Fall Arrest Strategy Training Improves Upper Body Response Time Compared to Standard Fall Prevention Exercise in Older Women: A Randomised Trial

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ABSTRACT

Introduction: Exercise can decrease fall risk in older adults but less is known about training to reduce injury risk in the event a fall is unavoidable. The purpose of this study was to compare standard fall prevention exercises to novel Fall Arrest Strategy Training (*FAST*); exercises designed to improve upper body capacity to reduce fall-injury risk in older women.

Method: Forty women (mean age 74.5 years) participated in either Standard (n=19) or *FAST* (n=21) twice per week for 12 weeks. Both interventions included lower body strength, balance, walking practice, agility and education. *FAST* added exercises designed to enhance forward landing and descent control such as upper body strengthening, speed and practice of landing and descent on outstretched hands.

Results: Both *FAST* and Standard significantly improved strength, mobility, balance, and fall risk factors from pre to post-intervention. There was a significant time by group interaction effect for upper body response time where *FAST* improved but Standard did not ($p = .038$).

Discussion: *FAST* resulted in similar gains in factors that reduce fall risk as a standard fall prevention program; with the additional benefit of improving speed of arm protective responses; a factor that may help enhance landing position and reduce injury risks such as head impact during a forward fall.

Introduction:

Determining effective and feasible interventions to prevent the downward spiral of failing health, admission to long-term care and even death following a serious fall-related injury is important to older adults, the health care team, policy makers and the public at large. Exercise programs focused on balance, strength and functional mobility decreases fall risk and improves fall risk factors in community-dwelling older adults;[1, 2] however the impact of training other modifiable aspects of injury protection such as response time and effective landing and descent strategies is unknown.

The risk of injury from falls depends on both the severity of impact and neuromuscular capacity such as bone and muscle strength of the affected body part.[3, 4] Women are at higher risk of fall-related injuries than men and are much more likely to sustain upper limb fractures from a fall.[5] The majority of reported falls in community-dwelling older women is forward, commonly due to tripping.[6] Forward falls usually occur with hand contact as a *protective response* to prevent head, hip or torso injury.[4] The effectiveness of these upper body protective strategies, including response time, unfortunately decreases with ageing.[7] Video surveillance studies in long-term care facilities have observed a high number of falls where head impact occurred with hand impact, but in the majority of observed falls, older adults were unsuccessful in utilizing the arms to prevent head impact, suggesting an ineffective protective response to prevent brain injury.[8]

There is growing evidence supporting interventions such as perturbation training designed to enhance lower extremity postural reactions in decreasing fall risk and fall rates in older adults and clinical populations,[9] but little is known about the effect of training upper body

strength and landing capacity to reduce fall and injury risk. Younger adults can modify forward fall arrest strategies to improve safe landing and reduce hand and wrist impact forces by learning to land with a "soft" slightly flexed elbow, "catching the ground", and a controlled descent.[10, 11] Other factors such as pre-impact configuration of the body may also be important to reduce injury risk.[4] The critically important question is whether fall arrest training practice focussed on enhancing upper body and upper extremity (UE) strength, response time and landing strategies, can enhance older adults' ability to react and effectively control a forward fall and diminish the risks of serious injury such as head injury.

The purpose of this study was to compare the effects of Fall Arrest Strategy Training or *FAST*, to Standard fall prevention exercise on fall risk factors including upper body strength, mobility and response time, in older women.

Method:

A randomized design compared effects of two interventions on fall and injury risk variables of interest (clinicaltrials.org NCT04844047). Ethics approval was received by the University of Saskatchewan Biomedical Ethics Review Board (Bio 16-72) and all participants signed consent prior to testing. Women aged 60 years or older were recruited via announcements and posters in the community in 2016-2017. Exclusion criteria included upper body injury or pain within the last 6 months, any fracture within the past year, a history of a distal radial fracture in the past two years or any history of more than one distal radial fracture, history of UE neurological conditions or medical conditions contradicting UE strength testing or training, signs of severe cognitive impairment or unable to safely ambulate independently in the community. A screening questionnaire as well as the Mini-Cog[12] determined presence of

any of the exclusion criteria noted above. Eligible participants were randomly assigned 1:1 to *FAST* or Standard by someone not directly involved in the study using a computer generated random allocation (https://www.randomizer.org). Participants received a sealed envelope with group assignment after pre-testing, prior to commencement of the intervention. Trained testers, blinded to group assignment, conducted testing at a laboratory-testing site. Outcome measures for strength, mobility, response time and fall risk are described below. There were two cohorts resulting in four interventions: Two Standard and Two *FAST.*

1. <u>UE Muscle Strength</u>

Functional multi-joint UE strength measures reflected the muscle action, positioning and activation similar to the descent control required for a forward fall arrest.[13, 14] Three trials of concentric (CON) pushing and eccentric (ECC) resisting (Figure 1) were obtained utilizing an isokinetic dynamometer (Humac NORM Isokinetic Dynamometer, CSMi, Stoughton, MA) and a standardized protocol as described in previous publications with excellent test re-test reliability (ICC = 0.98; 0.97).[14] The Push Off Test (POT; Figure 2), originally described by Vincent et al,[15] used a calibrated handgrip dynamometer (Model #5030J1, JAMAR, DMM Canada) with the handle reversed, to measure the ability to push down on a stable surface. Angle of elbow flexion and shoulder extension were standardized (ICC = 0.92- 0.94). [14] Composite scores (Left + Right mean of three trials) were used for all strength measures.

<< INSERT FIGURE 1 AND FIGURE 2 HERE>>

2. <u>UE Mobility</u>:

Wrist extension (WrExt) and shoulder extension (ShExt) range of motion (active motion with passive overpressure) were measured with the participant sitting on a standard chair with no armrests, using a manual goniometer and a standardized protocol.[16] For both WrExt and ShExt, two measurements were taken for each arm and averages were used with composite scores (average L + average R) were calculated.

3. <u>UE Response Time:</u>

From a standing position with arms by their side, participants responded to an audible signal with randomized timing (1-5 seconds; Figure 3) by reaching either left or right or both arms together, as fast as possible, to touch a target on dual force plates (fs=2000Hz, OR6-7, AMTI, Watertown, MA, USA). Force and audio signal timing data were synchronously collected on the same system. Target height just below shoulder height was standardised to the participants' height and arm length. UE response time was defined as time from the audible signal to force plate contact. An average of five trials for each of left, right and both hands were used with excellent inter-trial reliability.[17]

<< INSERT FIGURE 3 HERE>>

4. <u>Fall Risk Factors:</u>

There were five standard measures used for fall risk. The FROP-Com (Fall Risk for Older People in the Community), a valid and reliable measure of multi-factorial fall risk status was administered via interview.[18] The timed up and go test (TUG) is a reliable and valid measure of fall risk and functional ability (ICC = 0.99).[19] Total time was recorded after one practice trial. The 30-second chair stand test (STS)[20] assessed the number of full sit to stand repetitions

performed in 30 seconds without the use of arms. Test re-test reliability reported as ICC 0.84-0.92[16]. Balance was measured using one leg standing (OLS).[21] Participants were given two attempts to reach the maximum of 60 seconds on both legs and the average was recorded with a composite score (L + R) used for analysis. The Activities-Balance Confidence Scale (ABC)[22] was used to monitor changes in fear of falls/balance confidence.

History of falls, including details regarding the reason for the fall, injuries sustained and the direction of the fall were recorded using a standard questionnaire.[23] The Physical Activity Scale for the Elderly (PASE)[24] monitored activity level outside of the intervention.

Intervention:

The Standard intervention consisted of a fall prevention exercise program designed for community-dwelling older adults[25] focussing on balance, leg strength, walking and mobility exercises. *FAST* intervention included the same exercises as Standard, but also incorporated *FAST* goals as described below. Both groups received a half-hour fall prevention education session once per week and attended twice per week exercise, 45 minutes in length, for 12 weeks at two assisted living sites in the community. Women living on site as well as in the community participated. The same two instructors; licensed physical therapists with more than 10 years of experience in fall prevention programming, led both interventions.

The overall goal of *FAST*[25] was to increase fall-arrest capacity or the neuromuscular ability to prevent and minimize injury during a fall by: 1) Increasing UE strength utilizing both CON and ECC contractions , 2) Improving trunk and neck postural control , and 3) Optimizing forward descent strategies for effective landing and controlled descent with hands. For

example, exercises in *FAST not* included in Standard: 1) wall push-ups with controlled and quick body descents, 2) floor activities (as able) weight shifting on hands and knees, 3) shoulder and elbow strengthening with elastic bands and light weights, 4) wrist extension and shoulder extension stretches, and 5) quick UE movement practice such as reaching activities, balloon and ball toss. Training progression for UE strength and body control included increasing the distance standing from the wall, progressing to one arm descents, increasing reps and speed and moving to greater gravity and body weight resistance such as hands and knees position on the floor as able. For example, wall push-ups progressed as follows: both hands 5 repetitions, both hands 10 repetitions, move away from wall (body lean approximately 45 degrees) both hands 5 repetitions, progress to 10 repetitions. This sequence was repeated with one hand push-ups as able. Push-ups using greater resistance on the floor were started once participants could easily do 10 reps against the wall both hands at body lean of approximately 45 degrees and if able to get up and down from the floor independently. Rapid hand and arm motion started with quick reach and touch to the wall in a static standing position, to reaching quickly with both hands to the wall and descending the body in a controlled fashion. Further progressions included increasing repetitions from 5 to 10, starting with the body further from the wall, and increasing speed. Other challenges to reaction speed included ball toss and balloon games which were interspersed throughout the 12 weeks. Instructions were provided to participants to progress at their own pace. Instructors monitored and encouraged participants to not progress to increased challenges if there was a loss of correct technique, excessive fatigue or pain. Individual progressions were not recorded but participants were asked to self-monitor and report any concerns to the instructors.

Analysis:

Based on previous pilot data, with an estimate of a 10% change in UE strength, a sample size n =22 per group was determined for an effect size 0.30, power = .90, α = .05).[25] Independent t-tests compared group pre-test values for age, height, weight, physical activity status, fall history status, and outcome variables. Intention to treat repeated measures MANOVA tests were used to determine time effects and group*time effects for the four primary outcome categories: 1) UE Strength (CON, ECC, POT), 2) UE mobility (ShExt, WrExt), 3) UE Response Time (Left, Right, Both) and 4) Fall Risk Factors (FROP-Com, TUG, STS, OLS, ABC). Significance level was set at α = .05. Frequency and descriptive data described number of falls, number of injurious falls and fall direction. A one-way repeated measures ANOVA compared pre to post self report of physical activity (PASE).

Results:

There were 21 women in *FAST* (age 73 ± 9 years) and 19 women in Standard (mean age 76 ± 7 years; Figure 4) with no significant differences between the groups for age, height, weight, body mass index (BMI), program attendance, physical activity status, number of prescription medications, or any pre-intervention outcome measures (Table 1). Ninety-five percent of the sample were right-handed. There were no adverse effects or events reported during the intervention period. At pre-intervention, 18 participants (46%) reported having a fall within the previous 12 months, 8 from *FAST* and 10 from Standard. Fall history for both groups is reported in Table 2. Twenty-four percent of the falls recorded at pre-intervention resulted in injury and 38% of the respondents who could recall the direction of the fall reported a forward direction either forward or combined forward with left or right direction. At post-intervention,

11 participants in total reported falling since pre-intervention, 5 from *FAST* and 6 from Standard.

<<INSERT FIGURE 4 and TABLE 1 and TABLE 2 HERE>>

Roy's largest root was used for all multivariate and univariate p-values. For UE strength there was a borderline significant multivariate time effect ($F_{3,36}$ = 2.87; p = .050; partial Eta^2 = .193) with significant univariate improvement for CON ($F_{1,38}$ = 5.41; p = .025; partial Eta^2 = .125) and ECC ($F_{1,38}$ = 6.58; p = .014; partial Eta^2 = .148). There was no significant time*group interaction (p = .391).

There were significant multivariate time effects for UE mobility ($F_{2,36}$ = 5.92; p = .006; partial Eta^2 = .248) with significant univariate improvements for WrExt ($F_{1,37}$ = 11.56; p = .002; partial Eta^2 = .238). There was no significant multivariate time*group interaction (p = .559).

There was no significant multivariate time effects for UE Response Time (p = .444) but there was a significant time*group interaction ($F_{3,36}$ = 3.12; p = .038; partial Eta^2 = .206) where only *FAST* improved UE response time. Univariate time*group interaction analysis revealed a significant right hand response ($F_{1,38}$ = 5.74; ; p = .022; partial Eta2 = .131; refer to Figure 5).

There were significant multivariate time effects for fall risk factors ($F_{5,34}$ = 6.96; p < .001; partial Eta^2 = .506) where significant univariate improvements for FROP-Com ($F_{1,38}$ = 10.52; p = .002; partial Eta^2 = .217), STS ($F_{1,38}$ = 27.29; p< .001; partial Eta^2 = .418) and OLS ($F_{1,38}$ = 5.73; p = .022; partial Eta^2 = .131). There was no significant time*group multivariate interaction (p = .318).

<<INSERT FIGURE 5 HERE>>

Discussion:

The purpose of this study was to determine the effect of 12 weeks of *FAST* compared to a Standard fall prevention program on upper body strength, mobility and response time, and fall risk factors in older women. The addition of *FAST* within the same allotted time of 45 minutes twice per week as Standard resulted in similar significant changes in functional performance known to decrease fall risk factors in older adults. Of importance, the addition of *FAST* improved UE response time, a finding not observed following the Standard program.

Balance recovery strategies such as taking a step, reaching to grasp an object or reaching the hands to land and protect the head from impacting the ground are all protective postural control reactions developed in the first year of life that persist into adulthood.[26] There is growing evidence supporting perturbation training designed to enhance lower extremity postural reactions in improving fall risk factors and decreasing fall rates in older adults and clinical populations.[9] Little is known about the effect of training upper body reactions that may help to control and diminish the impact of a forward fall and prevent injury risk such as head or other fall-related injuries. There are several age-related differences in UE reactions to a perturbation in older verses younger adults.[27] These include delayed onset of muscle activation and movement time, variation in strategies used (tendency to reach in the direction of the perturbation verses a counterbalancing motion), and greater forces sustained at impact.[7, 27] Older women, compared to younger women, also tend to land with stiffer arms, utilize less elbow flexion and absorb less energy during simulated forward fall landings and descents.[13, 14, 28] These age-related factors may partially account for differences seen in fall-

related injuries. Younger adults are more likely to experience less serious hand and wrist injuries as compared to older adults who are more likely to sustain serious injuries to the head.[29] In fact, video surveillance studies in long-term care facilities have observed a high number of falls where head impact occurred with hand impact, but the majority of observed falls were unsuccessful in utilizing the arms to prevent head impact.[8]

The results from both lab and video surveillance data helps to shed light on potential targeted training for older adults. The ability to quickly respond by reaching the hands forward following a perturbation such as a trip may result in being able to place the UE in a position where it is easier to utilize upper body strength to control the descent.[4] One could argue that rolling the body out of the fall might be another successful strategy to reduce upper body injury. However, based on findings where 97% of the time during forward falls older adults in long-term care respond with an UE protective response,[8] it appears that this reaction may be inherent and challenging to suppress, at least for older adults living in long term care. Training that might help to improve the capacity of the UE to react, place hands in a more effective position, with a stronger upper body to control the descent may add benefit to reducing injury risk. It remains unclear what the impact of this type of training has on preventing or reducing risk of serious injury such as head injury or other upper body injuries common to a fall such as a wrist fracture. There is evidence that both the positioning and the timing of the contraction of muscles on impact in the upper limb during a forward fall are important in reducing the risk of wrist fracture.[30]

Few studies have evaluated the effect of training on UE reaction or response time. There is some limited evidence that training voluntary stepping with reach and grasping a handrail can

result in improved arm movement times; however there are also observations of grasping errors which can delay contact or potentially impact other risks.[9, 27] A dynamic stretching program improved UE reaction time in younger adults.[31] Visual-motor training improved UE reaction time performance in athletes.[32] Research for older adults has focused primarily on interventions designed to train lower body reaction time through functional activities such as a balance obstacle course.[9]

FAST provided practice of responding quickly in targeted volitional practice as well as through functional and fun activities requiring quick responses. Each session incorporated practice of UE reaching and loading activities, typically against a wall or other firm surface. Unexpected audio cues were used for quick reaching activities with one hand or both hands. Progression of wall descent practice included reaching quickly with both hands to the wall and performing a controlled body lowering (reverse push-up). Other activities such as balloon "keep it in the air", ball toss, and obstacle courses including quick reaching and passing activities incorporated other training tasks designed to increase speed and accuracy of upper body motion. These activities were only in *FAST*, and therefore could explain the improvements seen in UE response time, as opposed to other aspects of improvement similar in both groups related to balance, upper limb mobility and strength. An interesting finding in this study, is the significant improvement for the right arm response time but not the left. We are uncertain of the reason for this, but ninety-five percent of the participants were right hand dominant. It is possible when training, participants tended to focus on their dominant hand or it was a tendency to use their dominant hand more during activities such as the balloon or ball toss. Future interventions should encourage equal practice using both hands.

Somewhat surprisingly, *FAST* did not result in significantly greater improvements in upper body strength and mobility compared to Standard. This finding may be explained by several factors. First, even functional practice of tasks to increase lower body strength, balance and general body agility inherently include some component of strength and mobility in the arms. For example, sit to stand practice was a common, similar activity for both groups. If participants could not control the movement with lower leg strength only, use of hands to push off was encouraged. Arm motion during balance practice also incorporates some UE strengthening and stretching components. Second, it was challenging to include the extent of time needed to progress upper body strength training in *FAST* within the allotted 45 minutes. Instructor feedback post-program recommended further modification in order to progress the strengthening component. Finally, it was difficult to control for other activities the participants were involved in outside of the program particularly in assisted living sites where recreational activities are encouraged and readily available.

The improvement in fall risk factors for both interventions after 12 weeks was encouraging. Systematic reviews have concluded that at least 6 months of exercise are required to obtain gains to decrease fall risk.[1, 2] This finding helps to support similar programming, still recognizing the importance of sustaining interventions for longer in order to realize sufficient clinically meaningful changes to improve fall risk factors. The women in this study represented a broad range of abilities and ages, suggesting fall prevention programming can meet the goals to challenge all levels of ability and retain safety for those at greater risk. The sample size was not adequate to explore difference in fall rates; however, it is interesting to observe that falling

forward was the most commonly reported fall direction in this study, similar to another study involving community-dwelling older women.[3]

One of the limitations of this study was the potential communication that may have occurred between groups as some participants resided in the same assisted living site. Although a randomized site design may have alleviated this cross contamination risk, it presents other difficulties when sites are not equivalent in resources, functional ability of participants or environmental factors. There were also real life challenges with a flu outbreak, and an environmental factor at one of the sites that resulted in more difficulty in recruitment and retention than our usual experience with this population.[25] A larger sample size may have resulted in significant findings in UE strength. Post-hoc power analysis revealed 44% power for concentric UE strength, with an estimated required sample n =46 per group for 80% power with beta 0.20 at $p < .05$ (https://clincalc.com/Stats/Power.aspx).

In conclusion, practical and feasible exercises designed to improve upper body fall arrest capacity improved fall risk factors, strength and mobility, *and* UE response time in older women. Further research needs to determine how UE response time alters the way older adults fall and land as well as determining if interventions such as *FAST* are beneficial in reducing risk of fall-related injuries such as head or other upper body injuries.

Clinical Messages:

- Exercises with balance, strength and functional mobility help to improve fall risk factors in older women after 12 weeks

- Training focused on upper body capacity to improve the protective responses inherent in forward fall landing and descent can increase movement speed which may help reduce forward fall-related injury risk

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Table 1: Demographic, Pre-Intervention and Post-Intervention Data for *FAST* (n = 21) and Standard (n = 19)

	FAST mean (SD)		STANDARD mean (SD)	
Variables	PRE	POST	PRE	POST
Demographic				
Age	73 (9)		76 (7)	
Height (cm)	160.4 (5.1)		159.9 (5.8)	
Weight (kg)	69.9 (10.9)		69.8 (12.4)	
BMI (cm/kg^2)	27.1 (3.1)		27.3 (5.2)	
% Attendance		74.6 (26.6)		75.4 (22.8)
# prescription meds	3 (2)		4 (3)	
PASE score	97.6 (46.4)	88.4 (50.1)	110.3 (52.9)	117.0 (50.0)
Upper Body Strength				
CON strength composite (kg)	20.9 (6.3)	22.6 (6.1)	20.9 (6.1)	21.2 (6.2)
ECC strength composite (kg)	29.2 (5.5)	31.0 (6.5)	29.3 (5.7)	30.6 (6.6)
POT composite (kg)	30.8 (8.2)	31.5 (8.0)	30.0 (5.7)	30.1 (5.9)
Upper Body Mobility*				
WrExt. ROM composite (^{o})	141.9 (15.3)	150.5 (15.1)	135.0 (16.1)	140.2 (15.5)
ShExt. ROM composite (^{o})	126.2 (15.4)	131.1 (16.2)	123.8 (21.3)	124.7 (16.6)
Upper Body Response Time*				
L hand (s)	0.62 (0.10)	0.60 (0.11)	0.62 (0.09)	0.64 (0.13)
R hand (s)	0.63 (0.13)	0.57 (0.10)	0.62 (0.11)	0.63 (0.13)
Both hands (s)	0.67 (0.16)	0.65 (0.10)	0.69 (0.11)	0.68 (0.14)
Fall Risk Factors*				
STS (#)	10.1 (3.2)	12.1 (3.8)	9.1 (3.4)	10.3 (3.4)
OLS composite(s)	45.8 (39.3)	62.3 (42.6)	43.8 (32.6)	48.3 (39.6)
TUG (s)	10.9 (3.2)	10.6 (3.4)	12.4 (7.8)	11.3 (5.5)
FROP-Com (/60)	7.8 (3.5)	6.8 (3.9)	8.4 (4.6)	6.5 (5.2)
ABC (/100)	78.3 (20.4)	84.1 (17.3)	75.4 (22.8)	74.7 (23.1)

*p<.05 multi-variate group X time interaction; ** p < .05 multi-variate time effect

Footnote: PASE: Physical Activity Scale for the Elderly; CON: Concentric; ECC: Eccentric; POT: Push-Off Test; WrExt: Wrist Extension; ROM: Range of motion; ShExt: Shoulder Extension; L: left; R: Right; STS: Sit to Stand; OLS: One-legged standing; TUG: Timed Up and Go; FROP-Com: Fall Risk for Older People Community Version; ABC: Activities Balance Confidence Scale.

Table 2: Number and Percentage of Participants with Fall History at Pre-Intervention (in the past 12 months) and at Post-Intervention (in the past 3 months)

	FAST		STANDARD	
	PRE (n=21) Number (%)	POST (n=20) Number (%)	PRE (n=18) Number (%)	POST (n=15) Number (%)
Fall History*				
No fall	13 (62)	15 (75)	8 (45)	9 (60)
One or > falls	8 (38)	5 (25)	10 (55)	6 (40)
	FAST		STANDARD	
	PRE (n=10) Number (%)	POST (n=5) Number (%)	PRE (n=19) Number (%)	POST (n=10) Number (%)
Reported Fall Descriptions (all falls described including multiple falls)				
Fall Direction Forward	4 (40)	3 (60)	7 (37)	1 (10)
Injury sustained	4 (40)	3 (60)	3 (16)	2 (20)

* no significant difference Pearson Chi square (p= .28) between *FAST* and Standard for fall history

A B

Figure 1: Concentric (CON) muscle strength test (A) and Eccentric (ECC) muscle strength test

Figure 2: Push-Off Test (POT)

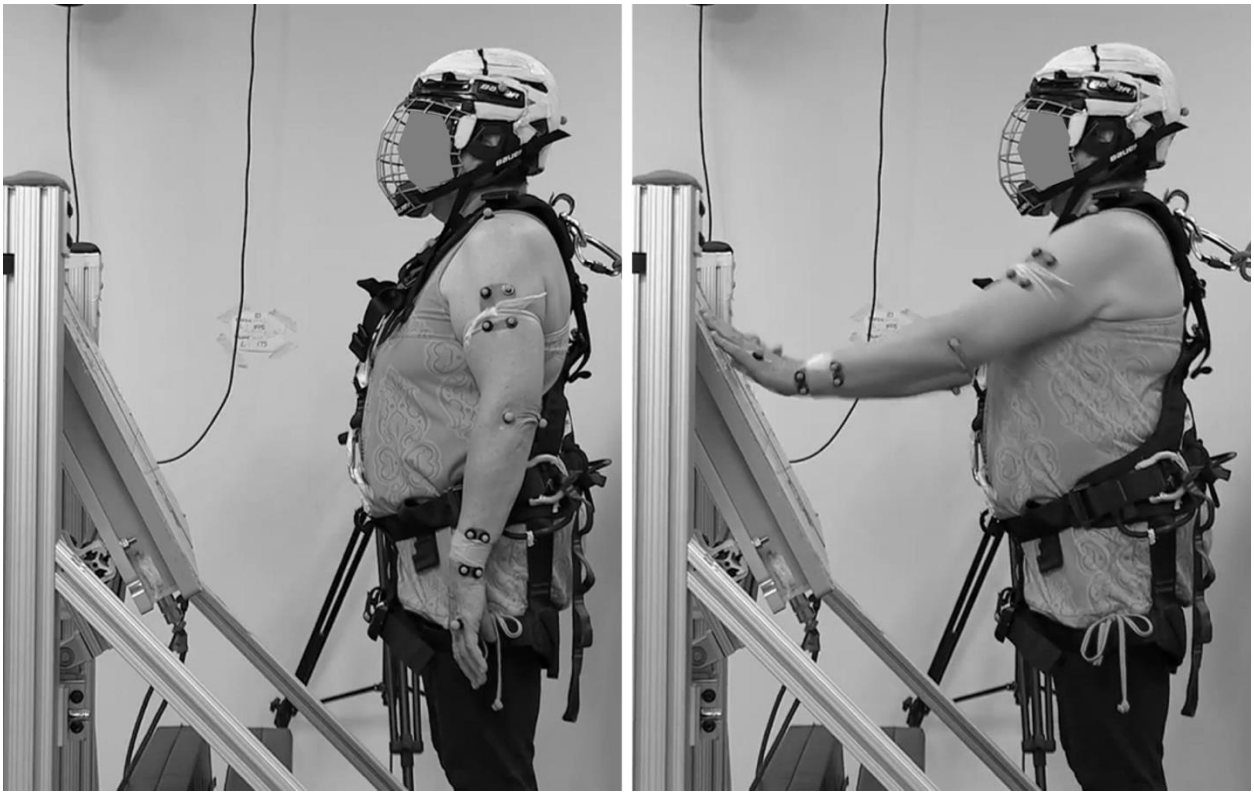


Figure 3: Measurement of Upper Extremity (UE) Response Time

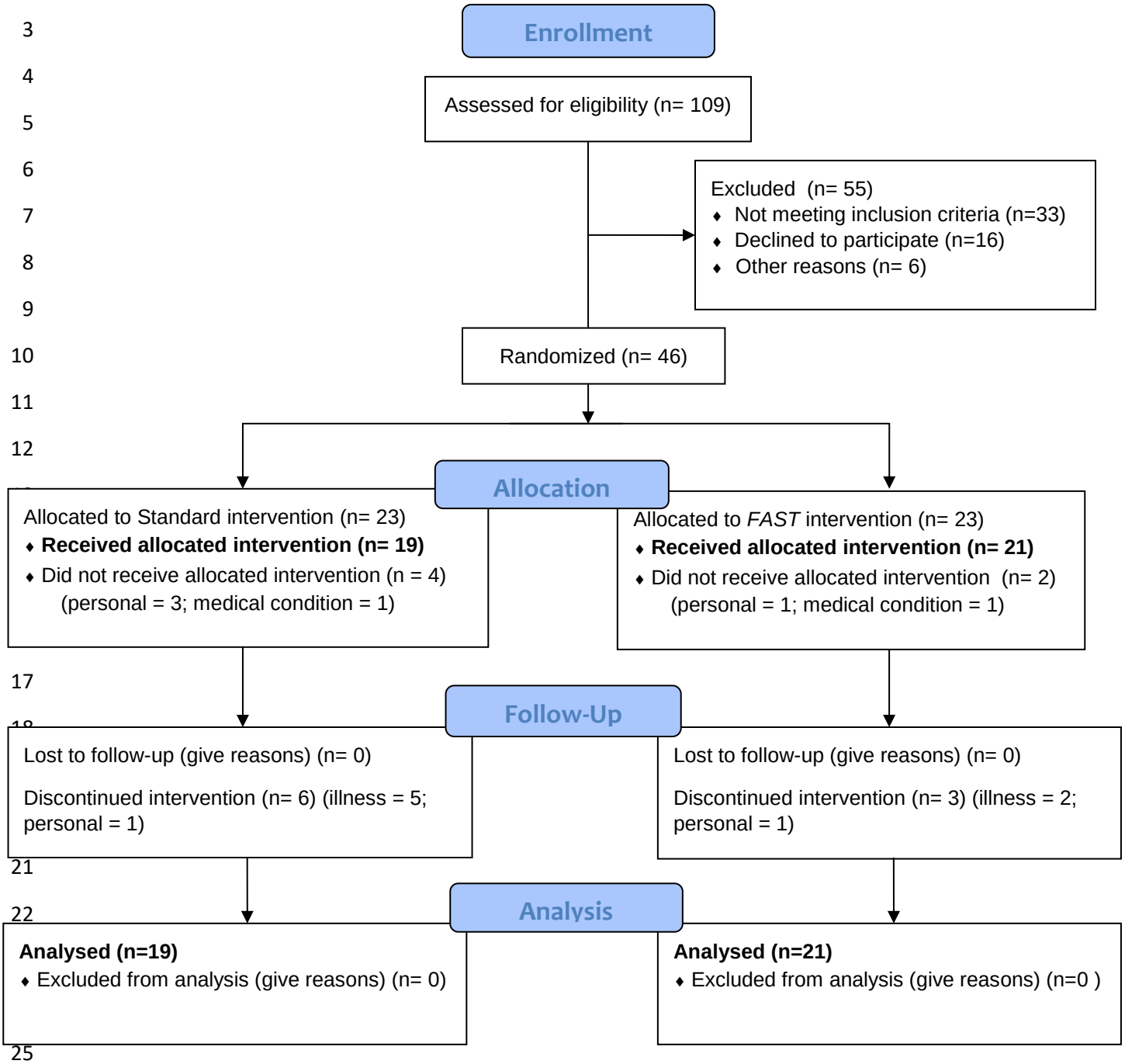
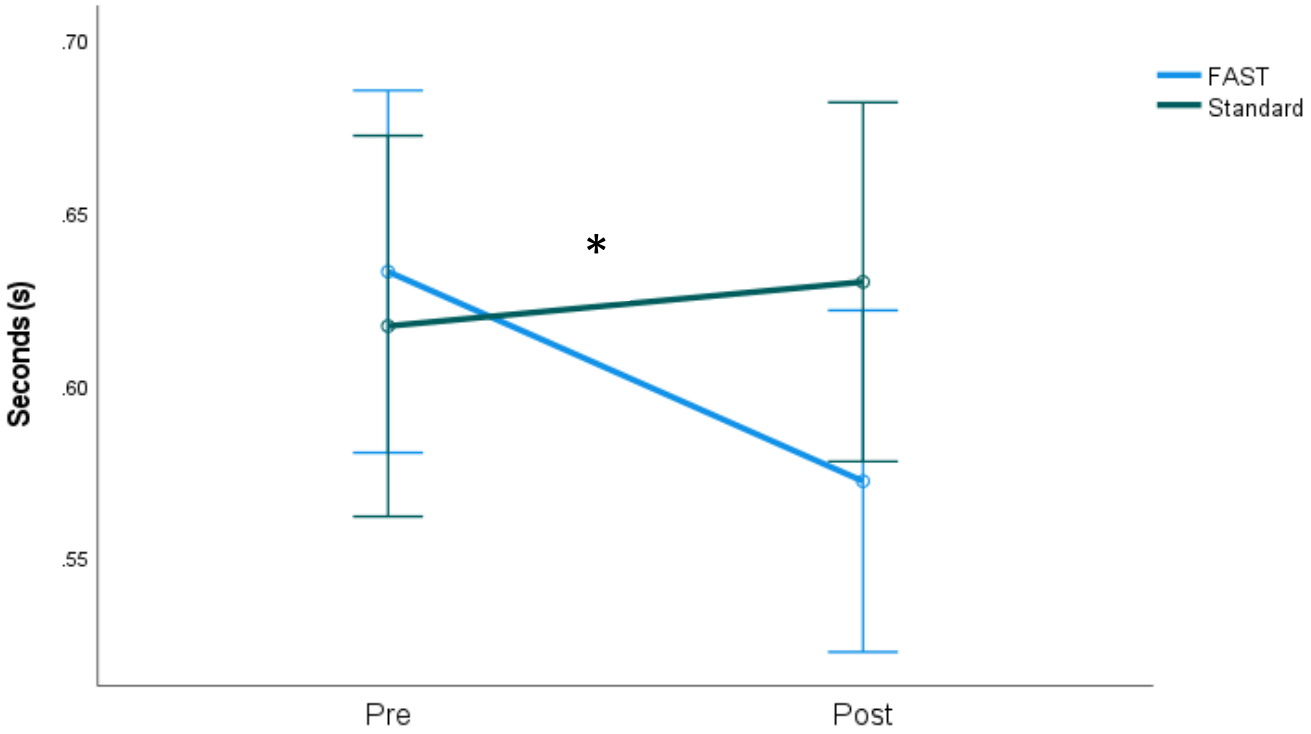


Figure 4. Participant Flow Diagram



Footnote: * $p < .05$

Figure 5. Right Upper Extremity (UE) Response Time with 95% Confidence Intervals