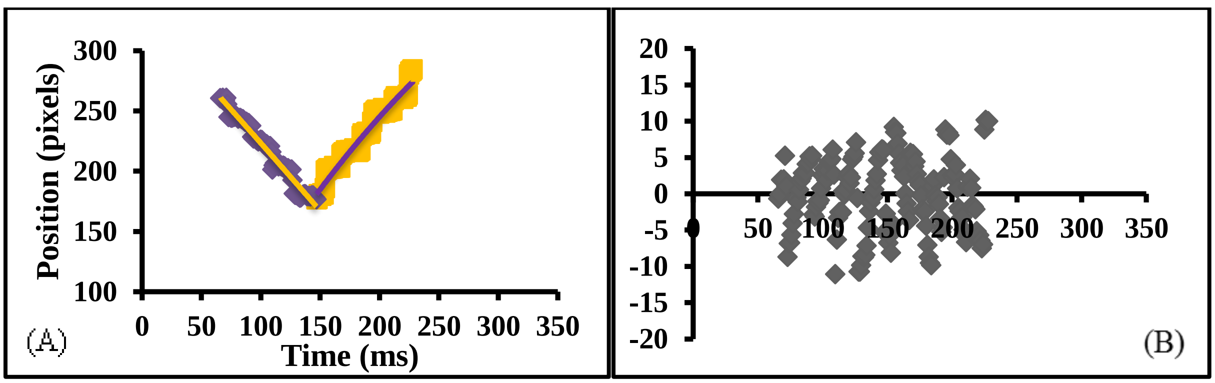

Figure 4: Representative vertical vision data for a triangle task from one individual. (A) Middle 60% of data set (B) Detrended data from A

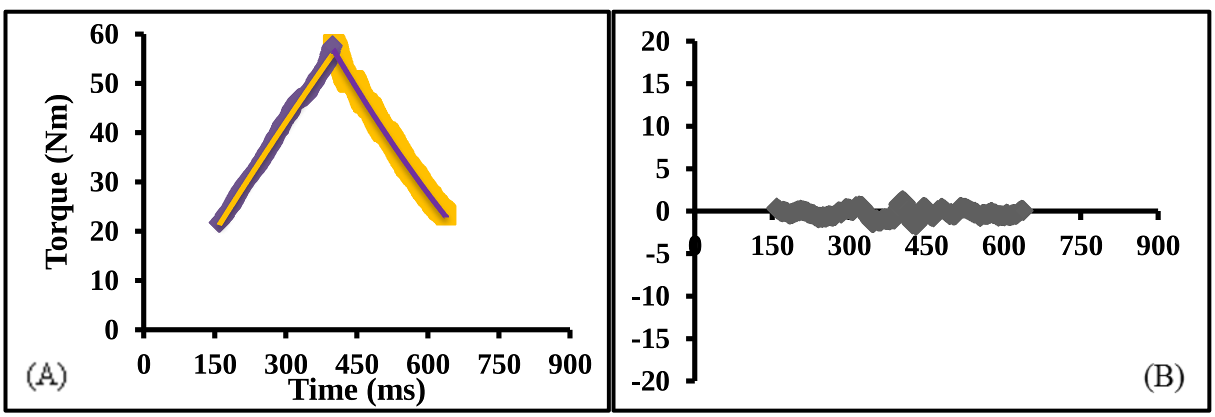

Figure 5: Representative force data for a triangle task from one individual. (A) Middle 60% of data set (B) Detrended data from A

Chapter 4 - Results

It was hypothesized that there would be direct relationships between visual steadiness and muscle force steadiness in both young and old adults, with the implication that reduced muscle force steadiness in older adults would be at least partially explained by reduced visual steadiness. The purpose of this study was to compare the relationships between eye movement, as a component of visual steadiness, and muscle force steadiness in young and old adults during isometric quadriceps contractions of constant and varying forces. We will use the term muscle force to represent the Nm output measured by the isokinetic dynamometer. This chapter is separated into the following sections: 1) Age-Related Differences in Muscle Force and Functional Ability, 2) Age-Related Differences in Muscle Force Steadiness 3) Age-Related Differences in Visual Capacity and 4) Relationships Observed between Visual Steadiness and Muscle Force Steadiness.

Age-Related Differences in Muscle Force and Functional Ability

In general, young and old adults displayed similar muscle force and functional ability. Old adults were 31% weaker than young adults ($p<0.05$) in terms of maximum voluntary strength (Table 2). The two groups displayed similar functional abilities as measured by the SPPB and SF-36 assessments (Table 3), indicating that our old adult subject pool consisted of very capable older adults. Although a t-test determined that the scores of the two groups were significantly different, we do not believe this to be a functional difference. The SPPB (Sayers et al. 2004) scoring guide states that a score of nine or greater out of 12 indicates a high level of functional ability. The SF-36 (Ware et al. 1994) scoring guide states that a score of 47 or above is average.

Table 2 - Muscle capacity

	MVC (Nm)
Young	209±68.4
Old	145±51.5
p	0.00*

Table 3 – Functional capacity

	SPPB Score (Out of 12 possible points)	SF-36 Score	
		Physical	Mental
Young	11.8±0.4	55.9±3.2	53.8±4.6
Old	11.4±0.9	52.7±5.0	56.4±4.8
p	0.04*	0.01*	0.05

*Young vs. Old, $p<0.05$

Age-Related Differences in Muscle Force Steadiness

We used the force data from the horizontal vision and torque conditions to quantify muscle force control in young and old adults. Table 4 shows muscle force steadiness values for each group in the absolute and relative force conditions. The absolute (Fig. 6) and relative (Fig. 7) horizontal vision- force conditions show similarities in muscle steadiness between the two groups and conditions. The target force for the absolute condition was 54.0Nm and the average target force for the relative condition was 83.8Nm and 58.0Nm for young and old, respectively. There were no significant differences between the young and old adults for force steadiness in the absolute condition ($p=0.19$) with young adults displaying an average force variability of 0.76±0.25Nm and old adults displaying an average force variability of 0.84±0.29Nm. Statistical significance was detected for the relative force condition ($p < 0.05$); however, these results were contrary to our expectations, with older adults showing less force variability with an average of 0.79±0.36Nm compared to young adults with an average of 1.16±0.44Nm.

Table 4 – Muscle Force Steadiness

	Relative 40% MVC (Nm)	Absolute (54Nm)
Young	1.16±0.44	0.76±0.25
Old	0.79±0.36*	0.84±0.29

Force steadiness is expressed as the SD of the force fluctuation in Nm; *Young vs. Old, $p<0.05$

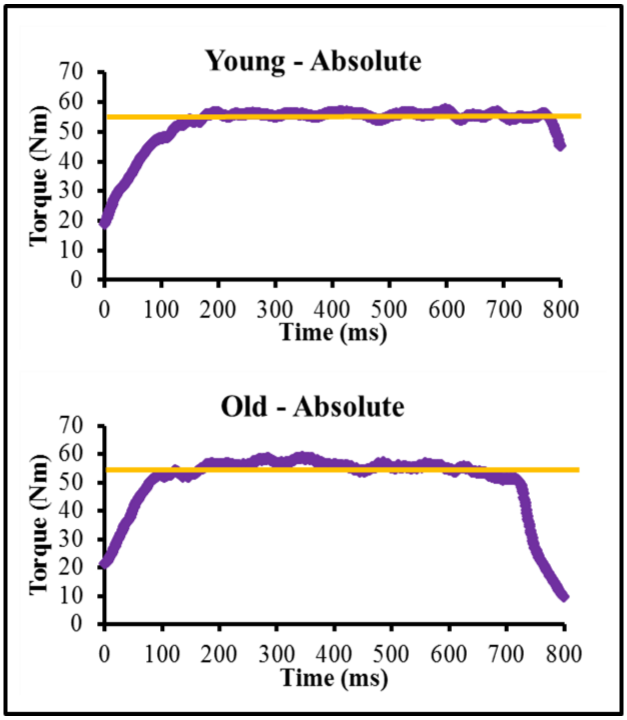

Figure 6: Representative force data from one young (A) and one old (B) individual. Data was collected during absolute horizontal vision and force condition. Yellow bar indicates target force (54Nm).

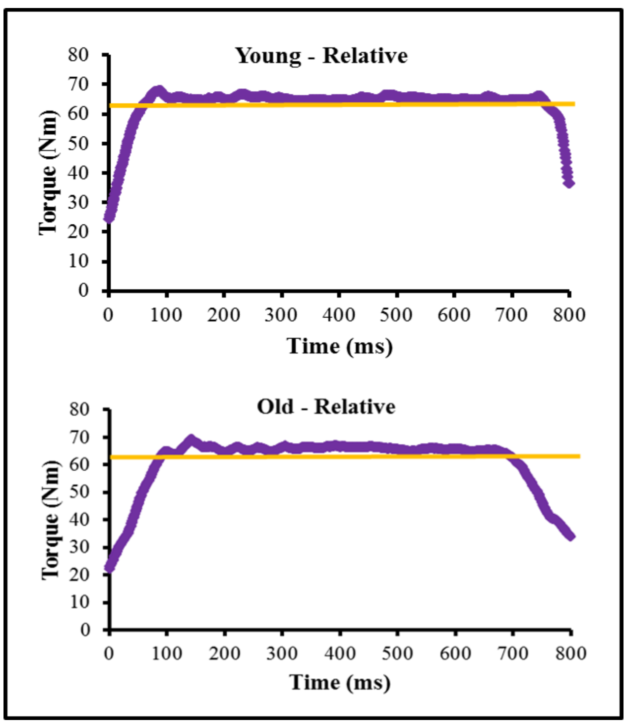

Figure 7: Representative force data from one young (A) and one old (B) individual. Data was collected during relative horizontal vision and force condition. Yellow bar indicates target force (~62Nm).

Age-Related Differences in Visual Capacity

Overall, both young and old adults displayed similar visual capacity, as measured by the three vision-only conditions. The static vision condition did not show a significant difference between the two groups for the horizontal ($p=0.08$) or vertical ($p=0.28$) visual components (Fig. 8). Similarly, the vision no-line condition (Fig. 9), which required the participant to visually track a cursor across a blank screen, and vision horizontal-line condition (Fig.10), which required the participant to visually track a cursor across a horizontal line on the screen, did not show a significant difference between young and old adults for the vertical vision component, $p=0.34$ and $p=0.47$, respectively. However, a significant difference was observed in the horizontal component for the two conditions, with older adults showing decreased visual steadiness compared to young adults ($p < 0.05$). Table 5 shows mean steadiness and standard deviation values for the static, no-line, and horizontal vision-only conditions.

Table 5 – Visual Steadiness

Condition	Young		Old	
	Horizontal (pixels)	Vertical (pixels)	Horizontal (pixels)	Vertical (pixels)
Static	2.13±1.83	2.75±1.04	2.59±1.12	3.09±2.26
No-Line	2.19±0.80*	2.66±0.85	3.59±1.61*	2.51±1.23
Horizontal	2.35±0.88*	2.56±0.68	3.91±2.70*	2.59±1.29

Force steadiness is expressed as the SD of the eye position in pixels, larger numbers indicate less steadiness; *Young vs. Old, $p<0.05$

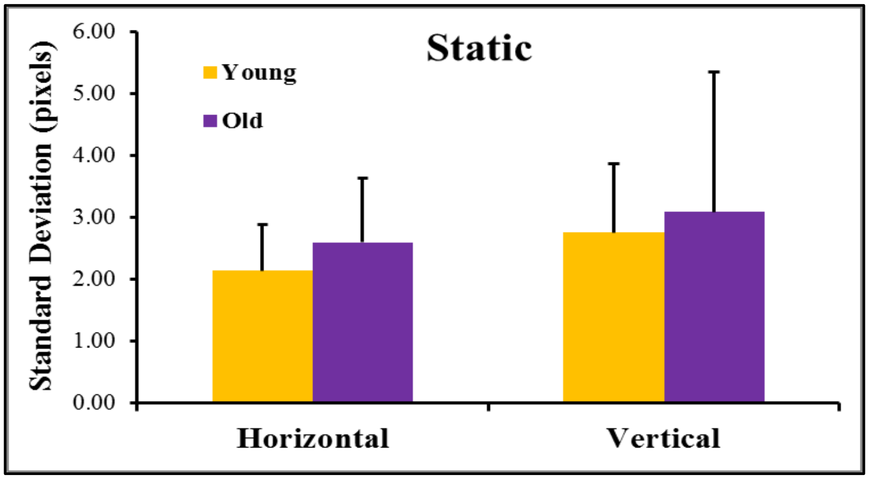

Figure 8: Average variation during the static vision condition for horizontal and vertical visual components.

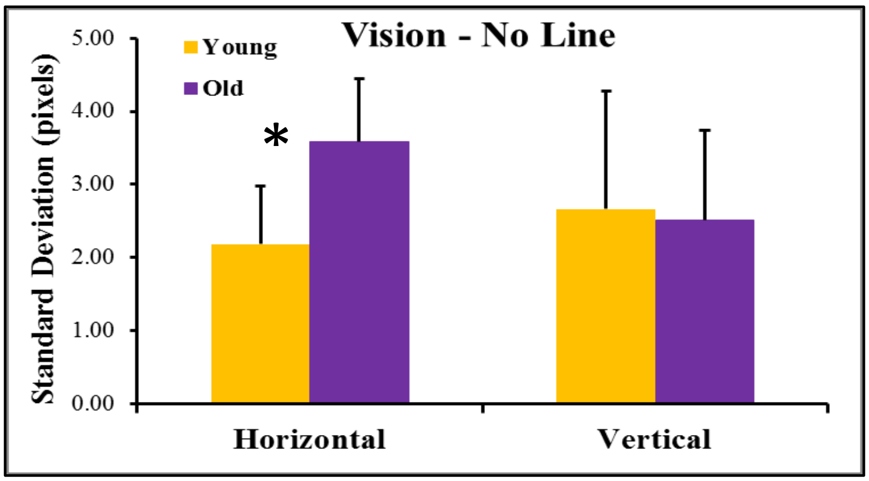

Figure 9: Average variation during the vision-horizontal condition for horizontal ($p< 0.05$) and vertical ($p= 0.47$) components

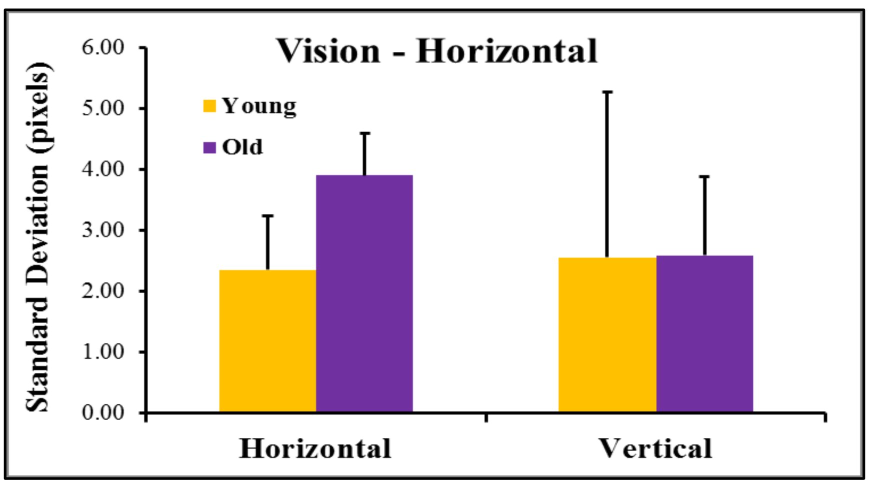

Figure 10: Average variation during the vision no-line condition for horizontal ($p< 0.05$) and vertical ($p= 0.34$) components

Relationships Observed between Visual Steadiness and Muscle Force Steadiness

Correlations performed between visual steadiness and muscle force steadiness showed a statistically significant relationship for the relative triangle condition (r=0.471) and failed to show statistical significance for any of the remaining conditions using the following critical values for a two-tailed test at $p<0.05$: young adults (df=17) =0.456, old adults (df=16) =0.468. Table 6 (relative) and Table 7 (absolute) show the correlation coefficient (r) values for each vision and torque condition. The resultant values of the vertical and horizontal vision components were used in the correlations. Figures 11 and 12 show the line of best fit between vision and torque along with the corresponding R^2 values for the triangle (Fig. 11) and parabola (Fig. 12) conditions. We were not able to identify any physiological relationship between muscle force steadiness and visual steadiness.

Table 6 – Correlation coefficients for relative conditions

	Young	Old
Horizontal	0.197	0.014
Triangle	0.083	0.471*
Parabola	0.083	0.241

*r value <> 0, p<0.05

Table 7 – Correlation coefficients for absolute conditions

	Young	Old
Horizontal	0.014	0.269
Triangle	0.195	0.169
Parabola	0.399	0.145

*r value <> 0, p<0.05

Triangle Condition

Young Adults Old Adults

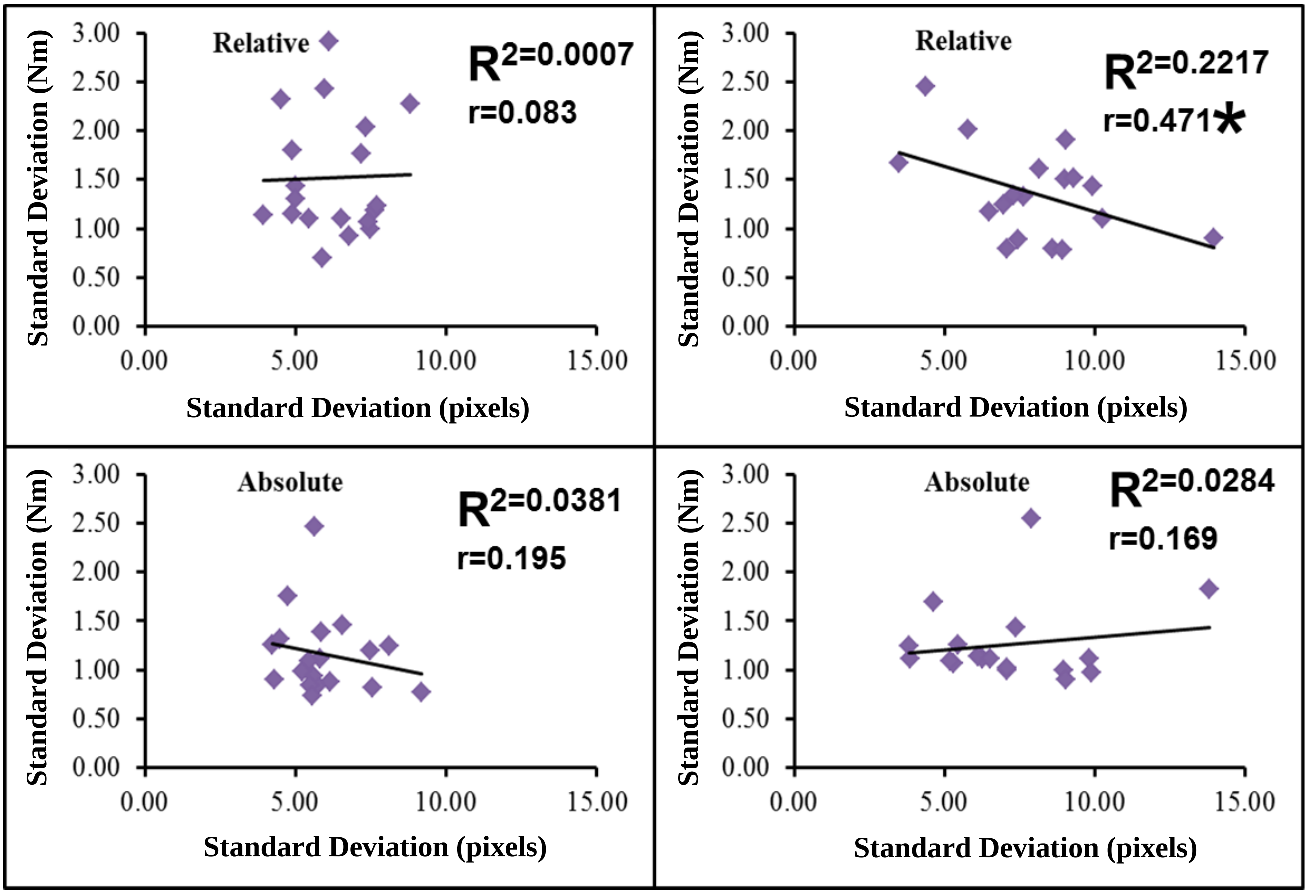

Figure 11: Correlations and coefficients of determination for the absolute and relative triangle conditions.

Parabola Condition

Young Adults **Old Adults**

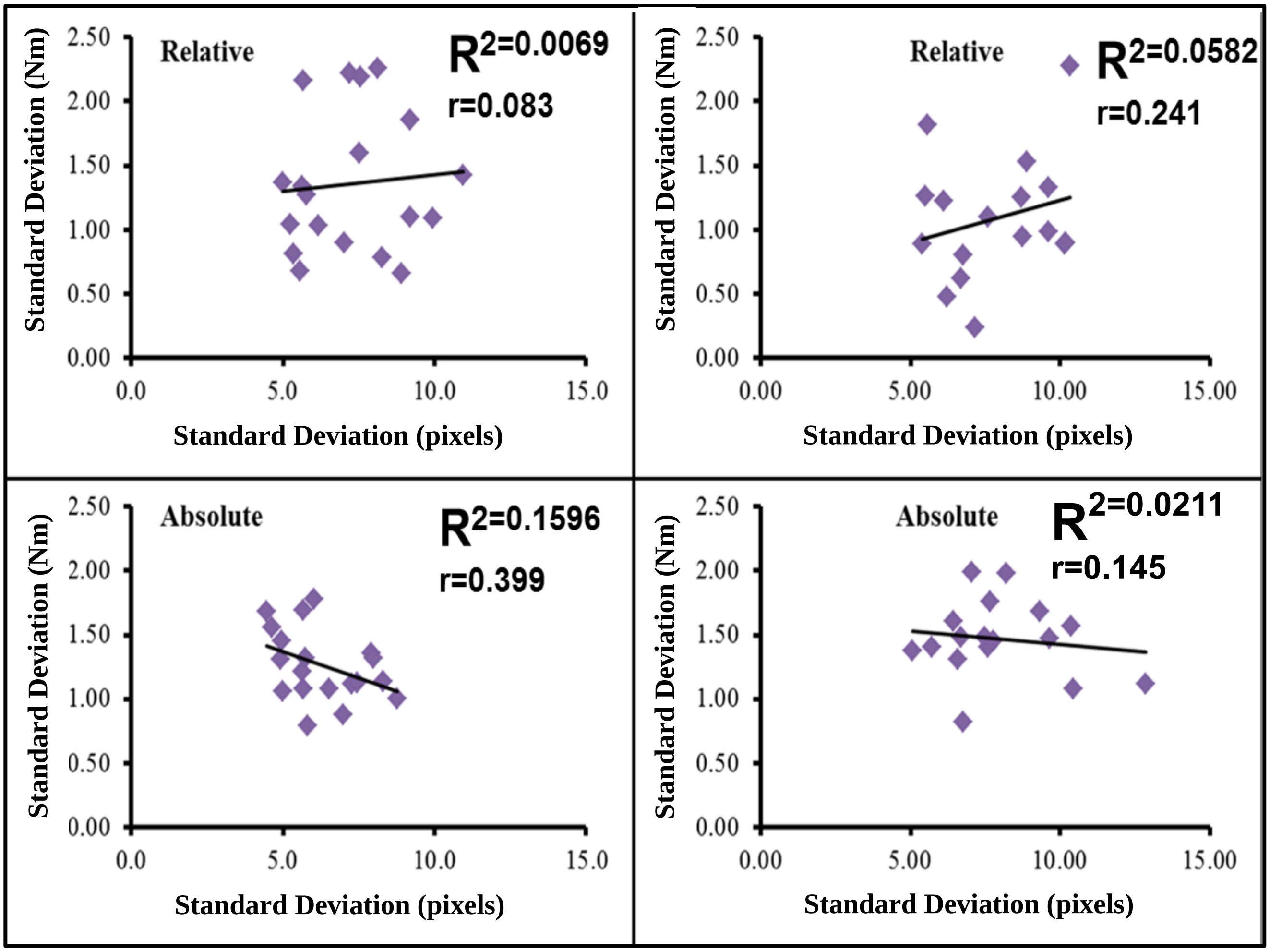

Figure 12: Correlations and coefficients of determination for the absolute and relative parabola conditions.

Chapter 5 – Discussion

The purpose of this study was to compare the relationships between eye movement, as a component of visual steadiness, and muscle force steadiness in young and old adults during isometric quadriceps contractions of constant and varying forces. It was hypothesized that there would be direct relationships between visual steadiness and muscle force steadiness in both young and old adults, with the implication that reduced muscle force steadiness in older adults would be at least partially explained by reduced visual steadiness. This chapter will discuss the methods and results in comparison to current literature and our hypothesis. It will be separated into the following sections: 1) Functional Capacity 2) Force Steadiness, 3) Visual Steadiness, 4) The Relationship between Force Steadiness and Visual Steadiness, and 5) Conclusions.

Functional Capacity

Young and old adults in the present study were healthy, mobile, and functionally capable individuals. The old adults in particular were high performing individuals in the extreme. The two groups differed only in age (by design) and maximal isometric quadriceps strength. The SPPB (Sayers et al. 2004) and SF-36 (Ware et al. 1994) test results, used to indicate functional ability and to quantify an individual's level of frailty, demonstrate the excellent mobility of the old adults. On the SPPB test, which included several balancing tasks and a timed sit to stand task, both the young and old adult groups had an average score close to the maximum total score of 12 (young 11.8±0.4, old 11.4±0.9). Young and old adults also had similar scores on the SF-36 measure of physical capacity (young 55.9±3.2, old 52.7±5.56), and old displayed a higher score compared to young adults on the SF-36 measure of mental capacity (young 53.8±4.6, old 56.4±4.8). The SF-36 scoring guide indicates that a score below 45 is representative of the below average population. Accordingly, physical component scores for frail older adults have been recorded to be apporoximately 24 points (Meng, King-Kallimanis, Gum, & Wamsley 2013; Stadnyk, Calder, & Rockwood 1998), which is roughly 50% below the scores of our older adult subjects. The older adults in this study scored higher on both the SPPB and SF-36 tests compared to other healthy older adults in the literature, indicating their excellent biomechanical capacity (Iannuzzi-Sucich, Prestwood, & Kenny 2002).

In addition, both the young and old adult groups displayed higher maximum isometric quadriceps strength compared to participants in similar studies. For example, Schiffman et al. (2002) reported MVC values of 161.3±31.3Nm for young adults and 104.3±25.1Nm for old adults which are roughly 23% and 28% below the MVC measures taken from our young and old adult subject groups, respectively. Likewise, average isometric quadriceps MVC values from Hortbágyi et al. (2001) are 12% lower than the young adults and 22% lower than the old adults tested in the current study, once again displaying their superior functional capacity. In order to make comparisons to studies with values reported in N, we divided our Nm values by an average lever arm of .28m.

Force Steadiness

In the current study, standard deviation was used to quantify muscle force steadiness rather than coefficient of variation which is often used in similar studies. Young adults displayed less force steadiness (higher standard deviation) than old adults at the 40% MVC relative force level. Likewise, Tracy and Enoka (2002) used standard deviation values to quantify steadiness and reported younger adults displayed larger force fluctuations at 5, 10, and 50% MVC when compared to older adults. Additionally, the two groups did not display a significant age-related difference in isometric quadriceps force steadiness at an absolute 54Nm force level; this is consistent with the findings of Hortbágyi et al. (2001) who showed no difference in isometric knee extensor steadiness between young and old adults at an absolute force level (4.0±1.0 for both the young adult and old adult groups). The force steadiness values we recorded for both the relative (young 4.14±1.57N, old 2.82±1.29N) and absolute (young 2.71±0.89, old 3.00±1.04) conditions are slightly less than steadiness values reported in the literature for healthy, mobile individuals. For example, Christou and Carlton (2001) reported values of 3.4±1.2N and 6.5±2.7N for young and old adults, respectively, at a target force level of 35N. Similarly, Tracy and Enoka (2002) reported 50% MVC isometric quadriceps steadiness values that were approximately 36% higher than both our young and old adult groups in the relative condition. This is indicates that our older adults displayed more force steadiness than old adults in similar studies.

The high level of functionality that the older adult participants exhibited may have partially contributed to the unexpected force steadiness results. We did not control for strength training history when recruiting participants, unlike similar studies (Welsh et al. 2007, Tracy 2007, Tracy et al. 2007, and Tracy et al. 2002) that excluded individuals who had participated in a strength training program in the year before joining the study. However, light-load training has been shown to decrease force variability in knee extensor muscles during isometric contractions over a range of force levels (Kobayashi, Koyama, Enoka, & Suzuki, 2012), even in the most unsteady subjects (Tracy et al. 2006). Thus, if the older participants in the current study were engaging in a strength training program on a regular basis they would have displayed less force variability than sedentary individuals. This presumption is supported with the observations of Sosnoff and Newell (2006b) that decrements in force steadiness are more closely related to strength than to chronological age; and that stronger individuals are less variable than weak individuals at low and moderate force levels (Sosnoff and Newell, 2006b).

Previous research demonstrates support for the idea that practice may decrease muscle force variability, which might offer an explanation to account for the relatively low force variability displayed by our participants. Cirillo et al. (2011) reported that young and old adults displayed similar task specific improvement after short-term training with a complex visuomotor task. Our subjects performed the visual steadiness and force steadiness tasks on two separate occasions which may have induced an unintended learning effect. Vaillancourt and Russell (2002) provide some evidence refuting this notion by showing that there were no changes in the amount of force variability over the course of a 20 second constant-force trial after one practice trial. In contrast to Vaillancourt et al., we provided our subjects with extensive practice. Participants visited the lab twice within a seven day period; on the first day, after going through functional testing and MVC testing, the subjects performed a "practice protocol," executing an identical set of tasks and conditions that they would perform on their second visit to the lab Although the order of the vision and force tasks was selected randomly, the 54Nm absolute value at which our subjects were tested corresponded to 28.5±9.0% and 42.8±17.9%, of the young and old adult average MVC values, respectively. Thus, the difference between the 54Nm absolute and 40% MVC relative target levels for the old adults was only about ~3% while the difference for the young adults was ~11%. This negligible change in target force levels for older adults could have also contributed to the learning effect through repetition. The substantial amount of practice trials that our subjects completed prior to data collection may be a contributing factor to the relatively high force steadiness participants in the present study displayed.

Visual Steadiness

Although the young and old adult groups were similar in terms of visual steadiness, it is important to note that there was a statistically significant age-related difference in horizontal eye movement for the no-line and straight-line vision only conditions. In the current study, old adults showed less horizontal eye movement steadiness than young adults. Visual steadiness was quantified as the standard deviation of eye movement in pixels as a response to a visual target. Our analysis showed that young adults had horizontal visual steadiness values ranging from 2.13 to 2.35pixels, and the old adult group had horizontal steadiness values ranging from 2.59 to 3.91pixels. Vertical visual steadiness values between the two groups were quite similar with young adult ranging from 2.56 to 2.75pixels and old adults with a range of 2.51 to 3.09pixels. This discrepancy is consistent with literature suggesting that older adults show increased variability along the horizontal direction compared to the vertical direction (Kosnik et al. 1986). Interestingly, there was not a significant difference between the two groups for the static task, during which, the visual target did not move. Therefore, one might postulate that the movement of the visual target in the no-line and straight-line tasks evoked a different visual response than the non-moving target from older adults, resulting in decreased horizontal eye movement steadiness. These results are in agreement with the observations of O'Connor et al. (2010) that young and old adults exhibited similar eye movements during a static fixation task, yet, during a pursuit task, older participants displayed decreased eye movement control compared to young adults.

We did not perform any standardized visual acuity (as opposed to visual steadiness, which we measured in this study) tests on our subjects to measure clarity of vision. For example, having participants read aloud using the Snellen eye chart. However, any individuals with degenerative eye conditions or eye orientation conditions were excluded after the initial phone interview. During testing, none of the participants reported any problems clearly viewing the computer monitor displaying force feedback. It is common to forgo visual acuity testing when investigating the roles of visual processing or visual control on force steadiness (Welsh et al. 2007, Tracy et al. 2007). Furthermore, Sosnoff et al. (2006a) found no correlation between visual acuity and force steadiness regardless of the amount of feedback presented on the screen. Therefore, it is unlikely that an age-related difference in visual acuity, the clarity of vision (as opposed to visual steadiness), would have had an effect on muscle force steadiness between the two groups.

This was the first time that an attempt has been made to quantify visual steadiness using eye movement recordings from an eye-tracking instrument while assessing force steadiness. Previously, eye-tracking devices similar to the one used in this study have been used to relate eye movement to large-scale tasks. For example, quantifying gaze patterns when walking to a target at the end of a hallway (Turano et al. 2003), or identifying focal points while driving (Land and Lee, 1994). It is possible that this particular device was not able to sufficiently detect the small variation in eye movement needed to quantify visual steadiness. In addition, there may be some concern over the amount of head movement from the participants during tracking tasks as we did not immobilize the subjects' heads during testing. Although we gave several verbal commands instructing participants to only track the target by moving their eyes, and to keep their head as still as possible, we cannot rule out the possibility that head movement contributed to our visual steadiness findings.

Relationships between Force Steadiness and Visual Steadiness

Despite a few small differences in visual steadiness between young and old adults, we were unable to establish a relationship between visual steadiness and isometric knee extensor force steadiness in young and old adults. Our analysis showed correlation coefficients ranging from r=0.014 to 0.471 between muscle force steadiness and visual steadiness in the three relative force conditions, only one of which produced a weak significant correlation. From the three absolute force conditions, our analysis showed correlation coefficients ranging from r=0.014 to 0.399 between muscle force steadiness and visual steadiness in the absolute force conditions, none of which were significant.

Contrary to our findings, there appears to be a well-documented relationship between visual feedback and muscle force steadiness, showing that the presence of visual feedback provoked an increase in the amount of force variability in older adults compared to young adults (Tracy 2007, Tracy et al. 2007, and Welsh et al. 2007). In fact this observation was a foundational issue for our hypothesis. Welsh et al. (2007) demonstrated that age-related differences in motor unit firing rate variability are only observed in the presence of visual feedback. In addition, age-related deficits in muscle force steadiness have been identified as a response to complex versus simple visual feedback (Ofori et al. 2010) and in response to increased amounts of visual feedback through manipulating visual gain, or pixels per unit force (Sosnoff and Newell 2006a). With these factors in mind, one could presume that while we were unable to identify a relationship between visual steadiness and force steadiness, there may be some other age-related deficits affecting the way older adults view and respond to visual information that is likely related to force output variability. Several factors, other than the presence of visual feedback, have also been shown to influence force variability. For example, the presence of physiological stressors (Christou, 2005; Christou, Jakobi, Critchlow, Fleshner, & Enoka 2004), emotional state (Naugle, Coombes, and Janelle 2010), altered levels of respiration (Baweja, Patel, Neto, & Christou 2011), and aging (Enoka et al. 2003). Further interpretation might suggest these factors are indicative of the notion that there may be physiological factors other than muscle force control that influence muscle force steadiness.

Conclusion

We were not able to identify any physiological relationship between muscle force steadiness and eye movement, as a component of visual steadiness. Therefore, there is no evidence to support our hypothesis that there would be direct relationships between visual steadiness and muscle force steadiness in both young and old adults, with the implication that reduced muscle force steadiness in older adults would be at least partially explained by reduced visual steadiness. Thus, it is possible that the relationship between force steadiness and visual feedback identified in previous research is due to decrements in visual processing capabilities and not due to a decline in visual steadiness. Additionally, the interactions between force steadiness and aging observed in the literature might in fact be due to reduced neuromuscular control with aging. Regardless, we were not able to detect the influence of visual capacity on muscle force steadiness in young or old adults. As this was a novel approach to investigating visual steadiness, future research should explore alternative methods to measure visual steadiness in relation to muscle force steadiness.

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Appendix – Consent Form

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
1L-09 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · www.ecu.edu/irb

Notification of Initial Approval: Expedited

From: Biomedical IRB
To: Paul DeVita
CC:

Patrick Rider
Date: 11/4/2011
Re: UMCIRB 11-000968
Age, Visual Acuity and Muscle Control

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 11/4/2011 to 11/3/2012. The research study is eligible for review under expedited category #4, 6, and 7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description
Aging - Vision Control & Muscle Control - Protocol Summary - Sept 2011.docx | History	Study Protocol or Grant Application
Announce & Daily Reflector Announcements.doc | History	Recruitment Documents/Scripts
Informed Consent Form - Aging - Vision - Muscle - Control - Fall 2011.docx | History	Consent Forms
Phone Interview - Initial Health Survey.docx | History	Surveys and Questionnaires
SF36.pdf | History	Surveys and Questionnaires

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

Informed Consent to Participate in Research Study

Title of Research Study: Age, Visual Acuity and Muscle Control
Principal Investigator: Paul DeVita, Ph.D.
Institution/Department or Division: Department of Kinesiology
Address: 332 Ward Sports Medicine Building
Telephone #: 252.737.4563

INTRODUCTION:

I have been asked to participate in a research study being conducted by Paul DeVita, Ph.D. The purpose of this study is to examine the contribution of visual steadiness on force steadiness. The decision to take part in this research is entirely up to me.

PLANS AND PROCEDURES

Why am I being invited to take part in this research?
I am being invited to participate in this research because I meet the inclusion criteria and have no apparent contraindication to participating in the study. Inclusion criteria are: between the ages of 18 and 25 years or 70 and 85 years, am healthy and free of skeletal, nervous, and mental impairments, not overly heavy, and am willing to participate in the tests and measurements.

I understand I should not volunteer for this study if I am a smoker, not between the ages listed above, suffered a serious injury to my legs, had or have a medical condition (for example stroke, heart attack, cancer, diabetes), a history of falls, surgery on my legs, am unable to walk independently, use walking aids, have uncontrolled high blood pressure, take medications that cause dizziness, am overly heavy, have a heart condition, am pregnant or breastfeeding, or currently lift weights more than once per week.

Where is the research going to take place and how long will it last?
The research procedures will be conducted in the Biomechanics Laboratory, room 332 Ward Sports Medicine Building at ECU. I will visit the Lab twice within several days of each other.

What will I be asked to do?

During the first visit to the Lab, I will:
1. read and sign this informed consent form
2. provide personal information about my general health and my general movement capabilities,
3. complete a short survey about my general health,
4. have my height and weight measured,
5. perform a 5 minute test of my walking and balance abilities,
6. warm up on a stationary bicycle,
7. be shown the instruments to measure my thigh muscles force and my eye movements,
8. have my blood pressure and my maximal thigh muscle strength measured.

UMCIRB Number:__ **11-000968** _________

Consent Version # or Date:__11/4/2011_______
UMCIRB Version 2010.05.01

____
Participant's Initials

9. have the 10 tests explained to me and then practice the tests with the force measuring and eye-tracking instruments,

During the second visit to the Lab, I will:

1. have my blood pressure measured,
2. warm up on a stationary bicycle for five minutes,
3. perform the tests shown to me during the first visit.

What possible harms or discomforts might I experience if I take part in the research?
As with any strong muscle effort, there is a possibility for muscle strain to occur. A thorough familiarization and warming up will minimize the risks for muscle strain and soreness.

What are the possible benefits I may experience from taking part in this research?
I may not receive substantial benefits personally but I will contribute to medical knowledge related to the decline in muscle control with age. The information derived from my tests may be used to develop improved exercise programs for older adults.

Will I be paid for taking part in this research?
I will be paid $25 after the completion of the two Laboratory sessions.

What will it cost me to take part in this research?
It will not cost me any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?
To do this research, ECU and the people listed below may know that I took part in this research and may see information about me: Paul DeVita, the main investigator, Patrick Rider, the study coordinator, and the graduate students doing the testing.

How will you keep the information you collect about me secure? How long will you keep it?
Data files will be kept for 5 years after the study is completed. The investigators will keep my personal data in strict confidence by having my data coded. Instead of my name, I will be identified in the data records with an identity number. My name and code number will not be identified in any subsequent report or publication. The study investigators and the research students will be the only persons who know the code associated with my name and this code as well as my data will be kept in strict confidence.

What if I decide I do not want to continue in this research?
If I decide I no longer want to be in this research after it has already started, I may stop at any time. I will not be penalized or criticized for stopping. I will not lose any benefits that I should normally receive.

Who should I contact if I have questions?
The people conducting this study will be available to answer any questions concerning this research, now or in the future. I may contact the main investigator, Paul DeVita, at 252.737.4563 (work days, between 8 am to 5 pm).

If I have questions about my rights as someone taking part in research, I may call the Office for Human Research Integrity (OHRI) at phone number 252-744-2914 (days, 8:00 am-5:00 pm). If I would like to report a complaint or concern about this research study, I may call the Director of the OHRI, at 252-744-1971.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask me to read the following and if I agree, I should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

____

Participant's Name (PRINT) **Signature** **Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

Paul DeVita, Ph.D., study director____

Person Obtaining Consent (PRINT) **Signature** **Date**

____

Family physician / Nurse (PRINT) **Signature** **Date**