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SHORT COMMUNICATION

Brisk walking with practical blood flow restriction did not induce impairment of knee proprioception and fatigue

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Impaired proprioception can provide faulty sensory feedback to the brain during movement, resulting in an increased risk of injury. Although several safety concerns about blood flow restricted exercise have been investigated, no research has observed how this exercise affects proprioception.

Objectives: To investigate the effects of walking with and without practical blood flow restriction (pBFR) on muscle fatigue and knee proprioception.

Design: Within-subject Randomized Crossover Design

Methods: Fourteen healthy young adults (9 males and 5 females) walked on a treadmill at 5.6 km/h with a fixed grade for fifteen minutes either with or without elastic belts (using the moderate perceived tightness, "7 out of 10"). Absolute angular error of a standing position sense test (index of proprioception) and peak/average power outputs of countermovement jumps (index of fatigue) were measured before and immediately after exercise.

Results: For absolute angular error, there was no evidence of a difference ($BF_{10} = 0.64$) between walking with and without pBFR [pBFR: $\Delta -1.5 \pm 3.8^\circ$ vs. Control: $\Delta\ 0.19 \pm 3.8^\circ$]. The change in peak power was not different ($BF_{10} = 0.28$) between conditions [pBFR: $\Delta -34.5 \pm 1019$ W vs. Control: $\Delta\ 150 \pm 1616$ W]. Similarly, the change in average power was also not different ($BF_{10} = 0.28$) between conditions [pBFR: $\Delta\ 9.1 \pm 53$ vs. Control: $\Delta -3.4 \pm 73$ W].

Conclusions: There was no evidence that walking with pBFR induced fatigue or impairment of knee proprioception, suggesting that walking with pBFR might be safely performed without increasing the risk of injury.
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Key words: aerobic exercise ■ injury prevention ■ position sense ■ power output ■ countermovement jump

INTRODUCTION

Low-intensity aerobic training with blood flow restriction has been shown to increase muscle size and strength as well as improve anaerobic capacity in young adults, elderly adults, and athletes.[1] In experimental and clinical settings, the pressure is commonly applied using a pneumatic cuff with a pressure-controlling device in order to precisely apply the target pressure that partially restricts arterial flow into the target muscle and largely occludes venous outflow from the muscle.[2] However, these devices are not easily used outside of the experimental and clinical settings due to cost and accessibility. One practical alternative to the inflatable devices includes the use of elastic belts/wraps as a method to induce blood flow restriction.[3]

Overall, the risks of blood flow restricted exercise (e.g., blood clotting and muscle damage) appears comparable to traditional exercise without blood flow restriction.[1,4] However, no study has investigated the potential injury risk to muscle, bone, and soft tissues surrounding joints following blood flow restricted exercise. For example, there could be greater chances for a joint injury when performing fatiguing exercise due to impaired proprioception (which controls the placement of limbs).[5] The local and central fatigue during the fatiguing exercise could change afferent input from muscle receptors (e.g., muscle spindles) and efferent output, which may impair position sense of the lower extremity, leading to an increased risk of injury.[6] However, a previous study reported that walking in combination with blood flow restriction did not result in a large amount of fatigue.[7] One point to consider is that the study utilized the loss of maximal voluntary isometric knee extension strength as an index of fatigue, but walking is a dynamic exercise. Although local muscle strength might not be altered, whether the loss of dynamic performance (e.g., power output during a jump) occurs following walking with blood flow restriction is still unknown. In addition, the effect of this exercise on proprioception is an important consideration because upright exercise with cuffs/wraps altered normal walking gait pattern.[8] Although the exercise may not

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result in large amounts of fatigue, the shift in normal gait may lead to changes in proprioception.

Therefore, the purpose of this study was to compare the effects of low-intensity aerobic exercise (walking) with and without practical blood flow restriction (pBFR) on knee proprioception and fatigue. To investigate this, changes in absolute angular errors[9,10] and power outputs[11] were assessed before and after the exercise protocol in healthy young adults.

METHODS

Participants

Fifteen healthy males (n = 10) and females (n = 5) were recruited by word of mouth on the university campus. Before each visit, participants were asked to not participate in high intensity endurance and/or resistance exercise 48 hours before and to refrain from alcohol and caffeine 24 hours before every visit. All the participants filled out a medical history questionnaire and gave written informed consent before starting any experimental procedure. This research was approved by the University's institutional review board.

Procedure

Participants completed three total visits. After paperwork and the assessment of basic anthropometrics (body mass and standing height), resting heart rate was measured using a Polar FT 7 heart rate monitor (Polar Electro Inc. Bethpage, USA). 40% of heart rate reserve was calculated using the Karvonen method.[12] For the use in experimental visits, we determined the incline to elicit 40% of their heart rate reserve at a consistent speed (i.e., 5.6 km/h).[13] Subsequently, participants were familiarized with the pBFR and testing procedures. For the second and third visits, participants performed a brisk walking protocol on a treadmill with or without pBFR in randomized order. Participants began with three minutes of a comfortable self-selected speed on a 0% graded treadmill. Once the warm-up ended, baseline assessments of countermovement jumps[11] and absolute angular error[9,10] were performed (in that order). After shaving and cleaning the skin, a wireless near-infrared spectroscopy (NIRS) sensor with a light-reducing flap was placed on the mid-point between anterior superior iliac spine and lateral epicondyle of femur over the vastus lateralis and secured with athletic wrap around the thigh. Then, elastic belts (5 cm width) were applied on the proximal portion of both legs near the inguinal crease (only for the pBFR visit) with a moderate perceived pressure "7 out of 10," previously described as a snug but not painful tightness.[14] After preparation, participants started walking on a treadmill with or without elastic belts at 5.6 km/h at the grade determined on the first visit. Participants took approximately 1-3 minutes to reach their 40% of heart rate reserve. Once achieving their target heart rate, participants walked for fifteen minutes (Figure 1 within the Park et al.[13] paper depicts what this exercise looked like). The heart rate was recorded every three minutes (Table 1). Immediately following the exercise, elastic belts were removed (only for the pBFR visit), and the assessments of countermovement jumps and absolute angular error were performed, respectively. The visits were spaced at least 48 hours apart from one another.

Countermovement Jumps

Participants stood just in front of a small hole made on a wooden box. A linear position transducer (Tendo Sports Machines, Trencin, Slovak Republic) was placed underneath the hole. This device was suggested as a reliable and valid system for measuring movement velocity and estimating power[15]. A wire from the transducer was vertically pulled through the hole and was strapped onto the frontal part of the belt on the participants' waist. Participants performed three countermovement jumps with 30 seconds of rest between each jump before and immediately after the exercise. The instruction of countermovement jumps is described elsewhere.[11] Peak and average power of these three countermovement jumps were measured, and the best values within the three were analyzed for the result.

Absolute Angular Error

Before participants' arrival, the order of four angles (30°, 45°, 60°, and 90°) were randomized each experimental visit and unchanged for pre- and post- assessment. Before beginning the test, participants were asked to stand near a wall and wear an eye-mask to eliminate the visual senses. Similar to a previous study,[9] the same investigator flexed the knee of the participants dominant leg at the randomly selected angle by using a goniometer and held for three seconds, and then returned to the starting position. Afterwards, the participants were instructed to repeat the angle on their own, to hold for two seconds, and then to return the leg back to the starting position. All the trials were recorded by a digital video cam-

Table 1 Heart rate during the walking bouts.

	Heart Rate (beat/min)		% HRR	
	pBFR	CON	pBFR	CON
Time Start	126 (7)	125 (6)	41 (4)	40 (4)
3 minutes	134 (9)	130 (10)	47 (7)	44 (5)
6 minutes	138 (10)	133 (10)	50 (7)	46 (6)
9 minutes	140 (11)	135 (9)	52 (6)	48 (5)
12 minutes	142 (11)	137 (11)	54 (7)	50 (6)
Time End	142 (11)	138 (12)	53 (6)	51 (6)

Values represented as mean (standard deviation). Participants walked on the treadmill with practical blood flow restriction (pBFR) or without pBFR (CON) at same speed and incline. Time started once participant achieved 40% of heart rate reserve (HRR), which was 124 (9) beats/min.

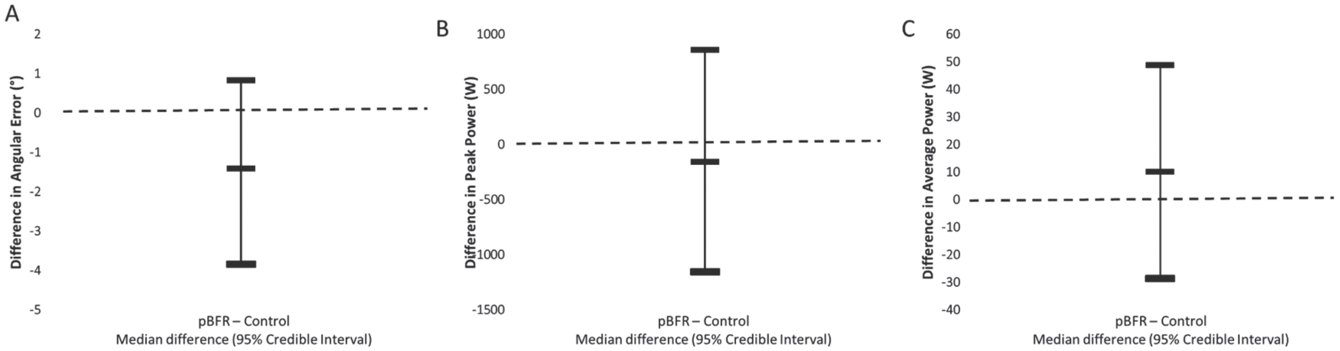

Figure 1 The difference in angular error (A), peak power (B), and average power (C) between walking with practical blood flow restriction (pBFR) and without (Control). The median difference is the middle bar and represents the posterior density of the difference under the alternative hypothesis and the upper and lower bars represent the 95% credible interval of that posterior density. Pre values for each variable are located in the results section.

era and analyzed by a two-dimensional video analysis software, Kinovia (0.8.15, Sports Sensing). The absolute angular errors, the differences between passively positioned and actively reproduced angles in absolute values, were computed for the result. The day to day reliability (minimal difference) for angular error is approximately 9 degrees. Although the reliability of importance in the current study is how consistent the measures are over a short time frame (~15-20 minutes), we did not have that data.

Near-Infrared Spectroscopy (NIRS)

Moxy Muscle Oxygen Monitor (Fortiori Design LLC, Hutchinson, MN, USA) was used to estimate muscle oxygenation.[16] Measurements were started once the participant reached 40% of heart rate reserve. Data was averaged over 30 second intervals. There were 3 time-points in the analysis; the start of the measurement, 3 minutes following, and the last half minute of exercise.

Statistical Analysis

Data was analyzed using RStudio version 1.2.1335 (https://www.r-project.org/) using the Bayes Factor package (0.9.12-4.2) and JASP (0.10.2, Amsterdam, The Netherlands). The dependent variables included changes in absolute angular error, peak power output, and average power output. Bayesian paired samples t-test was used to examine differences between conditions in the aforementioned variables. As recommended by Wagenmakers and colleagues, uninformed priors of (Cauchy distribution) 0.707 (centered on zero) were used for all dependent t-tests.[17] For muscle oxygenation, a condition x time Bayesian repeated measures ANOVA was run to determine if there was a main effect of condition (interaction was not of interest since there was no true baseline). Uninformed priors of 0.5 were implemented. Evidence for or against the null was quantified with Bayes Factors (BF_{10}). For example, a Bayes Factor of 0.33 indicates that the null hypothesis is 3x more likely and a Bayes Factor of 3.0 indicates that the alternative hypothesis is 3x more likely. Data are presented as mean ± standard deviation unless otherwise stated.

RESULTS

Participant characteristics were age 21 ± 2 years old, height 174.5 ± 10.5 cm, and body mass 70.5 ± 11.9 kg. A male participant decided not to participate after the familiarization session due to the discomfort of the elastic belt application. Therefore, the data from fourteen participants (males, n = 9; females, n = 5) were collected and analysed. For NIRS data analysis, two subject's data were excluded because the data was not recorded appropriately; hence, the data from twelve participants was analysed.

Absolute Angular Error

There was no evidence of a difference ($BF_{10} = 0.64$, Figure 1A) between walking with pBFR [Pre: 8.1°, Δ−1.5 ± 3.8°] and without (Control) [Pre: 5.5°, Δ 0.19 ± 3.2°].

Countermovement Jumps

For peak power, there was evidence ($BF_{10} = 0.28$, Figure 1B) for the null when comparing the difference between pBFR [Peak pre: 7060 W, Δ−34.5 ± 1019 W] and Control [Peak pre: 6763 W, Δ 150 ± 1616 W]. Similarly, for average power, there was evidence ($BF_{10} = 0.32$, Figure 1C) for the null when comparing the difference between pBFR [Average Pre: 1271W, Δ 9.1 ± 53] and Control [Average Pre: 1319 W, Δ:−3.4 ± 73].

Near-Infrared Spectroscopy (NIRS)

Muscle oxygen saturation was different ($BF_{10} = 9689$) with pBFR being lower on average than the control condition [median difference (95% credible interval) of−6.6 (−9.2, −3.28) %].

DISCUSSION

The main findings were that walking with pBFR did not increase fatigue or impair knee proprioception compared to walking without pBFR. This study was the first to investigate the effect of low intensity aerobic exercise with pBFR on knee proprioception. Of note, the credible intervals are wide and future research is needed to confirm our reported findings.

Similar to our results, Ogawa et al.[7] found that acute changes in maximal knee extension strength were not different between walking (5.3 km/h) with or without blood flow restriction. The lack of fatigue in the current and previous study might be related to the low metabolic accumulation associated with slow walking in combination with blood flow restriction.[18] However, metabolites were not quantified in the present study.

Changes in absolute angular error did not differ between the brisk walking with and without pBFR, indicating that the application of pBFR in addition to the exercise did not affect knee proprioception. Previous work has shown that neuromuscular fatigue induces the laxity of ligaments in the knee, which impairs the proprioception,[6] possibly leading to increased risk of injury.[9] The absence of muscular fatigue may be the reason why we did not observe a difference in joint proprioception in the present study. Our result supports that walking with pBFR could be safely utilized for the healthy individuals. However, there was not sufficient evidence to completely rule out the alternative hypothesis with respect to differences in angular error.

Our study is not without limitations. The experimental procedure started when participants reached 40% of heart rate reserve. This is a limitation because the heart rate in the blood flow restricted condition might reach 40% of heart rate reserve more quickly (due to reductions in venous return),[19] possibly leading to a lower exercise duration compared to walking without blood flow restriction. In addition, the workload was set to the heart rate response of a non-restricted bout of exercise. This likely resulted in differential intensities being applied between conditions. In addition, the exercise bout started at 40% of heart rate reserve, but the intensity of exercise was not changed to maintain this heart rate target. In other words, both conditions were exercising at approximately 52 % of their heart rate reserve by the end of the exercise session. Another limitation is the use of the perceived tightness scale for the application of pBFR. Since this method relies on the subjective perception of tightness, the applied elastic belts could under- or over-restrict blood flow.[20] Nevertheless, our estimate of muscle oxygenation indicated that pBFR created physiologically different condition compared to control condition. Lastly, this present study had a smaller sample size leading to insufficient evidence for the null or alternative hypothesis for our measure of proprioception. Future work could use our posterior distribution as their initial prior to better understand the effects of pBFR on proprioception.

CONCLUSIONS

Additional work is needed to better understand whether brisk walking with pBFR affects knee proprioception. It is possible that proprioception is minimally impacted with this protocol due to the absence of fatigue with walking in combination with pBFR.

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CONFLICTING INTERESTS

All authors declare that there is no conflict of interest.

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