Acute exercise effects on balance outcome measures in healthy older adults: Preliminary results

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Abstract

Approximately one third of Canadian seniors experience a fall each year and one quarter suffer serious injuries as a result. Preventative exercise programs are commonly recommended; however, the current methods used to assess the risk associated with these programs do not include the effects of exercise on fall risk. The purpose of this study was to determine the effects of acute exercise on balance in elderly individuals. We hypothesized that acute exercise in healthy seniors would negatively affect balance outcome measures in those seniors who had a prior history of at least one fall in the past year. During the study participants were separated into two groups: those who had experienced a fall in the last year (fallers) and those who had not (non-fallers). All participants underwent static and dynamic tests to determine balance outcome measures under fatigued and control (non-fatigued) conditions. To represent the fatigued condition, the Naughton treadmill protocol was used to safely increase heart rate to 60-69% HR_{max} . Although it was expected that performance in the balance outcome measures would be adversely affected by the acute exercise bout in patients at a high risk of falling, conclusive results could not be drawn as the data collected were all from participants who had not experienced a fall within the past year. However, preliminary results are presented for data collected from six participants classified as non-fallers.

Keywords: acute exercise; balance; fall risk; older adults

Introduction

Second only to motor vehicle accidents, falls are the leading cause of injury-related hospitalizations for all ages (Public Health Agency of Canada 2005). However, with advanced age, generalized functional degradation is inevitable, which makes seniors much more susceptible to falls than other demographics (Talbot et al. 2005). Sixty-two percent of injury-related hospitalizations for seniors are the result of falls and those over the age of 65 have a fall-injury rate nine times that of those under 65 (Public Health Agency of Canada 2005).

Current methods of fall risk assessment include balance and gait tests that evaluate ability to stand up from a chair without the use of arms, and briefly walking before returning. This is known as the "Get Up and Go" test (Mathias et al. 1986). If patients encounter difficulty performing these tasks, they proceed to further testing where a history of patient risk factors is collected including medications, acute and chronic medical problems, and mobility levels. These are examined further on gait, balance, visual, neurological and cardiovascular tests. These assessments attempt to accurately determine fall risk;

however, because they do not include the effects of exercise on fall risk, they are not fully useful (Podsiadlo and Richardson 1991).

Long-term exercise and remaining active has shown to prevent falls in the elderly (Campbell et al. 1997; Barnett et al. 2003; Kannus et al. 2005). Exercise is used as a fall prevention intervention and can decrease risk factors associated with falls including reduced muscle strength and impaired balance and gait (Barnett et al. 2003). Impaired vision and the side effects of medication are also strong risk factors for falling, but require alternate intervention methods (Lord et al. 2010; Tinetti and Kumar 2010; Al-Aama 2011). Several studies have been conducted to determine how long-term exercise affects the risk of falling, but they fail to focus on how acute exercise can affect immediate balance outcome measures. For example, fatigue encountered immediately after exercise can change the force capacity of muscles and decreases the sense of position at the ankle. The effects of acute exercise could increase the ability of balance tests to detect differences in fallers (Simoneau et al. 2006; Sherrington 2008).

A study that examined the effect of gastrocnemius muscle fatigue on postural control ability in the elderly found that during a single leg stance, mediolateral stability and accuracy were negatively impacted by plantarflexor muscle fatigue (Nam et al. 2013). Although these results are not meant to reflect acute exercise, the methods used to simulate these conditions and assess postural balance follow similar guidelines as those that will be used in our study. This suggests that acute exercise may play a role in the depletion of posture and balance control. Additionally, studies that have used sit-to-stand tasks to mimic physical fatigue and to evaluate gait characteristics in elderly individuals have found similar results (Helbostad et al. 2007). Step-length variability and interstride trunk acceleration variability in the vertical direction were found to have increased in fatigued individuals, both of which are characteristic of an individual who is at risk of falling.

In this study, we assess the implications of acute exercise on balance outcome measures in healthy older adults classified as either fallers or non-fallers. We hypothesize a negative correlation between acute exercise and balance outcome measures for individuals who have suffered at least one fall in the past year, suggesting that acute exercise may have negative effects on balance for seniors with a prior history of at least one fall.

Methods

Sixty healthy adults over the age of 65 were recruited to participate in the study, though this article presents only preliminary results obtained from six participants. Prospective participants completed the Physical Activity Scale for the Elderly (PASE) instrument, Falls Efficacy Scale instrument, and a general health information sheet (Washburn et al. 1993). Exclusion criteria were set as having any systemic disorder or condition that would prevent completion of the tasks in the study (for example orthopaedic conditions, osteoarthritis, or the use of a walking aid) and a score of <25 on the Folstein Mini-Mental Status Exam. The Stroop test was also used as a physiologic assessment of the participants' mental vitality and flexibility (Bench et al. 1993).

The participants were classified into two groups: fallers and non-fallers. Fallers were those who had experienced a fall in the past year and non-fallers were those who had not. All participants completed the same tasks in the study to determine balance outcome measures under both fatigued (exercised) and non-fatigued (rested) conditions, with the non-fatigued tasks serving as the control. Balance tests under the two conditions were conducted on different days and the sequence was randomly determined.

To simulate the fatigued condition, the Naughton treadmill protocol was used. The Naughton treadmill protocol is designed to elevate heart rate to a level lower than the HR_{max} (maximum heart rate). In this test, participants start at a normal walking pace and slowly increase their intensity in specific minute intervals. In this study,

participants underwent the protocol while having HR monitored until they reached 60-69% HR_{max} (Johnson 2011).

Both static and dynamic tasks were used to determine balance outcome measures (**Table SA**). Balance outcome measures of these tasks were determined via nine clinical outcome measures, an instrumented walkway system (GAITRite® mat), and a force plate (AMTI©).

The nine tests comprising the clinical outcome measures used were: Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT-4), Four Square Step Test (FSST), Functional Reach (FR), Modified Physical Performance Test (MPPT), Dynamic Gait Index (DGI), Tinetti Performance Oriented Mobility Assessment – Balance Tests (POMA-B) and Gait Tests (POMA-G), Berg Balance Scale (BBS), and Timed-Up-and-Go (TUG).

Static tests comprised tasks that involved the feet remaining fixed. These tasks were assessed based on FICSIT-4, FR, MPPT, POMA-B and BBS clinical outcome measures, as shown in **Table 1**.

The BBS, POMA-B and FICSIT-4 tests use a scaled scoring system with ranges of 0-4, 0-2, and 0-1, where each number corresponds to factors such as use of arms, staggering, and the duration that a specific position is held. The totals from each test are added up and the resulting score corresponds to a level of fall risk (Berk 1992; Tinetti 1996). The MPPT test is a timed trial where a score of 0-4 is assigned to a specific time interval. The scores from this test are also summed to create an overall score that produces a corresponding level of fall risk. In the functional reach test, the distance that a participant can reach forward without taking a step is measured (Duncan et al. 1990; Brown 2000; Steffen et al. 2002).

Dynamic tests comprise tasks that involve either walking or running. These tasks were assessed based on BBS, POMA-B, MPPT, FR and FICSIT-4 clinical outcome measures, as shown in **Table 2**.

The BBS, POMA-B, FICSIT-4 and MPPT are used in specific dynamic tasks as well as static tasks. The FSST is a timed test where in a 2x2 grid, the participants step in each box (1-4) in a clockwise manner, then immediately reverse and step in each box in a counter-clockwise manner (facing forward throughout the entire sequence). A completion time below 15 seconds is considered to correspond to a low fall risk (Dite 2002). The DGI uses a scored scaling system for eight facets of gait, as shown in **Table 2**. The sum of all DGI scores corresponds to a specific level of fall risk. The POMA-G (gait) tests assess gait using a scored scaling system where the sum of all scores is combined with the final scores of POMA-B (balance) and a fall risk is established based on this combination. The TUG test is a timed trial where the participant stands up from a chair, walks three meters, and then returns to sit back down. Various cutoff times dictate fall risk. TUG-C (cognitive) and TUG-M (manual) tests are also used, which involve a standard TUG test accompanied by counting backwards and carrying a glass of water respectively (Shumway-Cook 1995; Shumway-Cook 2000).

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Table 1. Clinical outcome measures used in static tasks.

	Stand to Sit	Sit Unsupported	Sit to Stand	Stand: Eyes Open	Stand: Eyes Closed	Turn & Look over Both Shoulders	Parallel Stance: Eyes Open	Parallel Stance: + Nudges	Parallel Stance: Eyes Closed	Semi-Tandem Stance: Eyes Open	Semi-Tandem Stance: Eyes Closed	Full-Tandem Stance: Eyes Open	Full-Tandem Stance: Eyes Closed	Standing on One Leg	Functional Reach	Book Lift	Pick Up Object from Floor	Pick Up Penny From Floor	Put On/Off Jacket
BBS	X	X	X	X	X	X	X					X		X			X		
POMA-B	X	X	X	X				X	X										
MPPT			X				X			X						X		X	X
FR															X				
FICSIT-4							X		X	X	X	X	X	X					

Table 2. Clinical outcome measures used in dynamic tasks.

	Alternating Foot on Stool	Turn 360 Degrees	Four Square Step Pattern	Stairs	20' Walk Test	50' Walk Test	Walk: Initiation of Gait	Walk: Step Length & Height - R Swing Foot	Walk: Step Length & Height - L Swing Foot	Walk: Step Symmetry	Walk: Step Continuity	Walk: Path	Walk: Trunk	Walk: Walking Stance	Walk: + Change in Speed	Walk: + Horizontal Head Turns	Walk: + Vertical Head Turns	Walk + Pivot Turn	Walk: + Step Over Obstacle	Walk: + Step Around Obstacle	Timed Up & Go	Chair Transfer
FSST		X																				
MPPT				X		X																
DGI				X	X										X	X	X	X	X	X		
POMA-G							X	X	X	X	X	X	X	X								
TUG																					X	
BBS	X	X																				X
POMA-B		X																				

Table 3. Summed totals of 10 clinical outcome measures in all 6 participants.

	PARTICIPANT #1		PARTICIPANT #2		PARTICIPANT #3		PARTICIPANT #4		PARTICIPANT #5		PARTICIPANT #6		MAX SCORE
	C	E	C	E	C	E	C	E	C	E	C	E	
BBS	45	54	43	49	45	41	50	47	55	51	52	55	56
POMA	23	24	26	28	25	22	26	19	26	23	20	26	28
FICSIT-4	18	24	19	24	4	7	25	26	26	28	24	24	28
DGI	18	19	17	16	18	14	16	13	19	18	18	21	24
FSST	8.78	7.63	9.6	7.18	7.41	10.75	10.37	9.84	6.56	5.75	9.82	12.5	-
FR	30	34	26	28	36.36	34	10	13	31	32	35	37	-
MPPT	33	32	31	36	29	29	24	22	25	29	27	23	36
TUG	10.8	8.57	7.97	7.19	8.37	8.34	7.69	9.22	6.37	6.1	8.38	9.97	13
TUG-M	9.88	9.75	9.04	9.19	10.16	11.5	9.54	10.59	6.47	7.03	9.19	10.41	14.5
TUG-C	7.94	8.19	10.19	9	9.25	9.88	10.09	10.43	6.12	5.68	8.78	10.11	15

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Table 4. Stride length for participants 4,5 and 6 under fatigued and control conditions for dynamic tests 5a-5d and 5f (refer to **Table 2b**).

SUBJECT	CONDITION	5a	5b	5c	5d	5f
4	C	136.1	112.67	*	111.06	125.28
4	E	135.96	120.09	*	114.06	129.80
5	C	145.58	127.61	114.61	129.27	137.88
5	E	154.72	137.14	130.33	134.40	143.05
6	C	159.01	163.22	138.51	149.07	157.34
6	E	160.35	170.25	140.0	141.0	158.59
AVERAGE CONTROL		146.90	134.50	126.56	129.80	140.17
AVERAGE FATIGUE		150.34	142.49	135.17	129.82	143.81
PERCENT DIFFERENCE		102.35	105.94	106.80	100.02	102.60

*Participant 4 was unable to complete task 5c.

Table 5. Average percent differences for max/min values of F_x , F_y , COP_x and COP_y variables from the static tasks completed on the force plate.

	F_x	F_y	COP_x	COP_y
4a	101.50	94.85	111.85	166.06
4b	137.32	125.47	70.66	138.22
5	110.95	95.19	110.73	87.74
6a	119.26	90.03	115.91	116.38
6b	151.42	124.99	113.70	102.29
6c	147.75	165.57	115.79	166.67
7a	141.81	119.08	81.42	123.82
7b	122.27	92.65	102.43	83.08
8a	106.99	88.66	80.21	96.29
8b	191.24	64.96	87.79	97.27
9	218.90	151.89	162.79	192.14
10	274.69	105.31	107.18	95.39
11	214.17	103.51	108.96	92.15
12	175.09	136.60	106.15	133.14
13	134.03	112.49	60.19	86.81
14	233.29	136.50	128.85	113.63

In some of the tests relating to dynamic movement, balance outcome measures were measured via a walkway mat. This included walking straight and level and then with a change in speed, with horizontal head turns, with vertical head turns, and with stepping over an obstacle. Information regarding stride length, step length and stride time were collected and evaluated for balance levels.

In the tests relating to static movement, balance outcome measures were determined using a force plate, which provides information on forces in the medial-lateral (F_x), anterior-posterior (F_y), and vertical (F_z) directions as well as the moments around these axes. Center of pressure values (COP_x , COP_y) and averages were also calculated, along with minimum and maximum values.

Statistical analysis

Due to insufficient data, proper statistical analyses could not be conducted; however, once enough data have been collected, paired t-tests and linear regression will be used for statistical analysis.

Results and Discussion

All six participants involved in the study were classified as non-fallers. Therefore, the effect of acute exercise on balance outcome measures in fallers could not be determined with these data. However, **Table 3** displays the summed totals of the balance outcome measures for the existing participants (non-fallers), with tasks under the fatigued and control conditions completed on separate days.

Figure 1. Average participant scores for five clinical outcome measures with a maximum score under control and fatigued conditions. Values are expressed as a percent of the maximum possible score for each test with standard error bars included. The BBS (2.4% increase), POMA (2.74% decrease), FICSIT-4 (15% increase), DGI (4.7% decrease) and MPPT (1.2% increase) tests showed variation with increasing and decreasing balance outcome measures for the fatigued group. Significance is currently unknown as too few subjects were used to complete a t-test.

Figure 1 shows average clinical outcome scores of all participants for the following measures: BBS, POMA, FICSIT-4, DGI and MPPT. All of these tests have a maximum possible score that can be achieved (**Table SB**).

These preliminary data show no reduction in task performance in the fatigued state for non-fallers.

Figure 2. Average participant scores for the FSST and FR clinical outcome measures in control and fatigued conditions. These tasks do not have a maximum limit and thus cannot be expressed as percentages of the maximum possible score. The FSST (2.1% increase) and FR (5.7% increase) showed a slight increase in balance outcome measure scores in the fatigued group. Significance is currently unknown as too few subjects were used to complete a t-test.

Average participant scores for the FSST and FR test are shown in **Figure 2**. These measures do not have a maximum score, and show an increasing trend. Significant differences are unknown at this time, though the trend further indicates that there is no reduction in task performance in the fatigued state for non-fallers.

Figure 3. Average participant scored for the TUG clinical outcome measures in control and fatigued conditions. Values are expressed as a percent of the maximum cut-off score for each test. The TUG (0.4% decrease), TUG-M (7.7% increase) and TUG-C (1.7% increase) showed varied values for increased and decreased values in the fatigued group. Significance is currently unknown as too few subjects were used to complete a t-test.

Average scores for all participants undergoing the TUG tests are shown in **Figure 3**. The values are expressed as percentage values of the cut-off value for each particular test. The TUG test shows a very small decrease in values for the fatigued condition while the TUG-M and TUG-C show an increase in scores.

Use of the walkway mat was introduced after the third participant was tested; therefore, kinematic data were only recorded for subjects 4-6. Stride length was determined in the both the fatigued and control conditions. The averages are

expressed as percent differences between two groups, as shown in **Table 4**.

Stride length was the major kinematic variable assessed using the preliminary data that were presently available. Overall stride length in the exercised state increased for all tasks that took place on the mat except for walking with vertical head turns. The highest percentage difference between the two conditions was 5.94% for walking with a change in speed. This increase in stride length is not likely an attempt to maintain balance in the fatigued state as studies have shown that in the elderly, this tends to be accomplished via shorter stride lengths as opposed to longer ones (Shkuratova et al. 2004). Furthermore, the increase in stride length is quite minor and may not be significant. When the rest of the variables are analyzed, variability throughout the data would indicate poor balance while consistency would indicate good balance.

The variables that can be analyzed from the tasks completed on the force plate are F_x , F_y , COP_x and COP_y . Ranged determined from the maximum and minimum values are shown in **Table 5**. A large range indicates more movement on the force plate, which for a static task, signifies increased swaying and may signal impaired balance.

The largest difference in range values between the non-fatigued and fatigued conditions (from the averages of all participants) were seen in the following tasks: parallel stance with eyes closed, standing on one leg, forward reach, and putting on/removing a jacket. In the other extreme, the tasks where the range of motion decreased going from the rested to the exercised condition were: semi-tandem stance with eyes closed, full-tandem stance with eyes closed, and picking up a penny from the floor. Thus, the participants appeared to have difficulty remaining balanced in some tasks but not in others. Again, there was not a universal decrease in balance outcome measures for non-fallers.

Parreira et al. (2013) evaluated the effect of trunk extensor fatigue on balance in the elderly using a one-leg balance test and a force plate. Fatigue effects were observed immediately post-exercise and also at five, ten and twenty minutes after. Although elderly subjects had greater sway than young adults, the young adults had greater difficulty returning to pre-fatigued values after twenty minutes in comparison to elderly individuals. It is therefore possible that the variability in balance outcome measures in our study might in part be a result of the nature of the tasks as opposed to a consequence of impaired balance. For example, putting on and then taking off a jacket requires a lot of movement and thus an increased range between the two conditions may not necessarily correlate with decreased balance. Granacher et al. (2010) also reached similar conclusions when examining the effects of muscle fatigue on gait characteristics during single and dual-task conditions. Decreased stride length and gait velocity were observed in young adults while increases in these variables occurred in older adults. The differences seen between young and old participants may be a result of muscle motor unit remodeling that occurs in old age (Granacher et al. 2010). Denervation

followed by re-innervation results in a switch from type II to type I muscle composition. Type I are slow twitch fibers with larger volumes of myoglobin and oxygen and are thus less prone to fatigue (Roos et al. 1996). This physiological change could account for the fatigue-resistance seen in the elderly.

Furthermore, a study by Toebe et al. (2014) not only found that leg muscle fatigue did not negatively impact balance, but also showed a faster return to unperturbed gait patterns in response to perturbations than in an unfatigued condition. Unilateral leg muscle fatigue was achieved with the use of squat exercises. Although knee extension strength decreased from the unfatigued to the fatigued condition, balance control in gait was not negatively impacted as hypothesized. It would appear that these observations suggest that muscle fatigue did not have a negative impact on the elderly participants; however, Toebe et al.'s study looked specifically at fatigue in the knee extensor muscles and did not account for loss of balance as a result of fatigue in other muscles. It was also emphasized in this study that the fatigue protocol was not intended to simulate the fatigue experienced in everyday life, but rather to demonstrate how balance in gait is impacted by the capacity of muscle to produce force.

Limitations and Conclusion

Limitations of our study include that data collected from the clinical balance outcome measures may be subject to ceiling and floor biases. For example, on certain tasks, more participants than expected may perform well (a ceiling effect) or poorly (a floor effect) due to the specific nature of the task. Thus, it will be important to analyze kinematic and force plate data once all participants have been tested in order to obtain more conclusive results.

Data collected up to this point in our study cannot be used to evaluate the effect of acute exercise on balance outcome measures in those with a prior fall history, but does demonstrate that acute exercise does not appear to impair balance in non-fallers. This is useful preliminary information for seniors participating in exercise programs who have not experienced a fall in the past year.

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Supplementary Information

Table SA. Interpretation of the 10 clinical outcome measures.

Static Tasks		Dynamic Tasks
1	Standing to sitting	Four square step pattern
2	Sitting with back unsupported	Turn 360 degrees
3	Sitting to standing	Place alternating feet on stool
4a	Standing: eyes open	Chair transfers (4)
4b	Standing: eyes closed	
5a	Turn and look over both shoulders (5)	Level surface gait
5b		+ change in speed
5c		+ horizontal head turns
5d		+ vertical head turns
5e		+ pivot turn
5f		+ step over obstacle
5g		+ step around obstacle
6a	Parallel stance: eyes open	Timed up and go
6b	Parallel stance: with nudge	TUG-cognitive
6c	Parallel stance: eyes closed	TUG-manual
7a	Semi-tandem stance: eyes open	Stairs (7)
7b	Semi-tandem stance: eyes closed	
8a	Full-tandem stance: eyes open	
8b	Full-tandem stance: eyes closed	
9	Standing on one leg	
10	Forward reach	
11	Book lift	
12	Pick up object from floor	
13	Pick up penny from floor	
14	Put jacket on and then take jacket off	

Table SB. List of static and dynamic tasks.

Clinical Outcome Measure				
BBS	41-56 = low fall risk	21-40 = medium fall risk	0-20 = high fall risk	
POMA	25-28 = low fall risk	19-24 = medium fall risk	<19 = high fall risk	
FICSIT-4	Higher scores = lower risk of falling (Deshpande 2009)			
DGI	<19 = predictive of falls in elderly >22 = safe ambulator			
FSST	>15 second cutoff			
FR	>25 cm = adequate functional balance			
MPPT	32-36 = not frail function in community	25-32 = mild frailty	17-24 = moderate frailty	<17 = unable to
TUG	>13 second cutoff			
TUG-M	≥14.5 second cutoff			
TUG-C	≥15 second cutoff			