EFFECTS OF ECCENTRIC ENDURANCE TRAINING ON PHYSICAL AND COGNITIVE FALL RISK FACTORS

by
Samantha L. Johnson

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Dissertation Committee:

Dr. Jennifer L. Caputo, Chair

Dr. Sandra L. Stevens

Dr. Dana K. Fuller

I would like to dedicate this dissertation to my parents, sister, niece, and nephews.

Mom and dad, thank you for helping me become who I am today.

Through you, I have learned about hard work, sacrifice, and treating others with respect.

You helped me realize that when I feel I have nothing left to give, there is always more.

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even when the whole world would understand your weakness.

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ABSTRACT

A proactive approach to fall risk prevention may help minimize the likelihood of a fall for older adults not yet classified as being at high risk of falling. These studies focused on assessing how eccentric endurance training (EET) influenced physical and cognitive modifiable fall risk factors. Physical fall risk factor assessments included a 30-second sit-to-stand test (30CST), Berg Balance Scale (BBS), single leg stance with eyes closed (SLS-EC), Functional Gait Assessment (FGA), and Timed Up-and-Go (TUG). Maximal eccentric strength (MES) was also assessed. Cognitive fall risk factor assessments included one measure of dual-tasking, the cognitive Timed Up-and-Go (TUGcog), and two measures of executive function, the Trail Making Test (Parts A and B) and the Stroop Test (Conditions A, B, and C).

The sample included 30 older adults (68.2 ± 3.7 years; 16 females, 14 males), with 15 participants completing the EET training (69.0 ± 4.4 years; 8 females, 7 males) and 15 participants in the control group (67.5 ± 2.6 yearsy; 8 females, 7 males). Training group participants completed 1 week of familiarization and 8 weeks of twice weekly EET training. Participants in the control group were asked to maintain their normal activities throughout the 9 week study duration. For both groups, pre-assessments were conducted on the second day of the familiarization week, mid-assessments were conducted on the first day of Week 5, and post-assessments were conducted within 1 week of completing Week 9.

There were significant improvements in 30CST, BBS, FGA, and TUG performance. In contrast, no significant changes in SLS-EC or MES were observed.

Although a significant change and a large effect size were observed for the BBS, the near maximal scores at pre-assessment made it improbable to elicit meaningful changes. While scores within 1 point of perfect were less frequent on the FGA, there remains to be information regarding minimum detectable changes for this outcome. As such, the 2.2 point increase in performance should be interpreted with caution. The 30CST and TUG also yielded significant improvements and large effect sizes. While minimum detectable changes have not been reported, the 2.6 repetition increase in 30CST and 0.9 second decrease in TUG performance are notable.

In contrast, there were no significant differences in the cognitive function outcomes. The TUGcog was the only assessment that did not exhibit a potential learning effect, as there was no significant main effect for time. Although not significant, a 0.66 second improvement was observed for the EET group. In contrast, the Trail Making Test (Part B) and Stroop Tests (A, B, and C) exhibited a main effect for time with no significant interaction. This indicates all participants improved over time, which was likely the result of a learning effect. As such, there is a need for measures of executive function that are less influenced by time.

In summation, 8 weeks of EET yielded improvements in physical function without cognitive performance changes. The largest and most meaningful changes were observed in muscular fitness and overall physical function. This mode of training is promising in that a small time commitment is required to see significant improvements in several physical outcome variables associated with one's risk of falling, specifically for those who do not yet exhibit deficits in performance.

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CHAPTER I

INTRODUCTION

One in three community-dwelling adults exceeding 65 years of age are anticipated to experience a fall each year (Centers for Disease Control and Prevention, 2017; Nevitt, Cummings, Kidd, & Black, 1989; Stevens, Corso, Finkelstein, & Miller; 2006; Tinetti, Speechley, & Ginter, 1988). With the anticipated increase in the number of older adults in the United States by 2050 (Ortman, Velkoff, & Hogan, 2014), it is imperative to consider the influence this will have on the number of falls that will be incurred. This is particularly true considering the significant economic burden (Burns, Stevens, & Lee, 2016; Stevens et al., 2006) and concomitant implications for social parameters and maintenance of independent living (Gill, Desai, Gahbauer, Holfrod, & Williams, 2001; Sattin et al., 1990; Tinetti & Williams 1997; Zijlstra et al., 2007). With these negative effects, there is value in the ability to identify those who are likely to fall in the future and minimize the risk of this occurring.

The risk of falling can be predicted with a number of risk factors. These risk factors are classified as either extrinsic or intrinsic and modifiable or non-modifiable (Cesari et al., 2002; Graafmans et al., 1996; Lord, Sherrington, & Menz, 2001; Muir Berg, Chesworth, Klar, & Speechley, 2010; Nevitt, Cummings, & Hudes, 1991; Rubenstein, 2006; Rubenstein & Josephson, 2002; Tinetti et al., 1995; Tromp et al., 2001). While understanding the influence of non-modifiable risk factors is valuable, the trainability of modifiable risk factors makes them of particular interest. Extrinsic risk factors are modifiable to some extent and include environment (Carter, Campbell, Sanson-Fisher, Redman, & Gillespie, 1997; Lord et al., 2001; Tideiksaar, 1996) and medication use (Campbell et al., 1989; Deandrea et al., 2010; Ensrud et al., 2002; Hartikainen, Lonnroos, & Louhivrouri, 2007; Woolcott et al., 2009).

While there is an extensive list of intrinsic risk factors, those that are the most easily modified include muscular weakness, low muscular power, and deficits in balance and gait (Campbell et al., 1989; Davis et al., 1999; Graafmans et al., 1996; Hausdorff, Rios, & Edelberg, 2001; Muir et al., 2010; Rubenstein, 2006; Rubenstein & Josephson, 2002; Schwartz et al., 1999; Tinetti, Williams, & Mayewski, 1986; Tinetti et al., 1995; Tromp et al., 2001; Vellas, Wayne, Garry, & Baumgartner, 1998). When considering single interventions, exercise has been shown to reduce the risk of falling and the severity of injury if a fall occurs (Chang et al., 2004; Franco, Periera, & Ferreira, 2012; El-Khoury, Cassou, Charles, & Dargent-Molina, 2013; Gillespie et al., 2012; Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011). While in a broad sense exercise has been shown to benefit risk factors and reduce fall risk, there are multiple types of exercise training that can be implemented. These include group, home-based, balance, aerobic, and progressive resistance training (Ballard, McFarland, Wallace, Holiday, & Robertson, 2004; Barrett & Smerdely, 2002; Barnett, Smith, Lord, Williams, & Baumand, 2003; Buchner et al., 1997a; 1997b; Bunout et al., 2005; Carter et al., 2001; Carter et al., 2002; Dennison et al., 2013; Fielding et al., 2002; Jorgensen, Laessoe, Hendriksen, Nielsen, & Aagaard, 2013; Lesinski, Hortobágyi, Muehlbauer, Gollhofer, & Granacher, 2015; Liu & Latham, 2009; Lord, Ward, Williams, & Strudwick, 1995; Lovell, Cuneo, & Gass, 2010; Maritz & Silbernagel, 2016; Means, Rodell, & O'Sullivan, 2005; Miszko et al., 2003; Nicholson, McKean, & Burkett, 2015; Nitz & Choy, 2004; Orr et al., 2006; Robertson, Campbell, Gardner, & Devlin, 2002; Rubenstein et al., 2000; Schlicht, Camaione, & Owen, 2001; Sherrington et al., 2011; Weerdesteyn et al., 2006).

Group and home-based exercise interventions are multifaceted, commonly including aerobic, strength, balance, and/or flexibility components. Although properly structured group exercise programs can elicit improvements in the aforementioned modifiable fall risk factors, limitations include difficulty with program individualization and the likely need for a high training volume may be required for improvement for healthy, community-dwelling older adults (Ballard et al., 2004; Barnett et al., 2003; Bunout et al., 2005; Carter et al., 2001; Carter et al., 2002; Lord et al., 1995; Means, et al., 2005; Rubenstein et al., 2000; Weerdesteyn et al., 2006). Similarly, home-based programs may not provide sufficient intensity or duration of training for meaningful improvements in fall risk and fall risk factors for healthy, community-dwelling adults beginning training without apparent deficits (Campbell et al., 1997; Campbell, Robertson, & Gardner, 1999a; Campbell et al., 1999b; Robertson, Devlin, Garner, & Campbell, 2001).

There are also types of exercise training that are composed primarily of one component, including balance, aerobic, and progressive resistance training. As the principle of specificity would predict, balance training appears to be the most influential training method for improving balance (Jorgensen et al., 2013; Maritz & Silbernagel, 2016; Nitz & Choy, 2004). However, in terms of increasing multiple risk factors with one type of training, this mode of exercise appears to be limited (Jorgensen et al., 2013; Maritz & Silbernagel, 2016; Nitz & Choy, 2004). Although thorough investigation regarding the effect of aerobic training on fall risk has not been conducted, improvements in multiple fall risk factors can be anticipated (Buchner et al., 1997a; 1997b; Denison et al., 2013; Lovell et al., 2010). However, the literature indicates that a combination of aerobic and resistance training is more effective than aerobic training alone (Sousa, Mendes, Silva, & Oliveira, 2017). Thus, it is important to determine if the increased benefit of combined aerobic and resistance training is additive or if resistance training alone can elicit similar improvements.

Traditional progressive resistance training (PRT) has been shown to trend towards reducing the rate of falling in older adults (Liu & Latham, 2009). In addition, PRT has been shown to yield consistent improvements in muscular strength (Barrett & Smerdely, 2002; Csapo & Alegre, 2016; Fielding et al., 2002; Liu & Latham, 2009; Miszko et al., 2003; Nicholson et al., 2015; Orr et al., 2006; Schlicht et al., 2001). Less consistent improvements have been observed in balance following PRT (Barrett & Smerdely, 2002; Buchner et al., 1997a; Messier et al., 2000; Nichols et al., 1995; Orr et al., 2008; Wolfson et al., 1996).

Although traditional PRT has been shown to yield improvements in fall risk factors, other styles of resistance training may elicit equivalent or greater changes in fall risk factors. One example of this is eccentric exercise training. Eccentric exercise exhibits characteristics that make this modality of resistance training particularly applicable for use with older adults, including higher potential force output, lower oxygen requirement, and lesser attrition with aging (Hortobágyi et al., 1995; Katz, 1939; Komi & Buskirk, 1972; Lindstedt, LaStayo, & Reich, 2001; Lindstedt, Reich, Keim, & LaStayo, 2002; Poulin, Vandervoort, Paterson, Kramer, & Cunningham, 1992; Vandervoort, Kramer, & Wharram, 1990). There are several means of completing eccentric exercise, which include body weight, free weights, resistance training machines, and specialized equipment (Gault, Clements, & Willems, 2012; Gluchowski, Harris, Dulson, & Cronin, 2015; LaStayo, Marcus, Dibble, Frajacomo, & Lindstedt, 2014; LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003; Marcus, LaStayo, Dibble, Hill, & McClain, 2009; Leszczak, Olson, Stafford, & Di Brezzo, 2013; Mueller et al., 2009; Mueller et al., 2011; Raj, Bird, Westfold, & Shield, 2012; ; Reeves, Maganaris, Longo, & Narici, 2009; Takahashi, Melo, Quiterio, Silva, & Catai, 2009; Symons, Vandervoort, Rice, Overend, & Marsh, 2005; Theodorou et al., 2013; Valour, Rouji, & Pousson, 2004; Vandervoort et al., 1990).

While all methods have been shown to improve various fall risk factors, the specialized equipment utilized with eccentric endurance training (EET) allows for exclusively eccentric contractions with concomitant visual feedback (LaStayo et al., 2003; LaStayo et al., 2009). Eccentric exercise training on specialized equipment has been researched with several clinical populations and frail older adults. In consideration of interest in older adults, the two most applicable investigations observe the influence of eccentric ergometer training with frail, older adults (LaStayo et al., 2003) and eccentric stepper training with older adults 1 to 4 years following total knee arthroplasty (Lastayo et al., 2009). Both investigations identified improvements in muscular strength and balance following training (LaStayo et al., 2003; LaStayo et al., 2009). However, investigation of this training method with healthy, community-dwelling older adults remains to be reported.

Overall Purpose

This dissertation includes two studies of an 8-week EET intervention with older adults. The purpose of the first study was to determine the effects of the training on commonly assessed risk factors, including muscular strength, balance, and gait characteristics. It was hypothesized that the training would yield improvements in each outcome measure for the aforementioned fall risk factors from pre- to post-training. Furthermore, it was hypothesized that participants would finish training with a higher self-efficacy and lower behavioral avoidance. The second study was designed to assess how EET affects cognitive function, with specific attention to dual-tasking performance and executive function. It was hypothesized that EET would yield improvements in executive function and dual-tasking performance.

Significance of Studies

With the high prevalence and detrimental effects of falling experienced by older adults, it is imperative to identify training protocols that reduce the risk of incurring a fall. While the cost of falling and associated rehabilitation if injured from a fall are of concern, there is also potential for loss of physical independence after a fall. While extensive research has been completed regarding appropriate interventions, exercise is particularly tenable in regard to cost and resource efficiency. To this point, much research has been dedicated to improving fall risk for those already exhibiting deficits in fall risk factors. However, prevention of deficits may prove to be more efficient than recovering baseline function after deficits are presented.

Fall risk factors that are particularly modifiable with exercise include muscle weakness and deficits in balance and gait. Another fall risk factor that has been studied to a lesser extent, which may be modifiable with exercise, is cognitive function. Although many types of exercise training have been investigated regarding fall risk, EET may be a particularly defensible exercise modality for older adults, as eccentric contractions yield lesser physiological responses and exhibit less attrition with aging. There is a brevity of information regarding the efficacy of EET with older adults, particularly for those who are not already exhibiting deficiencies in the aforementioned fall risk factors. If EET is shown to be a beneficial training modality for improvement of fall risk factors in older adults, this method could be implemented as a component of fall prevention training programs.

CHAPTER II

LITERATURE REVIEW

This literature review begins with a synopsis of prevalence and consequences of falling in older adults. A description of the etiology of falling follows, with detailed descriptions and recommended assessments for modifiable risk factors. The next portion is dedicated to a description of how exercise interventions may be utilized to minimize or improve fall risk and the associated modifiable risk factors. This section includes a description of commonly utilized exercise interventions, leading to a discussion of novel types of exercise training. The literature review concludes with a description of the characteristics of and adaptations to eccentric exercise training, with emphasis on the brevity of information regarding this training modality with healthy, community-dwelling older adults.

Prevalence, Cost, and Outcomes of Falls in Older Adults

It is estimated that the older population in the United States (≥ 65 years old) will increase from 43.1 million in 2012 to 83.7 million in 2050 (Ortman et al., 2014). As such, it is important to identify and minimize modifiable complications of the aging process. One such complication is falling. On an annual basis, greater than 33% of community-dwelling individuals > 65 years of age experience a fall (Centers for Disease Control and Prevention, 2017; Nevitt, Cummings, Kidd, & Black, 1989; Stevens et al., 2006; Tinetti, et al., 1988). At 80 years of age, this rate exceeds 50% (O'Loughlin, Robitaille, Boivin, & Suissa, 1993; Tinetti et al., 1988). It is also noteworthy that after one fall, the risk of a subsequent fall doubles (O'Loughlin et al., 1993) and as the likelihood of falling increases, there are concomitant rises in injury, morbidity, and mortality (Burns et al., 2016; Ellis & Trent, 2001; Scuffham, Chaplin, & Legood, 2003; Sterling, O'Connor, & Bonadies, 2001; Stevens et al., 2006).

Among the most prevalent consequences of falling is injury, where one in five falls results in a serious injury, including fractures and head injuries (Alexander, Rivera, & Wolf, 1992; Sterling et al., 2001). With respect to injury outcomes, the rate of injury is 4 to 5 times higher for individuals ≥ 85 years old in comparison to those between 65 and 69 years old (Stevens & Sogolow, 2005). The number of injuries resulting from fall, both non-fatal and fatal, is increasing as the elderly population increases. In 2000 and 2012, respectively, the number of medically treated non-fatal falls were 2.6 million and 3.2 million (Burns et al., 2016; Stevens et al., 2006). Similarly, in 2012, 24,190 healthy community-dwelling older adults in the United States sought medical treatment for falls that resulted in fatality, an increase from 10,300 reported in 2000 (Burns et al., 2016; Stevens et al., 2006).

Men generally exhibit higher fatality rates from falling, whereas women have a 2.3 times greater prevalence of non-fatal falls (Stevens et al., 2006; Stevens & Sogolow, 2005). The occurrence of non-fatal falls in women increases 40% from the 65-74 years, increases again from 75-84 years of age, and then decreases 14% from 75-84 years to ≥ 85 years of age (Stevens et al., 2006). Conversely, the incidence of non-fatal falls in men between the age of 65 and 84 years is constant, while the incidence decreases for men 85 years of age and older (Stevens et al., 2006).

While only 5 to 10% of falls result in severe injuries (Nivett et al., 1991), the direct costs of treatment following injurious falls in community-dwelling adults are significant. Similar to the trend for prevalence of falling from 2000 to 2012, the direct costs of non-fatal falls increased from $19 billion in 2000 to $30.3 billion in 2012 (Burns et al., 2016; Stevens et al., 2006). The direct medical costs for fatal falls showed an equivalent increase from $179 million to $616.5 million (Burns et al., 2016; Stevens et al., 2006). These values increased further in 2015, with direct costs of $31.3 billion for non-fatal falls and $627.5 million for fatal falls (Burns et al., 2016).

When assessing the net costs of fatal falls based on sex, costs for men between 65 and 74 years of age were 44% greater than for women in this age bracket and costs for women were greater than for men in those 85 years of age and older. Men and women had equivalent costs between 75 and 84 years of age. In contrast, at any age exceeding 65 years, the cost of non-fatal falls was 2 to 3 times greater for women than for men (Stevens et al., 2006). Among the most common non-fatal injuries are fractures, which also contribute to a large majority of associated medical care costs (Bishop et al., 2002; Nivett et al., 1991; Stevens et al., 2006). Thus, the reason for the greater cost of non-fatal falls in women is likely the treatment of osteoporotic fractures, most often, hip fractures (Stevens et al., 2006).

A secondary consequence of a fall injury is loss of independence. Sattin et al. (1990) estimated that approximately 50% of older adults discharged from the hospital after a fall at home are admitted to a nursing home. Furthermore, Tinetti and Williams (1993) indicated those who experienced an injurious fall were three times more likely to be admitted to a nursing home than those who had a non-injurious fall. In addition to the potential loss of independence, individuals who have fallen are likely to develop an increased fear of falling (King & Tinetti, 1995; Tinetti, De Leon, Doucette, & Baker, 1994; Vellas, Wayne, Romero, Baumgartner, & Garry, 1997a; Zijlstra et al., 2007). This decline in confidence is associated with a decline in self-sufficiency in performing activities of daily living and decreased participation in physical activity and social events (Gill et al., 2001; Tinetti & Williams, 1998; Tinetti et al., 1994; Tinetti, Williams, & Mayewski, 1986; Zijlstra et al., 2007).

Further highlighting the incidence and cost of falls in community-dwelling older adults is the summary statistics that, in 2012, 66 older adults suffered a fatal fall each day and 365 non-fatal falls occurred each hour (Burns et al., 2016). Furthermore, the cost per non-fatal fall was \$9,463 and the cost per fatal fall was \$25,487 (Burns et al., 2016), equating to daily costs of \$82.9 million and \$1.6 million for non-fatal and fatal falls, respectively. The incidence and associated burdens of falling are anticipated to increase, as the proportion of Americans ≥ 65 years old is anticipate to be 1 in 6 in 2020 and 1 in 5 by 2030 (Ortman et al., 2014). Thus, the high incidence and associated burdens of falling are of concern, particularly when considering the expected growth of the older adult population. As such, it is important to elucidate the etiology of falls in older adults, including understanding the modifiable and non-modifiable factors that contribute to fall risk.

Etiology of Fall Risk

With the aforementioned prevalence of falling and the associated burdens of falling, there have been numerous investigations aimed at identifying predictors of fall risk in community-dwelling older adults (Alexander & Hausdorff, 2008; Campbell et al., 1989; Cesari et al., 2002; Davis et al., 1999; Deandrea et al., 2010; Graafmans et al., 1996; Hausdorff et al., 2001; Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010; Holtzer et al., 2007; Luukinen, Koski, Kivela, & Laippala, 1996; Muir et al., 2010; Muir, Gopual, & Montero Odasso, 2012; Nevitt et al., 1991; Nevitt, Cummings, Kidd, & Black, 1989; Robbins et al., 1989; Rubenstein, 2006; Rubenstein & Josephson, 2002; Schwartz et al., 1999; Tinetti et al., 1995; Tinetti et al., 1994; Tinetti, Williams, & Mayewski, 1986; Tromp et al., 2001; Vellas et al., 1998). These studies have been conducted on the premise that identification of key predictors of falling is imperative for successful implementation of fall prevention programs. While identification of individual risk factors is important, the risk of falling also increases with the total number of risk factors exhibited (Muir et al., 2010; Nevitt et al., 1991; Tinetti, Speechley, & Ginter, 1988). Thus, it is important to recognize risk associated with single risk factors and how the sum of factors contributes to a larger system in regard to fall risk.

Although verbiage varies in the literature, it is common to classify risk factors as intrinsic versus extrinsic or non-modifiable versus modifiable. Intrinsic risk factors are characteristics of the individual while extrinsic risk factors are characteristics of the environment or surroundings. Extrinsic risk factors include environmental hazards and medications (Cumming, 1998; Deandrea et al., 2010; Gill, Williams, Robison, & Tinetti, 1999; Lord, Caplan, & Ward, 1993; Ray & Griffin, 1990).

Approximately 50% of all falls incurred by community-dwelling older adults occur within the home, commonly while a person is carrying out ordinary daily tasks (Campbell et al., 1990; Nevitt et al., 1989). Of these falls, 45% are reported to have been a result of an environmental factor (Nevitt et al, 1989; Tinetti et al., 1988). Common environmental hazards for older adults include slippery surfaces, poor lighting, stairs, general obstructions in walkways, and changes in floor level or texture (Carter et al., 1997; Lord et al., 2001; Tideiksaar, 1996). It has been suggested that environmental hazards are not independently responsible for most falls, but are instead, associated with the interaction between one's physical abilities and the surrounding environment (Lord et al., 2001).

Adding to the fall risk profile is the use of medication. It is estimated that 85% of older adults take at least one medication and 48% take three or more (Cumming et al., 1991). Medications consistently shown to increase fall risk include sedatives, hypnotics, antidepressants, anxiolytics, benzodiazepines, antipsychotics, and antiepileptics (Campbell et al., 1989; Deandrea et al., 2010; Ensrud et al., 2002; Hartikainen, Lonnroos, & Louhivrouri, 2007; Woolcott et al., 2009). In addition to the class of medication, the number of medications a person takes is also a predictor of fall risk (Deandrea et al., 2010). While any increase in the number of medications taken leads to an increase in the risk of falling, the consumption of 4 or more medications shows the largest influence of medication use on fall risk (Muir et al., 2009; Tromp et al., 2001). It is noteworthy that the increased risk of falling indicated with taking medication may be confounded by the presence of diseases or conditions, which are considered intrinsic factors.

Commonly reported intrinsic factors include history of falls, sex, age, fall self-efficacy, vision, blood pressure stability, bladder control, cognitive function, muscular strength, balance, and gait (Alexander & Hausdorff, 2008; Bento, Pereira, Ugrinowitsch, & Rodacki, 2010; Campbell et al., 1989; Cesari et al., 2002; Davis et al., 1999; Deandrea et al., 2010; Graafmans et al., 1996; Hausdorff et al., 2001; Herman et al., 2010; Holtzer et al., 2007; Luukinen et al., 1996; Muir et al., 2010; Muir et al., 2012; Nevitt et al., 1989; Nevitt et al., 1991; Perry, Carville, Smith, Rutherford, & Newham, 2007; Robbins et al., 1989; Rubenstein et al., 2006; Rubenstein & Josephson, 2002; Schwartz et al., 1999;

Tinetti et al., 1986; Tinetti et al., 1995; Tromp et al., 1998; Tromp et al., 2001; Vellas et al., 1998; Whipple, Wolfson, & Amerman, 1987). As evidenced by the aforementioned increase in prevalence of falls with advancing age, research indicates that age has a linear association with risk of falling (Deandrea et al., 2010; Nevitt et al., 1991; Rubenstein & Josephson, 2002).

The largest increase in fall risk occurs at and above 80 years of age, which is likely attributed to reductions in mobility and functional capacity, as well as increases in frailty (Nevitt et al., 1991; Rubenstein & Josephson, 2002; World Health Organization, 2008). Ganz, Bao, Shekelle, & Rubenstein (2007) reported in a systematic review of manuscripts regarding community-dwelling older adults, that age was only a significant risk factor of falling in 4 of 11 multivariate analysis studies. Furthermore, age was identified as a non-significant predictor of falls in 2 of 3 studies when controlling for other variables (Ganz et al., 2007). As such, although there is an association between aging and fall risk, age is not a reliable independent predictor of fall risk (Ganz et al., 2007).

Also in accordance with the prevalence previously reported, women have an increased risk of falling in comparison to male counterparts (Deandrea et al., 2010; Nevitt et al., 1991). It is postulated that this is not a direct effect of an individual’s sex, but is instead, the result of weaker quadriceps strength and greater dependence on visual cues (Lord et al., 1994). As such, the increased fall occurrence in women is likely a result of accompanying physiological changes experienced by females.

Bladder control is a commonly reported indicator of fall risk. In a systematic review, Thom (1998) estimated that 34% of older men and 55% of older women experience urinary incontinence. Tinetti et al. (1995) suggested that urinary incontinence may simply be a ‘geriatric symptom’ that is more indicative of a state of physical frailty than a causal risk factor for falling. However, regardless of direct causation, a strong association between urinary incontinence and fall risk has been consistently reported (Cesari et al., 2002; Luukinen et al., 1996; Nevitt et al., 1989; Robbins et al., 1989; Tinetti et al., 1988; Tromp et al., 1998; Tromp et al., 2001). As such, thorough fall risk assessments may include questions regarding this matter.

Among the most recently investigated risk factors for falling is cognitive function. While not well understood, there is accumulating evidence that cognitive function is an important component in determining falling risk (Alexander & Hausdorff, 2008; Gleason, Gangon, Rischer, & Mahoney, 2009; Herman et al., 2010; Holtzer et al., 2007; Nevitt et al., 1991; Muir et al., 2012). Among the important components of cognitive function are dual tasking, executive function, information processing, and reaction time (Alexander & Hausdorff, 2008; Gleason et al., 2009; Herman et al., 2010; Muir et al., 2009).

As expected, many investigations have identified that having fallen in the past makes an individual more likely to experience another fall (Campbell et al., 1989; Davis et al., 1999; Deandrea et al., 2010; Nevitt et al., 1991; Tromp et al., 2001). In their systematic review, Rubenstein and Josephson (2002) identified that a history of falls was a predictor of future falls in 12 of 13 studies. Furthermore, Ganz et al. (2007) identified that an individual has at least a 50% chance of falling in the next year if he or she has fallen within the past year. Thus, assessment of fall history is recommended as an initial means of identifying individuals in need of further fall risk assessment (Ganz et al., 2007).

Previous falls also have the potential to perpetuate a fear of falling, which has been indicated to further increase the risk of falling (Cumming, Salkeld, Thomas, & Szonyi, 2000; Friedman, Munos, West, Rubin, & Fried, 2002; Tromp et al., 2001). Fear of falling has been reported by 60% of fallers, while 30% of non-fallers may also exhibit this fear (Tinetti et al., 1988; Tinetti et al., 1994). Because the fear of falling plays dual roles as a potential risk factor and outcome of falling, Deandrea et al. (2010) conducted a systematic review and meta-analysis of prospective studies only. Fear of falling was among the top predictors of fall risk within the next year, with an odds ratio of 2.5 (Deandrea et al., 2010). Although history and fear of falling cannot be prevented, knowing this information may be useful when identifying individuals at increased risk of falling. When individuals who are likely to fall have been identified, it is also imperative to assess intrinsic risk factors that are modifiable to create a productive fall risk intervention.

In both primary research and systematic reviews, issues with vision have been identified as a significant risk factor for fall risk in community-dwelling older adults (Deandrea et al., 2010; Rubenstein & Josephson, 2002; Tromp et al., 2001). Components of vision that are reported to be associated with fall risk include impaired depth perception (Salonen & Kivela, 2012), decreased visual acuity (Tinetti et al., 1995), and contrast sensitivity (de Boer et al., 2010; Klein, Moss, Clein, Lee, & Cruickshanks, 2003; Patino et al., 2010). Overall, the impact of vision on fall risk is likely a result of an inability to identify edges of environmental obstacles. However, the impact of vision on fall risk may be minimized by appropriate vision correction.

As previously mentioned, another modifiable intrinsic risk factor of falling is uncontrolled blood pressure. Of particular concern is the combination of uncontrolled hypertension and systolic orthostatic hypotension, where individuals expressing both characteristics exhibit a 2.5 higher risk of recurrent falls than those expressing neither (Gangavati et al., 2011). Uncontrolled hypertension is defined as blood pressure exceeding 140/90 mm Hg or prescription of antihypertensive medications (Gangavati et al., 2011). Systolic orthostatic hypotension is defined as a decrease in systolic blood pressure of 20 mm Hg or more within 1 minute of changing from a supine to a standing position (Gangavati et al., 2011).

Although data from 2007 to 2008 indicate that approximately 55% of hypertension in individuals 60 years of age or older was considered uncontrolled (Egan, Zhao, & Axon, 2010), it is noteworthy that only 6% of community-dwelling older adults exhibit orthostatic hypotension (Mader, Joesphson, & Rubenstein, 1987; Masaki et al., 1998). This indicates that the prevalence of orthostatic hypotension in healthy, community-dwelling older adults is likely a result of pre-existing disease or medication use (Lord et al., 2001).

While the aforementioned modifiable risk factors can predict fall risk, the most noted predictors of future falls include lower extremity muscular strength, balance deficit, and impaired gait (Campbell et al., 1989; Davis et al., 1999; Graafmans et al., 1996; Hausdorff et al., 2001; Muir et al., 2010; Rubenstein, 2006; Rubenstein & Josephson, 2002; Schwartz et al., 1999; Tinetti et al., 1986; Tinetti et al., 1995; Tromp et al., 2001; Vellas et al., 1998). These risk factors are particularly modifiable through exercise intervention.

Muscle weakness of the quadriceps is reported among the top predictors of fall risk (Campbell et al., 1989; Davis et al., 1999; Graafmans et al., 1996; Lord et al., 2001; Muir et al., 2010; Rubenstein & Josephson, 2002; Rubenstein, 2006; Schwartz et al., 1999; Tinetti et al., 1986; Tinetti et al., 1995; Tromp et al., 2001). According to a systematic review, fall risk increases 4-fold with muscle weakness in both univariate and multivariate analyses (Rubenstein & Josephson, 2002). In addition, in all 11 studies included in the review, muscle weakness was identified as a significant predictor of a fall (Rubenstein, 2006).

Balance and gait impairments have also been identified as key factors in predicting fall risk (Campbell et al., 1989; Davis et al., 1999; Graafmans et al., 1996; Muir et al., 2010; Tinetti et al., 1986; Tinetti et al., 1995; Tromp et al., 2001; Vellas et al., 1998). Although assessments of gait and balance vary widely amongst available literature, there are components of movement that are commonly assessed. Balance impairments are defined when individuals exhibit difficulty maintaining the center of gravity over the base of support in a variety of situations including: sitting or standing with no support, transitioning from sitting to standing (and vice versa), standing with eyes closed, standing with feet together, maintaining a standing position when nudged, reaching forward with an outstretched arm, picking an object up off of the floor, turning 180 and 360 degrees, standing with one foot on a stool, tandem stance, and standing on one foot (Campbell et al., 1989; Davis et al., 1999; Graafmans et al., 1996; Muir et al., 2010; Schwartz et al., 1999; Tinetti et al., 1986; Tinetti et al., 1995; Tromp et al., 2001; Vellas et al., 1998). Gait impairments include abnormalities in gait initiation, altered step height and step length, lack of step symmetry, step discontinuity, increased path of excursion, increased trunk sway, or increased walking time (Hausdorff et al., 2001; Tinetti et al., 1986; Verghese, Holtzer, Lipton, & Wang, 2009).

Gait and balance deficits have been shown to yield a 3-fold increase in fall risk in univariate analyses (Rubenstein & Josephson, 2002). With multivariate analyses, gait impairment declines to a 2-fold increase in fall risk, while balance deficit remains a 3-fold increase in fall risk (Rubenstein & Josephson, 2002). Similar to that exhibited with lower extremity muscle weakness, impairments of balance and gait were identified as significant risk factors in 9 of 9 and 8 of 9 studies, respectively in the review conducted by Rubenstein (2006).

A less frequently recognized and assessed fall risk factor is cognitive function (Herman et al., 2010; Hofheinz & Mibs, 2016; Muir et al., 2012). The risk of falling has been shown to be particularly reflective of executive function and dual-tasking performances (Herman et al., 2010; Hofheinz & Mibs, 2016; Muir et al., 2012).

In summary, external risk factors include environmental factors and medication use. While these account for approximately half of the falls experienced, the extent to which they can be modified is limited. In contrast, there is an extensive list of modifiable intrinsic risk factors for falling. Among the most malleable risk factors on this list are muscular weakness, deficits in gait and balance, and cognitive decline.

Fall Risk Assessment

In the previous section, lower extremity strength, gait, balance, and cognitive function were presented as prominent modifiable risk factors. As such, interventions aimed at reducing risk of falling should assess these characteristics pre- and post-intervention to evaluate the efficacy of the program. Prior to discussing the expected changes in these risk factors following intervention, it is important to recognize the accepted assessment tools for each.

Lower extremity strength assessment. Even with heterogeneous methods of measuring lower extremity muscular strength, it is consistently an indicator of fall risk in the literature (Horlings, van Engelen, Allum, & Bloem, 2008; Menant, et al., 2017; Moreland, Richardson, Goldsmith, & Clase, 2004). Muscular strength assessments are referred direct or indirect (Horlings et al., 2008). Direct measures include assessment of strength by means of dynamometers, exercise equipment, or manual testing, while indirect measures test functional performance (Horlings et al., 2008). Although direct assessment of strength provides valuable quantitative information and a high degree of experimental control, the indirect measures are more indicative of an individual's ability to complete activities of daily living (Horlings et al., 2008). The most frequent direct strength assessments include evaluation of knee extension and ankle dorsiflexion strength, while the most common indirect assessments are chair stand tests (Moreland et al., 2004).

Direct assessments of muscular strength that have been previously analyzed in relation to fall risk in community-dwelling older adults include leg press (Schwartz et al., 1999), isometric knee extension (Campbell et al., 1989; Davis et al., 1999; Gerdhem, Ringsberg, Åkesson, & Obrant, 2005), and isometric knee flexion (Gerdhem et al., 2005). Of these direct measures, the only one not yielding a statistically significant association with fall risk was leg press (Schwartz et al., 1999). Based on the observation that indirect measures of lower body muscular strength are multi-dimensional assessments, with supplemental contributions of psychological factors, balance, and coordination to performance (McCarthy, Horvat, Holtsberg, & Wisenbaker, 2004), Horlings et al. (2008) made the recommendation that studies aiming to identify improved muscular strength following training should include a direct measure of strength. However, it is noteworthy that indirect measures of strength are more conveniently assessed, which is an important variable to consider in fall risk assessment.

As previously mentioned, the most common assessments of indirect lower body muscular strength are chair stand tests. There are two commonly utilized chair stand assessments with older adults including the five-time sit-to-stand test (5TSST) and the 30-second sit-to-stand test (30CST). Both tests assess an individual's ability to complete cycles of sitting and standing from a chair with the arms crossed over the chest, where the participant is required to exhibit controlled movement for the duration of the test. This means that the knee and hip joints should be fully extended, but not locked out, upon standing and the individual should fully sit between each stand. The 5TSST assesses the time it takes for an individual to stand up and sit down 5 times. The 30CST assesses how many times the participant can stand up and sit down in 30 seconds. Although chair stand tests are not independent assessments of muscular strength, they have been shown to be associated with fall risk and provide information regarding function, which is arguably more applicable to the older population than strength measures alone.

The 5TSST has been reported as a valid and reliable predictor of fall risk (Graafmans et al., 1996; Schwartz et al., 1999; Tromp et al., 2001). Although there are data supporting use of the 5TSST for predicting fall risk in community-dwelling older adults, it is recommended that the 5TSST be utilized for older adults with low levels of physical function (McCarthy et al., 2004). In contrast, the 30CST has been suggested an assessment for older adults with higher levels of physical function (McCarthy et al., 2004). The 30CST has excellent criterion validity when compared to relative 1-repetition maximum (1-RM) leg press performance (Rikli & Jones, 1999). Importantly, the test has excellent test-retest and interrater reliability specifically with community-dwelling older adults (Rikli & Jones, 1999). Furthermore, performance on the 30CST predictably declines with age, with average performance for older adults declining from 14 repetitions for 60-69 year old individuals, to 13 repetitions for those from 70-79 years, to 12 repetitions for 80 year old individuals (Rikli & Jones, 1999). The 30CST assessment differentiates between older adults with high and low levels of activity (Rikli & Jones, 1999) and age- and sex-specific cutoffs for maintaining physical independence later in life have been established (Jones, Rikli, & Beam, 1998; Rikli & Jones, 2013).

In summation, lower extremity strength is an established predictor of fall risk. Direct measures are recommended for determining strength improvement following an intervention, while indirect measures are convenient assessments of an older adult's ability to complete functional tasks.

Balance assessment. There are three components of balance that are commonly assessed, including the ability to maintain a static position, the ability to exhibit stability while completing voluntary movements, and the response to external disturbances (Berg, Maki, Williams, Holliday, & Wood-Dauphne, 1992). In addition, balance assessments are typically classified as either laboratory measures or functional measures. Laboratory measures often provide objective measurements more capable of detecting small changes and subclinical balance impairments (Berg et al., 1992). Functional assessments are more subjective, but provide information regarding aptitude to maintain stability in circumstances similar to those encountered in daily living.

Laboratory assessments of balance typically quantify postural sway using a force or specialized postural sway platform. Although assessments of anterior-posterior and medio-lateral sway are commonly completed using such platforms, there is evidence that the fall risk test (FRt) available with the Biodex Balance System SD accurately identifies individuals at high risk of falling (Prometti et al., 2016). It is noteworthy that the FRt yields a Fall Risk Index (FRI) value, which must be age-normalized to accurately predict fall risk (Prometti et al., 2016). In addition, the FRt exhibits good test-retest reliability in physically active older adults (Parraca et al., 2011).

When completing the FRt, the participant is asked to maintain stability while standing on an unstable circular platform. A constant stability level of 8 on the platform has been used to predict fall risk. The average from three, 20 second trials with a 10 second break between trials, is calculated. Results are normalized realtive to the maximal age-predicted FRI (Prometti et al., 2016). Those with an FRI exceeding 1 are considered at greater fall risk, while those with an FRI ≤ 1 are considered at lesser risk of falling. The main limitations of using the FRt are the availability of equipment and lack of functional application of the results.

Some of the functional assessments of dynamic balance include the four square step test (FSST), functional reach test (FRT), and timed up-and-go (TUG). During the FSST, participants step amongst four squares in a specified pattern as quickly as possible. Each square is separated by a 2.5 cm tall and 90 cm long barrier (Dite & Temple, 2002). Participant step forward from square 1 to square 2, step to the right from square 2 to square 3, step backwards from square 3 to square 4, and step to the left from square 4 back to square 1 (Dite & Temple, 2002). The pattern is then reversed until the participant arrives back in square 1. The participant faces the same direction for the entirety of the test and must make contact in each square with both feet (Dite & Temple, 2002). The FSST has excellent test-retest and interrater reliability and correlates with other accepted assessments of balance, including the TUG and step test (Dite & Temple, 2002). The primary limitation to using this assessment in determining the fall risk of community-dwelling older adults is that the only data available regarding validity of fall risk prediction and cut-off scores are in regards to the risk of experiencing multiple falls (Dite & Temple, 2002).

The FRT is a balance assessment that tests the maximum distance an individual can reach forward without moving the feet or losing balance (Weiner, Duncan, Chandler, & Studenski, 1992). During the assessment, the participant stands sideways next to a wall, with the shoulder of his or her dominant arm close to, but not touching, the wall. The participant then fully extends his or her dominant arm to the front, with the arm held parallel to the floor. The participant then reaches as far forward as possible without falling forward (Weiner et al., 1992). The distance from the start to the end position is measured in inches. It is recommended that participants receive two warm-up trials, followed by three test trials, which are averaged (Weiner et al., 1992).

With community-dwelling older adults, the FRT has excellent test-retest and interrater reliability, as well as strong positive correlations with walking speed, tandem walk, and single leg balance performance (Duncan, Weiner, Chandler, & Studenski, 1990; Weiner et al., 1992). An average reach less than 7 inches is an indication of limitations in mobility and activities of daily living (Weiner et al., 1992). However, data regarding a significant association between FRT performance and fall risk in community-dwelling older adults are lacking.

The TUG is unique in that it allows for concurrent assessment of dynamic balance and gait. The TUG is a timed assessment of functional balance for older adults, where individuals are asked to rise from a chair, walk 3 meters, turn 180 degrees, walk back to the chair, and return to a seated position (Podsiadlo & Richardson, 1991). Time begins on the command "GO" and ends when the person returns to the seated position. A time exceeding 13.5 seconds is indicative of high fall risk (Shumway-Cook, Brauer, & Woolacott, 2000), while a time exceeding 20 seconds indicates that an individual cannot safely maintain independent living (Podsiadlo & Richardson, 1991).

Scores on the TUG may have a limited capacity to predict fall risk, particularly for highly functional older adults (Barry, Galvin, Keogh, Horgan, & Fahey, 2014; Beuchet et al., 2011; Schoene et al., 2013). As such, it has been suggested that dual-task assessments may better predict fall risk in this population (Quinn & Horgan, 2013; Toulette, Thevenon, Watelain, & Fabre, 2006; Yamada et al., 2011). Accordingly, dual task modifications of the TUG have been developed and assessed, which will be further discussed in the cognitive function section (Hofheinz, 2010; Quinn & Horgan, 2013; Toulette et al., 2006; Yamada et al., 2011).

While the aforementioned assessments are primarily concerned with voluntary, dynamic balance performance, the Berg Balance Scale (BBS) and Balance Sub-scale of the Tinetti Performance-Oriented Mobility Assessment (POMA-B) are functional assessments of one's ability to maintain static postures, maintain stability during voluntary movement, and maintain stability following external disturbances. The POMA-B is a component of a total Tinetti Performance-Oriented Movement Assessment (POMA-T) score. Although good inter-rater and test-retest reliability have been demonstrated for the POMA-T and POMA-B, the POMA-T is a poor predictor of fall risk in older adults (Faber, Bosscher, & van Wieringen, 2006). In addition, Tinetti and Kumar (2010) did not recommend using this assessment for highly functional older adults.

According to Chiu, Au-Yeung, & Lo (2003), the ability to discriminate fallers from non-fallers is better for the BBS than for the TUG and the POMA-T. The BBS is a 14-item measure, including assessment of the ability to: Sit unsupported, stand with eyes closed, stand with feet together, stand tandem, stand on one leg, turn the trunk with fixed feet, pick an object up off the floor, turn 360 degrees, reach forward, and step on a stool (Berg, Wood-Dauphine, Williams, & Gayton, 1989). The BBS has excellent intra-rater and inter-rater reliability (Berg et al., 1989) and accurately predicts the transition from non-faller to faller in highly functional community-dwelling older adults using a cut-off of < 50/56 points (Muir et al., 2010).

In contrast, using a single cut-off criterion value to predict fall risk with the BBS has been shown to have suboptimal sensitivity in identifying the risk for future falls in heterogeneous samples of community-dwelling older adults (Muir, Berg, Chesworth, & Speechley, 2008). Furthermore, Muir et al. (2010) identified a ceiling effect of the BBS with highly functional community-dwelling older adults, with 67% of the sample exhibiting a score of 55 or 56 out of 56 possible points. With the presented limitations, the BBS may not be appropriate for use with community-dwelling older adults who demonstrate high levels of function.

While holistic assessments provide a broad understanding of a person's balance, assessment of individual components has also been deemed useful in predicting fall risk. The timed unipedal stance is one common means of assessing static balance which has been identified as a predictor of fall risk in community-dwelling older adults (Vellas et al., 1997b). During this assessment, the participant stands on his or her dominant leg, with eyes open and hands on the hips, for as long as possible. Time begins when the foot is lifted from the ground and is stopped if the hands leave the hips or if the lifted foot touches the ground or standing leg. Although the timed unipedal stance has been shown to predict future falls, data in review for publication with healthy, community-dwelling older adults observed no significant improvement. It is predicted that this was the result of average performances exceeding the expected averages and large variation in task performance. One modification that can be applied to this assessment that reduces these challenges is to have participants close their eyes during the assessment. The unipedal stance assessment with eyes closed has not been thoroughly investigated in healthy, community-dwelling older adults, particularly in consideration of fall risk. However, normative values have been reported for individuals between 60 and 69 years old, where the mean performance times for the average and best of 3 performances were 2.8 ± 2.2 and 4.4 ± 5.1 seconds, respectively (Springer, Marin, Cyhan, Roberts, & Gill, 2007).

In conclusion, the literature supports use of the TUG as a functional assessment of dynamic balance. In addition, the BBS is a warranted holistic assessment of balance. This is based on the premise that fall risk criterion have been established and validated for highly functional community-dwelling older adults who have not yet fallen (Muir et al., 2010). However, caution should be used in use of the BBS to track progress in highly functional community-dwelling older adults, as a ceiling effect has been demonstrated (Muir et al., 2010). As such, the single leg stance with eyes closed can be recommended as an additional assessment to minimize the chance of a ceiling effect.

Gait assessment. There have also been numerous investigations regarding the association between gait and fall risk (Hausdorff et al., 2001; Maki, 1997; Tinetti et al., 1986; Verghese et al., 2009). Although many researchers have assessed gait of older adults in some manner, there is a paucity of data regarding quantitative assessment of gait and fall risk prediction. Hausdorff et al. (2001) identified increased variation in stride time while walking at a comfortable pace as a significant predictor of falling. Verghese et al. (2009) utilized a computerized walkway to assess gait, with slower gait speed, decreased stride length, decreased swing phase, increased double-support phase, increased swing time variability, and increased stride length variability predicting fall risk over the next 20 months. Although these assessments provide quantitative data regarding gait, functional assessments are both more cost effective and applicable to one's ability to perform normal daily activities.

It is noteworthy that there is overlap between functional assessments of gait and dynamic balance. As such, many gait assessments either contain facets that assess dynamic balance or are subcomponents of a larger assessment including balance and gait tests. One assessment that has large overlap in assessment of dynamic balance and gait is the TUG, which has been previously described as an appropriate assessment for community-dwelling older adults. One assessment that includes gait as a subcomponent of the full assessment is the POMA-T, with the gait subscale being abbreviated as POMA-G (Tinetti et al., 1986). Although the POMA-G has been shown to have acceptable interrater and test-retest reliability, it also exhibits a ceiling effect (Faber et al., 2006). Based on the observed ceiling effect, the POMA-G is not an advisable gait assessment for community-dwelling older adults. The ceiling effect becomes particularly problematic when trying to assess progression following an intervention.

Another common gait assessment that exhibits a ceiling effect in community-dwelling older adults is the Dynamic Gait Index (DGI; Pardasaney et al., 2012). The DGI assesses a participant's ability to walk on a level surface, change gait speed, walk with horizontal and vertical head turns, turn while walking, step over and around obstacles, ascend stairs, and descend stairs (Shumway-Cook & Woollacott, 2011). Thus, similar to the statement regarding the POMA-G, the ceiling effect of the DGI also makes it a poor assessment of fall risk for highly functional older adults.

The Functional Gait Assessment (FGA) is a modification of the DGI with three additional assessments: Walking with a narrow base of support, walking with eyes closed, and walking backwards (Wrisley, Marchetti, Kuharksy, & Whitney, 2004). Stepping around obstacles was removed from the original list of DGI components (Wrisley et al., 2004). The revised protocol was developed to make the assessment more challenging, particularly for those with vestibular disorders (Wrisley et al., 2004). Performance on the FGA is significantly correlated with BBS and TUG performances (Wrisley & Kumar, 2010). The FGA has also been shown to have excellent interrater reliability (r = .93) when assessing community-dwelling older adults (Walker et al., 2007). A cut-off score of 22/30 on the FGA is recommended for identification of the risk of falling, specifically within the next 6 months (Wrisley & Kumar, 2010). Although evidence regarding a ceiling effect of the FGA with older adults is not currently available, it is noteworthy that the FGA was found to have better capacity to predict fall risk in the next 6 months for community-dwelling older adults than the DGI (Wrisley & Kumar, 2010). Furthermore, the addition of more challenging tasks makes a ceiling effect less probable.

While the previously described assessments provide a score based on observation of various gait characteristics, there are also gait assessments based only on the time to complete a specific task, including the TUG. Another example of a commonly utilized timed gait assessment is the 6-minute walk test (6MWT). During this assessment, participants cover as much distance as possible walking for 6 minutes. The 6MWT has been shown to have excellent test-retest reliability (Harada, Chiu, & Stewart, 1999; Steffen, Hacker, & Mollinger, 2002) and adequate validity with chair stand, standing balance, and gait speed (Harada et al., 1999). However, the 6MWT is more a test of overall mobility and physical function than of fall risk (Bautmans, Lambert, & Mets, 2004; Keskin et al., 2008; Lord & Menz, 2002). It is notable that substantial changes on the 6MWT are only expected when exercise capacity is adequately challenged during training, so tracking progress with this assessment may be of limited value depending upon the intervention. The lack of fall risk prediction and dependence on the mode of the intervention do not make this assessment ideal for the population and intervention style of the proposed study.

Based on the presented information regarding gait assessment, the FGA would be the most appropriate gait assessment for a community-dwelling older population. This assessment is the least likely to yield a ceiling effect and has been established as a predictor of fall risk in community-dwelling older adults (Wrisley & Kumar, 2010). As previously mentioned, the TUG is also an accepted assessment of gait regarding fall risk prediction. Based on the depth of the FGA and the brevity of the TUG, both assessments would be appropriately included in a fall risk assessment of community-dwelling older adults.

Cognitive function assessment. It is suggested that global measures of cognitive function are only able to be used to predict the risk of falls that result in serious injury (Muir et al., 2012). In contrast, it has been shown that impairment of executive function is associated with the risk of falling regardless of injurious outcome (Muir et al., 2012). In addition to the ability to predict all falls, deficits in executive function can be observed in otherwise healthy, community-dwelling individuals (Herman et al., 2010; Muir et al., 2012). Tests of executive function that have been shown to be predictive of fall risk include the Trail Making B (TMT-B) test and computerized neuropsychological tests (Herman et al., 2010; Muir et al., 2012; Nevitt et al., 1991).

The TMT-B assessment was incorporated into the Healstead-Reitan Battery for assessment of cognitive function (Reitan & Wolfson, 1985). The TMT-B assessment consists of 49 circles containing numbers and letters. Participants are asked to connect the circles in order, from 1 to A, A to 2, 2 to B, and so forth (Reitan & Wolfson, 1985). This pattern is followed for the duration of the alphabet and the time to complete the task is recorded. Tombaugh (2004) reported average TMT-B performances for older adults who completed 12 or more years of education as 64.58, 67.12, and 86.27 seconds for the age categories of 60-64, 65-69, and 70-74 years, respectively.

The computerized assessments of executive function include the Stroop and Go-No-Go tests (Herman et al., 2010). Many versions of the Stroop test have been presented in this literature (Herman et al., 2010; Neurotrax, 2003; Stroop, 1935). The original Color-Word Stroop test has been modified to be computerized, where participants are asked to select the font color of rows of XXXs and color words (i.e. red). In the color word assessment, the color word and font color do not ever match (Stroop, 1935). The initial test included 100 items (Stroop, 1935), while analyses with older adults have utilized 80 items (Liu-Ambrose et al., 2010). The difference in performance on these tasks, or Stroop interference, has been shown to increase with age and is used to assess executive function (Uttl & Graf, 1997).

Overview of recommendations for fall risk assessment. Based on the aforementioned information, the ideal fall risk assessment would include tests of muscular strength, balance, gait characteristics, and cognitive function. It is recommended that both direct and indirect assessments of muscular strength are completed, as direct assessments allow for greater experimental control during assessments. The recommended assessment for assessment of muscular strength is the 30CST. In contrast, indirect measures exhibit less experimental control, but are more reflective of one's ability to perform activities of daily living. The suggested assessments for balance include the TUG and TUGcog. The TUG is a commonly utilized assessment, while the TUGcog is a newer version of this assessment intended to provide information regarding dual processing. The TUG can also double as an assessment of gait, while the FGA is recommended as a second gait assessment. The recommended assessments for executive function and dual-task processing are the Color-Word Stroop test and TUG_{cog}, respectively.

Training to Reduce Fall Risk

According to the National Council on Aging, the efficacy of an exercise training program should not be determined exclusively by fall incidence rates following training (National Council on Aging, 2005). Other important outcomes to assess include the modifiable risk factors of muscular strength, balance, gait characteristics, and cognitive function. Training programs often center around exercise, as exercise can independently reduce fall risk (Chang et al., 2004; Franco et al., 2012; Gillespie et al., 2012; Sherrington et al., 2011) and reduce the severity of injury if a fall does occur (El-Khoury et al., 2013).

Exercise interventions to reduce fall risk should include moderate intensity activities with an emphasis on balance training (National Council on Aging, 2005; Sherrington et al., 2011). According to a meta-analysis of 54 studies, a net exercise dose of 50 hours is needed for significant decreases in fall risk, with a minimum of 2 hours of training per week to optimize benefits (Sherrington et al., 2011). Further, exercise interventions should target community-dwelling adults, as evidence shows a strong effect with high fall risk individuals who have a great need for prevention (Sherrington et al., 2011). A variety of modes of exercise have been shown to be successful at reducing fall risk and improving strength, balance, gait characteristics, and cognitive function, including group, home-based, balance, aerobic, and resistance training (Ballard et al., 2004; Barnett et al., 2003; Carter et al., 2003; Li et al., 2005; Rubenstein et al., 2000; Weerdesteyn et al., 2006; Wolf, Barnhart, Ellison, & Coogler, 1997; Voukelatos, Cumming, Lord, & Rissel, 2007). The most appropriate training modality will be determined by the population of interest.

Group interventions. Group exercise interventions with community-dwelling older adults are typically multifaceted, including training focused on strength, balance, coordination, aerobic capacity, and/or flexibility (Ballard et al., 2004; Barnett et al., 2003; Bunout et al., 2005; Carter et al., 2001; Carter et al., 2002; Lord et al., 1995; Means et al., 2005; Rubenstein et al., 2000; Weerdesteyn et al., 2006). The literature provides data on training program durations ranging from 5 weeks (Weerdesteyn et al., 2006) to 1 year (Barnett et al., 2003; Burnout et al., 2005; Lord et al., 1995). The number of training sessions ranges from once (Barnett et al., 2003), twice (Bunout et al., 2005; Carter et al., 2001; Carter et al., 2002; Weerdesteyn et al., 2006), to thrice (Ballard et al., 2004; Means et al., 2005) weekly, with session durations of 40 minutes (Carter et al., 2001; Carter et al., 2002), 60 minutes (Ballard et al., 2004; Barnett et al., 2003; Bunout et al., 2005), and 90 minutes (Means et al., 2005; Weerdesteyn et al., 2006).

In spite of the aforementioned variation in program structure, a systematic review conducted by Gillespie et al. (2012) indicated that multifaceted group exercise programs significantly reduce the rate and the risk of falling in community-dwelling older adults. Furthermore, low and high fall risk individuals exhibited similar reductions in the rate of falls following training (Gillespie et al., 2012). It is noteworthy that the review included investigations with supplementary home-based components of training and samples including low fall risk older women with osteoporosis (Gillespie et al., 2012). Although these characteristics do not negate the positive effect of group exercise training, the potential influence of these features on the results should be taken into account when interpreting the findings for application to healthy, community-dwelling older adults.

A second consideration is that while valuable information regarding the risk and rate of falling can be derived from the review, the effect of exercise training on factors known to influence fall risk, including strength, balance, gait, and cognitive function, were not assessed. As such, the remainder of this section will focus on the influence of group exercise training on these characteristics.

It has been suggested that the influence of group exercise training on physical outcome variables is associated with training status upon initiation of exercise, where individuals considered high fall risk or who exhibit low performance on factors associated with fall risk exhibit greater improvements following training than those with high performance at training initiation (Ballard et al., 2004; Barnett et al., 2003; Carter et al., 2002; Rubenstein et al., 2000; Weerdesteyn et al., 2006). In contrast to the perspective that training status influences responsiveness to training, it has also been suggested that an inappropriate selection of training volume or outcome variables may have contributed to the lack of improvement observed when studying healthy, community-dwelling older adults (Means et al., 2005; Weerdesteyn et al., 2006).

In accordance with the hypothesis that training volume may be insufficient to elicit adaptations in investigations of group exercise with healthy, community-dwelling older adults, a 6 week training program with 3 training sessions per week of 90 minutes per session yielded significant improvements in functional obstacle course performance (Means et al., 2005). These findings are similar to those reported by Weerdesteyn et al. (2006) in a sample of participants with a history of falling, who reported improvements following 5 weeks of 3 training sessions per week at 90 minutes per session. These findings, in combination with the finding that programs with less frequent and shorter training sessions yielded lesser results (Bunout et al., 2005), indicate that training volume may be more influential on responsiveness than initial training status.

Another similarity amongst training studies that yield improvements in physical outcome measures, regardless of initial training status, is the outcome variables assessed. Studies observing improvements utilized an obstacle course intended to reflect functional performance (Means et al., 2005; Weerdesteyn et al., 2006). Weerdesteyn et al. (2006) suggested that this is a more appropriate outcome measure than typical assessments based on the inclusion of cognitive requirements. As such, it is possible that the outcome variables commonly measured are simply not specific or sensitive enough for a highly functional population, leading to misinterpretation of a ceiling effect as a lack of training effect. Further research is warranted regarding the influence of high volume group exercise for healthy, community-dwelling older adults, with particular attention to selection of appropriate outcome variables.

The previous sections discussed how physical outcome measures are typically influenced by group training. However, dual-tasking performance has been shown to improve following 6 to 10 weeks of group exercise training (Agmon, Kelly, Logsdon, Nguygen, & Belza, 2015). Investigation of group exercise training on executive function has been limited.

While it was previously mentioned that structural variations exist amongst group exercise interventions, Tai Chi is a specific form of group exercise that is growing in popularity amongst older adults, thus warranting further discussion. A recent meta-analysis identified Tai Chi as an effective exercise modality for prevention of fall risk, with little influence of duration or style of training (Hu et al., 2016). Tai Chi training programs with community-dwelling older adults include 8 (Zhang, Ishikawa-Takata, Yamazaki, Morita, & Ohta, 2006), 12 (Audette et al., 2006), 15 (Wolf et al., 1997), 16 (Voukelatos et al., 2007), 18 (Maciaszek, Osiski, Szeklicki, & Stemplewski, 2007), and 26 (Li et al., 2005) week durations. Number and duration of training sessions also varied, with 1 (Voukelatos et al., 2007; Wolf et al., 1997), 2 (Maciaszek et al., 2007), 3 (Audette et al., 2006; Li et al., 2005), and 7 (Zhang et al., 2006) sessions per week at 45 minutes (Maciaszek et al., 2007) to 1 hour (Audette et al., 2006; Li et al., 2005; Voukelatos et al., 2007; Wolf et al., 1997; Zhang et al., 2006) per session.

In agreeance with the meta-analysis results, the risk and rate of falling has been shown to decrease following Tai Chi training (Li et al., 2005; Voukelatos et al., 2007; Wolf et al., 1997). Furthermore, regardless of variation in Tai Chi program structure, balance has been shown to consistently improve with Tai Chi training for community-dwelling individuals considered sedentary or at risk for falling upon initiation of training (Audette et al., 2006; Li et al., 2005; Maciaszek et al., 2007; Voukelatos et al., 2007; Wolf et al., 1997; Zhang et al., 2006). Changes in strength (Audette et al., 2006) and gait (Li et al., 2006) have also been observed in community-dwelling older adults following tai Chi interventions. Overall, there is a paucity of literature on the influence of Tai Chi training on individuals who do not initiate training with classification as sedentary. Further investigation regarding the influence of Tai Chi on individuals initiating training with a higher physical activity level is warranted.

Aside from potential improvements in the rate of falling and improvement in risk factors following group exercise, the opportunity for social interaction improves program adherence, with concomitant improvements in self-reported depression measures and exercise self-efficacy (DiBrezzo, Shadden, Raybon, & Powers, 2005; Makino et al., 2015). Thus, the benefits of group based exercise extend beyond the traditional physical characteristics and these additional benefits should be considered when designing exercise interventions. In contrast, the lack of individualization of group exercise may contribute to the lack of sufficient stimulus observed with moderate training volumes for individuals initiating training with low fall risk.

Overall, properly designed group exercise programs can reduce fall risk and associated risk factors when appropriate outcome variables are selected. General group exercise for healthy, community-dwelling older adults may require a high training volume to provide sufficient stimuli for improvements (Means et al., 2005; Weerdesteyn et al., 2006). Furthermore, individualizing the exercise program is challenging in a group setting, which may increase the dependence on high training volumes for those beginning training with low fall risk. Although investigations of Tai Chi indicate consistent improvements, there is a lack of research in more fit and active populations. There is a need to further investigate exercise programs for older adults that are more active and may have a lower initial fall risk.

Home-based interventions. Similar to group exercise interventions, home-based programs are typically multi-faceted and aimed at improving strength and balance. Home-based interventions are convenient without a need for access to transportation and, while they lack a social aspect, they do allow for a private exercise environment. When deciding between group and home-based programs, participant preference is an important consideration. Because some older adults prefer home-based interventions, it is important to evaluate the literature to determine the effectiveness of these programs in reducing fall risk and factors that influence fall risk.

A meta-analysis of four studies conducted by one research team revealed that home-based exercise training can reduce falls and injuries from falls in community-dwelling older adults (Robertson, Campbell, Gardner, & Devlin, 2002). Also, home-based programs have been successful with individuals older than 65 years old on psychotropic medications and those older than 75 years old (Campbell et al., 1997; Campbell et al., 1999a; Campbell et al., 1999b; Robertson, Devlin, Gardner, & Campbell, 2001; Robertson et al., 2002). The aforementioned training programs had durations of 6 months (Campbell et al., 1997), 1 year (Campbell et al., 1999a; Robertson et al., 2001) and 2 years (Campbell et al., 1999b). All studies included a minimum of 3 days of prescribed exercise training per week, with exercises completed using ankle weights when the addition of weight was appropriate (Campbell et al., 1997; Campbell et al., 1999a; Campbell et al., 1999b; Robertson et al., 2001). In addition, participants in each program were encouraged to complete either two (Campbell et al., 1999a; Robertson et al., 2001) or three (Campbell et al., 1997; Campbell et al., 1999b) days of walking per week. The outcomes of these investigations include reduced fall risk (Robertson et al., 2001), reduced rate of falling (Campbell et al., 1999a; Campbell et al., 1999b, Robertson et al., 2001), improved muscular strength (Campbell et al., 1997), and improved static balance (Campbell et al., 1997). Although there is limited information regarding the effect of home-based training on cognitive function, executive function increased following home-based exercise training in individuals exceeding 70 years of age who reported a history of falling (Liu-Ambrose et al., 2008). It is noteworthy that Liu-

Ambrose et al. (2008) utilized participants over 70 years old that reported a history of falling. Further research is needed to determine the effect of home-based training on healthy, community-dwelling older adults who have not reported a fall.

While the results of the home-based intervention studies indicate consistent improvement, it is noteworthy that the duration of the training programs exceeded that commonly utilized in other types of training. As such, comparison of this training modality to other training methods should be done with caution. It is also notable that there is a brevity of data supporting the use of home-based training with healthy, community-dwelling older adults. It could be postulated that the ankle weight training stimulus may not provide sufficient stimuli to yield adaptations in fall risk, balance, or strength for those initiating training at a high level of physical function. The current literature supports the use of home-based exercise training for older adults on psychotropic medications or who are older than 75 years old (Campbell et al., 1997; Campbell et al., 1999a; Campbell et al., 1999b; Robertson et al., 2001). When the goal is preventing or minimizing falls and losses in strength, balance, gait characteristics, and cognitive function before decrements occur, home-based interventions may not be the best method of intervention.

Balance training. Balance training is often a component of multifaceted exercise interventions designed to yield reduction in the risk of falling. Outcomes range from a 22 to 38% reduction in falls, depending on the difficulty and the duration of the balance training and whether or not a walking component was included in the intervention (Sherrington et al., 2011). With a high dose of balance training (> 50 hours training) and no walking component, a 38% reduction in falls has been documented (Sherrington et al., 2011). It has been reported that effective balance programs need to be 11 to 12 weeks in duration with 91 to 120 minutes of training per week (Lesinski et al., 2015). Lesinski et al. (2015) further recommended that 3 sessions of 31 to 45 minutes be completed each week of training.

The available literature on community-dwelling older adults contains a variety of intervention protocols. Furthermore, the majority of the programs highlighted in the literature do not meet the guidelines for useful balance training to reduce fall risk (Lesinski et al., 2015). Despite these concerns, improvements in balance have been documented (Jorgensen et al., 2013; Maritz & Silbernagel, 2016; Nitz & Choy, 2004), along with improvements in muscular strength (Jorgensen et al., 2013; Maritz & Silbernagel, 2016) and cognitive function (Granacher et al., 2010). Among studies where the independent efficacy of balance training with community-dwelling older adults was evaluated, program length varied with 5 (Maritz & Silbernagel, 2016), 6 (Granacher et al., 2010), 10 (Jorgensen et al., 2013; Nitz & Choy, 2004), and 12 (Roaldsen, Halvarsson, Sahlstrom, & Stahle, 2014) weeks of duration. Number of sessions per week and minutes per session also varied with 1 (Nitz & Choy, 2004), 2 (Jorgensen et al., 2013; Maritz & Silbernagel, 2016), and 3 (Roaldsen et al., 2014) sessions per week lasting 30 (Maritz & Silbernagel, 2016), 35 (Jorgensen et al., 2013), 45 (Roaldsen et al., 2014), or 60 (Nitz & Choy, 2004) minutes per session. Programs included Nintendo biofeedback-based training (Jorgensen et al., 2013), instructor led training in small groups (Nitz & Choy, 2004; Roaldsen et al., 2014), or individual training (Maritz & Silbernagel, 2016). The characteristics of the community-dwelling adults included in the studies also were inconsistent with some classified as healthy (Jorgensen et al., 2013; Maritz &

Silbernagel, 2016), some who had fallen in the previous year (Nitz & Choy, 2004), and some who exhibited balance deficits and a fear of falling upon initiation of training (Roaldsen et al., 2014). Although most of the aforementioned studies primarily assessed risk factors for falling, Nitz and Choy (2004) identified that the rate of falling post-balance training was reduced for those with a history of falling. Furthermore, although lab measurements of balance and strength were not obtained, Roaldsen et al. (2014) identified improvements in self-reported function in those that initiated training with balance deficits and fear of falling.

While improvements in the rate of falling and other fall risk factors are included in the literature, the combined variation in program design and sample makes it difficult to speculate the ideal balance training program for community-dwelling older adults. Although Lesinski et al. (2015) were able to identify a training program structure likely to elicit improvements in balance, further assessments regarding the structure required for improvements in the rate of falling, strength, and gait characteristics should also be completed. While a clear conclusion regarding balance training has yet to be reached regarding reduction in fall risk, this does not warrant dismissal of the efficacy of balance training. However, further research regarding it as an independent training modality is required to understand the necessary dose and accompanying influence on the risk of falling and outcome measures associated with falls.

Aerobic exercise training. There is limited evidence regarding the efficacy of aerobic training interventions on fall risk in community-dwelling older adults. In fact, in a recent review (Bouaziz et al., 2017), only one study was identified where the effect of aerobic training on the rate of falling was directly assessed (Buchner et al., 1997b). This 6 month training study of community-dwelling older adults included 3 training sessions per week, with each session lasting 30 to 35 minutes and with a target exercise intensity of 75% heart rate reserve (Buchner et al., 1997b). The cycle ergometer training was shown to yield an increase in time to first fall following 6 months of training and reduced the risk of falling in comparison to non-exercise controls (Buchner et al., 1997b). However, there were no significant differences in contributing factors to fall risk, including dynamic balance, gait speed, step length, or stair climb speed following the cycle ergometer training. This finding was attributed to participants exhibiting only mild impairments in balance and strength upon initiation of training, where cycle ergometry training alone may not have provided sufficient stimulation for improvement in the measured outcomes (Buchner et al., 1997b).

Cycle ergometer training studies have included samples of older adults with mild balance deficits (Buchner et al., 1997a; 1997b) and sedentary, healthy older adults (Dennison et al., 2013; Lovell et al., 2010). Various investigators have assessed the effect of cycle ergometer training with community-dwelling older adults. Two investigations implemented 12 week aerobic training programs with 3 sessions per week at 1 hour per session (Buchner et al., 1997a; Denison et al., 2013). Buchner et al. (1997a) utilized a training intensity of 75% heart rate reserve, while Denison et al. (2013) did not specify training intensity. Lovell et al. (2010) implemented a 16 week exercise program, with 3, 30 to 45 minute sessions per week at 50 to75% VO_2 max. The longest program implemented was that of Buchner et al. (1997b), which was 24 weeks in duration, with 3, 1 hour training sessions at 75% heart rate reserve. Improvements in balance, gait, and strength were reported in each of the studies (Buchner et al., 1997a; Buchner et al., 1997b; Denison et al., 2013; Lovell et al., 2010). Specific improvements reported included incline squat 1-RM (Lovell et al., 2010), peak torque (Buchner et al., 1997a), and TUG performance (Denison et al., 2013). However, in contrast, Buchner et al. (1997a) reported no improvement in balance and Denison et al. (2013) observed no improvements in muscular strength, as assessed by the 5TSST.

It is noteworthy that while Buchner et al. (1997a) assessed the efficacy of cycle ergometer training, this study compared the effects of walking, cycling, and general aerobic exercise. There have been two investigations of walking training on strength, balance, and gait characteristics with community-dwelling older adults (Buchner et al., 1997a; Sousa et al., 2017). Both of these walking programs included 3 sessions per week, with training program durations of 12 weeks (Buchner et al., 1997a) and 36 weeks (Sousa et al., 2017). Buchner et al. (1997a) utilized 35 to 40 minute walking sessions at 50 to 75% heart rate reserve, while Sousa et al. (2017) utilized 60 minute training sessions at moderate to vigorous intensity, as mediated by rating of perceived exertion values between 12 and 17 on the 6 to 20 Berg scale. Both investigations showed improvements in strength, balance, and gait performance following training (Buchner et al., 1997a; Sousa et al., 2017). The outcome measures utilized to determine this were walking speed, walking on a wide balance beam, walking on a narrow balance beam, and a summed score for lower extremity peak torque, including knee extensor, knee flexor, ankle plantar flexor, and ankle dorsiflexor measures. Although different outcome measures were utilized, Sousa et al. (2017) also identified improvements in strength using the 30CST and in dynamic balance with the TUG and FRT following the walking intervention. It is also worth noting that Buchner et al. (1997a) identified that walking yielded greater improvements in gait, dynamic balance and strength than cycling.

In addition to potential for improvement on physical outcome measures, cognitive function has also been shown to improve following a six month walking program, with 3 days of walking for 40 minutes per day (Gregory et al., 2017).

While walking performance yielded greater improvements than cycling in the Buchner et al. (1997a) study, Sousa et al. (2017) identified that when resistance training and walking were combined, greater improvements in TUG, 30CST, and FRT were observed than with walking alone. Furthermore, almost 60% of variation in TUG improvement between only endurance training and combined endurance and resistance training was explained by differences in exercise training (Sousa et al., 2017). Sousa et al. (2017) suggested that the difference in improvement on the TUG shows that the combined training method was more effective at increasing balance, and strength than endurance training alone. There remains to be an investigation comparing combined aerobic and resistance training with resistance training only, which would provide further means of comparison amongst training methods.

In accordance with the findings that combined resistance and aerobic training yielded greater improvements in balance and strength (Sousa et al., 2017), it is recommended that progressive resistance training (PRT) be included with aerobic training programs, particularly for older adults beginning with a high level of physical function (Bean, Vora, & Frontera, 2004). While understanding that inclusion of PRT is an effective component of multifaceted fall risk interventions, it is imperative to first assess the independent effect of PRT.

Progressive resistance training. The American College of Sports Medicine (2018) recommends that older adults complete at least 2 days of moderate-to-vigorous intensity resistance training per week, with an intensity range of 60 to 80% 1-RM or 5 to 8 on a 0-10 rating of perceived exertion scale. Specifically, the ACSM (2018) suggests completion of 2 to 3 sets of 8 to 10 exercises on each day of PRT. Although the ACSM provides guidelines regarding PRT for older adults, many researchers have examined the efficacy of programs that deviate from these recommendations.

While there are extensive data supporting the use of various PRT protocols with healthy, community-dwelling older adults, there is a brevity of information regarding the effectiveness of these programs in altering the rate of falling. In meta-analyses of adults exceeding 60 years of age with varying levels of function, Liu and Latham (2009) identified a trend towards reducing the rate of falling post-training, while Sherrington et al. (2011) found that PRT was not a necessary component of exercise interventions designed to prevent falls. It is noteworthy that Sherrington et al. (2011) also mentioned that short follow-up periods may have contributed to an oversight in the long-term benefits of improved muscular strength on prevention of future falls. In consideration of limited availability of data regarding the rate of falling post-PRT in healthy, community-dwelling older adults and the aforementioned contribution of muscular strength to fall risk, discussion of the effect of PRT on muscular strength is warranted.

As the primary goal of PRT is typically an increase in muscular strength, improvements in this characteristic are among the most consistent following training. Although the ACSM (2018) suggested that moderate-to-vigorous intensity PRT is necessary to elicit improvements in physical outcome measures, research has shown that low, moderate, and high intensity training yielded improvements in lower extremity strength in community-dwelling older adults (Barrett & Smerdely, 2002; Fielding et al., 2002; Liu & Latham, 2009; Miszko et al., 2003; Nicholson et al., 2015; Orr et al., 2006; Schlicht et al., 2001). The recommendation of higher intensity PRT may be the result of an apparent dose-response relationship between training intensity and strength gains in community-dwelling older adults (Latham, Bennett, Stretton, & Anderson, 2004; Steib, Schoene, & Pfeifer, 2010; Van Roie, Delecluse, Coudyzer, Boonen, & Bautmans, 2013). However, a recent meta-analysis indicated that improvements in strength following moderate (~45% 1-RM) and high (~80% 1-RM) intensity PRT were similar when volume was matched in community-dwelling older adults (Csapo & Alegre, 2016). In accordance, it is postulated that strength gains may be more dependent on training volume than intensity, although this has only been demonstrated when comparing moderate and high intensity PRT (Csapo & Alegre, 2016; Raymond, Bramley-Tzerefos, Jeffs, Winter, & Holland, 2013).

It is noteworthy that the consistency observed relative to muscular strength improvement following PRT is not demonstrated for all fall risk factors. For example, improved balance following training has only been reported in 22% of PRT investigations (Orr, Raymond, & Singh, 2008) and there is a lack of association between improvements in strength and balance (Orr et al., 2006; Wolfson et al., 1996). This has been partially attributed to training status upon initiation of PRT, where clinical and/or frail populations exhibit more consistent improvements in balance than healthy, community-dwelling older adults (Orr et al., 2008). Based on these results, it seems that PRT does not foster improved balance in older adults who are not yet considered frail.

However, the lack of balance improvement observed following PRT with healthy, community-dwelling older adults may also be attributable to varying outcome variables and program design.

The primary criticisms regarding outcome variables include the potential for a ceiling effect and influence of inconsistent assessment standards (Orr et al., 2008). A ceiling effect may be observed as a result of implementing cut-off scores or selecting variables that healthy individuals will perform exceptionally well on (Buchner et al, 1997b; Messier et al., 2000; Orr et al., 2008). While cut-off scores serve a purpose in categorizing fall risk, when assessment is stopped prior to achieving an individual's best performance, the sensitivity to improvements is reduced.

Static balance assessments have been measured in 40% of PRT investigations with older adults and are particularly vulnerable to the ceiling effect (Orr et al., 2008). Static assessments that are the most likely to exhibit a ceiling effect with healthy, community-dwelling older adults include the tandem and single leg stance tests with the eyes open (Orr et al., 2008). As previously discussed, this is attributed to implementation of cut-off scores. The cut-off scores utilized for these assessments have included 10 (Buchner et al., 1997b; Messier et al., 2000), 30 (eyes closed; Schlicht et al., 2001), and 60 (Rooks, Kiel, Parsons, & Hayes, 1997) seconds. In accordance, various investigations have exhibited no significant improvement in eyes open, single leg stance and tandem stance performances following PRT in healthy, community-dwelling older adults (Buchner et al., 1997b; Orr et al., 2008; Schlicht et al., 2001; Topp, Mikesky, Wigglesworth, Holt, & Edwards, 1993).

While there is potential that selection of outcome variables contributes to the lack of differences observed, it is also suggested that a training volume threshold for balance improvement may exist (Orr et al., 2008). This is evident in that short duration, high intensity (Barrett & Smerdely, 2002; Nichols et al., 1995; Wolfson et al., 1996) and long duration, low intensity (Messier et al., 2000; Rooks et al., 1997) programs yielded the most consistent improvements in balance. However, it is recommended that observed improvements in balance following low intensity training were likely in static balance only, while moderate to high intensity PRT yields neuromuscular benefits that will improve static and dynamic balance (Orr et al., 2008).

In accordance with the aforementioned influence of exercise intensity on improvements in balance, 40 weeks of PRT at a non-RPE based, self-determined intensity (Rooks et al., 1997) and 78 weeks of PRT using dumbbells and ankle weights (Messier et al., 2000) yielded significant improvements in static balance. The specific static balance assessments that yielded improvements include tandem stance with eyes open (Rooks et al., 1997), single leg stance with eyes open and closed (Rooks et al., 1997) and bipedal stance with eyes closed (Messier et al., 2000). Although there is evidence that low intensity PRT preferentially increases static balance, there is also limited data available regarding dynamic balance following low intensity training based on selection of outcome variables. One study did observe improvements in both static and dynamic balance following 12 weeks of resistance band PRT (Topp et al., 1993). In order to determine if low intensity PRT improves both static and dynamic balance, further research is warranted.

There is evidence of potential for increases in both static and dynamic balance following moderate to high intensity PRT (Barrett & Smerdely, 2002; Nichols et al., 1995; Wolfson et al., 1996). Studies included investigation of the influence of 10 weeks of resistance training at an RPE of “hard” to “very hard” (Barrett & Smerdely, 2002), 12 weeks at 50% 1-RM (Nichols et al., 1995), and 14 weeks at 75% 1-RM (Wolfson et al., 1996). These investigations yielded improvements in both static (Nichols et al., 1995; Wolfson et al., 1996) and dynamic (Barrett & Smerdely, 2002; Wolfson et al., 1996) balance. Static balance assessments included single leg stance with eyes open (Wolfson et al., 1996) and eyes closed (Nichols et al., 1995). Dynamic balance was assessed by means of dynamic stability platform assessments (Wolfson et al., 1996) and FRT (Barrett & Smerdely, 2002). While the current literature supports the conclusion that static balance is influenced by PRT of any training intensity and dynamic balance requires moderate to high intensity, investigations of low intensity training with carefully chosen static and dynamic balance should be conducted.

Although very few investigations of resistance training and executive function have been conducted with healthy, community-dwelling older adults, there is evidence that PRT yields improvements in cognitive function, as demonstrated by a one year resistance training program with only one or two days of resistance training per week (Liu-Ambrose et al., 2010). There remains to be an investigation of the effect of PRT on dual-tasking performance.

The information above demonstrates that there remains to be a clear consensus as to the appropriate outcome variables, training intensity, and program duration needed to yield optimal improvements in balance following PRT. However, it does appear that when variables of sufficient difficulty are assessed with no cut-off score and the program volume is sufficient, balance improvements can be induced (Orr et al., 2008). As previously mentioned, there is a disparity between strength and balance improvement following PRT. While the influence of training intensity, training duration, and outcome variables utilized likely have an influence, another potential explanation is that muscular power is more influential on balance than muscular strength, particularly when the balance performance is specific to reactive balance (Orr et al., 2008). This is applicable when considering the circumstances under which a fall occurs, where one is expected to exert force at a given rate to prevent falling. As such, it is appropriate to discuss improvements in muscular power following PRT.

In efforts to optimize improvements in muscular power, investigators have compared traditional PRT and high velocity PRT, which is also referred to as power training (Bottaro, Machado, Noguiera, Scales, & Veloso, 2007; Fielding et al., 2002; Henwood, Riek, & Taaffee, 2008). During power training, there is an emphasis on fast concentric contractions and slow eccentric contractions. When training volume is matched, power training yields greater increases in muscular power than traditional PRT (Fielding et al., 2002). Leg press and leg extension peak power, as measured by a pneumatic device, improved significantly following 16 weeks of traditional PRT and power training at 70% 1-RM with community-dwelling older adults (Fielding et al., 2002). Similarly, Bottaro et al. (2007) found that 10 weeks of power training at 60% 1-RM yielded greater improvements in muscular power than traditional PRT in community-dwelling older adults. Furthermore, increases in muscular power have been demonstrated from power training at a lower training volume in community-dwelling older adults (Henwood et al., 2008). This was demonstrated in a 24 week training study comparing traditional PRT and power training, where three sets of lifting were completed at 75% 1-RM for traditional PRT and the three sets progressed from 45 to 60 to 75% 1-RM for power training (Henwood et al., 2008). Henwood et al. (2008) also noted that the power training may influence average contraction speed to a greater extent than traditional PRT.

As the name suggests, power training improves muscular power. This has been shown to occur independent of exercise intensity with older adults, as equivalent improvements in muscular power were observed following 8 and 12 weeks of power training at low (20% 1-RM), moderate (50% 1-RM), and high intensity (80% 1-RM) (de Vos et al., 2005). Improvements in muscular strength have also been reported in community-dwelling older adults, as measured by improvements in 30 second repeated chair stand performance (Bottaro et al., 2007), maximal isometric muscular contraction (Caserotti, Aagaard, Larsen, & Puggaard, 2008; Henwood et al., 2008), and 1-RM assessments (de Vos et al., 2005; Henwood et al., 2008). In contrast to that observe with muscular power outcomes, moderate (50%) and high (80%) intensity power training is required for improved muscular strength (de Vos et al., 2005). Similarly, intensity appears to influence the effect of power training on balance, where low intensity (20%) training yielded the greatest improvement in static and dynamic balance, as assessed by single leg stance with eyes open and eyes closed and narrow bilateral stance on a moving platform (Orr et al., 2006). Based on this information, the selection of training intensity for power training should take into consideration whether improvements in muscular strength or balance are more desirable.

When considering changes in the risk of falling and the associated risk factors, power training has been investigated to a lesser extent than traditional PRT with community-dwelling older adults. As such, further examination regarding the influence of power training on fall risk factors is warranted. The current literature supports that both PRT and power training elicit similar responses in muscular strength and balance (Bottaro et al., 2007; Fielding et al., 2002). However, power training appears to elicit greater changes in muscular power than PRT (Bottaro et al., 2007; Fielding et al., 2002). Further comparisons of PRT and power training would provide more information regarding the benefits to each.

While power training was introduced and studied based on the influence of speed of muscle contraction on fall risk factors, resistance training programs with emphasized types of muscle contraction have also been assessed. One example of such training is that of eccentric contractions, which has recently gained increased attention in research with older adults.

Eccentric exercise training.

Physiological responses to eccentric exercise. When the magnitude of a force surpasses that exerted by the muscle, the muscle will lengthen. When tension is created during said muscle lengthening, it is termed an eccentric contraction. In comparison to isometric and concentric contractions, eccentric contractions exhibit greater force production (Katz, 1939; Komi & Buskirk, 1972; Lindstedt et al., 2001; Lindstedt et al., 2002) and lesser attrition with age (Hortobágyi et al., 1995; Poulin et al., 1992; Vandervoort et al., 1990). The combination of higher potential forces and greater preservation of maximal force throughout the lifespan yields higher potential total work, making this a potentially influential resistance training method for older adults (Johnson, 1972; Johnson, Adamaczyk, & Tennoe, 1976; Komi & Buskirk 1972).

Another characteristic of eccentric contractions that may be favorable for older adults is that they require less oxygen consumption than concentric contractions (Bigland-Ritchie & Woods, 1976). More specifically, a concentric contraction requires six times more oxygen than an eccentric contraction duration equal force generation. The observed difference in oxygen demand is the result of attenuated motor unit activation and less oxygen demand of the motor units that are activated during eccentric contraction (Bigland-Ritchie & Woods, 1976). This oxygen consumption difference allows eccentric exercise to be a beneficial resistance training exercise prescription component for older adults, particularly those who exhibit exercise intolerance (Lindstedt et al., 2001). Although oxygen consumption during exercise is lower with eccentric muscle contractions, extended excess post-exercise oxygen consumption (EPOC) has been observed following resistance training with emphasis on the eccentric portion of the movement (Dolezal, Potteiger, Jacobsen, & Benedict, 2000; Hackney, Engels, & Gretebeck, 2008). In one study EPOC was assessed following 8 sets of 6 leg press repetitions (Dolezal et al., 2000) and in another study it was assessed after 8 sets of 6 repetitions of 8 different exercises (Hackney et al., 2008). The elevation in EPOC has been shown to last up to 48 hours, which appears to be related to training status and is anticipated to be a result of greater muscle damage with eccentric contractions as compared to concentric or isometric contractions (Burt, Lamb, Nicholas, & Twist, 2014; Dolezal et al., 2000; Hackney et al., 2008).

Concomitant to the decreased oxygen requirement of eccentric exercise is a decreased cardiovascular response (Hortobágyi & DeVita, 2000; Overend, Versteegh, Thompson, Birmingham, & Vandervoort, 2000). There is less of a change in heart rate (HR), mean arterial blood pressure (MABP), systolic blood pressure (SBP), diastolic blood pressure (DBP), and rate pressure product (RPP) during eccentric exercise in comparison to concentric exercise in healthy, older adults (Hortobágyi & DeVita, 2000; Overend et al., 2000). The reduced RPP reflects a lower myocardial oxygen demand, indicating less stress on the cardiovascular system at an absolute exercise intensity (Hortobágyi & DeVita, 2000; Overend et al., 2000). It should be noted that the aforementioned responses to eccentric exercise may not be observed in those taking medications that alter these characteristics. In accordance with the cardiovascular differences during eccentric exercise, RPE has also been reported as being lower (LaStayo et al., 2003; Overend et al., 2000).

Although higher work rates and a reduced oxygen requirement are considered positive characteristics of eccentric exercise training, some skepticism has been presented regarding the high potential for muscle damage. In many articles on eccentric exercise, muscle damage is presented as an inevitable consequence (Armstrong, 1984; Ebbeling & Clarkson, 1989). A simple search of available literature demonstrated that searching “eccentric” in combination with either “injury or damage” or “rehabilitation and beneficial” yielded more than 1,000 and less than 50 results, respectively (LaStayo et al., 2014). The literature does support that eccentric exercise at extreme intensities elicits muscle damage (Brooks & Faulkner, 1990; Clarkson & Tremblay, 1988; Gibala, MacDougall, Tarnopolsky, & Stauber, 1995). However, gradual increases in intensity and duration from a light, 2 week exposure-adaptation phase to a progressive eccentric-negative work phase has been shown not to yield muscle damage (LaStayo et al., 2003; Marcus, Addison, Kidde, Dibble, & LaStayo, 2010; Reeves et al., 2009).

Muscle soreness following a gradually progressing eccentric exercise training program was investigated with frail older adults (LaStayo et al., 2003). There was a small, statistically insignificant level of leg soreness during the first 3 weeks of intervention, with essentially zero soreness in the following 8 weeks of training (LaStayo et al., 2003). This provides evidence that a properly prescribed eccentric exercise program will not elicit severe muscle damage or soreness, even in frail elderly individuals (LaStayo et al. 2003). Furthermore, ample evidence exists demonstrating eccentric training as a safe and feasible exercise modality for older adults (LaStayo et al., 2003; Mueller et al., 2009; Overend et al., 2000). The following will review the adaptations in relation to fall risk factors observed in the elderly when performing eccentric exercise. In addition, the potential modes of exercise and proper program structure will be identified.

Types of Eccentric Exercise Training. While the physiological responses to eccentric exercise training have been established in the literature, it is important to note that there are various modes of eccentric exercise training. These include completion of functional tasks or specialized movements using body weight for resistance and utilization of traditional exercise equipment with emphasis on the eccentric portion of the movement, specialized ergometers or steppers that target eccentric contractions only, and isokinetic dynamometers.

Eccentric exercise can be performed using body mass as the resistance during functional tasks or specifically designed movements (LaStayo et al., 2014). Functional eccentric movements primarily target the hip and knee flexors, including transitioning from a standing to a seated position (LaStayo et al., 2014; Vandervoort et al., 1990). Tai Chi is a training example of where body weight is used during eccentric contractions. With Tai Chi, progression is achieved by increasing range of motion or decreasing the rate of a movement (LaStayo et al., 2014). A benefit of body mass training is that there is limited or no equipment needed, however when using only body mass as the resistance, the extent to which programs can be increased in intensity is limited.

There are various ways to utilize traditional resistance training equipment to emphasize the eccentric portion of movements, where greater force can be generated. Katz, 1939; Komi & Buskirk, 1972; Lindstedt et al., 2001; Lindstedt et al., 2002). One way of doing this is completing both concentric and eccentric contractions, with an emphasis on increasing the work done eccentrically, which is called eccentrically biased resistance training (EBRT; Gluchowski et al., 2015; LaStayo et al., 2014). This can include an assisted concentric contraction following by an unassisted eccentric contraction (Leszczak et al., 2013) or a bilateral concentric contraction followed by a unilateral eccentric contraction (Gluchowski et al., 2015; LaStayo et al., 2014; Raj et al., 2012). Another method includes only performing the eccentric portion of the lift, which is referred to as eccentric resistance training (ERT; Gluchowski et al., 2015; LaStayo et al., 2014; Reeves et al., 2009; Valour et al., 2004). This requires a passive concentric portion, with completion of the movement by other individuals or a motor, and then a bilateral (Reeves et al., 2009) or unilateral (Valour et al., 2004) active eccentric portion. Due to lack of dependence on active assistance and the ability to easily modify intensity, the most practical of the aforementioned training modes is the bilateral concentric and unilateral eccentric contraction EBRT (LaStayo et al., 2014; Raj et al., 2012).

Another form of eccentric exercise that also requires use of specialized equipment is training with an isokinetic dynamometer (Takahashi et al., 2009). This equipment can be used to specifically train a given muscle group with exclusively concentric, eccentric, or isometric contractions. Studies comparing eccentric to concentric and/or isometric contractions with healthy, community-dwelling older adults trained the ankle dorsiflexors (Porter & Vandervoort, 1997), knee extensors (Takahashi et al., 2009; Symons et al., 2005), and knee flexors (Takahashi et al., 2009) have yielded improved eccentric torque (Takahashi et al., 2009), ankle dorsiflexor strength (Porter & Vandervoort, 1997), and peak isometric and isokinetic concentric and eccentric strength (Symons et al., 2005). In addition, stair ascent, stair descent, and gait speed were improved following isokinetic eccentric training (Symons et al., 2005).

Beyond the use of body weight or existent resistance training equipment to complete eccentric training, eccentric endurance training (EET) involves prolonged repetition of solely eccentric contractions. Examples of this include downhill walking (Gault et al., 2012), descending stairs (Theodorou et al., 2013), eccentric cycling (LaStayo et al., 2003; Marcus et al., 2009; Mueller et al., 2009; Mueller et al., 2011), and eccentric stepping (LaStayo et al., 2009). In terms of maximizing eccentric work and total training volume, LaStayo et al. (2014) suggested utilization of eccentric ergometers and steppers, which are specialized, motor-driven pieces of equipment where participants only complete eccentric contractions. Detailed descriptions of how to build eccentric ergometers are available for both upper (Elmer, Danvind, & Holmberg, 2013; Elmer &

Martin, 2013) and lower (LaStayo et al., 2003; Meyer et al., 2003; Rooyackers, Berkeljon, & Folgering, 2003) body. There are also commercially available eccentric ergometers (RBM elektronik-automation GmbH, Leipzig, Germany) and steppers (BTE Technologies, Hanover, MD).

Eccentric Exercise Program Structure. Among the various methods of eccentric training, the greatest extent of literature available is for ERT, EBRT, and EET. As such, there are published recommendations for program design of each (Krishnathasan & Vandervoort, 2000; LaStayo & Reich, 1999; LaStayo et al., 2003; LaStayo et al., 2009; LaStayo et al., 2014; Leszczak et al., 2013; Marcus et al., 2009; Raj et al., 2012; Reeves et al., 2009; Valour et al., 2004).

For ERT and EBRT training programs with older adults, progression from 70 to 100% 1-RM is recommended (Krishnathasan & Varndervoort, 2000), with a goal of exceeding 100% concentric 1-RM within 12 weeks (Marcus et al., 2009). Falling within this intensity range, an 8-week EBRT intervention with 3 sets of 8 to 12 repetitions of seated leg press, leg extension, and leg curl at 75% concentric 1-RM yielded improvements in lower extremity strength and dynamic balance in community-dwelling older adults (Leszczak et al., 2013). However, a lower intensity may be used when using the EBRT training technique of unilateral eccentric contractions for bilateral movements, as Raj et al. (2012) demonstrated improvements in various outcome variables with 3 sets of 10 leg press, toe press, bench press, and lat pull-downs at only 50% concentric 1-RM. Similarly, Valour et al. (2004) found improvements in muscular strength following 5 sets of 6 unilateral bicep curls training at 60 to 100% concentric 3-RM. Other researchers have successfully utilized eccentric 1-RM testing for intensity prescription, with improvements in muscular strength following ERT for knee extension and leg press at 80% eccentric 1-RM (Reeves et al., 2009).

There are also specific recommendations for the duration of eccentric contractions. During EBRT and ERT, it is recommended that the eccentric contraction duration be 4 to 5 seconds (Krishnathasan & Vandervoort, 2000). During EBRT, it is also recommended that concentric contractions last 2 seconds (Krishnathasan & Vandervoort, 2000). In accordance, Leszczak et al. (2013) used a 3 to 5 second eccentric contraction and a 1 to 2 second concentric contraction for seated leg press, seated leg extension, and seated leg curl EBRT. Similarly, Reeves et al. (2009) used a 3 second eccentric contraction during leg extension and leg press ERT. Some studies did not include the specific durations of the eccentric and the concentric contractions (Raj et al., 2012; Valour et al., 2004). Although the protocols of Leszczak et al. (2013) and Reeves et al. (2009) allowed for a slightly quicker eccentric contraction at 3 to 5 seconds in comparison to the 4 to 5 seconds recommended (Krishnathasan & Vandervoort, 2000), positive results were still observed.

Thus, if concentric 1-RM is used to prescribe bilateral eccentric exercise intensity, it is recommended that bilateral eccentric contractions should be between 70 and 100% 1-RM (Krishnathasan & Varndervoort, 2000) and unilateral eccentric contractions have been shown to be effect at 50% 1-RM (Raj et al., 2012). Although the efficacy of intensity mediation with multiple-repetition maximum has yet to be assessed for lower extremity exercise in older adults, upper extremity exercises at 60 to 100% 3-RM yielded improvements in upper extremity strength (Valour et al., 2004). Finally, in contrast to using concentric 1-RM, bilateral eccentric exercise prescribed at 80% of eccentric 1-RM has been shown to elicit improvements in muscular strength for community-dwelling older adults (Reeves et al., 2009). It should be noted that with this intensity, the concentric portion of the exercise would likely need to be at least partially assisted. For both EBRT and ERT training, the literature supports that the duration of eccentric contraction is 3 to 5 seconds (Krishnathasan & Vandervoort, 2000; Leszczak et al., 2013; Reeves et al., 2009). For EBRT, the concentric portion of the movement should take 1 to 2 seconds (Krishnathasan & Vandervoort, 2000; Leszczak et al., 2013).

As was previously mentioned, there are also recommendations for EET program design. The use of gradually progressing EET programs has yielded increases in muscle strength without inducing muscular damage in the elderly (LaStayo & Reich, 1999; LaStayo et al., 2003; Reeves et al., 2009). LaStayo et al. (2014) designed an EET prescription with a training frequency of 2 to 3 days per week for the entire program duration and recommended using RPE for intensity mediation instead of using a strength-based prescription. The first 2 weeks are designed to avoid the muscle damage that commonly occurs by limiting the duration of each exercise session to 5 to 8 minutes, with an RPE of “very light” on the Borg scale (Borg, 1970; LaStayo et al., 2014). The progression of duration is recommended as 10 to 12 minutes for weeks 3 and 4, 14 to 16 minutes for weeks 5 and 6, and 18 to 20 minutes for weeks 7 through 12 (LaStayo et al., 2014). The intensity, mediated by the Borg scale (Borg, 1970), should be “fairly light” during weeks 3 to 5, with a gradual progression to “somewhat hard’ during weeks 6 through 12 (LaStayo et al., 2014). The goal of the 12 week prescription plan is to eventually reach an intensity of “somewhat hard” on the RPE scale, with a duration of 20 minutes, two to three times a week (LaStayo et al., 2014).

A similar exercise prescription plan was successfully utilized with frail older adults and moderately obese older adults 1 to 4 years post knee arthroplasty (LaStayo et al., 2003; 2009). In contrast, a study of healthy, community-dwelling older adults showed that 8 weeks of twice weekly training sessions of only 10 minutes each were sufficient to yield increases in balance and strength when implementing training intensity as a percent of maximal eccentric strength (Johnson, Fuller, Donnelly, & Caputo, 2018). In addition, Johnson et al. (2018) set intensity based on eccentric 1-RM instead of RPE.

Based on the aforementioned EET recommendations and studies assessing their efficacy, it is recommended that 10 to 20 minute sessions are completed 2 to 3 times per week. In order to avoid excessive muscle damage, intensity should be gradually progressed from “very, very light” or “fairly light” to somewhat hard over a duration of approximately 8 weeks. Further research is warranted to determine appropriate percentages and proper progression when prescribing intensity based on eccentric 1-RM. In addition, the minimal duration for improvements has yet to be determined.

Fall Risk and Eccentric Exercise Training. At this point, there has not been a direct investigation of the impact of eccentric exercise on fall risk or rate of falling with older adults. Similarly, the literature does not provide information regarding the effect of eccentric exercise training on cognitive function for any population. In contrast, there is literature supporting the use of eccentric exercise to improve muscular strength, balance, and gait characteristics. Eccentric exercise training, regardless of the training method, yields equivalent or greater increases in strength when compared to traditional PRT (LaStayo et al., 2003; LaStayo et al., 2009; Leszczak et al., 2013; Mueller et al., 2009;

Porter & Vandervoort, 1997; Takahashi et al., 2009; Symons et al., 2005; Theodorou et al., 2013).

Many authors have reported improvements in functional outcome measures in older adults, including the TUG (Gault et al., 2012; Leszczak et al., 2013; Mueller et al., 2009; LaStayo et al., 2003; LaStayo et al., 2009), 30CST (Leszczak et al., 2013), 5TSST (Gault et al., 2012), stair descent and ascent time (LaStayo et al., 2003; LaStayo et al., 2009), and BBS (LaStayo et al., 2003).

It is noteworthy that the EET investigations yielded a consistent improvement in functional outcome measures in healthy, older adults (Gault et al., 2012; LaStayo et al., 2003; Marcus et al., 2009; Mueller et al., 2009; Theodorou et al., 2013). Furthermore, only one study showed greater improvements in functional outcome measures following traditional PRT than EBRT or ERT (Raj et al., 2012). However, the authors of this study note that the EBRT was approaching significant and suggested that the traditional PRT and EBRT yielded similar efficacy (Raj et al., 2012). In consideration of the increased strength with concurrent and distinctive improvements in functionality, EET is an appropriate training protocol for older adults. With this recommendation, a closer assessment of the EET studies and functional outcome variables is warranted.

There is limited research regarding the efficacy of EET with healthy, community-dwelling older adults. However, there have been investigations of older adults with stable medication and health conditions (Mueller et al., 2009), frail adults classified as high fall risk (LaStayo et al., 2003), post-menopausal women with impaired glucose tolerance (Marcus et al., 2009), and moderately obese older adults, 1 to 4 years post total knee arthroplasty (LaStayo et al., 2009).

The two studies with the most notable improvements in functional outcome measures following EET included frail older adults classified as high fall risk (LaStayo et al., 2003) and older adults, 1 to 4 years post total knee arthroplasty (LaStayo et al., 2009). In both studies, three training sessions per week performed and RPE was used for intensity mediation (LaStayo et al., 2003; 2009). With the high fall risk, frail adults, 11 weeks of eccentric ergometer training began at an intensity of “very, very light” and progressed to “somewhat hard” (LaStayo et al., 2003). The session durations in this study ranged from 10 to 20 minutes (LaStayo et al., 2003). The study following total knee arthroplasty implemented a 12 week eccentric stepper program, where intensity began at “fairly light” and progressed to “somewhat hard” (LaStayo et al., 2009). The session duration for this study was 20 minutes. In both studies, TUG and stair descent were assessed. The stair descent assessments included time to descent 2 flights of 12 stairs (LaStayo et al., 2003) and time to descend 1 flight of 10 stairs (LaStayo et al., 2009). LaStayo et al. (2003) also assessed the BBS, while LaStayo et al. (2009) assessed stair ascent and 6MWT performances.

It is noteworthy that all functional outcomes improved with EET in both investigations (LaStayo et al., 2003; 2009). However, EET yielded greater improvements that traditional PRT in timed stair descent (LaStayo et al., 2003; 2009) and TUG (LaStayo et al., 2003) performances. While improvement in TUG post-EET exceeding that post-traditional PRT is relevant, the results also implicated that individuals who completed EET were reclassified as low fall risk based on TUG performance, whereas those who completed traditional PRT maintained high fall risk classification (LaStayo et al., 2003).

As mentioned, there are no current investigations of EET with healthy, community dwelling older adults. While consistent improvements in strength and EET-specific improvements in functional outcome measures have been identified in clinical populations, the ability to use this type of training with older adults prior to health concerns to promote maintenance and progression in strength, balance, gait characteristics, and cognitive function is not currently evident in the literature.

Overall Summary

In summation, the combination of the high prevalence of falling and the negative consequences of falling on economic, social, and maintenance of independent living for older adults presents a need for minimizing fall risk. While measuring the risk and rate of falling directly is possible, this requires longitudinal investigations and does not provide predictive qualities for identifying those at an elevated risk of falling. As such, it is important to understand the primary risk factors of falling. Among the most predictive characteristics utilized to predict a fall are muscular strength, balance, gait characteristics, and cognitive function. Information in the literature supports exercise as the best independent intervention for minimizing fall risk. While standard exercise interventions have been shown to improve the risk of falling and improve fall risk factors, new approaches to exercise aimed at capitalizing on the physiological progression that occurs with aging have been identified. Eccentric exercise training is a particularly tenable training method for older adults, as eccentric contractions are characterized by higher force production, lower oxygen requirement, and less attrition with aging. In conjunction with evidence that EET benefits fall risk factors in older, clinical populations, this training modality may be ideal to implement with healthy, community-dwelling older adults.

CHAPTER III

EFFECTS OF ECCENTRIC ENDURANCE TRAINING ON PHYSICAL FALL RISK FACTORS IN COMMUNITY-DWELLING OLDER ADULTS

Introduction

The economic and social burdens associated with falling in older adults are evident (Burns, Stevens, & Lee, 2016; Stevens, Corso, Finkelstein, & Miller, 2006; Zijlstra et al., 2007). The population of older adults in the United States is expected to rise from 43.1 million in 2012 to 83.7 million in 2050 (Ortman, Velkoff, & Hogan, 2014) and 1 in 3 of these individuals older than 65 years will fall annually (Stevens, 2010; Stevens et al., 2006). As such, interventions designed to minimize and prevent falling have the potential to have a positive impact on this growing population.

While intervention efficacy for reducing fall risk can be directly measured with prospective assessments of falling, the ability to predict the risk of falling and monitor changes in fall risk following training are also valuable. Modifiable risk factors for falling include muscle weakness, low muscular power, and impairments in balance and gait (Cesari et al., 2002; Muir, Berg, Chesworth, Klar, & Speechley, 2010; Perry, Carville, Smith, Rutherford, & Newham, 2007). Exercise training is recognized as an intervention strategy to reduce these risk factors and minimize the risk of falling (Chang et al., 2004; Franco, Periera, & Ferreira, 2012; Gillespie et al., 2012; Sherrington, Tiedemann, Fairhall, Close & Lord, 2011).

Although many forms of exercise have been shown to yield improvements in at least one risk factor, the characteristics of and physiological responses to eccentric exercise make it a particularly tenable training modality for older adults (Bigland-Ritchie

& Woods, 1976; Hortobágyi & DeVita, 2000; Komi & Buskirk, 1972; Lindstedt, LaStayo, & Reich, 2001; Overend, Versteegh, Thompson, Birmingham, & Vandervoort, 2000). There is less attrition in eccentric force production in comparison to concentric and isometric contractions with aging and greater forces can be produced with eccentric contractions (Hortobágyi et al., 1995; Komi & Buskirk, 1972; Lindstedt et al., 2001). In addition, when eccentrically exercising at a given workload, lower oxygen consumption (Bigland-Ritchie & Woods, 1976), heart rate, and systolic blood pressure (Hortobágyi & DeVita, 2000; Overend et al., 2000) are observed. These attributes make this exercise modality particularly applicable to older adults, who likely exhibit some decline in exercise tolerance with aging. Training on exercise equipment designed to target eccentric contractions while maximizing training volume is referred to as eccentric endurance training (EET).

The current literature provides limited data regarding the effect of EET on fall risk factors with healthy, community-dwelling older adults. In older adults considered frail (LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003), 11 weeks of EET yielded greater improvements in lower extremity strength, balance, and stair descent abilities than traditional resistance training (LaStayo et al., 2003). In addition, the EET yielded a shift in classification of the participants from high to low fall risk, while traditional resistance training did not (LaStayo et al., 2003). Similarly, LaStayo et al. (2009) identified that older adults who had undergone total knee arthroplasty incurred improvements in knee extensor strength, balance, gait characteristics, and timed stair ascent and descent following 12 weeks of EET.

Due to the potential impact of an intervention to reduce fall risk factors and prevent falls, this study was designed to determine if EET would be as effective in community-dwelling older adults. Muscular strength, balance, and gait characteristics were assessed before and after 8 weeks of EET. In addition, the effect of the EET intervention on fall self-efficacy and behavior avoidance were assessed following EET.

Methods

Participants. The sample consisted of 30 community-dwelling adults (68.2 ± 3.7 years; 16 females, 14 males). Participants were randomly assigned to control (CON; 67.5 ± 2.6 years; 8 females, 7 males) and intervention (EET; 69.0 ± 4.4 years; 8 females, 7 males) groups. All participants completed a Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Exercise Preparticipation Health Screening Questionnaire. Medical clearance was obtained, when necessary, in accordance with the American College of Sports Medicine (2018) standards. Participants were required to be independently living in the community, as determined by self-reported ability to perform tasks in the home. An individual's capacity to complete tasks in the home was determined via completion of the Katz Index of Independence in Activities of Daily Living (Shelkey & Wallace, 2012). Per published recommendations, a score of 6 indicates full function (Shelkey & Wallace, 2012). In addition, participants who had fallen in the past year for unexplained reasons or underwent knee, hip, or back surgery within the previous year were excluded from the study. All participants signed an informed consent document and the study was approved by the university Institutional Review Board (see Appendix A).

Outcome variables.

30-second repeated chair stand. The 30-second repeated chair stand (30CST) was used to assess lower extremity muscular strength. This assessment has been shown to be valid and safe with older adults (Jones, Rikli, & Beam, 1999). The assessment began in a seated position in a chair with a seat height of 44 cm. On the command "Go," participants were instructed to stand up and sit down as many times as possible in 30 seconds. The command "Stop" was given when 30 seconds had lapsed. Repetitions were counted using a clicker and partial repetitions were not included in the recorded score. Participants were asked to demonstrate control throughout the whole movement and to fully extend, but not lock, the hip and knee joints upon standing.

Berg Balance Scale. The Berg Balance Scale (BBS) is a 14-item holistic assessment of balance with excellent intra-rater and inter-rater reliability (Berg, Wood-Dauphine, & Gayton, 1989). In addition, this assessment has been shown to predict transition from non-faller to faller in highly functional, community-dwelling older adults with a cut-off score of < 50 out of 56 points (Muir et al., 2010). The movements assessed with the BBS included: sitting unsupported, standing with closed eyes, standing with feet together, standing tandem, standing on one leg, turning the trunk with fixed feet, picking an object up off the floor, turning 360 degrees, reaching forward, and stepping on a stool (Berg et al., 1989). For each movement assessed, performance was ranked as a 0, 1, 2, 3, or 4 based on pre-defined criteria. The total score of the assessment is obtained by adding the score for each movement assessed.

Single leg stance, eyes closed. The single leg stance assessment with eyes closed on the dominant (SLS-EC:D) and non-dominant (SLS-EC:ND) were used as a second assessment of balance. During this assessment, participants were asked to stand on one leg with hands on the hips. Time began when the participant raised one leg from the ground and stopped when the hands left the hips or the raised leg touched the standing leg or the ground. Participants were given three attempts at the task and the highest value was assessed for SLS-EC:D and SLS-EC:ND.

Functional Gait Assessment. During the Functional Gait Assessment (FGA), participants are assigned a score of 0, 1, 2, or 3 on various gait tasks based on pre-established criteria (Wrisley, Marchetti, Kuharsky, & Whitney, 2004). A cut-off for fall risk with community-dwelling older adults has been established at a score of < 22 out of 30, which was found to yield sensitivity and specificity of 85 and 86%, respectively (Wrisley & Kumar, 2010). The gait tasks performed included walking 6 meters on a level surface, ability to change speed of walking, walking 6 meters alternating looking to the right and left every 3 steps, walking 6 meters alternating looking up and down every 3 steps, ability to turn and stop quickly, ability to step over a shoe box, 3.6 meters of tandem walking, walking 6 meters with eyes closed, walking 6 meters backwards, and walking up the stairs (Wrisley et al., 2004).

Timed-Up-and-Go. The TUG is a sensitive and specific assessment of fall risk with older adults (Shumway-Cook, Brauer, & Woollacott, 2000) that requires incorporation of muscular strength, balance, and gait. Participants began in a seated position and on the command “Go” were instructed to rise from the chair, walk 3 meters, turn 180 degrees around a cone, walk back to the chair, and return to the seated position. Time was stopped when participants were completely seated.

Maximal Eccentric Strength. Eccentric strength assessment was completed on the same specialized eccentric exercise equipment used for training (see Figure 1). The seat was set per manufacturer's instructions and recorded to minimize the risk of injury and ensure consistency. Previous studies have documented safe and effective use of similar equipment (LaStayo et al., 2003; LaStayo et al., 2009; Mueller et al., 2009). Assessment of maximal eccentric strength (MES) followed the recommended protocol of the manufacturer (BTE Inc., Hanover, MD). Participants began with a 2 minute warm up at a self-mediated intensity. MES was then assessed by asking participants to provide maximal resistance for 6 repetitions on each leg at a speed of 23 steps per minute. To avoid excessive strain, participants were asked to maintain normal breathing and posture throughout the assessment. Force was measured by dynamometers within the pedals. Participants completed one assessment at a rating of perceived exertion (RPE) of 10, one at an RPE of 15, and one at an RPE of 19-20 with 3 minutes of rest between each measurement.

Procedures. Participants were asked to come to the laboratory two times per week for a total of 9 weeks. This included 1 week of familiarization and 8 weeks of training. Upon arrival for the first day of familiarization, participants provided written consent and completed the PAR-Q+, Exercise Preparticipation Health Screening Questionnaire, and fall history questionnaire. Following completion of paperwork, shoeless height and body mass were assessed. Body mass was measured in kilograms to the nearest 0.1 kilogram with a Tanita BF-522 electronic scale (Tanita Corporation, Tokyo, Japan). Height was assessed to the nearest centimeter using a wall-mounted stadiometer (SECA model 222, SECA Corporation, Hamburg, Germany). Next, participants were familiarized with all assessments that were measured. Baseline assessments for each outcome variable were completed on the second day of familiarization. The same assessments were completed mid-training (Week 5, Day 1) and post-training (within one week of the last training session). Assessments were completed in the following order: FGA, BBS, 30CST, TUG, and MES. All assessment data was kept in a separate envelope immediately upon completion in order to minimize researcher bias.

Training was completed on a specialized eccentric exercise machine (see Figure 1). Each training session included approximately 1 minute of warm-up and cool-down in addition to the training duration. The training sessions during the familiarization week were intended to provide a self-mediated, gradual introduction to eccentric exercise and served as a means of setting exercise intensity for Week 1 of training. The training program is displayed in Table 1. Progression in intensity and duration was based on training accuracy. In order to progress to the next intensity and duration in the program, participants were required to exhibit 70% accuracy at the current training intensity and duration. Accuracy was determined by falling within 10% of the prescribed force output. The percentage increase displayed in Table 1 was obtained from the average force output of the previous week. Based on these parameters, the training protocol for some participants (*may have*) diverged from that displayed in Table 1.

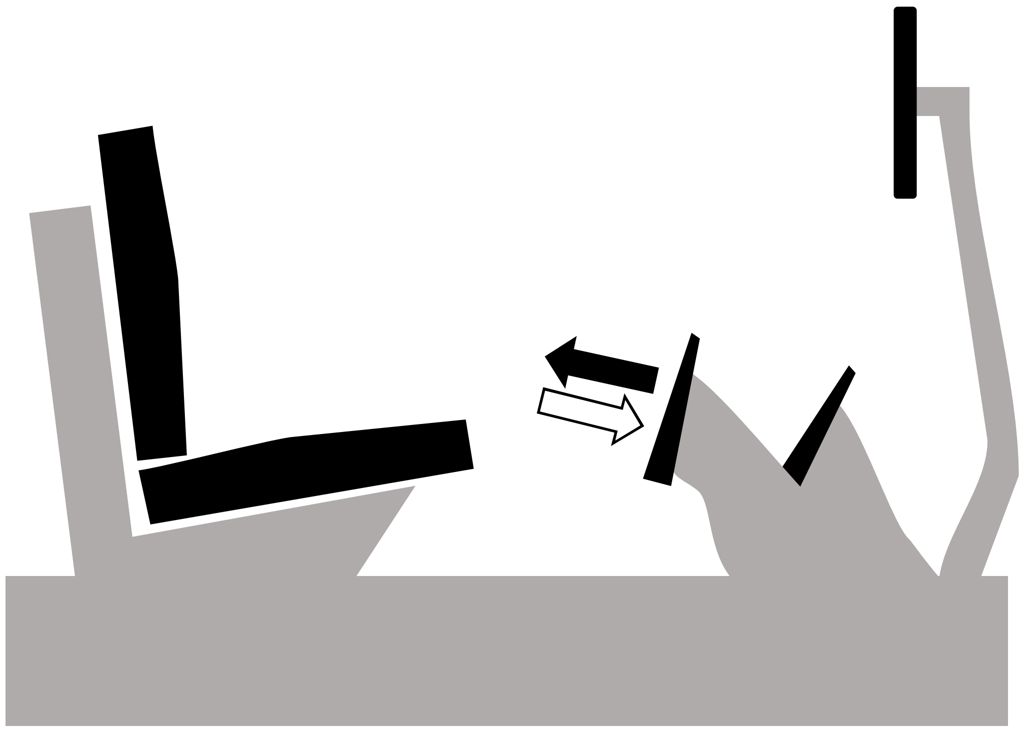

Figure 1. Depiction of eccentric exercise training. Pedals are driven in opposing directions by a 3-horsepower motor, producing a stepping pattern of motion. As each pedal drives toward the participant (knee and hip flexion; represented by black arrow), the movement is resisted (represented by outlined arrow). Since the power of the motor exceeds that exerted by the participant, the result is an eccentric contraction, or negative work. Unilateral force is measured by dynamometers within the pedals during this motion. As pedals are driven away (knee and hip extension), the participant is to provide no force against the pedal.

Table 1

Eccentric Training Program

Week	Intensity	Duration (min)
Familiarization	RPE of 8	5
1	+15%	6
2	--	8
3	--	10
4	+15%	10
5	+15%	10
6	--	12
7	--	15
8	+15%	15

Note. Intensity based on percentage of previous workload. RPE = Rating of perceived exertion on a 6-20 scale.

Statistical analysis. Data are presented as mean ± standard deviation. An a prior power analysis indicated a sample of 30 participants was required to have 80% power for detecting a medium effect size. An a prior alpha of .05 was utilized for statistical significance. For the EET group, one-way repeated measures analyses of variance (ANOVAs) were used to assessed changes in RPE and total weekly work between Weeks 1, 4, and 8. Two-way repeated measures ANOVAs with treatment group (control, exercise) as a between-subjects factor and time (pre, mid, post) as a within-subjects factor were used to predict the influence of treatment group on performance for each outcome variable. Simple-effect tests were performed as follow-up analyses for the two-way RM ANOVAs. Specifically, one-way repeated measures ANOVAs were used to assess changes in FGA, BBS, 30CST, TUG, and SLS-EC:ND between baseline, mid-training, and post-training for each group ($\alpha = .025$). Independent samples t-tests ($\alpha = .0167$) were used to compare performance of EET and CON groups at each time point (pre, mid, post). Data were analyzed using IBM SPSS (Version 23).

Results

There was no significant change in RPE across the program, F (1.65, 21.48) = 2.95, MSE = 2.20, p = .082, η_p^2 = .19. In contrast, there was a significant increase in work (kJ) across the program F (1.56, 20.29) = 20.59, MSE = 170.17, p < .001, η_p^2 = .61. Sidak pairwise comparisons indicated a progressive increase in total work among Weeks 1, 4, and 8 (see Table 2).

Mean performance for each outcome variable for the EET and CON groups is displayed in Table 3. The two-way ANOVA results are displayed in Table 4. There was a main effect of time for 30CST, BBS, and FGA performance. There was also a significant interaction for 30CST, BBS, SLS-EC:ND, FGA, and TUG. One-way repeated measures ANOVA simple effect test results are displayed in Table 5 and Sidak pairwise comparisons are in Figure 2. The only significant difference in pre-assessment performance between EET and CON groups was for SLS-EC(ND). There was a borderline significant difference for the pre-assessment performance on FGA (p = .018).

Discussion

When developing exercise recommendations for older adults, the potential of a training modality to minimize the future risk or occurrence of falls is an important consideration. In this study, the effect of EET on assessments reflective of fall risk and physical function was evaluated with community-dwelling older adults who were not yet identified as being at increased risk of falling (based on BBS, FGA, & TUG scores; Muir et al., 2010; Shumway-Cook et al., 2002; Wrisley & Kumar, 2010). Following EET, participants improved on measures of muscular fitness, gait, and balance.

Similar to previous findings (Johnson, Fuller, Donnelly, & Caputo, 2018), 30CST performance significantly improved following the 8 weeks of EET. The average improvement in 30CST performance pre- to post-training was 2.6 repetitions, with the primary significant change occurring between mid- and post-training (see Figure 2A). In contrast, previous findings indicated significant increases in 30CST performance between pre- and mid-training and mid- and post-training (Johnson et al., 2018). Additionally, the effect size of training for the current study (see Table 4; η_p^2 =.41) was lower than that previously reported (η_p^2 = .51; Johnson et al., 2018). In comparison to the findings of Johnson et al. (2018), the training program in the current study did not elicit as large of a

Table 2

Sidak Pairwise Comparisons for Total Work (kJ)

			95% CI for mean difference	
Time (i)	Time (j)	Mean difference (i – j)	Lower limit	Upper limit
Week 1	Week 4	-14.86*	-26.84	-2.88
Week 1	Week 8	-27.93*	-42.31	-13.55
Week 4	Week 8	-13.07*	-21.80	-4.35

Note. * represents statistical significance at $p < .05$.

Table 3

Mean (± SD) Performance for Physical Outcomes for Exercise and Control Groups

Variable	Group	Pre	Mid	Post
3OCST	Exercise	11.9 ± 3.1	13.1 ± 3.3	14.5 ± 3.8
	Control	11.9 ± 2.3	12.4 ± 2.5	12.2 ± 1.9
BBS	Exercise	54.4 ± 2.2	55.4 ± 1.3	55.2 ± 1.7
	Control	55.7 ± 0.5	55.6 ± 0.6	55.7 ± 0.6
SLS-EC: D	Exercise	4.3 ± 1.8	3.6 ± 1.6	4.0 ± 2.0
	Control	4.8 ± 3.4	4.0 ± 1.7	4.4 ± 2.5
SLS-EC:ND	Exercise	3.2 ± 1.3	4.0 ± 1.9	3.8 ± 2.4
	Control	7.5 ± 4.8	4.9 ± 3.0	4.3 ± 1.7
FGA	Exercise	26.0 ± 1.9	28.0 ± 2.0	28.2 ± 1.6
	Control	27.7 ± 1.7	27.7 ± 1.6	27.7 ± 1.9
TUG	Exercise	8.2 ± 2.1	7.9 ± 1.7	7.3 ± 1.9
	Control	7.5 ± 1.0	7.7 ± 0.6	7.8 ± 0.7
MES	Exercise	453.9 ± 214.6	493.0 ± 235.2	521.8 ± 248.8
	Control	422.8 ± 214.3	474.5 ± 252.3	488.4 ± 240.6

Note. 30CST = 30 second repeated chair stand; BBS = Berg Balance Scale; SLS-EC:D = single leg stance with eyes closed, dominant leg; SLS-EC:ND = single leg stance with eyes closed, non-dominant leg; FGA = Functional Gait Assessment; TUG = Timed Up-and-Go; MES = maximal eccentric strength.

Table 4

Two-way Repeated Measures Analysis of Variance Results for Physical Outcomes

Outcome	ANOVA test	Degrees of freedom	*F value*	*MSE*	*G-G p*	η_p^2
30CST	Time	1.7, 46.6	8.85	2.03	.001*	.25
BBS	Time	1.7, 44.7	5.15	0.39	.014*	.16
SLS-EC:D	Time	1.5, 40.1	1.11	3.76	.325	.04
SLS-EC:ND	Time	1.8, 49.2	2.93	4.69	.067	.10
FGA	Time	1.7, 43.6	5.81	2.10	.009*	.18
TUG	Time	1.9, 51.9	2.53	0.28	.092	.09
MES	Time	1.4, 34.1	4.78	9596.44	.026*	.16
30CST	Interaction	1.7, 46.6	6.01	2.03	.007*	.18
BBS	Interaction	1.7, 44.7	7.58	0.39	.003*	.22
SLS-EC:D	Interaction	1.5, 40.1	0.01	3.76	.984	< .01
SLS-EC:ND	Interaction	1.8, 49.2	7.17	4.69	.002*	.21
FGA	Interaction	1.7, 43.6	6.12	2.10	.007*	.19
TUG	Interaction	1.9, 51.9	9.68	0.28	< .001*	.26
MES	Interaction	1.4, 34.1	0.07	9596.44	.870	< .01

Note. F values were based on Greenhouse-Geiser tests and effect sizes represent η_p^2. * represents statistical significance. G-G = Greenhouse Geiser; 30CST = 30 second repeated chair stand; BBS = Berg Balance Scale; SLS-EC:D = single leg stance with eyes closed, dominant leg; SLS-EC:ND = single leg stance with eyes closed, non-dominant leg; FGA = Functional Gait Assessment; TUG = Timed Up-and-Go; MES = maximal eccentric strength.

Table 5

Simple Effect Tests of Time for Physical Outcomes

Variable	Treatment group	Degrees of freedom	*F value*	*MSE*	*G-G p*	η_p^2
30CST	Exercise	1.7, 22.3	8.94	3.19	.002*	.41
	Control	1.7, 24.3	0.97	0.98	.381	.07
BBS	Exercise	1.4, 18.6	9.25	0.59	.003*	.42
	Control	1.9, 27.0	0.38	0.24	.678	.03
SLS-EC:D	Exercise	1.9, 25.2	1.87	0.77	.176	.13
	Control	1.4, 19.7	0.37	6.67	.625	.03
SLS-EC:ND	Exercise	1.9, 24.1	0.94	2.64	.400	.07
	Control	1.7, 24.5	7.08	6.84	.005*	.34
FGA	Exercise	1.7, 20.3	12.73	1.82	< .001*	.52
	Control	1.7, 23.4	0.01	2.34	.978	< .01
TUG	Exercise	1.9, 24.5	8.89	0.34	.001*	.41
	Control	2.0, 27.4	1.49	0.22	.243	.10
MES	Exercise	1.6, 21.4	5.78	3404.17	.013*	.31
	Control	1.3, 15.4	1.47	16528.42	.253	.11

Note. *F* values were based on Greenhouse-Geiser adjusted one-way repeated measures ANOVA tests and effect sizes represent η_p^2. * represents statistical significance. G-G = Greenhouse Geiser; 30CST = 30 second repeated chair stand; BBS = Berg Balance Scale; SLS-EC:D = single leg stance with eyes closed, dominant leg; SLS-EC:ND = single leg stance with eyes closed, non-dominant leg; FGA = Functional Gait Assessment; TUG = Timed Up-and-Go; MES = maximal eccentric strength.

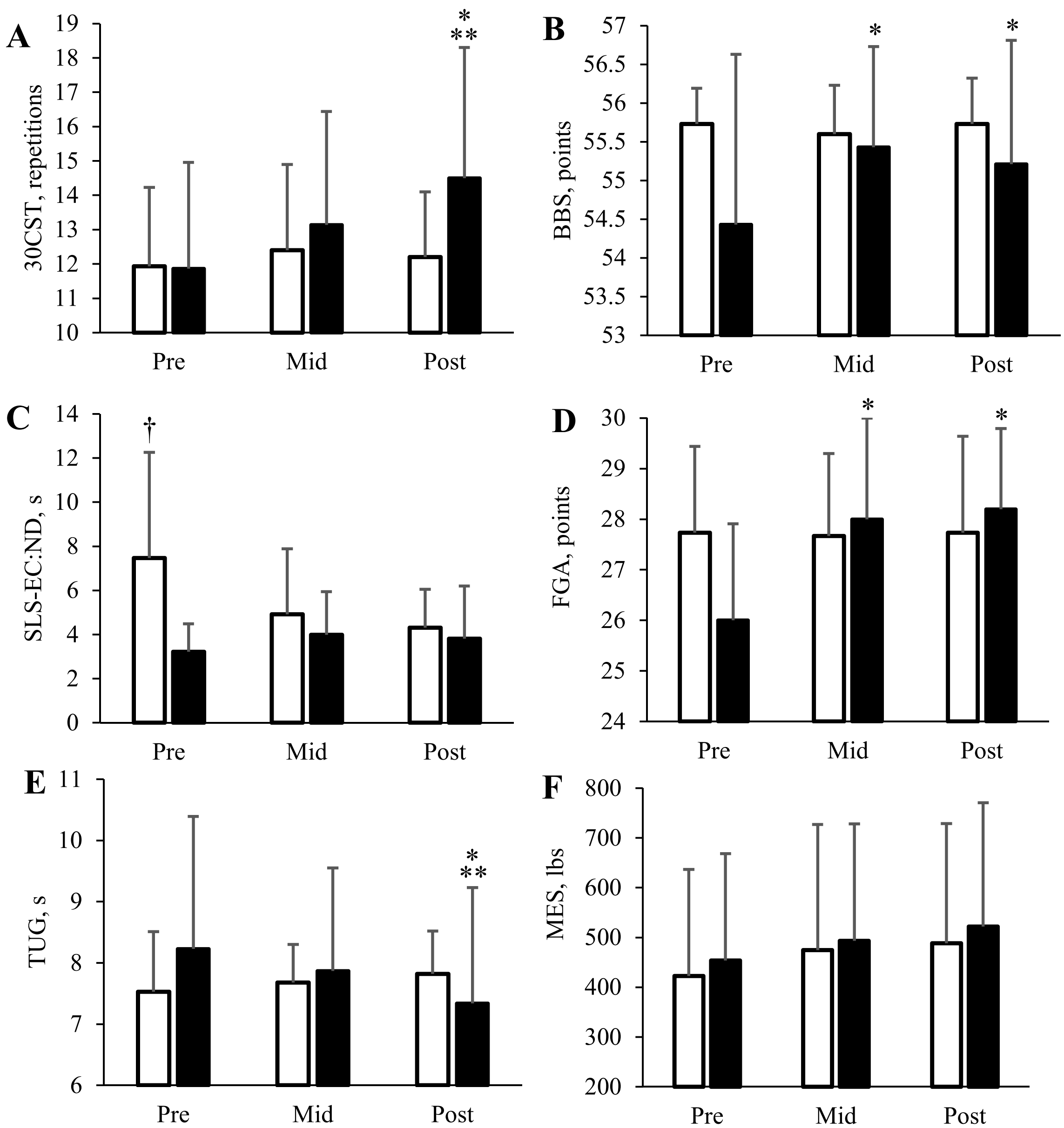

Figure 2. Average performance on outcome variables for eccentric training and control groups at pre-, mid-, and post-assessment. White columns represent mean performance for the control group. Black columns represent mean performance for the exercise training group. Error bars represent standard deviation. 30CST = 30-second sit to stand. BBS = Berg Balance Scale. SLS-EC:ND = Single leg stand with eyes closed on non-dominant leg. FGA = Functional Gait Assessment. TUG = Timed Up-and-Go. MES = Maximal eccentric strength. * = significantly different from pre-assessment; ** = significantly different from mid-assessment; † = pre-assessment for exercise training group significantly different from pre-assessment for control group.

response in 30CST performance and improvements were not observed until the second half of the training program. This is likely attributable to differences in training protocols. However, in spite of these differences, the training program was sufficient to elicit improvements from below average to at/above average for the 30CST. Training began with 8 individuals below age- and sex-matched average 30CST performance (Jones et al., 1999) and ended with only 4 individuals who had yet to achieve average performance. Those who did not attain the average 30CST performance tended to start farther from the criterion value, with an average need to increase 5 repetitions for those who ended training below average.

The improvement observed in TUG performance following EET is also consistent with previous investigations (Johnson et al., 2018; LaStayo et al., 2003; Mueller et al., 2009). On average, participants in the EET group improved on the TUG by 0.9 seconds, with the only significant difference occurring from pre- to post-training (see Figure 2E). This contrasts with an earlier change in TUG performance from pre- to mid-training (Johnson et al., 2018). There was also a lower effect size for this variable (see Table 4; η_p^2 =.41) than that previously reported (η_p^2 = .69; Johnson et al., 2018). Again, it appears that although this EET training program yielded a significant reduction in TUG time, it did not have as large of a training effect as that previously reported (Johnson et al., 2018). When comparing the current sample to age- and sex-matched normative values (Steffen, Hacker, & Mollinger, 2002), 6 participants in the exercise group initiated training with a TUG performance below average. However, only 1 improved performance enough to attain average performance. As such, while the training yielded significant improvements in TUG performance, the change was not large enough to elicit improvements in the

TUG performance sufficient to achieve age- and sex-matched averages in only 8 weeks of EET. Additionally, the pairwise comparisons (see Figure 2E) indicate that the largest improvement in performance happened between Weeks 4 and 8, indicating a later adaptation. There is potential that a longer training protocol may elicit greater improvements in this outcome.

The current study chose to assess static balance with the SLS-EC:D and SLS-EC:ND based on the lack of significance and potential ceiling effect reported by Johnson et al. (2018) when performing the task with eyes open. However, the current study also observed no statistically significant changes in static balance from EET. Although there was not a statistically significant difference across time for the EET group, it is noteworthy that the interaction between time and group was significant for SLS-EC:ND performance (see Table 4). However, the p-value indicates a non-significant effect of time for the EET group and a significant decrease in SLS-EC:ND performance for the CON group (see Table 5). Mean and standard deviation for the SLS-EC:ND performance of the EET and CON groups is displayed in Figure 2C, where the significant difference in pre-assessment performance is denoted. When assessing the differences in pre- and post-training means, the EET group exhibited an average increase of 0.6 seconds on the non-dominant leg and an average decrease of 0.3 seconds on the dominant leg. There is not a minimally clinical important difference reported in the literature for this assessment. As such, it is not clear if the 0.6 second improvement is clinically important or if this a normal intraindiviudal variation. Future research should be done to identify minimum detectable differences in SLS-EC:D, SLS-EC:ND, and other static balance assessments.

In contrast to that observed with static balance, the changes in the BBS indicate a significant improvement in functional balance following EET (see Figure 2B). This is consistent with the findings of LaStayo et al. (2003). However, all participants in the study of LaStayo et al. (2003) were classified as high fall risk based on BBS performance, which means attaining a score of less than 50 out of 56 points (Muir et al., 2010). In contrast, the current sample included only one participant below the fall risk cut-off, with a score of 49 points. While the results indicate a significant increase in BBS performance with a large effect size (see Table 4), Donoghue and Stokes (2009) suggested a minimum detectable change for this variable of 4 points. As demonstrated by the mean increase of 0.8 points, this minimum change was not attainable with an average pre-test BBS score at or exceeding 53 points for all participants in the EET group. Furthermore, 11 participants in the CON group demonstrated a perfect score at pre-assessment, while only 5 participants in the EET group initiated training with a perfect score. As such, a ceiling effect may have been observed in both the EET and CON groups, as the EET group did not improve enough to exhibit meaningful changes and the CON group had little room for improvement on BBS performance. This emphasizes the need for a more sensitive test of functional balance for older adults who perform well on the BBS.

To the knowledge of the authors, FGA performance has not yet been assessed following EET. A significant improvement in FGA performance was identified for the EET group, with a mean increase of 2.2 points (see Figure 2D). This increase in performance occurred between pre- and mid-training for EET participants, with little change occurring between mid- and post-training. It should be noted that a meaningful change has not been identified for older adults with the FGA, so it is not clear if the changes attained from EET indicate clinically important differences. In addition, the pre-assessment FGA performance was close to significant, with the EET group initiating training with a mean 1.7 points lower than that of the CON group. However, compared to age- and sex-matched normative data (Walker et al., 2007), 8 participants in the EET group initiated training below average and only 2 remained below average following the training. Further research is warranted to determine if gait characteristics are improved with EET. In addition, research should be conducted to determine the minimum detectable change for the FGA with community-dwelling older adults.

In contrast to previous literature (Johnson et al., 2018), there was not a significant change in MES following EET (see Figure 2F). It is plausible that the lack of increase in MES, along with the differences observed in effect size for 30RCS and TUG from previous findings (Johnson et al., 2018), is a result of differences in training intensity. In the current study, starting intensity for the program was set based on average force output from a 5 minute EET session at an RPE of 9 on the 6 to 20 scale (Borg et al., 1970). While this structure allowed participants to subjectively determine starting intensity, it yielded a large standard deviation for starting intensity when expressed as a percent of pre-training MES (24.1 ± 10.2%). When comparing individual starting intensity to the previously reported starting intensity of 30% MES (Johnston et al., 2018), only 3 participants began at or above 30% MES. Furthermore, the intensity of this program progressed slower, with ending intensities rarely exceeding 30% of the MES measured mid-training, while Johnson et al. (2018) ended with a training intensity of 50% MES.

Interestingly, the difference in starting intensity was not reflected in RPE. The reported RPE for Week 1 of the current study (11 ± 2) was higher than that reported when starting intensity was set based on a percent of MES (Johnson et al., 2018) or programs that prescribe intensity using only RPE (LaStayo et al., 2003; LaStayo et al., 2009; LaStayo, Marcus, Dibble, Wong, & Pepper, 2017; Mueller et al., 2009). Although RPE began comparatively higher, it is noteworthy that there were no significant changes in RPE throughout the training program. When evaluating volume of training, the average weekly negative work output (measured in kJ) tripled from Week 1 to Week 8 of training (see Table 2), which is similar to that previously reported with EET (Johnson et al., 2018; LaStayo et al., 2003).

While various similarities in results were explained above, there are several notable differences in training mode, sample characteristics, program design, and outcome variables of the current study in comparison to other studies (Johnson et al., 2018, LaStayo et al., 2003; LaStayo et al., 2009; LaStayo et al., 2017; Mueller et al., 2009). Similar to that of Johnson et al. (2018), the sample of the current study consisted of community-dwelling older adults with no history of falling. The differentiating characteristic of this study's sample was a higher mean age. Furthermore, the current study also differs from that of Johnson et al. (2018) with the addition of a CON group, strengthening the study design. Regardless of these differences in sample characteristics, the current study supports that 8 weeks of RPE-based EET is enough to elicit responses with only 2 sessions per week. However, the maximum session duration was 15 minutes in the current study, while Johnson et al. (2018) utilized a maximum of 10 minutes. Other studies reporting improvements have included 12 weeks of training with maximum session durations of 15 (LaStayo et al., 2017) and 20 (LaStayo et al., 2009; Mueller et al., 2009) minutes, respectively. These studies also included different samples, including older adults who had a history of falling (LaStayo et al., 2017), were classified as high fall risk (LaStayo et al., 2003), had recently undergone total knee arthroplasty (LaStayo et al., 2009), or individuals with stable medical conditions ranging from 71 to 89 years old (Mueller et al., 2009). Altogether, the current study reinforces the notion that 8 weeks of twice weekly training is sufficient to elicit improvements with EET, even for a sample that initiated training with high performance on outcome variables.

As mentioned, the program design of the current study is unique in that it incorporated RPE and set training intensities. Additionally, a neuromuscular benefit is anticipated utilizing this equipment because the machine does not restrict an individual to a given workload. Instead, the pedals of the apparatus measure force during movement and the exerciser must provide the appropriate amount of force to fall within the set target range (± 20% of prescribed force), requiring neuromuscular control. While this is a unique component of this EET on the recumbent step machine at a set intensity, there remains to be an investigation regarding changes in neuromuscular control following training with older adults. As such, future studies should consider adding an assessment of neuromuscular control to the outcome variables.

A limitation of the current study is that the training intensity was set based on a single 5 minute exercise session at an RPE of 9 on the 6 to 20 scale (Borg et al., 1989). While training intensity increased throughout the program, participants could not adjust training intensity based on changes in subjective feelings throughout training. In addition, setting intensity based on RPE yielded large variations in training intensity and RPE throughout the training program, which likely yielded equivalent variation in outcome variable changes. Future studies should incorporate both RPE and set intensity training throughout the program to allow for comfortable training intensities while allowing opportunity for neuromuscular training. Another limitation is that the current study only included individuals considered low fall risk and who generally performed close to age- and sex-matched averages on the outcome variables. Participants who are further from average performance or who meet the cut-off for increased risk of falling based on assessment performance may benefit from future research.

In summation, the outcome variables were chosen based on their ability to predict a person's risk of falling, while the sample of the study was targeted to assess changes in performance for those who do not yet meet the criteria for increased fall risk. This design was used to determine if EET could be used to proactively improve performance on fall risk factors for those who do not yet present an increased risk of falling. Although it remains unclear if EET yields significant and meaningful improvements in balance, improvements in muscular fitness, gait characteristics, and overall physical function are evident following 8 weeks of EET, with a time commitment of approximately 30 minutes per week.

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APPENDICES FOR STUDY I

APPENDIX A

IRB Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research
Compliance, 010A
Sam Ingram Building,
2269 Middle
Tennessee Blvd
Murfreesboro, TN
37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Friday, September 29, 2017

Principal Investigator	**Samantha Johnson** (Student)
Faculty Advisor	Jenn Caputo
Co-Investigators	Dana Fuller and Sandra Stevens
Investigator Email(s)	*slj4x@mtmail.mtsu.edu; jenn.caputo@mtsu.edu*
Department	Health and Human Performance
Protocol Title	***Effect of eccentric endurance training on physical and cognitive fall-risk factors in community-dwelling older adults***
Protocol ID	**17-2270**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year
Date of expiration	**8/31/2018**
Participant Size	40 (FORTY)

Participant Pool	General participants between the ages 60 to 75
Exceptions	1. Permitted to recruit participants over 65 (Restrictions apply). 2. Full committee review not required - ACSM screening permitted. 3. Recording identifiable contact information is permitted to allow project management, coordination and follow up.
Restrictions	**1. Mandatory signed informed consent; The PI must provide a signed copy of the informed consent document to each participant.** **2. Participant exclusion criteria MUST be followed as provided in the protocol application.** **3. Additional care must be taken when working with older subjects.** **4. Identifiable information must be destroyed after data analysis.**
Comments	NONE

This protocol can be continued for up to THREE years (**8/31/2020**) by obtaining a continuation approval prior to **8/31/2018**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	7/31/2018	TO BE COMPLETED
Second year report	7/31/2019	TO BE COMPLETED
Final report	7/31/2020	TO BE COMPLETED

Post-approval Protocol Amendments:

Date	**Amendment(s)**	**IRB Comments**
09.29.2017	Approved to recruit participants using the email script provided.	IRB Review

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

CHAPTER IV

EFFECTS OF AN ECCENTRIC ENDURANCE EXERCISE INTERVENTION ON COGNITIVE FUNCTION IN COMMUNITY-DWELLING OLDER ADULTS

Introduction

Declines in cognitive function are commonly observed in older adults, even in those considered otherwise healthy (Park, O'Connell, & Thomson, 2003). While the direct benefits of cognitive function to daily activities and independence are apparent, cognitive decline has also been identified as a risk factor for falling (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010; Hofheinz & Mibs, 2016; Muir, Gopaul, & Monter Odasso, 2012; Shumway-Cook, Brauer, & Woollacott, 2000). Specifically, declines in executive function are predictive of increased risk of falling in healthy, community-dwelling older adults (Herman et al., 2010; Muir et al., 2012). Dual-tasking assessments, where physical and cognitive tasks are tested simultaneously, also predict risk of falling in this population (Hofheinz & Mibs, 2016; Shumway-Cook et al., 2000). Exercise has been proposed as an intervention to concurrently improve cognitive function and fall risk in older adults.

There is evidence that a variety of exercise training modes yield improvements in executive function and dual-tasks. Although results have been equivocal, aerobic, resistance, and coordination training can induce positive changes in executive function (Jonasson et al., 2016; Liu-Ambrose et al., 2010; Voelcker-Rehage, Godde, & Staudinger, 2011). There is also evidence that dual-task performance can be improved in community-dwelling older adults following exercise training, most often in group sessions (Agmon, Kelly, Logsdon, Nguygen, & Belza, 2015; Granacher et al., 2010;

Gregory et al., 2017; Plummer, Zukowski, Giuliani, Hall, & Zurakowski, 2016; Theill, Shoemaker, Adelsberge, Martin, & Jancke, 2013; Uemura et al., 2012). There is a brevity of information regarding the effect of eccentric endurance training (EET) on these outcome variables. This training modality is unique in that participants are completing only eccentric contractions, a muscle movement characterized by reduced oxygen consumption and cardiovascular responses, which is ideal for older adults with potentially reduced exercise tolerance (Bigland-Ritchie & Woods, 1976; Hortobágyi & DeVita, 2000; Overend, Versteegh, Thompson, Birmingham, & Vandervoort, 2000). Furthermore, EET can provide cognitive-motor training with specialized equipment, where participants are asked to accurately regulate force output based on computerized biofeedback.

Improvements in balance, reaction time, and fear of falling have been observed following computerized biofeedback training, which has been primarily implemented with dynamic balance training in healthy, community-dwelling older adults (Bisson, Contant, Sveistrup, & Lajoie, 2007; Hinman, 2002; Wolf, Barnhart, Ellison, & Coogler, 1997). To our knowledge, the effect of cognitive-motor EET on executive function and dual-task performance has yet to be investigated. Thus, the purpose of the current study was to assess the effect of a twice weekly, 8-week EET program on executive function and dual-tasking in community-dwelling older adults.

Methods

Participants. The sample consisted of 30 community-dwelling adults (68.2 ± 3.7 years; 16 females, 14 males). Participants were randomly assigned to control (CON; 67.5 ± 2.6 years; 8 females, 7 males) and intervention (EET; 69.0 ± 4.4 years; 8 female, 7 male) groups. All participants provided written consent prior to participation. Independence was determined based on completion of the Katz Index of Independence in Activities of Daily Living (Shelkey & Wallace, 2012). Participants needed to achieve a score of 6 or higher (indicating full function) to participate in the study (Shelkey & Wallace, 2012). Participants also completed a fall history questionnaire and Physical Activity Readiness Questionnaire for Everyone (PAR-Q+). If necessary, written medical clearance was obtained in accordance with the American College of Sports Medicine (ACSM; 2018). Participants who had fallen in the past year for unexplained reasons or underwent knee, hip, or back surgery within the previous year were excluded from the study. All participants signed an informed consent document and the study was approved by the university Institutional Review Board (see Appendix A).

Outcome variables.

Dual-Tasking Timed Up-and-Go. The cognitive timed up-and-go (TUG_{cog}) has been shown to predict fall risk and has been recommended for those initiating training with high physical function (Hofheinz, 2010; Hofheinz & Mibs, 2016; Shumway-Cook et al., 2000). The mean score reported for older adults without a history of falling is 9.7 seconds with a mean age of 78 years old and a score of 15.0 seconds has been shown to accurately identify fallers for older adults with a mean age of 82 years old (Shumway-Cook et al., 2000). Another study identified a fall risk cut-off of 10.0 seconds for identifying individuals who will fall within the next year (Hofheinz & Mibs, 2016). In addition, average performance of a sample with a mean age of 72 years was reported as 9.82 seconds (Hoheinz, 2010). The assessment has high criterion validity, interrater reliability, and intrarater reliability (Hofheinz, 2010; Hofheinz & Mibs, 2016).

Prior to completing the TUG_{cog}, participants completed a standard timed up-and-go assessment (TUG) in order to allow for calculation of the dual-task cost (DTC) associated with the TUG_{cog}. On the command "Go" participants rose from the chair, walked 3 meters, turned 180 degrees around a cone, walked back to the chair, and returned to the seated position. Time was started on the command "Go" and stopped when participants were fully seated again and was recorded to the nearest 0.1 second. In addition, the number of steps taken during the TUG were recorded.

For the TUG_{cog}, participants were asked to complete the TUG while concurrently counting down by increments of 3. Participants were randomly assigned a starting value of 60, 70, 80, 90, or 100. When completing the task, participants were asked not to repeat the number they were assigned, but to start with the first calculated value. Time to complete this task was recorded to the nearest 0.1 second. The DTC was calculated using the following formula for time to completion: [(dual task-single task) / (single task)] x 100 (Doumas, Rapp, & Krampe, 2009). Time to completion for the TUG_{cog} and DTC were analyzed.

Trail Making Tests. The Trail Making A (TMT-A) and B (TMT-B) tests were conducted to assess executive function. The TMT-B has also been recognized as a predictor of fall risk (Herman et al., 2010; Muir et al., 2012; Nevitt, Cummings, & Hudes, 1991). The TMT-A consists of circles containing the numbers 1 through 25, where participants connect the circles in chronological order (Reitan & Wolfson, 1985). The TMT-A was completed to allow for calculation of a normalized score. The TMT-B consists of 49 circles containing numbers and letters. Participants were asked to connect the circles in order, connecting 1 to A, A to 2, 2 to B, and so forth through the entirety of the alphabet (Reitan & Wolfson, 1985). Participants completed the TMT-A followed by the TMT-B and the time to complete each task was assessed to the nearest 0.1 seconds. In addition, a normalized time was calculated using (B-A)/A to isolate the executive component of the assessment (Herman et al., 2010). The completion time for TMT-B and normalized score were analyzed.

Color-Word Stroop Test. During the Color-Word Stroop test (Stroop, 1935), participants were asked to complete three conditions on a computer. The first was to read color words (e.g. red) typed in black font. The second was to state the font color of ###s. The third was to state the font color of incongruent color words (e.g. red printed in blue ink). Conditions were completed in this order for all participants. Participants first completed a familiarization of 10 test screens per condition. Then, the time to complete 80 test screens for each condition was recorded to the nearest 0.1 second. A one minute rest was given between each condition. The time to complete and time difference between the second and third conditions, termed the Stroop score, were then recorded and used for data analysis. This method of assessment has been previously reported with older adults (Liu-Ambrose et al., 2010).

Procedures. Participants in the EET group were asked to come to the laboratory twice per week for 9 weeks. This included 1 week of familiarization and 8 weeks of eccentric training. Participants in the CON group were asked to maintain normal physical activity levels and came to the lab for the familiarization week and assessment days only. On the first day of familiarization, participants provided written consent and completed the PAR-Q+, Katz Index of Independence in Activities of Daily Living, and fall history questionnaire. Following completion of paperwork, shoeless height and body mass were assessed. Height was assessed to the nearest 0.1 centimeter using a wall-mounted stadiometer (SECA model 222, SECA Corporation, Hamburg, Germany). Body mass was measured in kilograms to the nearest 0.1 kilogram with a Tanita BF-522 electronic scale (Tanita Corporation, Tokyo, Japan). Next, participants were familiarized with each assessment that would be measured. On the second day of familiarization, baseline assessments for each outcome variable were completed. The same assessments were repeated mid-training (Week 5, Day 1) and post-training (within one week of the last training session). Assessments were completed before eccentric exercise was completed in the following order: TUG, TUG_{cog}, TMT-A, TMT-B, and Color-Word Stroop tests. Following each day of assessments, data was immediately stored in a separate envelope in another room to minimize researcher bias.

Eccentric training was completed on a recumbent step machine (see Figure 1). Each eccentric training session included approximately 1 minute of warm-up and cool-down in addition to the training duration. The training sessions during the familiarization week were intended to provide a self-mediated, gradual introduction to eccentric exercise and served as a means of setting exercise intensity for Week 1 of training. The training program is displayed in Table 1. Progression in intensity and duration were based on training accuracy. In order to progress, participants were required to exhibit 70% accuracy at the current training intensity and duration. Accuracy was determined by falling within 10% of the prescribed force output. The percentage increase displayed in Table 1 was obtained from the average force output of the previous week. Based on these parameters, the training protocol for some participants may have diverged from that displayed in Table 1.

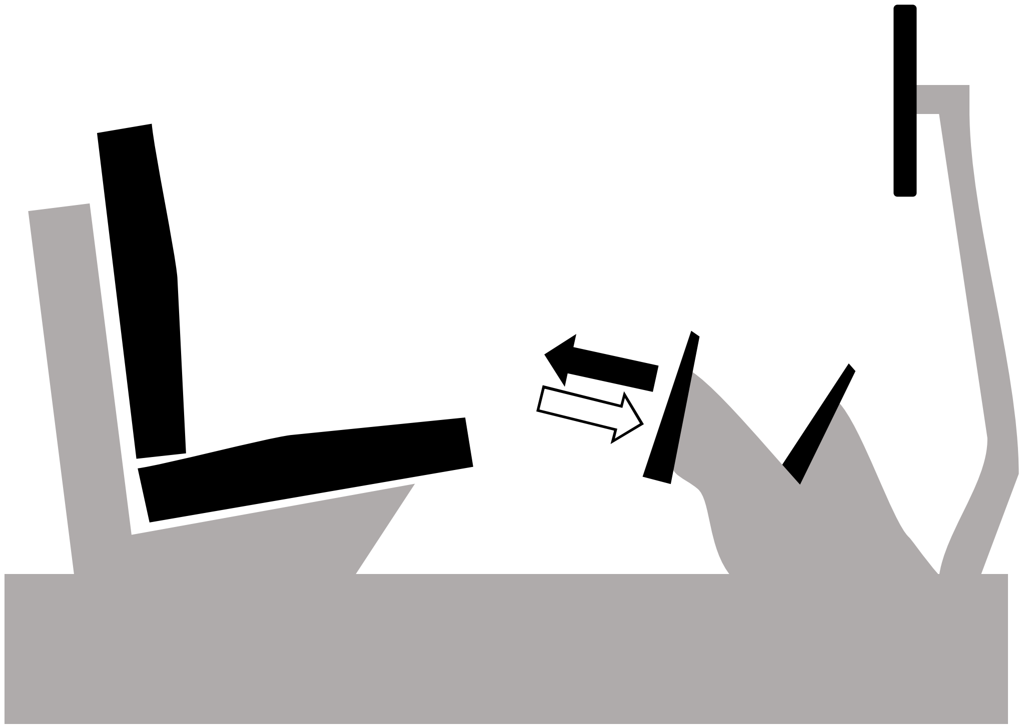

Figure 1. Depiction of eccentric exercise training. Pedals are driven in opposing directions by a 3-horsepower motor, producing a stepping pattern of motion. As each pedal drives toward the participant (knee and hip flexion; represented by black arrow), the movement is resisted (represented by outlined arrow). Since the power of the motor exceeds that exerted by the participant, the result is an eccentric contraction, or negative work. Unilateral force is measured by dynamometers within the pedals during this motion. As pedals are driven away (knee and hip extension), the participant is to provide no force against the pedal.

Table 1

Eccentric Training Program

Week	Intensity	Duration (min)
Familiarization	RPE of 8	5
1	+15%	6
2	--	8
3	--	10
4	+15%	10
5	+15%	10
6	--	12
7	--	15
8	+15%	15

Note. Intensity based on percentage of previous workload. RPE = Rating of perceived exertion on a 6-20 scale.

Statistical analysis. Data are presented as mean ± standard deviation. An a priori power analysis indicated that a sample of 30 participants was required to have 80% power for detecting a medium effect size. An a priori alpha of .05 was utilized to determine statistical significance. Two-way repeated measures analyses of variance (ANOVAs) with treatment group (control, exercise) as a between-subjects factor and time (pre, mid, post) as a within-subjects factor was used to predict the influence of treatment group on performance for each outcome variable. All data were analyzed using IBM SPSS (Version 23).

Results

There were no significant interactions between group and time for the TUGcog, DTC, TMT-B, TMT score, Stroop B, Stroop C, or Stroop score (see Table 2). However, there was a significant main effect for time on the TMT-B, Stroop B, and Stroop C (see Table 2). Although no statistically significant changes were found for the EET group in comparison to the CON group, Table 3 displays mean performance for each outcome variable at pre-, mid-, and post-assessment for the EET and CON groups.

Discussion

One modifiable risk factor for falling is cognitive decline (Herman et al., 2010; Hofheinz & Mibs, 2016; Muir et al., 2012; Shumway-Cook et al., 2000). The purpose of this study was to determine if 8 weeks of EET elicited improvements in cognitive function, as measured by assessments of dual-tasking and executive function. To the knowledge of the authors, this was the first study to assess changes in cognitive function following EET. There was no statistically significant increases in dual-tasking function,

Table 2

Two-way Repeated Measures Analysis of Variance Results for Cognitive Outcomes

Outcome	ANOVA test	Degrees of freedom	*F value*	*MSE*	*G-G p*	η_p^2
TUG_{cog}	Time	1.8, 51.2	1.78	0.98	.181	.06
DT cost	Time	1.8, 50.2	0.65	1.00	.513	.02
TMT-B	Time	2.0, 55.5	5.83	197.25	.005*	.17
TMT score	Time	1.8, 50.3	0.93	0.39	.392	.03
Stroop B	Time	1.9, 52.1	8.32	77.58	.001*	.23
Stroop C	Time	1.1, 31.2	7.51	454.73	.008*	.21
Stroop score	Time	1.2, 34.0	1.40	497.10	.252	.05
TUG_{cog}	Interaction	1.8, 51.2	1.09	0.98	.340	.04
DT Cost	Interaction	1.8, 50.2	0.99	1.00	.371	.03
TMT-B	Interaction	2.0, 55.5	0.95	197.25	.391	.03
TMT score	Interaction	1.8, 50.3	1.86	0.39	.169	.06
Stroop B	Interaction	1.9, 52.1	1.32	77.58	.275	.05
Stroop C	Interaction	1.1, 31.2	0.45	454.73	.530	.02
Stroop score	Interaction	1.2, 34.0	1.24	497.10	.283	.04

Note. *F* values were based on Greenhouse-Geiser tests and effect sizes represent η_p^2. * represents statistical significance. G-G = Greenhouse Geiser; TUG_{cog} = cognitive Timed Up-and-Go; DTC = dual tasking cost; TMT-B = Trail Making Test B; TMT score = Trail Making Test score.

Table 3

Mean (± SD) Performance for Cognitive Function Assessments for Exercise and Control Groups

Variable	Group	Pre	Mid	Post
TUGcog	Exercise	10.6 ± 3.7	10.6 ± 4.5	10.0 ± 3.6
	Control	9.4 ± 1.7	9.7 ± 2.1	9.4 ± 1.6
DTC	Exercise	1.8 ± 1.2	2.1 ± 1.9	2.2 ± 1.6
	Control	1.8 ± 1.1	2.0 ± 1.9	1.6 ± 1.1
TMT-B	Exercise	85.2 ± 50.4	80.6 ± 53.3	73.3 ± 59.4
	Control	82.8 ± 25.9	69.6 ± 21.4	71.0 ± 23.6
TMT score	Exercise	1.5 ± 1.1	1.6 ± 1.1	1.3 ± 0.9
	Control	1.6 ± 0.8	1.2 ± 0.6	1.4 ± 0.6
Stroop B	Exercise	89.6 ± 14.3	80.6 ± 17.1	77.6 ± 18.4
	Control	87.0 ± 19.7	83.6 ± 17.9	81.6 ± 16.5
Stroop C	Exercise	104.0 ± 18.4	98.0 ± 19.6	91.4 ± 20.0
	Control	120.1 ± 39.3	107.2 ± 13.5	101.0 ± 14.0
Stroop score	Exercise	15.1 ± 12.9	17.3 ± 12.1	13.8 ± 12.5
	Control	33.1 ± 44.5	23.4 ± 18.9	19.3 ± 15.0

Note. TUG_{cog} = cognitive Timed Up-and-Go; DTC = dual tasking cost; TMT-B = Trail Making Test B; TMT Score = Trail Making Test score.

as measured by the TUGcog (see Table 2). Similarly, there were no training-related increases in the tests of executive function.

Although the literature does not yet contain information regarding the effects of EET on dual-task performance, other modalities of exercise training have been assessed. Investigations ranging from 6 weeks to 6 months have demonstrated significant increases in dual-tasking performance following aerobic, balance, and holistic exercise training (Agmon et al., 2015; Granacher et al., 2010; Gregory et al., 2017; Thiell et al., 2013). It is noteworthy that the protocol for assessing dual-tasking has varied among studies. Most studies have included a gait analysis walkway to assess a variety of gait characteristics, including speed, stride length, and stride time variability (Granacher et al., 2010; Gregory et al., 2017; Thiell et al., 2013). As in the current study, Agmon et al. (2015) utilized, the TUGcog to assess dual-tasking following 10 weeks of training with 18 total hours of holistic exercise training, including aerobic activity, strength training, stretching, and balance training.

Argmon et al. (2015) found a 1.6 second difference in pre- and post-measures. In contrast, in the current study, there was an improvement of 0.66 seconds. It is possible that the difference in TUG_{cog} improvement is partially attributable to the lower training volume in the current study. Participants in the EET group completed 3.6 hours of exercise across the training protocol. In addition to the potential contribution of total exercise volume to dual-tasking improvements, the study may have been underpowered based on the effect size observed for TUG_{cog} following EET (η_p^2 = 0.115).

Although statistically significant changes were not observed in TUG_{cog} or DTC, there were some notable improvements in TUG_{cog} performance. On average, those in the

EET group decreased time to complete the TUG_{cog} by 0.66 seconds, while those in the CON group increased TUG_{cog} time by 0.13 seconds. However, the literature does not currently provide normative data or minimum detectable changes for TUG_{cog} performance. Further research is warranted in these areas. Although progress in the current study cannot be compared to normative data, a comparison of the current study's results to mean data reported for non-fallers with a mean age of 78 years (Shumway-Cook et al., 2000) and for older adults with a mean age of 72 years (Hofheinz, 2010) can be made. Although the means slightly differed, classification of participants in the current study as slower or faster than the mean did not vary based on which mean was utilized. At pre-assessment, the number of participants were slower than the mean for EET and CON was 9 and 6, respectively (Hofheinz, 2010; Shumway-Cook et al., 2000). In contrast, both groups ended with 5 participants slower than mean performance indicated by Hofheinz (2010) and Shumway-Cook et al. (2000).

The literature does provide cut-off values for determining fall risk. Different cut-offs for determining fall risk have been proposed including ≥ 15 seconds (Shumway-Cook et al., 2000) and > 10 seconds (Hofheinz & Mibs, 2016). Although Hofheinz and Mibs (2016) demonstrated lower specificity and sensitivity for identifying fallers, the mean age of their study participants (72.2 years) was more similar to the participants in the current study than the total sample mean age of 82 years reported by Shumway-Cook et al. (2000). Therefore, in comparison to the recommended cut-off criterion of Hofheinz and Mibs (2016), 6 participants in EET and 5 participants in CON were classified as having a pre-test increased risk of falling. At post assessment, 2 participants in EET were no longer classified as high fall risk whereas all 5 participants in CON remained at the high fall risk classification based on TUGcog performance. Based on these comparisons, 8 weeks of EET may not be sufficient to elicit enough improvement to change a high fall risk classification.

A potential effect of EET on executive function was hypothesized, even with the shorter training duration, due to the cognitive-motor component of the training program. However, significant improvements in executive function were not observed following the 8 weeks of EET. This finding is consistent with the literature, which shows significant improvements in measures of executive function following longer training durations, with 24 weeks (Cassilhas et al., 2007) and 12 months (Liu-Ambrose et al., 2010) of training being reported. There is also evidence that overall training volume may influence the program duration needed to elicit improvements in executive function. For example, Liu-Ambrose (2010) found that resistance training once or twice a week improved cognitive function following 12 months, but found no significant improvements at the 6 month assessment. In contrast, Cassilhas et al. (2007) found significant improvements in cognitive function following only 6 months of thrice weekly resistance training. The time for training in these studies also exceeded that utilized in the current study, with 60 minutes per session (Cassilhas et al., 2007; Liu-Ambrose et al., 2010). Thus, in future studies it should be determined how training volume influences changes in executive function. It should be noted that the efficacy of extended duration EET has not been determined. In this regard, it may be best to integrate EET into a holistic exercise program that provides a greater training duration and overall increased training volume.

Furthermore, there is evidence that the assessments used to measure executive function were influenced by practice, as there was a main effect for time for the TMT-B, Stroop B and Stroop C tests (see Table 2). In addition, there were also large effect sizes for time. Therefore, participants improved over time regardless of the treatment group they were assigned to, indicating a learning effect may have occurred. This was observed even with a familiarization day prior to baseline testing. However, the TMT normalized score and Stroop score were not influenced by time (see Table 2), indicating that these are the more appropriate outcomes for executive function in future investigations. In addition, researchers should consider the motivation of participants in completing an executive function assessment, as this may influence performance. Future studies should incorporate more measures of executive function that do not exhibit a learning effect and provide sufficient motivation for participants to perform their best each time.

In conclusion, 8 weeks of EET did not significantly improve cognitive function. In general, it does appear training volume influences the effect of exercise on cognitive function. There is evidence that EET may help improve TUG_{cog} performance based on mean increases in performance. However, a program with greater duration or volume may be needed to elicit significant changes. Furthermore, data for normative comparisons and minimum detectable changes are needed to determine if non-significant changes are practically meaningful.

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APPENDICES FOR STUDY II

APPENDIX A

IRB APPROVAL LETTER

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research
Compliance, 010A
Sam Ingram Building,
2269 Middle
Tennessee Blvd
Murfreesboro, TN
37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Friday, September 29, 2017

Principal Investigator	**Samantha Johnson** (Student)
Faculty Advisor	Jenn Caputo
Co-Investigators	Dana Fuller and Sandra Stevens
Investigator Email(s)	*slj4x@mtmail.mtsu.edu; jenn.caputo@mtsu.edu*
Department	Health and Human Performance
Protocol Title	***Effect of eccentric endurance training on physical and cognitive fall-risk factors in community-dwelling older adults***
Protocol ID	**17-2270**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year
Date of expiration	**8/31/2018**
Participant Size	40 (FORTY)
Participant Pool	General participants between the ages 60 to 75

Exceptions	4. Permitted to recruit participants over 65 (Restrictions apply). 5. Full committee review not required - ACSM screening permitted. 6. Recording identifiable contact information is permitted to allow project management, coordination and follow up.
Restrictions	**5. Mandatory signed informed consent; The PI must provide a signed copy of the informed consent document to each participant.** **6. Participant exclusion criteria MUST be followed as provided in the protocol application.** **7. Additional care must be taken when working with older subjects.** **8. Identifiable information must be destroyed after data analysis.**
Comments	NONE

This protocol can be continued for up to THREE years (**8/31/2020**) by obtaining a continuation approval prior to **8/31/2018**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	7/31/2018	TO BE COMPLETED
Second year report	7/31/2019	TO BE COMPLETED
Final report	7/31/2020	TO BE COMPLETED

Post-approval Protocol Amendments:

Date	**Amendment(s)**	**IRB Comments**
09.29.2017	Approved to recruit participants using the email script provided.	IRB Review

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

CHAPTER V

OVERALL CONCLUSIONS

The focus of this dissertation was to determine the effect of EET on fall risk factors in community-dwelling older adults who did not yet exhibit a high risk of falling. The first study was designed to assess how EET affected physical outcomes associated with fall risk, including assessment of balance, gait, and overall physical function. The second study assessed how EET affected cognitive fall risk factors.

The study consisted of 2 groups, an EET group and a control (CON) group. Individuals who completed the EET training were asked to complete 1 week of familiarization and 8 weeks of training, with 2 sessions per week. Individuals in the CON group were asked to maintain normal daily activity levels for the 9 week duration. The 8 week EET protocol yielded a program that had no change in RPE across time. In contrast, the weekly work rate was increased 3 fold from Week 1 to Week 8. This emphasizes the efficacy of EET, as work was tripled while the subjective rating of exertion remained the same.

The physical outcome measures assessed included the 30CST, BBS, SLS-EC, FGA, TUG, and MES. Participants exhibited statistically significant improvements in 30CST, BBS, FGA, and TUG. The changes observed in BBS performance should be interpreted with caution, as the average performance at pre-assessment was 54.4 out of 56 potential points. However, the minimum detectable change for this assessment has been reported as 4 points (Donoghue & Stokes, 2009). As such, most participants in the sample could not have attained a meaningful change on this assessment. Although participants began with scores further from the maximum score for the FGA (26 out of 30 points), the significant improvement and large effect size should be interpreted with some caution as there is no published minimum detectable change data for this assessment. However, the mean increase in FGA score was 2.2 points (8% improvement).

Individuals were less likely to experience a ceiling effect on 30CST and TUG performances. As such, the significant changes in 30CST (+2.6 repetitions; 22% improvement) and TUG (-0.9 seconds; 11% improvement) performance and large effect sizes are indications of meaningful changes. There were no significant improvements in SLS-EC or MES. The lack of improvement in MES is not surprising based on the low to moderate intensity and longer duration of training. The lack of improvement in static balance is consistent with previous findings following 8 weeks of EET (Johnson et al., 2018).

The cognitive fall risk factors assessed included the TUGcog, TMT-A, TMT-B, Stroop A, Stroop B, and Stroop C. There were no statistically significant improvements in these measures following EET. Although the changes observed in the TUGcog were not statistically significant, there was a 0.66 second improvement in the EET group. Because the literature does not provide normative data or minimum detectable changes for the TUGcog, the practical significance of these changes cannot be discerned. Furthermore, the current study may not have had sufficient program duration or volume to elicit significant improvements in performance.

There were no significant differences in the effect of time on Trail Making and Stroop Test performance across the intervention between the EET group and the CON group. However, there was a significant main effect for time in these assessments, indicating a learning effect was observed. As such, it is evident that other outcome measures are needed to determine the effect of EET on executive function. The motivation level to perform one's best on these assessments should also be considered.

Overall, the findings of the current studies suggest that 8 weeks of twice weekly EET had the most meaningful influence on lower extremity muscular fitness (30CST) and overall physical function (TUG). Changes in gait were apparent (FGA), but a minimum detectable change is not known for this assessment. There were not meaningful changes in balance (SLS-EC & BBS) or strength (MES). For individuals considering application of EET with older adults, it is important to consider baseline performance on the outcome measures when determining anticipated results. This study aimed to determine how EET affected fall risk factors for individuals who did not yet exhibit performance indicative of deficits and/or risk of falling. The purpose of this was to take a proactive approach in fall risk prevention. From this perspective, EET appears to be the most effective at improving 30CST and TUG performances. The TUG performance of the sample improved within the first 4 weeks of training, while the 30CST performance did not exhibit significant improvements until the second half of the training program. In addition, the data of the current study indicate the effect of only EET training. With the small time commitment of EET in the current study, it is also plausible to incorporate similar training into a more holistic exercise program that may yield even greater improvements in the measured outcome variables. This incorporation may also increase the program volume to a sufficient level to elicit changes in cognitive function.

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