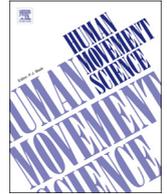




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## Anticipatory postural adjustments during a Fitts' task: Comparing young versus older adults and the effects of different foci of attention



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## ABSTRACT

Anticipatory postural adjustments (APAs) are an integral part of standing balance. Previous research with balance control has shown that adopting an external focus of attention, compared to an internal focus of attention, yields better performance during motor skills. Despite the importance of APAs, especially among older adults, and the potential benefits of adopting an external focus of attention, studies investigating methods for improving APAs are limited. The aim of this study was to compare behavioral, kinematic and APAs measures while adopting different foci of attention among young and older adults when performing a lower extremity Fitts' task. Ten young adults (mean age 24 years  $\pm$  4.37) and ten older adults (mean age 75 years  $\pm$  5.85) performed a lower-extremity reaching task (Fitts' task) while adopting an external focus (focus on target) and an internal focus (focus on limb) in a within-subject design. A motion capture system was used to record participants' movement data. Custom software derived movement time (MT), peak velocity (PV), time to peak velocity (ttPV) and variability at target ( $SD_T$ ). Electromyography (EMG) was used to determine APAs onset and magnitude. The findings showed that an external focus of attention led to significantly shorter MT, higher PV, shorter ttPV and more accuracy when reaching the target ( $SD_T$ ) for both age groups. Also, EMG results showed that, with an external focus, APAs onset occurred earlier and APAs magnitude was more efficient. As predicted by Fitts' Law, participants spent more time executing movements to targets with higher indices of difficulty. Older adults compared to young adults were more adversely affected by the increase of difficulty of the Fitts' task, specifically, on measures of APAs. In conclusion, adopting an external focus of attention led to better overall movement performance when performing a lower extremity Fitts' task. The task used in the present study can distinguish between APAs for older and young adults. We recommend that future studies expand on our findings in order to establish a performance-based objective measure of APAs to assess clinical interventions for postural control impairment.

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## 1. Introduction

The focus of attention concept postulates that when performing a motor task, it is better for motor performance to direct attention towards the effects that the movement has on the environment (an external focus of attention) than directing attention to the movement itself (an internal focus of attention) (Wulf, Höß, & Prinz, 1998). Numerous studies investigated the focus of attention concept, and it was found to be beneficial when performing and learning motor skills (Wulf & Lewthwaite, 2016; Wulf, 2013). Adopting an external focus of attention leads to improved movement efficiency and movement accuracy. Further, the benefits of adopting an external focus of attention were found to be true in different motor skills (e.g., balance, sports, fine and gross motor skills) (Lohse, Sherwood, & Healy, 2010; Marchant, Greig, & Scott, 2009; McNevin & Wulf, 2002), and different populations (e.g., non-disabled young and older adults and people with neurological impairments) (Chiviawsky, Wulf, & Wally, 2010; Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002).

When examining the literature related to focus of attention, evidence suggests that adopting an external focus of attention yields improved performance in postural control tasks (Chiviawsky et al., 2010; McNevin & Wulf, 2002; Wulf, Weigelt, Poulter, & McNevin, 2003). However, no previous study related to focus of attention has examined the relation between anticipatory postural adjustments (APAs) and adopting different attentional foci. These APAs play an essential role in fall prevention, especially among individuals with balance impairments such as older adults (Aruin, 2016; de Azevedo, Claudino, Conceicao, Swarowsky, & Santos, 2016; Kanekar & Aruin, 2014a, 2014b). Yet, studies that investigate methods for improving APAs are limited (Aruin, 2016; Tisserand, Robert, Chabaud, Bonnefoy, & Cheze, 2016). Given that older adults show vulnerability in postural control and APAs (Inglin & Woollacott, 1988; Kanekar & Aruin, 2014b; Rogers, Kukulka, & Soderberg, 1992; Woollacott & Manchester, 1993), studies that investigate methods for assessing and improving APAs among older adults are warranted. This is especially important given that impairments in APAs are linked to the risk of falling (Horak, 2006; Hyodo et al., 2012; Kanekar & Aruin, 2014b; Muir, Berg, Chesworth, Klar, & Speechley, 2010; Uemura, Yamada, Nagai, & Ichihashi, 2011).

The definition of APAs are changes in the activity of postural muscles prior to a voluntary movement in order to maintain vertical equilibrium (Massion, 1992). Previous research suggests that an earlier onset of APAs indicates greater postural preparation in anticipation of the expected disturbance associated with voluntary movement (e.g., step initiation) (Aruin, Kanekar, Lee, & Ganesan, 2015). Further, improvement in postural control has been shown to influence the performance of reaching movements. Previous studies have shown that an improvement in APAs led to improvement in motor performance in terms of accuracy, movement time, and peak velocity (Saito, Kominami, Yamanaka, Takeda, & Fukushima, 2011; Saito, Yamanaka, Kasahara, & Fukushima, 2014). As such, improvement in kinematic and behavioral measures is associated with overall better postural control.

A few studies have investigated APAs during a lower extremity Fitts' task, and reported that APAs are predictable when participants performed a Fitts' task (Bertuccio & Cesari, 2010; Bertuccio, Cesari, & Latash, 2013; Danion, Duarte, & Grosjean, 1999; Duarte & Freitas, 2005; Duarte & Latash, 2007). The use Fitts' law is advantageous as it is resistant to learning and has varying difficulty levels (Schmidt & Lee, 2011). Since the introduction of this law, several studies have shown the robustness of Fitts' law and its applicability to different movement types (Plamondon & Alimi, 1997). The formal linear relationship of Fitts' law is  $MT = a + b \log_2(2A/W)$ , where MT is movement time,  $a$  and  $b$  are empirical constants,  $A$  and  $W$  are amplitude of movement and width of target, respectively. The logarithmic function of this formula is called the index of difficulty (ID),  $ID = \log_2(2A/W)$ , and is measured in bits (Fitts & Peterson, 1964; Fitts, 1954). In other words, Fitts' law can be described as a relationship between MT and task difficulty; when aiming for a target, MT increases with task difficulty.

Studies that looked into APAs during a lower extremity Fitts' task have only investigated participants who were young, non-disabled adults. To our knowledge there are no previous studies related to APAs during a Fitts' task among individuals in several age groups. On the other hand, studies that looked into APAs among older adults indicate that APAs are significantly delayed and lower in amplitude among older adults compared to young adults (Inglin & Woollacott, 1988; Kanekar & Aruin, 2014b; Rogers et al., 1992; Woollacott & Manchester, 1993). Further, studies that investigated Fitts' law tasks among older adults report that Fitts' law holds; however, older adults performed significantly slower than younger participants, and showed more variability in performance (Passmore, Burke, & Lyons, 2007; Sleimen-Malkoun, Temprado, & Berton, 2013). Additionally, as mentioned above no previous study has investigated the effects of different foci of attention on APAs. Investigating APAs within the context of focus of attention and Fitts' law may lead to identifying methods for assessing and improving APAs among older adults.

### 1.1. Aims and hypotheses

The primary aim of this study was to investigate the effects of different foci of attention on APAs parameters (measured as electromyography [EMG] onset and magnitude) during a lower extremity Fitts' task among young and older adults. The secondary aims include: (1) to compare the differences in movement time (MT) between young and older adults during a lower extremity Fitts' task with different attentional foci; and (2) to compare the kinematic variables of movements to varying targets (peak velocity [PV], time to peak velocity [tTPV] and variability at target endpoint [ $SD_T$ ]) between young and older adults with different attentional foci.

Based on previous studies, we hypothesized that when adopting an external focus of attention participants would show earlier APAs onset and more efficient (lower) APAs magnitude. Further, we anticipate that when adopting an external focus of attention the improvement in APAs is accompanied with improved performance in behavioral and kinematic measures. This improved performance is seen as shorter MT, higher PV, shorter tTPV and more accurate target endpoint ( $SD_T$ ).

## 2. Methods

### 2.1. Participants

Ten older adults (65 years or older) and ten young adults (18–40 years) were recruited for this study. Footedness was assessed using the Waterloo Footedness Questionnaire-Revised (WFQ-R) (Elias, Bryden, & Bulman-Fleming, 1998). The WFQ-R includes thirteen questions that are answered on a 5-level Likert-type scale to determine whether the right foot or left foot is the most often used. Responses were assigned a value between  $-2$  and  $2$ , with scores closer to  $0$  reflect equal foot preference, score closer to  $-2$  indicate left foot preference, and  $2$  right foot preference (Elias et al., 1998). An a priori power calculation ( $\beta = 0.8$ ,  $\alpha = 0.05$ ) with published data for APAs onset time during Fitts' law tasks determined a sample size of 9 participants per group was sufficient. All participants in our study provided an informed consent prior to data collection. The Health Research Ethics Board at the University of Manitoba approved all procedures.

### 2.2. Inclusion and exclusion criteria

All participants had to answer 'no' to all questions in the PAR-Q (Thomas, Reading, & Shephard, 1992). The Physical Activity Readiness Questionnaire (PAR-Q) was used ensure that participants do not have medical problems that might negatively impact them after participation in this study. All participants were required to score above '53' on Berg balance scale or would not be eligible to participate in the study (Berg, Wood-Dauphine, Williams, & Gayton, 1989). This score  $-53-$  on the Berg balance scale was chosen as a cut-off as previous research suggests that older adults with this score and higher were more likely to have greater balance ability and functional independence (Berg, Maki, Williams, Holliday, & Wood-Dauphinee, 1992; Berg, Wood-Dauphinee, Williams, & Maki, 1992; Steffen, Hacker, & Mollinger, 2002). The need to define a minimum score on the Berg balance scale was determined as the task in this study requires participants to stand independently and perform a lower extremity task with one foot, while supporting weight on the other lower extremity. One consistent author (SA), who is experienced with the above tests, always administered the previous measures. After the previous information was collected, and the participants met the criteria, a session for the experiment was scheduled.

### 2.3. Apparatus

The instruments that were used in this study included an optoelectronic motion capture system and an EMG system. The motion capture system used for this study was the Optotrak 3D-investigator (Northern Digital Inc. [NDI], Canada). This system records the 3-dimensional displacement of infrared-emitting diode markers. The movement kinematics of two markers was recorded using this system. These two markers were placed bilaterally on the distal aspect of the great toe. Data were collected at 200 Hz.

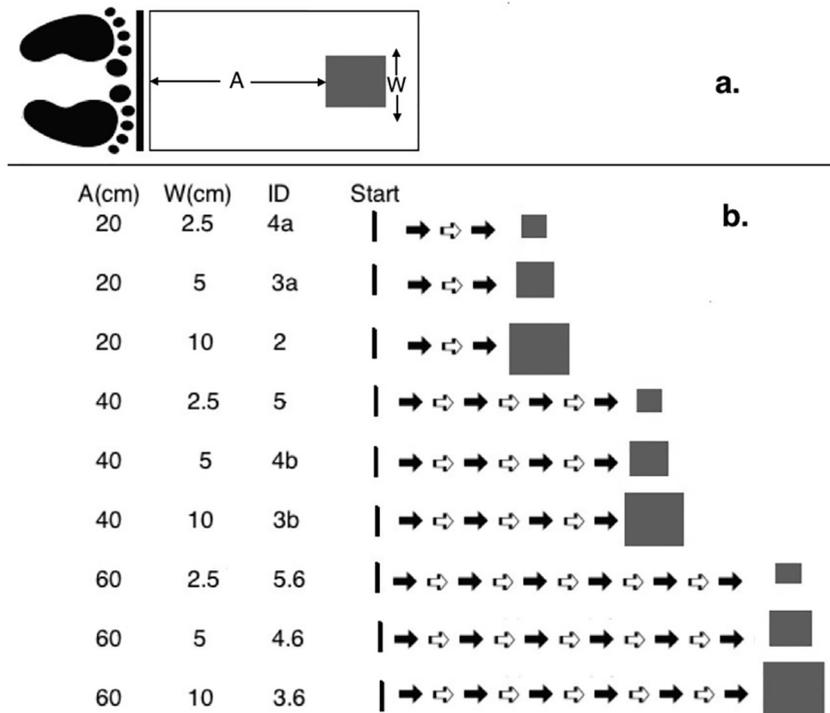
The EMG system used for this study was the Power 1401 data acquisition system with its software 'Signal' (Cambridge Electronic Design [CED], UK). This EMG system uses snap connection leads to attach to disposable pre-gelled Ag/AgCl, bipolar electrodes that mount directly to the skin with an adhesive pad. The EMG signal was sampled at 2000 Hz. Muscle activity of the soleus and tibialis anterior muscles were recorded. These muscles were chosen because they are part of the main lower extremity postural muscles and can provide an overall representation of APAs (Nashner, 1977). The above muscles in the stance and moving limbs were recorded. Electrode placement for the EMG was done in accordance with Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guidelines (Hermens et al., 2000; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The Optotrak and EMG systems were synchronized during data collection using a trigger pulse and linked to their respective software and computer.

### 2.4. Procedure

The protocol for this study involved participants standing with bare feet on a level surface with their feet shoulder-width apart and their arms at their sides. Participants were asked to align the distal tips of both great toes to a straight line shown on the floor in front of them (i.e., the starting position). An adjustable walker was placed in front of participants, and to this walker, a digital projector was mounted to project 30-inch images on the floor. Each participant was instructed to point with the tip of the great toe to a square target on the floor displayed by the projector. Targets had a predefined width ( $W$ ) and were located at a predefined amplitude ( $A$ ). Target position was anterior to the participant, in the sagittal plane. The task in this study involved a single discrete movement to the target. The instructions given to each subject prior to a block of trials was a typical Fitts' task instruction: "be as fast and as accurate as possible in your pointing movement." Participants were also asked to hold the position of the foot after completing the task until the end of trial in order to ensure proper data collection.

Each trial lasted 10 s and it started with the participant standing in the starting position. The image for the block of trials was presented to the participant. A 'go' auditory signal from the computer system indicated that participants should initiate the movement towards the target. Three movement amplitudes ( $A = 20, 40$  and  $60$  cm) and three target widths ( $W = 2.5, 5$  and  $10$  cm) were used in this study. The combinations of these amplitudes and widths yield 9 different conditions with an ID ranging from 2.00 to 5.58 bits (Fig. 1). The amplitude was measured from the center of the target to the line of the starting position. The nine combinations were presented in a random order, with each combination presented six times. Participants were given practice trials (1–3) prior to each condition. Once completed, the procedure was repeated with the opposite foot (108 trials).

Each participant underwent the previous procedure twice (216 trials total) in order to investigate the effects of adopting different



**Fig. 1.** Experimental setup of our study. a. Shows the starting position for performing the task. b. Shows the nine combinations of movement amplitude and target width with the resultant index of difficulty. A = amplitude, W = width, ID = index of difficulty.

types of attentional foci. This was done by giving participants additional instructions during trials to manipulate focus of attention. During the internal focus of attention condition, participants were told to “focus on your foot; concentrate on your foot’s motion when you reach forward with your foot.” During the external focus condition, participants were told to “focus on the target; concentrate on the middle of the target.” Participants had to perform the previous experiment under both foci of attention conditions. To rule out order effects, half of the participants performed the experiment under the internal focus condition followed by the external focus condition, while the other half of participants started with the external focus condition followed by the internal focus condition. Instruction reminders (for Fitts’ task and focus of attention) were provided to participants prior to each Fitts’ task condition. It was anticipated that each participant would perform the experiment in one session and within two hours. Between conditions participants were asked to rest or walk around, as they preferred, in order to minimize attentional and physical fatigue.

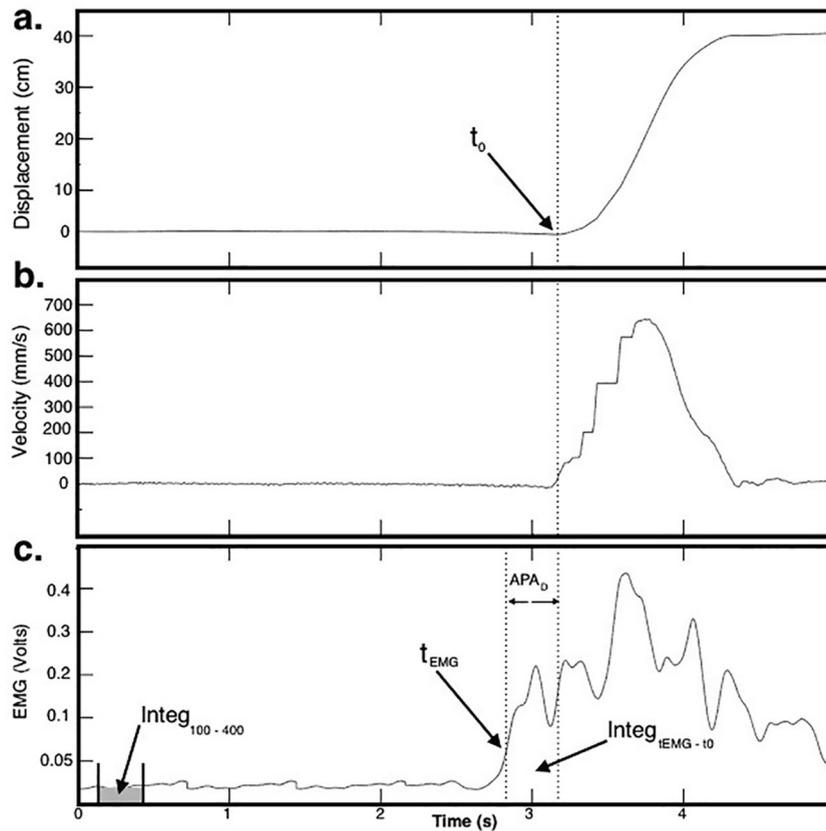
## 2.5. Data processing and analyses

### 2.5.1. Data processing

Data processing was done using a custom computer software developed using Matlab (release 2014b, The Mathworks Inc., USA). For kinematic data, only sagittal plane data was analyzed, as this was the main plane of movement. Position data was low-pass filtered at 10 Hz. Peak velocity (PV), measured in millimeter/second (mm/s), and time to peak velocity (ttPV), measured in millisecond (ms), were determined from the velocity profile in the sagittal plane of the marker on the great toe of the pointing foot. We defined PV as the greatest velocity attained in the sagittal plane of movement by the great toe. The ttPV definition was the time following movement onset to reach peak velocity (ms). Movement onset ( $T_0$ ) was defined as the first frame when velocity in the primary axis of movement reached 35 mm/s during a particular trial. Movement end time ( $T_{END}$ ) was defined as the frame where after  $T_0$  when velocity in the primary axis of movement fell below 35 mm/s and remained below for at least 100 ms. Movement time (MT) was defined as the time between  $T_0$  and  $T_{END}$ . Variability at target ( $SD_T$ ) was estimated in the primary axis of movement using the standard deviation of the movement endpoints relative to the center of the target.

For EMG data, the raw signals were first band-pass filtered (40–500 Hz), then full-wave rectified and then low-pass filtered at 10 Hz. A zero-lag, 4th order Butterworth filter was used for processing. Subsequently, onset of EMG activity ( $T_{0\_EMG}$ ) was determined. This was done by detecting the first increase above 2  $SDs$  from EMG baseline. Baseline level was defined as the mean EMG activity between 100 and 400 ms of data recording. The net time between  $T_{0\_EMG}$  and  $T_0$  was defined as APA duration ( $APA_D$ ).

To quantify APA magnitude ( $APA_M$ ), we performed the following procedure. First, the integral of EMG activity from 100 ms to 400 ms was determined ( $Integ_{100-400}$ ). Second, the integral of EMG activity from  $T_{0\_EMG}$  to  $T_0$  was determined ( $Integ_{T_{0\_EMG}-T_0}$ ). Finally, the  $APA_M$  measure was defined as the following ratio (Fig. 2):



**Fig. 2.** Example of a movement trial of one of the participants (older adult). Displacement and velocity profiles of the moving leg are shown in a and b. Movement onset is labeled as  $t_0$ . c. Shows the EMG profile for the soleus muscle of the stance leg. Beginning of EMG activity is labeled as  $t_{EMG}$  and the duration between  $t_{EMG}$  and  $t_0$  is the duration of anticipatory postural adjustment ( $APA_D$ ). The integral of EMG activity within  $APA_D$  was determined ( $Integ_{t_{EMG}-t_0}$ ). Also, the integral of EMG between 100 and 400 ms was determined ( $Integ_{100-400}$ ). Using  $Integ_{t_{EMG}-t_0}$  and  $Integ_{100-400}$  magnitude of anticipatory postural adjustment was determined.

$$APA_M = (Integ_{t_0EMG - t_0} - Integ_{EMG100-400}) / Integ_{EMG100-400}$$

The EMG data for both limbs during both conditions (stance and moving) were processed to obtain  $APA_D$  and  $APA_M$ .

### 2.5.2. Dependent variables and statistical analyses

The dependent variables were: MT, PV, ttPV,  $SD_T$ ,  $APA_D$  and  $APA_M$ . For all dependent variables separate: 2 age groups  $\times$  2 foci of attention  $\times$  3 amplitudes  $\times$  3 target widths, mixed model analyses of variance (ANOVA) with repeated measures were conducted. Age group was a between-subject factor and the remaining were within-subject factors. We tested for simple effects on interactions and we have adjusted alpha ( $\alpha$ ) for post-hoc tests. Post-hoc analyses were performed using Tukey's HSD procedure. The significance level for all statistical analyses was set to  $\alpha = 0.05$ . A preliminary analysis was performed to confirm that order didn't interact with attentional focus. The analysis involved comparing participants who started with an internal focus against those who started with an external focus across the same population (i.e., older adults and young adults). Statistical analyses were performed using SPSS statistical package software. Only significant effects are reported in the results below.

## 3. Results

Twenty participants were recruited, ten older adults and ten young adults. The session time required to complete the experiment was 1.5–2.5 h (mean = 2.13). Three females and seven males from each age group were recruited. The mean age for young adults was 24 years ( $\pm 4.37$ ) and mean age for older adults was 75 years ( $\pm 5.85$ ). Results of the WFQ-R showed that participants were predominantly right-footed. All participants had a score of above 54 on the Berg balance scale. Summary of participants' characteristics is shown in Table 1.

**Table 1**  
Participants' characteristics.

Demographics	Older adults	Young adults
N (males/females)	10 (7/3)	10 (7/3)
Age (mean $\pm$ SD)	75 years $\pm$ 5.85	24 years $\pm$ 4.37
Height (mean $\pm$ SD)	175.6 cm $\pm$ 6.57	174.3 cm $\pm$ 5.86
WFQ-R <sup>‡</sup> score (median)	5.5	9
Berg balance scale <sup>†</sup> score (median)	54	56

SD: Standard deviation; WFQ-R: Waterloo Footedness Questionnaire-Revised.

\* The WFQ-R includes thirteen questions that are answered on a 5-level Likert-type scale to determine whether the right foot or left foot is the most often used. Responses are assigned a value between  $-2$  and  $2$ . The total score can be used to determine footedness, with a score of  $-7$  or less considered left-footed, a score of  $-6$  to  $+6$  considered mixed-footed, and a score of  $+7$  or higher considered right-footed.

<sup>†</sup> Berg balance scale is a 14-item observational rating scale that provides a measure of functional balance and has an overall score of 56.

### 3.1. Behavioral and kinematic measures

#### 3.1.1. Movement time

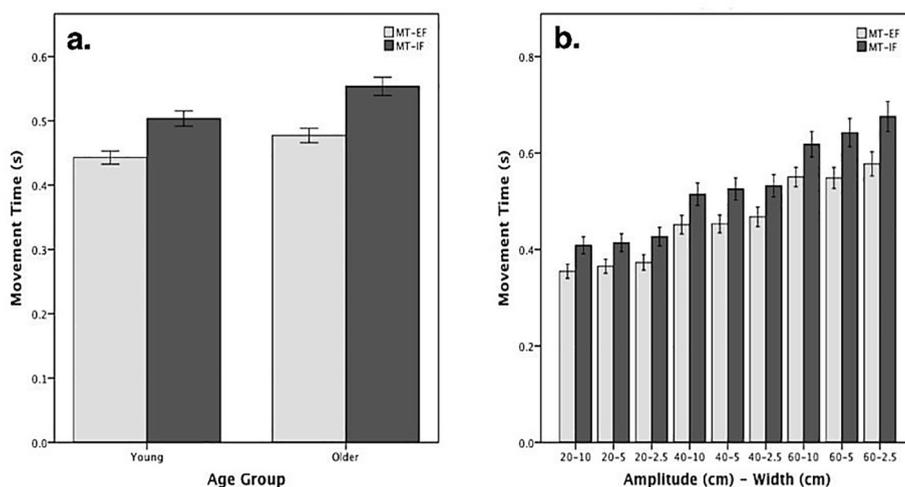
MT was significantly lower with an external focus of attention compared to an internal focus,  $F(1,18) = 62.9$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.78$ . Older adults had longer MT compared to young adults,  $F(1, 18) = 12.5$ ,  $p = 0.002$ ,  $\eta_p^2 = 0.41$  (Fig. 3-a). In addition, higher amplitude resulted in longer MT,  $F(2, 36) = 146.7$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.89$ . Smaller width resulted in longer MT  $F(2, 36) = 12.5$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.41$  (Fig. 3-b). Significant interactions were found for focus of attention by amplitude  $F(2, 36) = 8.5$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.32$ , and focus of attention by age group  $F(1, 18) = 4.6$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.21$ . Post hoc analyses showed that all amplitudes resulted in different MTs,  $p < 0.001$ ; and only widths 2.5 and 10 cm resulted in significantly different MT,  $p < 0.05$ . All other comparisons were not significant.

#### 3.1.2. Peak velocity

PV was significantly higher with an external focus of attention compared to an internal focus,  $F(1,18) = 46.2$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.72$  (Fig. 4-a). Results also showed that as amplitude increased PV increased,  $F(2, 36) = 202.1$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.92$ . Also, as width increased PV increased,  $F(2, 36) = 127.3$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.88$  (Fig. 4-b). Post hoc analysis showed that all amplitudes and widths resulted in different PV,  $p < 0.001$ . No significant differences were found between age groups. All other comparisons were not significant.

#### 3.1.3. Time to peak velocity

Results showed that ttPV was significantly lesser with an external focus compared to an internal focus,  $F(1,18) = 27.8$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.61$  (Fig. 5-a). In addition, higher amplitude resulted in longer ttPV,  $F(2, 36) = 113.9$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.86$  (Fig. 5-b). Smaller width resulted in longer ttPV,  $F(2, 36) = 18.9$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.51$ . Post hoc analysis indicated that all amplitudes and widths resulted in different ttPV,  $p < 0.01$ . No significant differences were found between age groups. All other



**Fig. 3.** Results of movement time (MT). a. Shows the difference in MT between young and older adults. b. Shows MT plotted against the different combinations of movement amplitude and width. Error bars reflect standard error of the mean.

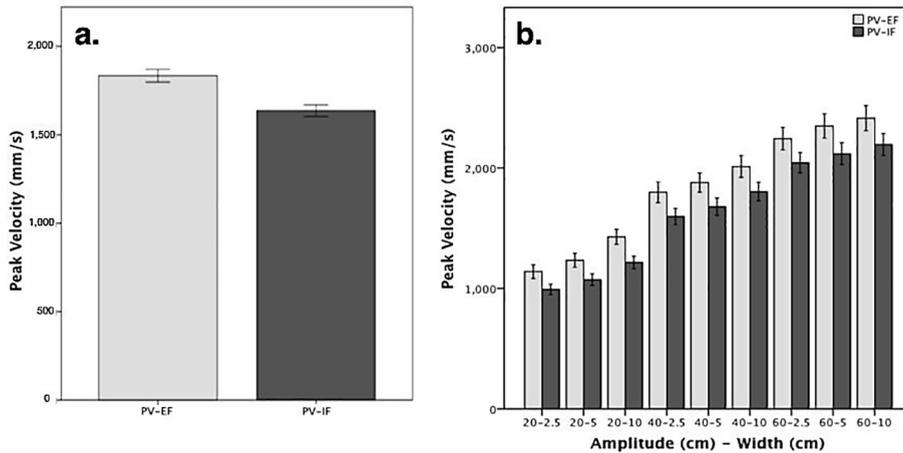


Fig. 4. Results of peak velocity (PV). a. Shows the difference in PV when focusing externally (PV-EF) and when focusing internally (PV-IF). b. Shows PV plotted against the different combinations of movement amplitude and width. Error bars reflect standard error of the mean.

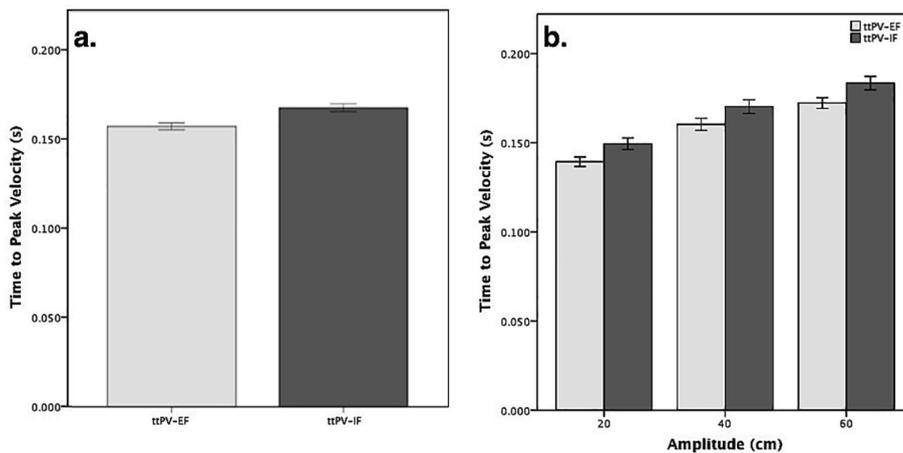


Fig. 5. Results of time to peak velocity (ttPV). a. Shows the difference in ttPV when focusing externally (ttPV-EF) and when focusing internally (ttPV-IF). b. Shows ttPV plotted against the different movement amplitudes. Error bars reflect standard error of the mean.

comparisons were not significant.

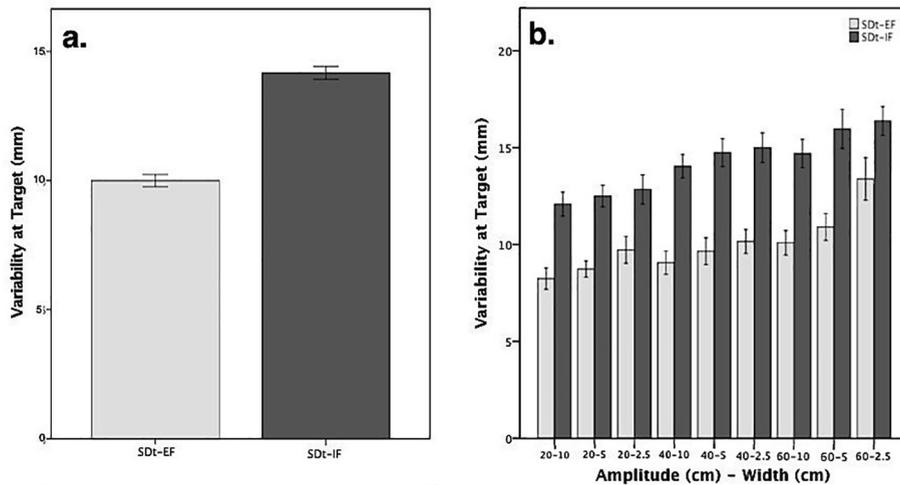
### 3.1.4. Variability at target

$SD_T$  was significantly lesser with an external focus of attention compared to an internal focus,  $F(1,18) = 332.0$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.95$  (Fig. 6-a). Results also showed that shorter amplitude led to smaller  $SD_T$ ,  $F(2, 36) = 3.8$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.17$ . Larger width resulted in lesser  $SD_T$ ,  $F(2, 36) = 10.9$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.38$  (Fig. 6-b). Significant interactions were found for focus of attention by amplitude  $F(2, 36) = 3.5$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.16$ , and focus of attention by width  $F(2, 36) = 9.7$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.35$ . Post hoc analysis showed that 20 and 60 cm amplitudes resulted in significantly different  $SD_T$  ( $p < 0.001$ ). Similarly, widths 2.5 and 10 resulted in significantly different  $SD_T$  ( $p = 0.026$ ). Overall, an external focus of attention led to lesser  $SD_T$ , shorter amplitude led to smaller  $SD_T$  but only for external focus, bigger width led to lesser  $SD_T$  (only for external focus). No significant differences were found between age groups. All other comparisons were not significant.

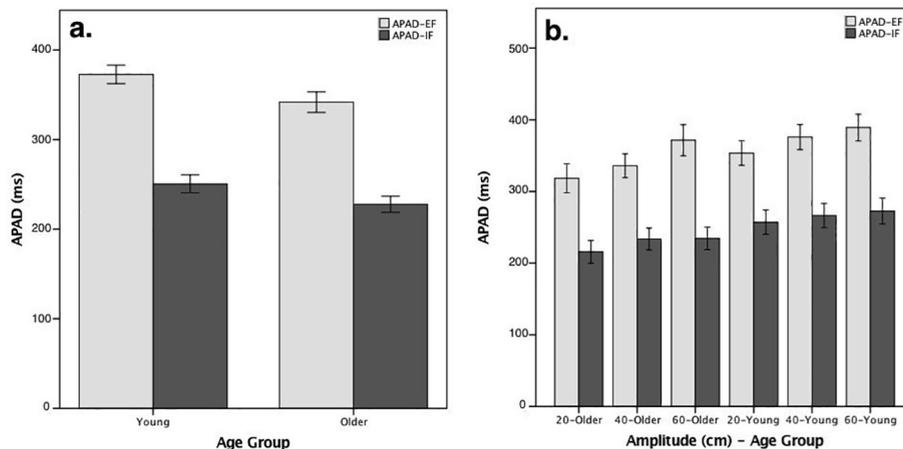
## 3.2. Anticipatory postural adjustments measures

### 3.2.1. Anticipatory postural adjustments duration

Results showed that adopting an external focus of attention led to earlier onset of APAs for both muscles, tibialis anterior (TA) and soleus (SO) during both conditions, moving and stance, TA moving:  $F(1,18) = 91.6$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.84$ , TA stance:  $F(1,18) = 126.1$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.88$ , SO moving:  $F(1,18) = 130.6$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.88$ , and SO stance:  $F(1,18) = 180.8$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.91$ . Results also showed that young adults exhibited earlier APAs onset compared to older adults for TA stance  $F(1, 18) = 8.3$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.32$ , and SO stance  $F(1, 18) = 4.9$ ,  $p = 0.04$ ,  $\eta_p^2 = 0.21$  (Fig. 7-a). Significant interactions were



**Fig. 6.** Results of variability at target (SDt). a. Shows the difference in SDt when focusing externally (SDt-EF) and when focusing internally (SDt-IF). b. Shows SDt for internal and external focus plotted against the different combinations of movement amplitude and width. Error bars reflect standard error of the mean.

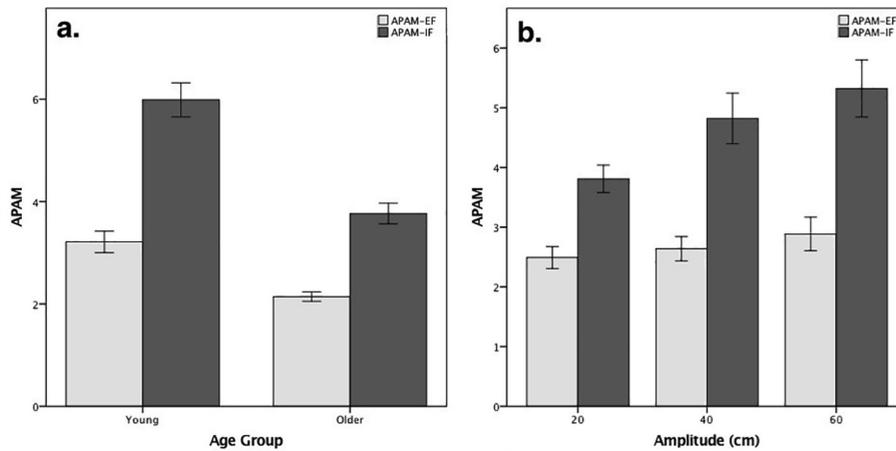


**Fig. 7.** Results of Anticipatory postural adjustment duration (APAD). a. Shows the difference in APAD between young and older adults for the soleus muscle in stance condition. b. Shows APAD plotted against the different movement amplitudes separated by age for soleus muscle in stance condition. Error bars reflect standard error of the mean.

found for focus of attention by age group for TA stance  $F(1, 18) = 7.2$ ,  $p = 0.01$ ,  $\eta_p^2 = 0.29$  and SO stance  $F(1, 18) = 6.2$ ,  $p = 0.02$ ,  $\eta_p^2 = 0.27$ . A significant interaction was found for focus of attention by amplitude by age group for SO stance  $F(2, 36) = 7.3$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.29$ . For both age groups, as amplitude increased APAs onset occurred earlier but this was only seen with external focus and for the stance soleus muscle (Fig. 7-b). No significant effects were found for width on  $APA_D$ . All other comparisons were not significant.

### 3.2.2. Anticipatory postural adjustments magnitude

$APA_M$  was significantly smaller with an external focus of attention compared to an internal focus for both TA and SO during both moving and stance conditions, TA moving:  $F(1,18) = 11.6$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.39$ , TA stance:  $F(1,18) = 12.7$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.41$ , SO moving:  $F(1,18) = 29.7$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.62$ , and SO stance:  $F(1,18) = 53.9$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.75$ . Results also showed that young adults exhibited larger  $APA_M$  compared to older adults for SO moving,  $F(1, 18) = 20.5$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.53$ , and SO stance,  $F(1, 18) = 31.9$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.64$  (Fig. 8-a). Increased amplitude led to larger  $APA_M$  for TA moving,  $F(2, 36) = 4.7$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.21$ , and TA stance,  $F(2, 36) = 4.2$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.19$  (Fig. 8-b). Significant interactions were found for focus of attention by age group for SO stance  $F(1, 18) = 13.7$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.43$ . A significant interaction was found for focus of attention by amplitude for TA moving  $F(2, 36) = 3.3$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.15$ . No significant effects were found for width on  $APA_M$ . All other comparisons were not significant.



**Fig. 8.** Results of Anticipatory postural adjustment magnitude (APAM). a. Shows the difference in APAM between young and older adults for the soleus muscle in stance condition. b. Shows APAM plotted against the different movement amplitudes for moving tibialis anterior muscle. Error bars reflect standard error of the mean.

#### 4. Discussion

This study investigated APAs and other movement parameters among young and older adults when performing a lower extremity Fitts' task and adopting different foci of attention. We conducted the present study in order to assess if the reported positive effects of adopting an external focus of attention extend to APAs among both older and young adults when performing a lower extremity Fitts' task. Due to the importance of APAs in fall prevention, it is imperative to investigate methods for improving them. This is especially important given that older adults show impairments in APAs, which have been linked to the risk of falling (Horak, 2006; Hyodo et al., 2012; Kanekar & Aruin, 2014b; Muir et al., 2010; Uemura et al., 2011).

Both age groups in this study benefited from adopting an external focus of attention when performing the Fitts' task. The beneficial effect of adopting an external focus was evident in the shorter movement times, larger peaks of velocity, shorter times to peak velocity and the more accurate target endpoints. Further, the benefits of adopting an external focus were evident in measures of APAs, as APAs occurred earlier with an external focus and magnitude of APAs was lower and more efficient. The beneficial effects of adopting an external focus of attention were shown repeatedly across multiple experimental studies (Wulf & Lewthwaite, 2016; Wulf, 2013). These beneficial effects ranged from movement effectiveness (e.g., maintaining balance, reaching accuracy) to movement efficiency (e.g., muscular activity, force production, speed). Wulf and colleagues proposed the constrained action hypothesis as a testable explanation for the effects of different foci of attention (Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001). According to this view adopting an internal focus promotes conscious control of movement, which leads individuals to constrain their motor system by interfering with automatic control processes. Conversely, an external focus induces an automatic mode of control by using unconscious, fast, and reflex-like control processes. Several experimental studies support this hypothesis and provide evidence related to changes in attentional capacity, movement-adjustments frequency and reduced reaction time detected under different attentional foci (Kal, van der Kamp, & Houdijk, 2013; Lohse, 2012; McNevin, Shea, & Wulf, 2003; Wulf, McNevin, et al., 2001; Wulf, Shea, et al., 2001).

The results of our study show that target amplitude had a more prominent effect on outcome measures than the width of the target. This finding is seen in the higher effect size of amplitude in behavioral and kinematic measures and the lack of a significant effect of width on measures of APAs. It was possible that participants adjusted their movement planning primarily based on movement amplitude. This finding was supported by the fact that there was no effect of target width on variability at movement endpoint when participants were adopting an internal focus. However, when movement planning was managed under an external focus of attention, target width had a significant effect on variability at target. This finding also supports the constrained action hypothesis mentioned above. When participants were consciously controlling their movements they perceived the difficulty of the task based on movement amplitude. However, when adopting an external focus, movement planning was more automatic and thus all variables of difficulty affected performance. This finding was similar to previous studies that also reported a more prominent effect of movement amplitude rather than target width (Bertuccio & Cesari, 2010; Duarte & Latash, 2007; Passmore et al., 2015).

The older population in our study showed significant differences in outcome measures compared to young adults. This finding was similar to previous studies that utilized similar outcome measures (Inglin & Woollacott, 1988; Kanekar & Aruin, 2014a; Passmore et al., 2007; Rogers et al., 1992; Sleimen-Malkoun et al., 2013; Woollacott & Manchester, 1993). This finding supports the general slowing hypothesis (GSH) among older adults. The GSH suggests that slowing is not exclusive to the cognitive domain, but extends to the motor domain (Sleimen-Malkoun et al., 2013). Nonetheless, there were no differences in peak velocity and time to peak velocity between the age groups. The equivalency between age groups in peak velocity and time to peak velocity does not necessarily mean age groups were similar in overall performance. Older adults during a Fitts' law task tend to show more movement adjustments (i.e., shifting between acceleration to deceleration) and do not perform the task similarly to young adults (Goggin & Meeuwse, 1992;

Sleimen-Malkoun et al., 2013).

Our results showed that the two age groups and amplitude had an effect on onset of APAs. However, this effect was only observed when the leg was in stance position and not while moving. When performing the Fitts' task, individuals in our study shifted from a bipedal to a unipedal stance. Therefore, the stance leg was responsible for maintaining equilibrium while performing the task. Given the above results, it is reasonable to suggest that the aforementioned parameters (i.e., age group and amplitude) affected the stance leg more than the swing leg. Further, previous studies related to APAs also reported that onset of APAs, as measured by EMG, of the stance leg was more affected by the study parameters such as movement amplitude (Bertuccio & Cesari, 2010; Ito, Azuma, & Yamashita, 2003; Yiou, Caderby, & Hussein, 2012).

For APA magnitude, the results showed that movement amplitude only affected the TA muscles, while differences between age groups were only seen in the SO muscles. These findings suggest that, during movement planning, the difficulty of the task was interpreted by the amplitude of movement and the load was carried out primarily by the TA muscles. Further, our findings suggest that the TA muscles were not affected by the different age groups as only the SO muscles were affected. The above findings are consistent with previous research, which indicates that TA muscle strength only shows difference between age groups after the age of 80 years (McNeil, Doherty, Stashuk, & Rice, 2005). Given that the mean age for the older group was 75 y, it is expected that the age group did not affect the TA muscles.

The overall findings of our study can be interpreted within the context of the challenge point framework (Guadagnoli & Lee, 2004). The challenge point framework relates the variables of a task to the skill level of the performer, the difficulty of the task and the information related to the motor skill. Guadagnoli and Lee (2004) state that as the difficulty of a motor task increases, the overall performance decreases depending on the ability of the performer. However, the authors suggest that in order to achieve maximum performance of a motor skill, there is an "optimal challenge point" in the degree of task difficulty and availability of information, which leads to optimal performance of motor skills. At this optimal challenge point the individual is optimally challenged with the task difficulty relative to their skill level, and then efficient performance and learning of a motor skill can occur.

In our study, the findings suggest that the optimal challenge point for a task similar to our study is different between older and young adults. The difference in the optimal challenge point between the two age groups can be seen in their differences in movement planning as assessed by the onset of APAs. In other words, as amplitude increased (i.e., difficulty increased) the differences between the two groups became more pronounced. Therefore, when assessing APAs among older adults using longer amplitudes would be more indicative of APAs impairments than smaller movement amplitudes. Another interesting finding in our study was that adopting an external focus of attention seemed to alter the optimal challenge point. This alteration of the optimal challenge point can be seen in the target endpoint variability. When participants adopted an internal focus their target endpoint variability was similar for amplitudes 40 cm and 60 cm. However, when adopting an external focus of attention a difference was present between the two aforementioned amplitudes. This difference suggests that an external focus of attention helps distinguish between the different levels of difficulty and thus promote performance by adequately identifying the optimal challenge point for the performer.

The findings in our study have important clinical implications. Adopting an external focus of attention appears to promote beneficial effects for both young and older adults. The beneficial effects can be seen in the behavioral and kinematic measures of the study as adopting an external focus led to shorter movement time and time to peak velocity, higher peak velocity, more endpoint accuracy. Previous studies suggest that an improvement in behavioral and kinematic measures is associated with overall better postural control (Saito et al., 2011, 2014). Further, these benefits were seen with APAs measures as adopting an external focus led to earlier activation of APAs and decreased muscle activation. These findings were similar to previous studies that investigated focus of attention and indicated that adopting an external focus led to improved movement accuracy and efficiency (Wulf & Lewthwaite, 2016; Wulf, 2013). Although studies of attentional foci in motor behavior had shown the benefit of adopting an external focus, clinical and community uptake has lagged behind. Several studies had shown that during training of motor skills, clinical practitioners provide learners with statements that promote an internal focus of attention (Durham, Van Vliet, Badger, & Sackley, 2009; Johnson, Burridge, & Demain, 2013; Porter et al., 2010). The previous studies suggest that there is a need to promote the utilization of an external focus of attention during motor training.

The findings in our study also provide the groundwork for determining the challenge point at which older adults are at a higher risk of falling and thus in need of clinical intervention. As mentioned above, APAs impairment is linked to risk of falling (Horak, 2006; Hyodo et al., 2012; Muir et al., 2010; Uemura et al., 2011). The task used in our study can be used as a performance-based objective outcome measure of APAs. By utilizing higher movement amplitudes, APAs parameters show more pronounced differences between young and older adults. Further, by establishing a point at which older adults are at higher risk of falling, the task in our study can serve as a useful tool for rehabilitation clinicians.

## 5. Conclusion

The present study showed that adopting an external focus of attention yields beneficial effects for both older and younger adults when performing a lower extremity Fitts' task. Furthermore, the task distinguished between young and older adults in terms of behavioral, kinematic and APAs measures. Movement amplitude had the greatest effect on performance for both age groups. Finally, the results found in our study should be extended in order to investigate a cut-off point at which APAs are impaired and are in need of clinical intervention.

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