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Andreas Germanos
Chapman University

Tessa Heiberg
Chapman University

Annie Jeon
Chapman University

Emi Heisterkamp
Chapman University

Hao Giang
Chapman University

See next page for additional authors

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Authors

Andreas Germanos, Tessa Heiberg, Annie Jeon, Emi Heisterkamp, Hao Giang, Jessica Cota, Laura Corona, Thomas Loi, Vincent Bovino, Shayce Cordero, Sunny Kim, Michael Shiraishi, and Rahul Soangra

Bruce Protocol Test affects Postural Stability in Healthy Young Adults

Andreas Germanos¹, Tessa Heiberg¹, Annie Jeon¹, Emi Heisterkamp¹, Hao Giang¹, Jessica Cota¹, Laura Corona¹, Thomas Loi¹, Vincent Bovino¹, Shayce Cordero¹, Sunny Kim¹, Michael Shiraishi¹, Rahul Soangra^{1 & 2}

¹Department of Physical Therapy, Crean College of Health and Behavioral Sciences, Chapman University
Irvine, CA 92618 USA

²Fowler School of Engineering, Chapman University, Orange, CA 92866 USA

Maintaining balance is key in avoiding falls and injury. However, little is known on how increased cardiac activity may affect postural stability. This study investigated if increase in cardiac activity to 85% maximal heart rate (HR) when exercising with standard Bruce Protocol Test (BPT) influence postural sway. Ten young adults were tested for three postural stances, quiet bilateral standing with i) eyes open, ii) eyes closed, and iii) tandem stance, before and after performing the BPT. Resting Heart Rate (HR) and HR variability along with standard postural sway parameters like sway velocity, sway area, turn index, and power frequency in the anterior-posterior (AP) and medial-lateral (ML) directions were evaluated. We found significant increases in postural sway values for turn index values due to HR changes. Thus, balance demanding tasks may be avoided immediately after performing submaximal cardiac activities in order to avoid fall risk and injury.

Introduction

Balance is defined as an individual's ability to maintain their center of gravity (COG) within their base of support (BOS)(Shumway-Cook et al., 1988), and is facilitated by somatosensory, visual, and vestibular feedback (Derave et al., 2002). The somatosensory system is the dominant sensory system and consists of input from golgi tendon organs (GTOs), muscle spindles, joint receptors, and cutaneous receptors (Grace Gaerlan et al., 2012). The visual system generates field-of-view information for self-motion(Wade & Jones, 1997), and the vestibular system within the inner ear senses linear and angular head motion in space(Forbes et al., 2015). The central nervous system is responsible for integrating the feedback from all of these sensory systems and activate effector muscles to maintain balance. When there is a perturbation to balance, correction of the altered body position is undertaken by muscles involved in postural control such as ankle plantar/dorsi-flexors and hip abductors/adductors(Winter et al., 1996). Poor postural control is associated with falls, increased potential for injury, and diminished movement performance(Cuevas-Trisan, 2017). Balance and fall risk are especially pertinent to the older adult population. Deficits in somatosensory, visual, and vestibular feedback are largely responsible for these adverse changes to balance. Aside from the role of changes in sensory inputs, little is known about other potential physiological disturbances which may impact balance and postural sway. Specifically, the effects of heart rate on balance have not been fully elucidated. Heart rate is controlled by both the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), which are branches of the autonomic nervous system (ANS)(Gordan et al., 2015). During exercise, the SNS is activated and heart rate is increased due to multiple mechanisms. The baroreceptor reflex involves stretch mechanoreceptors in the atria, which are able to detect distension due to increased blood volume from exercise. The

receptors in turn increase heart rate via sympathetic activation (HakumÄKi, 1987). In addition, contraction of skeletal muscles and their metabolic demand also causes an increase in sympathetic stimulation and heart rate, known as the exercise pressor reflex(Grotle et al., 2020). Central command is another mechanism controlling heart rate, whereby exercise ultimately induces parasympathetic withdrawal and sympathetic activation as a function of exercise intensity and muscle mass recruited (Nobrega et al., 2014). In each mechanism of increased sympathetic stimulation, the hormone norepinephrine is released by the postganglionic neurons of the SNS. Norepinephrine then binds to $\alpha 1$ and $\beta 1$ receptors present in the SA node, AV node, and atrial and ventricular cardiomyocytes of the heart to ultimately increase heart rate(Gordan et al., 2015).

This study aimed to determine if the increase in heart rate with exercise such as standard Bruce protocol test has an effect on balance. Playing sports, running, working, and other common activities of daily living all have the effect of increasing cardiac output as individuals exert energy in order to perform. Heart rate has become a parameter that is commonly used to assess health(Seravalle et al., 2021). Although, exercise and physical activity, high intensity interval training (HIIT) has been suggested to increase factors such as exercise capacity and quality of life(Ellingsen et al., 2017). But knowledge on influence of heart rate on one's balance is limited. Thus, the purpose of this study is to determine how increased heart rate influences balance.

Methods

Ten healthy young adults with an average age of 24.16 ± 2.59 (50% male, 50% female) (Table 1) participated in this study. The study's independent variable was heart rate (with normal and high levels) and the dependent variables were RR interval (milliseconds), and postural sway parameters from forceplates such as sway velocity (mm/s), sway area (mm²),

turn index (# of turns), and frequency of sway in the anterior-posterior and medial-lateral direction (Hz). Some confounding variables in this study were muscle fatigue as well as varying shoe type between participants which were not controlled or standardized. The goal of this study was to have subjects achieve 85% maximal heart rate via the Bruce protocol test (Table 2) and then determine influence on balance through postural sway parameters and compare during normal heart rate and after performing the Bruce protocol test.

Table 1. Mean and standard deviation of the demographics of the participants involved in the study.

Age	Height (cm)	Weight (kg)	Resting HR (bpm)	Max HR (bpm)	75% HR Max (bpm)	85% Max HR (bpm)	Pre-RPE (6-20)	Post-RPE (6-20)
24.3 ± 2.57	171.3 ± 7.96	75.9 ± 26.37	88 ± 13.02	195.6 ± 7.257	146.92 ± 2.02	166.3 ± 2.02	6	11.96 ± 2.22

Table 2. Duration, treadmill belt Speed and inclination grades during Bruce protocol test.

Stage	Duration (min)	Speed (MPH)	Grade (%)
1	3	1.7	10
2	3	2.5	12
3	3	3.4	14
4	3	4.2	16
5	3	5	18
6	3	5.5	20
7	3	6	22

All participants signed a written consent form approved by Chapman University IRB prior to participation.

Baseline Assessments: Before the Bruce protocol test was performed, subjects performed three postural balance stances, quiet standing with i) eyes open, ii) eyes closed, and iii) tandem stance, on the forceplate for one minute trial interval. Participants were randomly assigned to any of these testing conditions. Baseline assessment of HR was recorded using Polar H-10 Heart Rate monitor around their sternum. Resting heart rate and Ratings of Perceived Exertion (RPE) were recorded before and after Bruce protocol test. The participant stood quietly on forceplate with eyes open or closed with feet shoulder-width apart. For tandem stance, the participant stood toe to heel with their dominant leg in front of their non-dominant leg. Each postural condition was held for a minute while heart rate (bpm) and postural sway values were collected.

Bruce protocol test (BPT): The participant's HR was raised to 85% maximal HR which was determined using the $[(220 - \text{subject age}) * 0.85 = 85\% \text{ max HR}]$ equation. The Bruce protocol test was performed until subjects achieved the target heart rate. The BPT is administered in three-minute stages until the subject achieves 85% of their age-predicted max heart rate to evaluate fitness and cardiac function (Hamlin et al., 2012). The treadmill test began at 1.7 mph with a 10% grade. After 3 minutes, the speed increased to 2.5 mph with a

12% grade. At 6 minutes, speed increased to 3.4 mph and grade to 14%. At 9 minutes, the test increased to 4.2 mph and 16% grade (Hamlin et al., 2012).

The test was stopped once subjects achieved the target heart rate and the post-test balance data was then recorded. To ensure HR was within the target parameters, participants were instructed to continue the Bruce Protocol Test if their heart rate dropped below the target range (75%-85%). Postural sway parameters such as sway area, sway velocity, turn index, median power frequency in the anterior-posterior and medial-lateral direction were then compared before and after reaching 85% max heart rate. For data analysis, the MANOVA was applied for to determine differences in fixed effects and post hoc analysis was evaluated using Tukey HSD (JMP 16 Pro, SAS Institute Inc., Cary, NC) for statistical significance.

Results

The mean ratings of perceived exertion (RPE) before the BPT was found as 6, after the BPT, the RPE increased to mean rating as 11.96 and SD as 2.22. The resting HR during eyes open was 92.18 ± 3.6 and 85% of maximum HR was 135.8 ± 8.33 bpm. The HR changes during eyes open and eyes closed conditions are given in Figure 1.

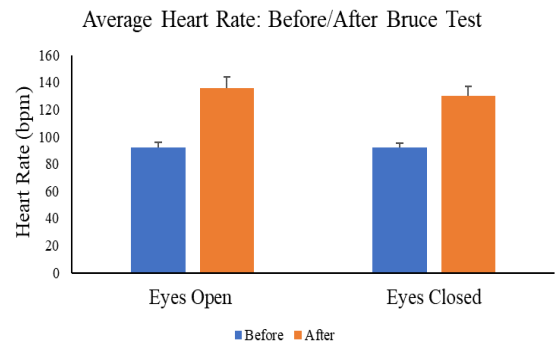


Figure 1. Average Heart Rate (beats per minute) values before and after the Bruce Protocol test (BPT).

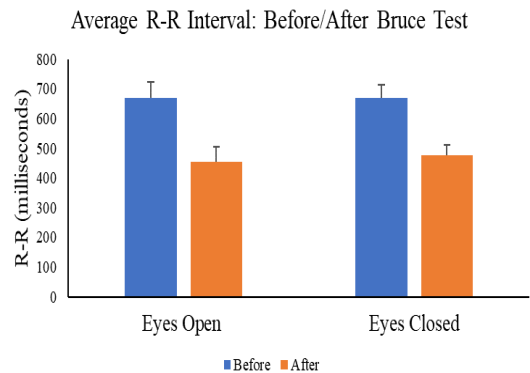


Figure 2. Average R-R Interval (milliseconds) values before and after the Bruce Protocol test (BPT).

After the BPT, the sway area (mm^2) increased in the eyes closed condition (303%) compared with the eyes open condition (13%) (Figure 3).

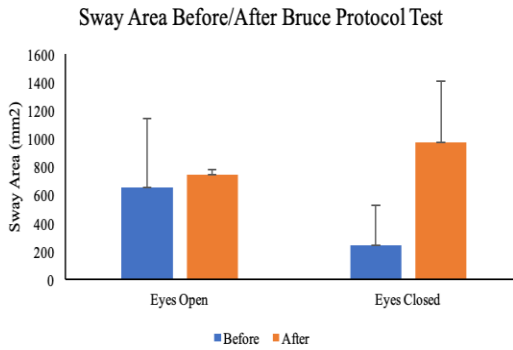


Figure 3. Presents the Sway Area (mm²) values before and after performing the Bruce Protocol test (BPT).

The median power frequency in the anterior-posterior (AP) direction (Hz) decreased significantly ($p=0.0085$) in the eyes open condition (before BPT 55.96 ± 12.27 and after BPT 21.30 ± 5.774) (Figure 4).

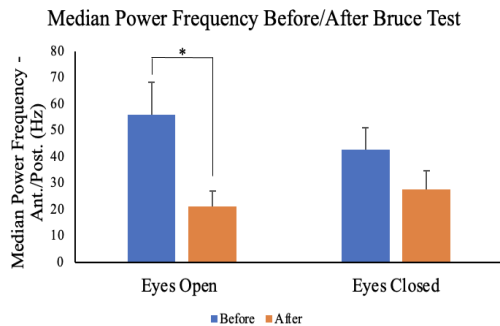


Figure 4. Presents the values for Median Power Frequency (Hz) in the Anterior-Posterior direction before and after the Bruce protocol in eyes open and eyes closed.

Turn index (number of turns) during eyes open condition significantly decreased after BPT (before BPT $32,944 \pm 3,898$ and after BPT $21,789 \pm 3,380$) ($p=0.008$). A similar trend was found in turn index during eyes closed condition ($p=0.008$) (before BPT $30,171 \pm 11,167$ and after BPT $21,939 \pm 11,442$) (Figure 5).

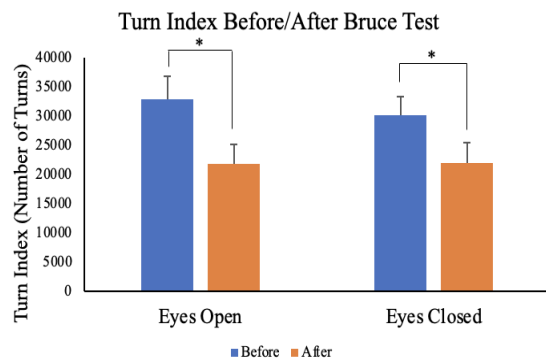


Figure 5. Presents the values for Turn Index before and after the Bruce protocol in eyes open and eyes closed.

Table 2. Significant changes in turn index, median power frequency sway in the anterior-posterior direction. Table is divided into the different conditions the participants completed, before and after completing the Bruce protocol.

	Eyes Closed Before-BPT	Eyes Closed After-BPT	Eyes Open Before-BPT	Eyes Open After-BPT	Tandem Before-BPT	Tandem After-BPT	p-value
Turn Index (number of turns)	30171 ± 11167	21939 ± 11442	32944 ± 13502	21789 ± 11710	9791 ± 4956	9642 ± 4376	0.008
Median Power Frequency Sway A-P (Hz)	42.76 ± 28.06	27.53 ± 23.36	55.96 ± 42.51	21.30 ± 20	1.714 ± 0.821	1.864 ± 1.204	0.008
Sway Area (mm ²)	241.3 ± 124	973.1 ± 1433	655.8 ± 1680	743.4 ± 978	943.8 ± 548.7	890.9 ± 515.9	N.S.
Heart Rate (bpm)	91.89 ± 3.48	130.1 ± 7.12	92.18 ± 3.6	135.8 ± 8.33	91.9 ± 3.23	121.1 ± 3.65	N.S.
R-R Interval	668.5 ± 45.32	476 ± 34.31	668.7 ± 52.94	452.9 ± 51.88	683.3 ± 44.95	504 ± 42.4	N.S.

Discussion

This study investigated how high heart rate influenced postural balance in healthy young adults. Postural control is dependent on the musculoskeletal components such as the range of motion pertaining to the joints, the flexibility of the spine, the muscles' properties, and the biomechanical relationship of body segments. The muscles that maintain upright posture are controlled by the brain and its reflex mechanisms (Widmaier et al., 2006). The brain sends signals to the musculoskeletal system through adaptive and anticipatory mechanisms to control posture. Adaptive mechanisms modify sensory and motor systems when an individual changes tasks or due to environmental demands. Anticipatory mechanisms prepare sensory and motor systems for postural demands based on previous experience and learning during postural control. Other contributing factors to postural control include internal representations, sensory strategies, neuromuscular synergies, and individual sensory systems in particular visual, vestibular, somatosensory systems (Shumway-Cook & Woollacott, 1995). After implementation of the BPT, participants displayed a lower, overall mean score as displayed in median power frequency (figure 4) and turn index (figure 5). Participants also showed higher sway area after BPT (figure 3). This indicates that the participants were more rigid in maintaining stance and less resilient to perturbation. The lower values depict a reduction in adaptability, therefore overall balance decreased. These results may be relevant for geriatric populations because with age, body rigidity tends to increase therefore there is a greater risk for falls as balance is compromised (Fujio & Takeuchi, 2021). We found differences in the anterior-posterior direction in which elderly fallers demonstrate significantly greater postural sway compared to younger subjects (Laughton et al., 2003). Our results demonstrate significant decrease in A-P power frequency in the eyes open condition which indicates increased postural sway and decreased ability to maintain COG (Sakanaka et al., 2021). Howcroft et al. found that increased postural sway in the A-P direction was a direct predictor of increased multiple falls in elderly subjects (Howcroft et al., 2017). The results from the current study may suggest that increasing cardiac activity can negatively affect the ability to adjust to perturbation and lead to increased fall risk. It can be suggested

that when working with balance impaired individuals or elderly populations, balance demanding tasks may be avoided immediately after performing submaximal cardiac activities in order to avoid fall risk and injury.

It should be noted that those who have a higher risk of falling have increased postural sway values between eyes open and eyes closed with the eyes closed sway area usually higher (Howcroft et al., 2017). When an individual is unable to maintain COM in small sway area, they are at an increased risk of fall especially at older age(Howcroft et al., 2017). In this study, we observed the sway area during the eyes closed condition after the bruce protocol test was 303% (Figure 3) higher which could be an indicator of increased fall risk post cardiac activity at submaximal heart rate(Howcroft et al., 2017). Post achieving submaximal heart rate, individuals may rely more heavily on visual input to maintain a smaller sway area and center of gravity in order to maintain balance(Widmaier et al., 2006). This is observed in the current study by the large difference between the sway area percent change with eyes open, 13% sway area increase, versus eyes closed, 303% sway area increase (Figure 3). It is critical for older adults who have impaired vision. Since vision plays a key role in maintaining a smaller sway area (Figure 3), those who have impaired vision should be especially cautious when performing balance demanding activities after increasing cardiac activity to a submaximal level in order to maintain good balance.

Turn index demonstrates how many times the participant changed directions while trying to maintain an upright position. This is recommended as the primary standard way of measuring static posture stability(Blaszczuk et al., 2016). An increased turn index value indicates that the brain's reflex systems are working properly and quickly. Contrasting, a decreased turn index indicates a delayed reflex from the brain to maintain the upright position. This study revealed that after reaching a submaximal heart rate, turn index was significantly decreased, suggesting slower reflexes in the body's balance mechanisms (Figure 5).

There were time limitations due to heart rate rapidly decreasing over the span of data collection. The Bruce Protocol was used to reach the subject's target heart rate. However, after the initial postural sway data collection, the protocol had to be continued for a second time to return the participant to the target heart rate. Secondly, heart rate was measured using the Polar H10 heart rate monitor chest strap and not ECGs which are considered the "gold-standard" for measuring heart rate(Nelson & Allen, 2019). Another limitation was all participants reported a post-RPE score higher than their pre-RPE score. This could suggest that general fatigue could have a confounding effect on balance rather than heart rate or that they both contribute in undetermined amounts.

This study contributed in understanding how increased cardiac activity at a submaximal heart rate will impact fall risk by affecting balance. A relationship was found between heart rate and balance when researchers measured balance after increasing heart rate during BPT. It is important for clinicians to know how balance is affected by increased heart rate, especially when high fall risk population is involved.

Clinicians can use this in the real world by ensuring their patients get proper breaks to allow their heart rate to decrease before performing another exercise to prevent an injury.

Limitations: The study is limited to healthy young subjects, thus the results cannot be generalized for older population. Although falls have more severe consequences of older adults, our future studies will focus on effects of Bruce test on postural stability of older adults. Another limitation of this study is Bruce protocol is quite fatiguing for the postural muscles in trunk and lower limbs. Although Bruce protocol has affected balance but it is difficult to determine causal relationship of whether increase of heart rate or muscular fatigue could have led to postural instability. The study is limited to small sample size.

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