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**Does functional performance and upper body strength predict upper extremity reaction and movement time in older women?**

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**Abstract**

*Background:* Reaction time to initiate upper limb movement and movement time to place hands on the landing surface may be important factors in forward fall landing and impact, contributing to injury reduction. The aim was to investigate the relationship of physical function and upper body strength to upper limb reaction and movement time in older female participants.

*Methods:* 75 female participants (72 ± 8 yrs) performed 5 arm response trials. Reaction time (signal to initiation of movement), and movement time (initial movement to contact), were collected using 3D motion capture. Additional variables were: handgrip; sit-to-stand; shoulder flexion and elbow extension strength measured by hand-held dynamometry; one-legged balance; fall risk; and physical activity scores. Prediction variables for reaction and movement time were determined in separate backward selection multiple regression analyses. Significance was set at *P*<0.05.

*Findings:* Significant regression equations for RT (r2 = .08, *P* = 0.013) found a relationship between stronger handgrip (Beta = -.002) and faster reaction time, accounting for 8% variance. For movement time (r2 = .06, *P*= .036) greater shoulder flexion strength (Beta = -.04) was related to faster movement time, explaining 6% variance. Stronger SF strength was related to a decrease in MT by 4%.

*Discussion:* A relationship between arm strength measures and faster upper body reaction and movement time was shown, with 10-20% higher strength associated with a 5% faster response time. Even though this was a relatively weak relationship, given that strength is a modifiable component this provides a potential avenue for future intervention efforts. This in turn could have an impact on forward fall landing and potential reduction of injury risk.

*Keywords:* fall prevention, aging, upper limb

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Older adults, especially women, are at risk of injury following a forward fall (DeGoede, Ashton-Miller, & Schultz, 2003; O’Neill et al., 1994; Sattin et al., 1990). Forward falls account for more than 50% of falls in community-dwelling older adults (O’Neill et al., 1994) and are associated with injuries to the upper limb. Women are at a higher risk of fall-related injury (DeGoede et al., 2003; O’Neill et al., 1994; Sattin et al., 1990), and experience considerably more upper limb fractures than men (Sattin et al., 1990). A woman is almost five times more likely to experience a distal radial fracture in her lifetime compared to a man (Brogren, Hofer, Petranek, Dahlin, & Atroshi, 2011). This increased fracture rate may partly be explained by a combination of reduced forearm muscle density and strength and wrist bone strength in women compared to men (Riggs et al., 2004). Reaching forward with arms to break a fall is an automatic protective reaction to a forward balance perturbation, initiated in order to reduce the risk of injury to the head and trunk (DeGoede et al., 2003; Hsiao & Robinovitch, 1998; O’Neill et al., 1994). With nearly 60% of fall injuries occurring to the upper limb, head or trunk (Public Health Agency of Canada, 2014), and falls responsible for 80 % of hospital admissions for traumatic brain injury (Harvey & Close, 2012), forward fall-related injuries can have a substantial impact on an individual’s independence and generate a strain on the health care system (Public Health Agency of Canada, 2014).

The pre-impact responses of initiating arm motion towards a sturdy surface and then placing the hands and arms in a landing position helps to determine the effective neuromuscular management of the impact forces (DeGoede et al., 2003). During forward fall landing on outstretched hands, there is a requirement on the upper extremity to absorb the forces generated and to reduce the body’s momentum (Nevitt & Cummings, 1993). Video footage of falls in a long-term care setting found that the odds of head impact was almost three times greater in forward falls compared to backwards or sideways falls with hand impact. In 97% of falls initiated in a forward direction, there was head impact suggesting that older adults in long-term care may be utilizing an UE protective response that is ineffective in reducing head impact (Schonnop et al., 2013). Older adults may avoid serious fall-related injuries, such as those to the head and trunk, by initiating these pre-impact strategies and thus, mitigating the body’s response to the impact forces (DeGoede et al., 2003; Kim & Ashton-Miller, 2003). Early onset arm responses are necessary to achieve this timely pre-impact response to avoid or mitigate a fall by counterbalancing or reaching in a protective manner (Borrelli, Zabukovec, Jones, Junod, & Maki, 2019; Lo & Ashton-Miller, 2008). In order to achieve this, upper limb reaction time (RT, initiating an arm response to a balance perturbation) and movement time (MT, adjusting the arms to a protective position) are important pre-impact response factors contributing to an older adult’s upper limb protective arm response capacity (DeGoede et al., 2003; Kim & Ashton-Miller, 2003).

Previous studies have focused on RT and MT differences between younger and older adults (DeGoede, Ashton-Miller, Liao, & Alexander, 2001; Maki & McIlroy, 2006; Robinovitch, Normandin, Stotz, & Maurer, 2005). The speed with which arm movements are initiated and executed is approximately 20% slower for older female participants in comparison to younger adults (DeGoede et al., 2001; Robinovitch et al., 2005). Older adults who exhibited reflexive arm responses, as opposed to a selected movement, generated greater forces upon impact and exhibited an abrupt stop to body movement during simulated falls (Kim & Ashton-Miller, 2003). This finding suggests that reflexive pre-impact actions can be detrimental during force attenuation at impact. Securing sufficient arm movement time to implement a pre-impact protective arm response and reducing excessive pre-impact reflexive responses may lead to a reduction in injuries to the upper limb, head and trunk (Kim & Ashton-Miller, 2003).

A better understanding of factors that can improve pre-impact arm movement responses is needed to reduce the risk of injuries to the upper limb, head or trunk during falls in older adults (Kim & Ashton-Miller, 2003). Muscle strength has been associated with an individual’s ability to perform appropriate and timely arm responses (DeGoede & Ashton-Miller, 2003; Robinovitch et al., 2005). In addition, insufficient upper extremity strength may reduce the ability of the arms to withstand an impact following a fall (DeGoede et al., 2003; DeGoede & Ashton-Miller, 2003; Nevitt & Cummings, 1993; Sran, Stotz, Normandin, & Robinovitch, 2010). Upper limb reaction time is included as a fall risk component in some comprehensive assessment tools (Lord, Sherrington, Menz, & Close, 2003), however, it is measured via hand responses in a seated position. This provides limited insight into the pre-impact arm responses, in particular the movement time, required to reach for a support to prevent a fall or preparing for impact. Age-related declines in upper limb muscle strength and reaction time may reduce an older adult’s ability to implement a sufficient pre-impact strategy, resulting in poor impact management and subsequent occurrence of injuries (DeGoede et al., 2003; Robinovitch et al., 2005). Physical function factors such as balance, leg strength and physical activity have been strongly linked to an individual’s risk of falling and related injuries (Smee, Anson, Waddington, & Berry, 2012), however little is known about the relationship of these more global fall risk factors to the pre-impact arm responses in a forward fall.

Currently there is limited research (DeGoede et al., 2001; Kim & Ashton-Miller, 2003; Robinovitch et al., 2005) investigating the relationship of physical function, strength and risk of falling to upper extremity pre-impact arm response RT and MT in adults over the age of 60. An individual who has slow RT and MT may not be able to move into an optimal pre-impact position to control the landing and descent of a forward fall which may lead to injury to the head or trunk. The purpose of this study is to investigate the relationship of physical function, upper and lower body strength and RT and MT in female participants over the age of 60 during a task simulating rapid hand and arm repositioning seen during protective arm responses in forward fall impact preparation.

**Methods**

***Participants***

A convenience sample of 75 older female participants (72 ± 8 yrs, 1.6 ± 0.05 m, 72 ± 14 kg) was recruited from the local community via poster advertisements at senior housing, e-mails through senior advocacy organizations and newspaper advertisements. Prior to testing, all participants were informed of the experimental risks and provided signed, informed consent. Participants were excluded during a telephone screening process if they had: any recent upper body (hand, wrist, shoulder, trunk, neck) injury or painful joint problem that limited day-to-day activities or resulted in pain on a daily basis; prior distal radius fracture in the past 2 years, or multiple fractures of the wrist or forearm; any history of upper extremity neurological problems (i.e. stroke, MS, Parkinson’s disease, reflex neuropathy); and those who were unable to safely ambulate independently (with or without a walking aid) in the community. The study was approved by the BLINDED Biomedical Ethics Review Board.

***Study Design***

RT and MT were recorded using an 8-camera 3D-motion capture system (fs=200Hz, VICON Nexus, VICON, Centennial, CO, USA). The wrist joint centres were established using the mean locations of the radial and ulnar epicondyles and were tracked using a cluster of four retro-reflective markers placed on distal forearms. From a standing position with arms by their side (Figure 1a), participants responded to a randomised audible signal, by reaching both arms forward, as fast as possible, to touch a target on dual force plates (fs=2000Hz, OR6-7, AMTI, Watertown, MA, USA), positioned below shoulder height, with bilateral hand contact (Figure 1b). The height of the force platform target was standardised to the participants height and arm length. To ensure consistent hand contact across trials, participants were required to touch above a marked line, the same target was used for all participants, resulting in a consistent height form the target. Kinematic, force and audio cue timing data were synchronously collected on the same system. Five trials were conducted, and the raw kinematic data were exported and processed with a 4th order zero-lag Butterworth low-pass filter (fc=10Hz) implemented in MATLAB (R2019b, Mathworks, Natick, MA, USA). The initiation of wrist movement was determined as the onset of movement exceeding 10% of peak movement velocity (Teasdale, Bard, Fleury, Young, & Proteau, 1993). The same algorithm was utilized to establish the rise in force to distinguish initial contact with the force platforms (Teasdale et al., 1993). RT was categorised as time from initial audio cue to initiation of wrist movement and MT categorised as time from wrist movement initiation to contact. An average of the five trials collected was utilised for statistical analysis (Cronbach’s Alpha ICC RT: a = 0.78 and MT: a = 0.93).

***Strength/functional assessments:***

The selected physical function and strength variables described in more detail in Table 1 were one-legged balance (OLB (Michikawa, Nishiwaki, Takebayashi, & Toyama, 2009)), sit-to-stand (STS (Jones, Rikli, & Beam, 1999)), a Physical Activity Scale for the Elderly (PASE (Washburn, Smith, Jette, & Janney, 1993)) score and falls risk. Three maximal repetitions of handgrip (HG (Nitschke, McMeeken, Burry, & Matyas, 1999)), hand-held dynamometry (HHD) shoulder flexion (SF (Andrews, Thomas, & Bohannon, 1996)), and HHD elbow extension (EE (Andrews et al., 1996)) were collected. For the upper limb strength tests and OLB a composite score of the left- and right-side average scores were used for analysis.

***Statistical analysis***

Two separate analyses were conducted to model the dependent variables of RT and MT to establish which measures are the most significant predictors of RT and MT in adults over the age of 60. All variables were assessed for normality, those with a non-normal distribution were log transformed. To check for multicollinearity, Pearson’s Correlation Coefficient analysis was utilized. Independent variables (EE, HG, OLB, PASE, SF, STS, and number of falls) with a significant *r* value >0.5 were identified for inclusion within the model. Concurrently, bivariate linear regressions, between each independent variable and RT or MT were conducted; variables with a criterion relationship (*P*<0.20) in the linear regressions and which did not violate multicollinearity assumptions were included in the multiple regression step-wise backward selection model. Significance was set at *P*<0.05 for the multiple regression analysis.

**Results**

Mean physical function and strength variables and bivariate regression results are reported in Table 2. The range of RT shown in this cohort was 0.126 – 0.298 ms and for MT the range exhibited was 0.178 – 0.686 ms. Significant models (Figure 2) were found for both RT (r2 = .08, *P* = 0.013) and MT (r2 = .06, *P* = .036). Faster RT was associated with stronger HG (Beta = -.002, *P* = .013), accounting for 8% of the variance in RT. Having a stronger HG by five-kilograms resulted in a tenth-of-a-second reduction in RT. Additionally, participants with stronger SF (Beta = -.04, *P* = .036) had faster MT, with the model explaining 6% of the variance. Stronger SF strength by one-kilogram resulted in a decrease in MT by 4%. For both models (RT and MT), age was not a confounding factor.

**Discussion**

This study provides insight into the relationship of muscle strength and physical function to RT and MT during a task simulating rapid protective arm responses similar to the movement required to land and control a forward fall on outstretched hands. The group mean RT and MT reported in this study are congruent with those of previous research investigating older female participants of a similar age (DeGoede et al., 2001; Robinovitch et al., 2005). To our knowledge, only three previous studies have examined the RT and MT components of pre-impact protective arm responses associated with fall arrest capacity in older adults (DeGoede et al., 2001; Kim & Ashton-Miller, 2003; Robinovitch et al., 2005). This study examined the relationship of strength and physical function to an older female participant’s RT and MT capabilities.

Age-related reductions in muscular strength have been well documented, with upper extremity strength seeing a decrease of over 30% from the second to eighth decade in female participants (Metter, Conwit, Tobin, & Fozard, 1997). Similarly, age-related declines in performance of RT and MT have also been shown in female participants from the second to eighth decade of 51% and 48% respectively (Hodgkins, 1962). Within this study cohort, age was not related to RT and MT, when added to the best fit regression models it did not have a confounding effect. RT is reflective of neurocognitive processing and responses. Within the present sample, faster RT was associated with stronger handgrip, a global functional measure of strength (McGrath, Kraemer, Snih, & Peterson, 2018). HG has been strongly associated with an individual’s physical function, cognitive function, mobility and mortality (Rijk, Roos, Deckx, van den Akker, & Buntinx, 2016). The findings of this study suggest that in older participants a higher HG, by five-kilograms, is related to a tenth-of-a-second reduction in RT. Given the limited time window to implement pre-impact strategies, approximately 680 ms to hand impact (Hsiao & Robinovitch, 1998), small improvements in RT could be the difference between a successful and unsuccessful pre-impact arm response following a balance perturbation. Decreasing an individual’s RT increases the amount of time available to implement a pre-impact strategy (Kim & Ashton-Miller, 2003). Given the evidence supporting the relationship of pre-impact strategies to post-impact responses to enable effective neuromuscular strategies and manage impact forces (DeGoede et al., 2003; Kim & Ashton-Miller, 2003), having a successful pre-impact response is necessary to mitigate injuries generated at impact to the upper limb, head or trunk (DeGoede et al., 2003; Kim & Ashton-Miller, 2003).

SF strength was related to MT in the community-dwelling older participants who participated in this study, accounting for only 5% of the variance in overall MT. Previous research has shown a significant inverse relationship between SF strength and MT (*r* = -.0487) in female participants during a forward fall protective arm response simulation (Robinovitch et al., 2005). The muscle groups assessed during the SF strength assessment are the same muscles activated during the primary movement pattern of moving the arms into the pre-impact brace position in preparation for a forward fall impact (Lattimer et al., 2016). The participants in this study with stronger SF strength exhibited faster MT, this relationship indicated a stronger SF by one-kilogram was associated to a decrease in MT by 4%. This may have potential implications for those engaging in fall prevention program prescription with an upper extremity strength training component. Implementing SF strength exercises into a fall prevention programming routine may have a positive impact on an older female participant’s pre-impact protective arm movement strategy MT.

After a fall initiation, in young adults, hand impact with the ground generally occurs within 550 to 800 ms, with an average of 680 ms (Hsiao & Robinovitch, 1998). Within the present study, 16% (12/75) of older participants exceed the hand impact time threshold exhibited by younger individuals, suggesting in the event of a real fall the olderparticipants would be unable to respond and reposition their arms in an appropriate pre-impact protective manner to arrest the fall impact. The slower overall times exhibited by these individuals appear to be due to slower MT, with an average MT of 0.542 ms and an average RT of 0.242 ms. In addition to this, pre-impact arm response MT (from the initiation of movement to impact) has been shown to take between 220-550 ms in older adults (DeGoede et al., 2001; Robinovitch et al., 2005). All participants in the current study who met, or were quicker than, the hand impact threshold (550 to 800 ms) were within the MT window reported in Robinovitch et al. (2005) and DeGoede et al. (2001). MT appears to be an integral component to achieve safe and effective arm responses for forward landing. In agreement with Robinovitch et al. (2005), the majority of older participants in this study had the necessary reaction and movement capacity to complete the suitable pre-impact protective arm responses that would be required during a forward fall event. In sideways falls, failure to generate a sufficient upper-limb pre-impact protective movement strategy to arrest a fall has been shown to increase impact forces substantial enough to generate a fracture at the hip (Lo & Ashton-Miller, 2008).

The physical function characteristics of leg strength and balance, measured in this study by STS and OLB, have been linked to an individual’s risk of falling (Smee et al., 2012). Despite meeting the criteria for entry into this study’s final regression model analysis, these physical characteristics were not significantly related to the pre-impact strategy components of RT and MT. Likewise, the number of falls a participant had in the preceding twelve months and their physical activity level, measured by the PASE (Washburn et al., 1993), did not correlate to the speed in which the older participants responded and moved their upper limb. A better understanding of any relationships between these functional measures and upper body RT and MT can help inform future fall prevention efforts that focus on improving the reactive components of balance.

The relationships identified in this study between UE strength capacity and pre-impact arm response RT and MT has biological plausibility. If strength and speed improvements were found to lead to improved pre-impact arm responses in longitudinal study designs, it could be a potential intervention avenue for preventing fall related injuries such as head impact. Fall observational studies have also recommended attention to upper-limb strength training as well as consideration of training other landing techniques (Schonnop et al., 2013). Global progressive resistance training has been shown to be beneficial for improvements in muscular strength and functional capacity related to fall risk (Latham, Bennett, Stretton, & Anderson, 2004; Peterson, Rhea, Sen, & Gordon, 2010). Less is known about the efficacy of incorporating targeted upper body strengthening specifically focused on concentric and eccentric control in activities simulating the control of a forward fall. There is promising evidence of efficacy for inclusion of activities such as a reverse push-up against a wall or on the floor in fall prevention programming (Arnold, Walker-Johnston, Lanovaz, & Lattimer, 2017). Adding in progressive speed challenges for UE motion can also result in improved UE reaction time (Engeroff et al., 2019). The findings in this study support efforts to further explore activities incorporating SF motion and overall UE strength into fall prevention interventions.

One limitation of this study is the lab simulation aspect of the design, where actual responses to a balance perturbation and forward fall may be quite different than this simulation. However, the measurement of RT and MT used in this study may be more representative of the requirements in an actual forward fall (DeGoede et al., 2003; Kim & Ashton-Miller, 2003) than other tests of upper limb reaction time used in fall risk assessments (Lord et al., 2003). The testing of RT and MT for this study was part of a larger study design where components of forward landing and descent were simulated after the testing of RT and MT in the standing position (Lattimer et al., 2017, 2018). Simulation can provide some information related to the phases of falling but are difficult to extrapolate to an actual fall event/ For example, an auditory cue utilised to initiate an arm response is not representative of the cues for response initiated by a balance perturbation. An individual’s true response time may be different during a real fall. Similar to that of previous work (Robinovitch et al., 2005), due to safety constraints of implementing actual falls, this study does not account for the urgency and associated fear response instigated by a fall.

**Conclusion**

Upper limb reaction and movement speed is consistently and significantly associated with higher hand grips and stronger shoulder flexion capacity. RT was related to global functional measures (HG) while MT was related to specific arm strength measures (SF). The findings suggest stronger arm strength measures were related to faster upper body reaction and movement time, with 10-20% higher strength associated with a 5% faster response time. An understanding of the relationship of the modifiable factors to arm RT and MT provides important information for practitioners working with older female participants, especially when designing fall injury prevention programs.

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**Figures**



**Figure 1:** Experimental set-up for reaction and movement time. From a standing position with arms by their side (left), participants responded, as fast as possible, to an audible signal presented after a randomized delay, by reaching both arms forward to touch dual force plates (OR6-7, AMTI, Watertown, MA, USA), positioned below shoulder height. Participants were instructed to contact the targets as ‘‘quickly as possible’’ with both hands after hearing the auditory cue (right).

**Figure 2:** Regression analyses of handgrip (HG) strength with reaction time (left, linear regression) and the shoulder flexion (SF) strength with movement time (right, transformed linear regression).

**Tables**

**Table 1**: Overview of variable definitions and physical function and strength measure protocols

|  |  |
| --- | --- |
|  | **Protocol:** |
| Handgrip | HG was assessed using a calibrated handgrip dynamometer (Model #5030J1, JAMAR, DMM, Canada) with the handle positioned in the second notch. The participant was seated in a chair, back supported, feet flat on the floor with the elbow at 90 degrees, wrist in neutral and the shoulder adducted to the body (Nitschke et al., 1999). Participants received the same instruction and motivational cues, resulting in a hold of approximately 5 seconds. |
| Sit to Stand | Participants started seated in a standard chair with their feet flat on the floor and arms crossed on their chest. Participants were instructed to stand up to a fully upright position and sit back down in a controlled manner, this was considered one repetition. Participants completed maximum repetitions in a 30 second period (Jones et al., 1999). One trial was used after one practice sit to stand. |
| SF | Laying supine on a standard plinth, with the shoulder flexed to 90° with 90° of horizontal adduction and the forearm neutrally rotated with palm facing medially. The HHD was placed proximal to the elbow joint on the anterior border of the upper, the tester provided support at the lateral border of the scapula (Andrews et al., 1996). A 5 second make test (Stratford & Balsor, 1994) was administered. |
| EE | Laying supine on a standard plinth, with their upper arm adducted to the body and their elbow flexed to 90 degrees, the participant's forearm was neutrally rotated with the palm facing medially. A small towel rolled underneath the arm ensured stabilization of the upper arm and the tester provided support at the distal end of the biceps muscle near the elbow joint. The HHD was placed on the lateral border and proximal to the styloid process of the ulna (Andrews et al., 1996) and a 5 second make test (Stratford & Balsor, 1994) was administered. |
| OLB | Participants were asked to stand on one leg on a hard-floor surface for as long as possible or until a 60 second period had been completed. Two trials were conducted on each leg, the trial was stopped if any-body part or the non-contact leg made contact to a surface for balance (Michikawa et al., 2009). For safety, the test was completed next to a support table. |
| PASE | The Physical Activity Scale for the Elderly (PASE) (Washburn et al., 1993) questionnaire, collecting physical activity reports in the past 7 days |
|  | **Definition:** |
| RT | Time from the audible sound to initiation of movement |
| MT | Time from initial arm movement to contact with the target |
| Fall Risk | Determined by having one or more falls in the previous 12 months. A fall was defined as any body part coming to rest on the ground, floor or a lower surface. |
| Age | Chronological age |

HG: handgrip, STS: sit-to-stand, SF: shoulder flexion, EE: elbow extension, OLB: one-legged balance, PASE: Physical Activity Scale for the Elderly, HHD: hand-held dynamometer (Model #01165, Lafayette Instrument Inc., Lafayette, Indiana, USA). RT: reaction time, MT: movement time.

**Table 2**: Means and standard deviation (SD) for all variables, the corresponding bivariate linear regression significance values for each variable with RT and MT.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Mean ± SD** | **Bivariate Regression**  **(*P* value)** | |
|  |  | **RT** | **MT** |
| Age (yrs) | 72 ± 8 | .100**a** | .352 |
| RT (sec) | .21 ±.03 | - | - |
| MT (sec) | .35 ± .11 | - | - |
| Handgrip (kg) | 20.69 ± 5.62 | .013 a^ | .064 a |
| SF (kg) | 6.35 ± 1.70 | .102 a | .036 a # |
| EE (kg) | 6.18 ± 1.39 | .138 b | .329 |
| STS (reps) | 10.45 ± 3.26 | .025 a | .156 a |
| OLB (sec) | 28.78 ± 20.77 | .188 a | .156 a |
| PASE | 120.72 ± 61.38 | .722 | .518 |
| Number of falls | .39 ± .49 | .594 | .639 |

RT: reaction time, MT: movement time, HG: handgrip, STS: sit-to-stand, TUG: timed-up and go, SF: shoulder flexion, SA: shoulder abduction, EE: elbow extension, OLB: one-legged balance, PASE: Physical Activity Scale for the Elderly. Number of falls reflects previous 12-months.

a included in the multiple regression step-wise backward selection model.

b not included in multiple regression step-wise backward selection model, strongly correlated to SF (*r*=.645, *P*<0.05), violation of multicollinearity.

^ Final predictor variable for RT (Beta = -.002) following multiple regression step-wise backward selection model.

# Final predictor variable for MT (Beta = -.04) following multiple regression step-wise backward selection model.