The Effects of Upper -Body and Lower -Body Fatigue on Standing Balance

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No conflicts of interest declared.

Abstract

The purpose of our study was to analyze the effects of upper-body fatigue and lower-body fatigue on post-exercise standing balance. Force plates were used to assess static balance by measuring the displacement of the Center of Pressure (COP) while subjects stood on the plate. Ten healthy male undergraduate students (mean age 20.7 years, SD = 1.3) each participated in one session. All subjects were considered to be physically fit, as determined by self-reported vigorous physical activity in hours per week (mean activity 7.1 hours, SD = 3.7). During sessions, participants performed two control trials and two fatigue trials, with each trial consisting of subjects standing motionless on a force plate for 20 seconds. Participants completed one upper-body fatiguing protocol and one lower-body fatiguing protocol in random order. Standing balance trials were completed before and immediately following each fatigue protocol. Lower-body fatigue was achieved by participants performing a maximum number of body-weight squats, while upper-body fatigue was attained by participants performing a maximum number of push-ups. Subjects reported their Rate of Perceived Exertion (RPE), which was used to determine individuals' subjective level of exhaustion on a scale of 6-20 (mean squat RPE = 14.9, SD = 2.2; mean push-up RPE = 15.4, SD = 1.3). Each subject was required to rest during a 15-minute recovery period between each fatigue protocol. The upper-body fatigue protocol produced significant ($p < 0.05$) mediolateral variability of the COP when compared to the control condition, and additionally, the lower-body fatigue protocol resulted in a significantly greater path length in comparison to the control trials. There was no significant difference in standing balance between upper and lower-body fatigue trials. The most paramount findings of the present study indicate that the selective fatigue of upper-body musculature greatly impairs standing balance, particularly by causing significant mediolateral deviations.

Introduction

Muscular fatigue is defined as the acute impairment of performance, as well as the inability to produce a desired force [1]. Balance is considered to be essential for both everyday activities and physical activities [2]. Due to balance having an impact on skillful performance in many physical activities, it is important to identify the muscle groups that contribute to balance, and further, which muscles contribute to imbalance upon fatigue [3].

Several studies have illustrated that the selective fatiguing of lower-body musculature, as well as non-specific, whole-body fatigue, have a detrimental effect on static balance [4-6]. Researchers agree that fatigue impairs balance in general, and therefore, increases the risk of injury [6-8]. Further, Steinberg et al. recommend that one should rest immediately following exercise in order to prevent injury [8].

Despite the risk of injury associated with muscular fatigue and its impact on performance, there has been minimal research investigating the influence of upper-body musculature fatigue on standing balance. Previous research has found that upper-body fatigue produced no significant balance impairments [9-11]. However, this previous literature has only employed the arm crank ergometer as the mode of exercise to attain upper body fatigue [9-11]. These conclusions are not generalizable, as fatigue is isolated to the upper extremities only. The current study aims to improve on this by inducing fatigue in a larger portion of the upper body.

The purpose of the present study was to determine the degree to which static balance was impaired due to upper-body fatigue when compared to lower-body fatigue. It was hypothesized that (1) following upper-body fatigue, static balance would be impaired significantly, and that (2) lower-body fatigue would result in a greater balance impairment than upper-body fatigue.

Methods

Participants

Ten male subjects (mean age 20.7 years, SD=1.7 years; mean height 176.9cm, SD=4.7cm; mean weight 82.7 kg, SD=13.7 kg) participated in the study. Subjects volunteered to participate in the study by responding to posters distributed around Western University's campus. Subjects on average spent 7.1 hours/week participating in vigorous activity (SD=3.7 hours/week). No participants identified a reason to precluded them from participating in physical activity.

Instrumentation

A piezoelectric Kistler force plates (9287B and 9287BA, Kistler Holding AG, Winterthur, Switzerland) was used to measure the ground reaction force and moments about all axes (X, Y, and Z). In-

formation regarding these variables was transferred from the force plate to the computer via a connector. The analog-to-digital converter program within the computer converted a continuous physical quantity to a digital numeric representation. Data was recorded at a rate of 100Hz. The force plate was reset before each control trial.

Procedure

This study was approved by the University of Western Ontario's ethics board and all participants provided informed *consent* and completed a questionnaire prior to participating in the experiment. The questionnaire was used to determine the activity levels and types of exercise performed by participants. Each subject conducted their experimental trial independently from other participants.

Subjects performed two control trials and two fatigue trials (one upper-body and one lower-body). Trials consisted of participants performing quiet standing balance anywhere on the force plate for 20 seconds. Participants completed a control trial prior to performing the assigned fatigue protocol. Immediately following the completion of the fatigue protocol participants performed a fatigue trial. Upper-body and lower-body fatigue protocols were assigned at random. Number of completed repetitions and rate of perceived exertion on scale of 6-20 was recorded following the fatigue protocols. Fatigue protocols consisted of completing as many repetitions of the prescribed exercise as possible until technical break-down or until the participant desired to stop. Feedback was not given to participants. A rest interval of 15 minutes was taken between the completion of the first fatigue trial and the commencement of the second control trial.

Participants performed squats for the lower-body fatigue protocol and performed push-ups for upper-body fatigue protocol. Squat form was as follows: each squat must have begun from standing position with feet shoulder-width apart, knees fully

extended, and hips extended. With a straight back, participants must have squatted down until their knee reached at least 90 degrees of flexion. Participants then returned to the starting position. This was considered to be one repetition.

Push-up form was as follows: subjects began with a straight back, hips extended, hands underneath the shoulders, and elbows fully extended. Participants were able to decide whether to complete push-ups by pivoting on their knees or feet. Participants then lowered themselves towards the floor until their elbows reached at least 90 degrees of flexion. Participants then returned to starting position by extending their elbows and adducting their shoulder. This was considered to be one repetition.

Calculations

Center of Pressure (COP) in the Mediola-teral (M-L) and Anterior-Posterior (A-P) axes were calculated via the following formulas:

$$COP_{A-P} = \frac{M_x + cF_y}{F_z}$$

$$COP_{M-L} = -\frac{M_y + cF_x}{F_z}$$

Where:

- M = Moment
- c = location of the origin of the force plate coordinate system
- F = ground reaction force

Data was normalized via the following:

$$COP_{normal} = COP_{original} - COP_{mean}$$

Where:

- COP_{normal} = Normalized COP
- $COP_{original}$ = Original COP calculated
- COP_{mean} = Mean COP

Path length was determined via the following formulas:

$$\Delta COP_{M-L_n} = COP_{M-L_n} - COP_{M-L_{n-1}}$$

$$\Delta COP_{A-P_n} = COP_{A-P_n} - COP_{A-P_{n-1}}$$

$$Pathlength = \sum_{i=1}^{n=2000} \Delta COP_i = \Delta COP_i + \Delta COP_{i+1} + \dots + \Delta COP_{n-1} + \Delta COP_n$$

$$\Delta COP_n = \sqrt{\Delta COP_{M-L_n}^2 + \Delta COP_{A-P_n}^2}$$

Where:

- ΔCOP_{M-L_n} = displacement of COP on M-L axis at data point n
- ΔCOP_{A-P_n} = displacement of COP on A-P axis at data point n
- ΔCOP_n = displacement of COP at data point n

Data Analysis

T-Tests were performed between the following trials: control-upper and control-lower; control-upper and fatigue-upper; control-lower and fatigue-lower; fatigue-upper and fatigue-lower. T-tests were two-tailed and paired. P-values of 0.05 were used to determine significance. Range was the measure used for COP variability

Results

The upper-body fatigue protocol produced significant ($P=0.0499$) M-L variability of the COP when compared to the control trial, while A-P variability and path length showed no significant difference (A-P: $P=0.361$, path length: $P=0.762$). The

	Squat		Push ups	
	Reps	RPE	Reps	RPE
Mean	97.0	14.9	47.5	15.4
SD	77.7	2.2	16.5	1.3

Table 1: Subjects' ($n=10$) mean ($\pm$ SD) number of squat and push-up reps and self-reported RPE.

lower-body fatigue protocol produced significantly longer path length when compared to the lower body control protocol ($P=0.0426$) while differences in A-P and M-L variability were not significant (A-P, $P=0.214$; M-L, $P=0.180$). No significant differences were found between upper and lower body fatigue trials (A-P: $P=0.0381$, M-L: $P=0.182$, path length: $P=0.258$) and no significant difference was found between upper and lower body control trials (A-P: $P=0.585$, M-L: $P=0.692$, path length: $P=0.647$). Mean repetitions completed and RPE can be found in Table 1.

Discussion

The most important findings of the study were that upper and lower body fatigue produced similar balance impairments. It was first hypothesized that upper body fatigue would impair static balance, and additionally, our second hypothesis stated that lower body fatigue would produce a greater balance impairment than upper body fatigue. In this study, upper-body fatigue resulted in significantly greater variability of the COP in the mediolateral axis when compared to control trials, and lower-body fatigue resulted in a significantly greater path length than control trials. Thus, the first hypothesis was confirmed, but our second hypothesis was not confirmed.

The findings of the study are consistent with results of past studies in that lower body fatigue impairs static balance [4-6, 13]. In one such study, the effect of lower-body fatigue on standing balance was tested [13]. The subjects were fatigued via an isokinetic dynamometer to less than 50% of their initial tested force. As a result, it was determined that lower body fatigue significantly reduced scores on bilateral static balance tests. Their results, similar to ours, demonstrated that lower body fatigue caused a significant reduction in standing balance, and further, it was concluded that fatigue increased susceptibility to musculoskeletal injury.

Although the literature has deduced that general fatigue and lower-body fatigue impairs balance, in addition to balance impairment increasing the risk of various injuries, there have been only a

few studies investigating the impact of upper-body fatigue on balance. The current study found significant M-L variability following upper body fatigue; however, previous studies investigating postural sway following upper body fatigue identified no significant differences in M-L variability [9-11]. The findings of the study supported previous research in that A-P variability and path length showed no significant difference following upper-body fatigue [9-11]. These prior studies investigated upper body fatigue only through using an arm crank ergometer, thereby isolating the exercise to a specific set of upper body muscles.

Limitations and Future Directions

The population of our study was solely male. The authors were unable to recruit a sufficient number of female volunteers, and thus, decided to make the current study exclusively male. Seeing as sex-based balance disparities may exist, this could potentially limit the validity of the study's results in a female population. Future studies should investigate possible differences in balance impairments resulting from fatigue that may exist between males and females. In addition, all ten subjects were young, healthy and physically fit, allowing for further research within different age and disability groups.

The current study did not distinguish between aerobic and anaerobic fatigue, and only tested groups of upper-body muscles or lower-body muscles. Further research should be done to investigate whether there are differences in balance as a result of either aerobic muscular fatigue or anaerobic muscular fatigue in the upper and lower body. Additionally, the isolated fatiguing of individual muscles could yield important information regarding relative contributions to balance and imbalance.

Dynamic balance was not tested in the current study, but past literature has shown that it is affected negatively by upper body fatigue [12]. Moving forward, investigating both dynamic and static balance with the same fatiguing protocols will provide a more comprehensive result.

Furthermore, the small sample size of 10 is a limitation of the current study. To better represent the population, future studies should utilize larger sample sizes.

Conclusions

The results of our study indicate that the fatigue of upper body musculature presents implications for balance and increases the risk of injury in young, healthy males, and warrants further research. There needs to be further investigation of different populations, as well as the employment of different methods of attaining fatigue in various muscles in the upper-body. Further, future studies should utilize larger sample sizes.

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