**Title:**

**Effects of neuromuscular electrical stimulation, light intensity walking and a seated exercise trainer on venous return in healthy young adults**

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**Abstract**

**Background:** The present study investigated the change in venous blood flow, heart rate and blood pressure after 8 minutes of using the Leeper device, Circulation Booster® and light intensity walking.

**Methods:** A quasi-experimental cross over study involving 11 participants (8 female, 3 male, mean (SD) age=23.91 (1.04) years) was conducted using three exercise conditions; Leeper; Circulation Booster® and walking. During each condition participants exercised for 8 minutes, and blood flow was recorded at 0, 4 and 8 minutes of each condition. Heart rate (HR) and blood pressure (BP) were recorded at 0 and 8 minutes. Blood flow was the primary outcome measure and heart rate, and blood pressure were secondary outcomes. Participants rested for 10 minutes between conditions. A two-way repeated measures ANOVA was utilised to analyse the effect of condition and time on blood flow, blood pressure and heart rate.

**Results:** There was no significant interaction between condition and time on blood flow (p=0.180) indicating that blood flow did not change differently over time depending on condition. There was no significant main effect of time on blood flow (p=0.206) indicating that no condition caused a significant increase or decrease in blood flow after 8 minutes of exercise.

**Conclusion:** The interventions involving Leeper device, Circulation Booster® device and light intensity walking did not appear to significantly increase blood flow in young adults after any exercise condition. Further studies involving participants from older age groups and those with pathological conditions are warranted to examine the potential effectiveness of the interventions.

**Introduction**

The prevalence of sedentary behaviour, defined as ‘activity with low energy expenditure, undertaken primarily sitting or lying down’ (Population Health Team, 2019) is increasing and is associated with poor health outcomes independent of physical activity (World Health Organization (WHO), 2020). Uninterrupted sitting can reduce blood flow and endothelial function and increase glucose and insulin concentration (Bailey *et al.,* 2019; Carter *et al.,* 2019). These changes are associated with increased risk of deep vein thrombosis, diabetes, cardiovascular disease, cardiovascular disease mortality and all-cause mortality (Bailey *et al.,* 2019; Healy *et al.,* 2010; Patterson *et al.,* 2018). On average, adults (aged 15-60 years) and older adults (>60 years) engage in sedentary behaviour for 8.2 and 8.5 hours a day (Bauman *et al.,* 2018). Mortality risk increases above 6-9.5 hours therefore this is of concern (Ekelund *et al.,* 2019; Patterson *et al.,* 2018). Hence, it is imperative to explore ways in which sedentary behaviour and associated problems can be reduced.

The WHO sedentary behaviour guidelines (2020) state that adults should minimise prolonged sedentary behaviour, replacing it with physical activity of any intensity. There is insufficient evidence to recommend frequency and duration, however walking at light intensity for 8 minutes every 2 hours has been shown to prevent the decline in blood flow and endothelial function induced by uninterrupted sitting (Carter *et al.,* 2019). Walking promotes blood flow and venous return by activating the calf muscle pump. Calf muscles contract, expelling blood from the lower extremities back towards the heart (Recek, 2013). Walking also lowers plasma glucose and insulin concentration (Peddie *et al.,* 2013) which are associated with increased risk of diabetes, cardiovascular disease and mortality. Therefore, interspersing sedentary behaviour with light intensity activity is beneficial.

Some individuals cannot avoid prolonged periods of sitting, including those who have limited mobility and are unable to stand and walk frequently or independently. In these circumstances, sedentary behaviour can be broken with seated exercise (WHO, 2020). Electrical muscle stimulation (EMS) is another option for individuals who cannot avoid uninterrupted sitting. Electrical impulses delivered through a footplate or electrodes and stimulate motor neurones causes involuntary contractions which activate the calf muscle pump. Revitive is a device that has been shown to increase blood flow (Actegy Ltd, 2016), however studies are limited and present conflicting evidence. Using the Circulation Booster® for 15-30 minutes has been found to significantly improve blood flow in comparison to no EMS, in healthy individuals and those with chronic venous disease (Ravikumar et al., 2021; Varatharajan et al., 2014). However, no significant improvements have also been reported after healthy participants used the device for 20 minutes (Zaidell et al., 2014). The Leeper is a prototype exercise trainer which enables individuals to complete ankle dorsiflexion and plantarflexion exercises whilst seated. It was designed to help improve venous return by activating the calf muscle pump. It is targeted at anyone who is sat for prolonged periods but highlights potential benefits for individuals with reduced mobility.

There is limited evidence on the Leeper and no comparison to other interventions. Hence, the present study aimed to investigate change in venous blood flow, BP and HR before and after using the Leeper, Circulation Booster® and light intensity walking in young healthy adults and compare any differences between conditions.

**Methods**

A quasi-experimental cross over design was utilised where independent variables were exercise condition (Leeper, Circulation Booster® and Walking) and time (pre- and post- condition) and dependent variables were blood flow, BP and HR. The primary outcome was blood flow, indicative of venous return, and secondary outcomes were BP and HR. A cross over design enabled participants to complete all conditions, allowing within-subject comparisons. It was hypothesised that the NMES and Leeper would both significantly increase blood flow.

Ethical approval was obtained from the Faculty of Environmental and Life Sciences ethics committee and participants provided written informed consent prior to taking part in the study.

***Participants***

Eleven participants (female=8, male = 3, mean (SD) age=23.91 (1.04) years, height=168.05 (9.66) cm, body mass=71.00 (16.94) kg) were recruited from the University of Southampton. Participants aged 18-35 years at least moderately physically active, reported using the International Physical Activity Questionnaire, were studied. Exclusion criteria included smoking, high BP, BMI ≥30kg/m2 and a haematological, cardiovascular or metabolic condition. Participants were free from any injury or neurological disorder which prevented normal gait or ankle range of motion and were asked to abstain from exercise, alcohol and caffeine 24 hours before data collection. Testing was conducted between 10am – 3pm over several weeks.

***Data collection***

Participant’s height and weight (Seca 755 column scale, Hamburg, Germany) were recorded and participants completed a 10-minute seated rest, allowing blood flow parameters to return to resting levels. Baseline measurements for blood flow (DMX Dopplex, Huntleigh Healthcare Ltd, Cardiff, UK), BP (Cazon Electronic Blood Pressure Monitor, BSX516, Willich, Germany) and HR (Fingertip Pulse Oximeter, MD300C13, Beijing Choice Electronic Technology Co., Ltd, Beijing, China), were recorded at 10 minutes.

Blood flow was measured at the posterior tibial vein of the right ankle. Participants were seated on a chair with the foot flat on the floor. Water-soluble hypoallergenic ultrasound transmission gel (Parker Laboratories, Inc, New Jersey, USA) was applied directly behind the medial malleolus. Participants were informed that adverse reactions to ultrasound gel are rare but were advised to inform researchers if any symptoms developed. The doppler probe (EZ8XS High Sensitivity 8MHz Widebeam Probe, Huntleigh Healthcare Ltd, Cardiff, UK) was placed over the gel in the transverse plane and the measurement recorded when a consistent waveform was visible on the doppler. The location of the posterior tibial vein was marked using a washable marker pen to enhance reliability of repeated measures. Blood flow measurements took approximately 15 seconds and all measurements were taken in a seated position.

Three conditions were completed in a random order; Leeper; Circulation Booster®; walking. During each condition participants exercised for 8 minutes. Blood flow was recorded at 0, 4 and 8 minutes of each intervention and BP and HR recorded at 0 and 8 minutes. Each intervention was followed by a 10-minute rest period where blood flow was recorded at 0, 5, and 10 minutes and BP and HR at 0 and 10 minutes.

***Leeper***

Participants sat on a chair with feet on the Leeper (C.T: Designs Ltd, Surrey, UK) (Figure 1). Participants were asked to dorsiflex and plantarflex each foot to the maximum range permitted by the device, alternating between right and left feet on the beat of the metronome (30 beats per minute). Participants stopped moving feet when blood flow measurements were taken. All conditions were performed bare foot. The protocol was developed specifically for this study as there is currently no literature pertaining to the Leeper.

***[Insert Figure 1 near here]***

***Circulation Booster®***

Participants sat on a chair with feet on the Circulation Booster® (CBV3, NEUWEI Co., Ltd, Cheonan City, Republic of Korea) (Figure 2). The auto programme was selected, and EMS intensity (1-50Hz frequency, 9mA maximum output current) increased until a tolerable contraction of the calf muscle was elicited, as recommended by the manufacturer. The average electrical muscle stimulation used by the participants was 19±7.17. Participants were asked to refrain from voluntarily contracting lower limb muscles. Feet were removed from the device when blood flow measurements were taken.

***[Insert Figure 2 near here]***

***Walking***

Participants walked between two points marked on the laboratory floor. To control pace at light intensity exercise, HR monitors were worn, and participants asked to maintain HR at 40%HRmax. HR Percentages were estimated using the equation 220- Age. Blood flow measurements were taken with participants sat on a chair.

***Statistical analysis***

Data from the doppler were transferred to Dopplex DR5 software (Huntleigh Healthcare Ltd, Cardiff, UK) to calculate time averaged mean velocity without reverse flow, indicative of blood flow. Evidence suggests that systolic BP increases with exercise and diastolic BP remains unchanged (Fletcher *et al.,* 2001) therefore systolic values were analysed.

The Shapiro-Wilk test of normality was used to assess distribution of data. Statistical significance was set at p<0.05. Two-way repeated measure analysis of variance (ANOVA) was used to analyse the effect of condition (Leeper, Circulation Booster®and walking) and time (pre- and post-) on blood flow, BP and HR (IBM SPSS Statistics 27, IBM Corp, Armonk, New York). Greenhouse-Geisser corrections were applied when the data violated the assumption of sphericity. Where there was a significant interaction effect, simple main effects were analysed to determine significant differences at individual levels of condition and time. Main effects were analysed where the interaction effect was non-significant.

**Results**

Group mean values for time averaged mean velocity, systolic BP and HR are presented in Table 1.

***[Insert Table 1 near here]***

***Time averaged mean velocity***

The TAMV data was recorded on the Dopplex device and then analysed further using DR5 software programme. Time averaged mean velocity was normally distributed (p>0.05) except for pre-Leeper (p=0.002). A two-way repeated measures ANOVA revealed no significant two-way interaction between condition and time (F(2, 20)=1.871, p=0.180, ηp2=0.158) indicating that blood flow did not change differently over time depending on condition. The main effect of time showed no significant difference in time averaged mean velocity between pre- and post- time points (F(1,10)=1.832, p=0.206, ηp2=0.155) indicating that no condition significantly altered blood flow. Group mean values are displayed in Figure 3.

***[Insert Figure 3 near here]***

***Systolic blood pressure***

There was no significant two-way interaction between condition and time (F(2, 20)=0.135, p=0.874, ηp2=0.013) indicating that systolic BP did not change differently over time depending on condition. The main effect of time showed no significant difference in systolic BP between pre- and post- time points (F(1,10)=0.430, p=0.527, ηp2=0.041) indicating that no condition significantly altered systolic BP. Group means are presented in Figure 4.

***[Insert Figure 4 near here]***

***Heart rate***

Heart rate was normally distributed (p>0.05) except for pre-Leeper and pre-Walking (p=0.030). There was a significant interaction between condition and time (F(2,20)=13.204, p<0.001, ηp2=0.569) indicating that HR changed differently over time depending on the condition.

There was no significant difference between HR pre-Leeper (76.00 ± 15.03), pre-Circulation Booster® (76.73 ± 16.86) and pre-Walking (73.00 ± 18.31) (F(2,20)=1.880, p=0.179, ηp2=0.158). However, there was a significant difference between HR post-Leeper (75.45 ± 13.14), post-Circulation Booster® (72.91 ± 16.86) and post-Walking (88.45 ± 18.43) (F(2,20)=8.347, p=0.002, ηp2=0.455). Heart rate post-Walking was significantly higher than post-Circulation Booster® (p=0.023), a mean difference of 15.55 bpm (95% CI 2.18-28.91). Group means are presented in Figure 5.

***[Insert Figure 5 near here]***

**Discussion**

There was no significant main effect of time or interaction effect between condition and time on blood flow velocity in young healthy individuals. This suggests that no intervention increased venous blood flow in the study population and there was no change in systolic BP however, HR significantly increased after walking.

The results contrast evidence that voluntary ankle exercises increase blood flow, including preliminary research on the Leeper that found blood flow velocity increased. Arterial blood flow velocity was measured whilst the present study measured venous velocity which is significantly slower than arterial (Klarhöfer *et al.,* 2001). The present results also contrast published research on similar exercise devices, reporting increased velocity (Sochart and Hardinge, 1999; Tanaka *et al.,* 2016). These studies measured blood flow at the femoral vein whereas the present study used the posterior tibial vein. Blood flow velocity is affected by vessel diameter and proximal blood vessels have larger diameters (Jin *et al.,* 2017; Lee *et al.,* 2017). Therefore, difference in diameters between the posterior tibial and femoral vein could explain the contrasting results. Different measurement sites limit how results can be compared to existing literature.

Type of movement could have affected blood flow. The devices used in previous studies allowed dorsiflexion, plantarflexion, inversion and eversion whereas the Leeper only permitted dorsiflexion and plantarflexion (Sochart and Hardinge, 1999; Tanaka *et al.,* 2016). Sochart and Hardinge (1999) found that blood flow velocity increased to a greater extent when exercise combined all four movements. This could explain why velocity did not increase for the Leeper condition. However, normal gait involves dorsiflexion, plantarflexion, inversion and eversion (Brockett and Chapman, 2016), therefore it does not explain why velocity did not increase during walking. The duration of the rest period also differed between studies. This study utilised a 10-minute rest, whereas those reporting increased blood flow ranged from 20 minutes to 2 hours (Carter *et al.,* 2019; Tanaka *et al.,* 2016). Sitting causes blood flow to decline and pool in the lower extremities (Thosar *et al.,* 2015). Blood flow velocity during exercise is affected by the amount of pooling beforehand (Sochart and Hardinge, 1999), therefore studies utilising longer rest periods could have found larger changes in velocity due to increased blood pooling. The duration of sedentary behaviour of the participants prior to their participation was not recorded and may have impacted the distribution of blood throughout their lower limbs. However, each participant completed a seated rest period of 10 minutes in which blood flow measurements have been shown to return to pre-exercise levels, prior to beginning the first intervention (Carter et al., 2019).

Previous literature on the EMS is conflicting. Our findings are similar to Varatharajan *et al.,* (2014) who reported no increase in venous blood flow velocity but contrast Ravikumar *et al.,* (2021) who report increased velocity. EMS intensity and duration could be contributing factors, in this study the device was used for 8 minutes and intensity increased until a tolerable calf muscle contraction was elicited. Ravikumar *et al.,* (2021) used the device for 30 minutes and intensity was set at double the intensity required to elicit a visible calf muscle contraction, therefore duration and intensity were higher and could explain increased blood flow velocity. However, Varatharajan *et al.,* (2014) used the same intensity and duration as Ravikumar *et al.,* (2021). Therefore, there are likely other contributing factors, such as dry skin preventing EMS transmission and equipment reliability (Ravikumar *et al.,* 2021).

The results contrast previous evidence that voluntary and involuntary muscle contractions increase blood flow, therefore the reliability of the equipment used in this study could have influenced the results. The posterior tibial vein was marked during the first blood flow recording, a consistent waveform was recorded at this site during the first measurement however this varied for subsequent measures. Blood flow could often be heard through the doppler’s audio function, but no waveform was visible. The probe was moved until a waveform was observable however this took approximately 15 seconds per recording and this may have had an impact on the rate of blood flow. Blood flow velocity can return to baseline values within 5 minutes of exercise cessation, therefore velocity might have increased during exercise but decreased before the waveform was recorded (Thosar *et al.,* 2015).

Systolic BP did not significantly increase after any condition. The Frank-Starling mechanism states that increased venous return causes increased cardiac output and arterial BP (Tansey *et al.,* 2019). The results indicate that venous return did not increase, therefore increased BP would not be expected. Alternatively, BP could have decreased before it was recorded. Blood pressure was measured after blood flow to ensure that movement or compression did not influence blood flow. However, the time it took to record blood flow was variable and systolic BP can return to resting values within 3-4 minutes (Dimpka and Ugwu, 2009). Therefore, BP could have returned to baseline before recordings were taken.

Heart rate was significantly higher after walking but not after other conditions. Walking intensity was controlled by maintaining HR at 40%HRmax, therefore increased HR between pre- and post- time points was expected. It is possible that intensity of the walking condition was greater than other conditions, causing increased skeletal muscle contraction. Similarly, walking could have activated additional muscle groups compared to the seated conditions, increasing muscle contraction. Increased muscle contraction results in greater oxygen requirement which in turn increases HR (Burton *et al.,* 2004). Therefore, increased contractions from higher intensity or number of muscle groups could explain why HR increased for walking but not other conditions. However, the exact cause cannot be determined because exercise intensity was not standardised and HR was controlled during one but not all conditions.

Further research is warranted to identify whether the Leeper could increase venous return after a longer period of sedentary behaviour and reduce poor health outcomes. However, the minimal clinical important difference in blood flow required to reduce the risks associated with sedentary behaviour should be defined before conclusions are made on the Leeper’s ability to do this. While frequent interruptions to sitting may be physiologically beneficial, practically this may be difficult to implement in everyday scenarios such as the workplace, creating scope for the use of non-invasive interventions that can be used in the work environment. The findings include data on the prototype device and may help provide evidence for an alternative method of portable and affordable seated exercise that health professionals can potentially implement with people in the wider community to combat the effects of prolonged sedentary behaviour.

**Conclusion**

Blood flow did not appear to significantly increase after using the Leeper, Circulation Booster® or walking in young healthy adults. Due to limitations, the results should be interpreted with caution. Further studies are warranted to determine the Leeper’s suitability to increase venous return and reduce communicable diseases associated with sedentary behaviour including participants from older age groups and people with pathological conditions.

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**Conflict of Interest**

There are no conflicts of interest.

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*Table 1. Time averaged mean velocity, systolic blood pressure and heart rate pre- and post-Leeper, Circulation Booster® and Walking conditions (Mean (SD)).*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Leeper** | | **Circulation Booster®** | | **Walking** | | **Interaction effect (p)** |
| **Pre-** | **Post-** | **Pre-** | **Post-** | **Pre-** | **Post-** |
| **Time averaged mean velocity (cm/s)** | 2.34 (2.18) | 2.14 (0.98) | 1.81 (0.69) | 2.02 (1.10) | 1.43 (0.68) | 2.23 (1.28) | 0.180 |
| **Systolic blood pressure (mmHg)** | 124.91 (13.24) | 125.09 (13.10) | 123.45 (11.12) | 124.91 (14.38) | 126.36 (14.35) | 127.64 (12.23) | 0.874 |
| **Heart rate (bpm)** | 76.00 (15.03) | 75.45 (13.14) | 76.73 (16.86) | 72.91 (16.86)b | 73.00 (18.31)b | 88.45 (18.43)ac | p<0.001\* |

*Superscript \* indicates significant interaction effect between time and condition. Superscriptsabc indicate significant simple main effects when compared to pre-Walking(a), post-Walking(b) and post-Circulation Booster®(c).*