HUMAN MOVEMENT (ISSN 1899-1955)
2021; 22(2): 78–86

COMPARISON AND ASSOCIATION OF ACUTE PHYSIOLOGICAL AND POSTUROGRAPHIC EFFECTS IN FOUR EXERCISES ON STABLE AND UNSTABLE SURFACES WITH OR WITHOUT PARTIAL BLOOD FLOW RESTRICTION

original paper
DOI: https://doi.org/10.5114/hm.2021.100016

CARLOS BAHAMONDES-AVILA[1], FELIPE PONCE-FUENTES[1], CLAUDIO HERNÁNDEZ-MOSQUEIRA[2], LUIS BUSTOS-MEDINA[3], LUIS ANTONIO SALAZAR NAVARRETE[4], FRANCISCO JOSÉ BERRAL DE LA ROSA[5]

[1] Escuela de Kinesiología, Facultad de Ciencias, Universidad Mayor, Temuco, Chile
[2] Department of Physical Education, Sports and Recreation, Universidad de La Frontera, Temuco, Chile
[3] CIGES Centre of Excellence, Department of Public Health, Universidad de La Frontera, Temuco, Chile
[4] Centre of Molecular Biology and Pharmacogenetics, Universidad de La Frontera, Temuco, Chile
[5] Department of Sport and Information, Pablo de Olavide University, Seville, Spain

ABSTRACT
Purpose. Prior research has shown that running squats on unstable surfaces may be useful in increasing antagonist muscle and body centre activity; nonetheless, the evidence for improved muscle strength-power is contradictory. In parallel, low-intensity strength training with partial blood flow restriction is effective in developing strength, hypertrophy, and muscular endurance. Combining both modalities could complement the benefits of exercising on unstable surface. Our objective was to compare the acute effects of 4 exercise types with or without partial blood flow restriction under stable and unstable conditions.
Methods. Seven volunteers performed 4 protocols: exercises with high-intensity overload and stable conditions, low-intensity overload with blood flow restriction and stable conditions, unstable conditions without blood flow restriction, and unstable conditions with blood flow restriction. At the beginning, end, and recovery of each protocol, physiological variables were measured: heart rate, subjective perception of effort, blood lactate, and posturographic variables (total distance with eyes open and closed).
Results. Exercises with stable surfaces generated greater physiological stress than both exercises on unstable surfaces. Furthermore, incorporating blood flow restriction into unstable exercise allowed an increase in the physiological demand without altering postural balance. There were only significant changes in postural balance in the high-intensity protocol with stable conditions.
Conclusions. Exercises combining partial blood flow restriction on stable and unstable surfaces increase the physiological demands without altering postural balance compared with high-intensity exercise on a stable surface.
Key words: Kaatsu, unstable exercise, stable exercise, blood flow restriction, training, posturographic variables

Introduction

Exercising under unstable conditions is an important strategy in sports practice, fitness, and rehabilitation, given the great demand placed on the neuromuscular [1] and postural system [2]. Unstable training involves endurance exercises with body mass or with external loads as resistance, which are performed on an unstable surface or device [3]. This type of exercise promotes a transient decrease in postural stability, reflected in an increase in postural balance during unipodal support with open eyes [2], and an increase in the distance travelled and velocity of the centre of pressure once the exercise has been completed [4]. Squats on unstable surfaces have been shown to be useful in increasing antagonist musculature and body centre (core) activity; however, results in improving physical qualities such as strength and muscle power

Correspondence address: Carlos Bahamondes-Avila, Escuela de Kinesiología, Universidad Mayor, Avenida Alemania 281, Temuco, Chile, e-mail: carlos.bahamondesa@mayor.cl

Received: August 1, 2019
Accepted for publication: March 3, 2020

Citation: Bahamondes-Avila C, Ponce-Fuentes F, Hernández-Mosqueira C, Bustos-Medina L, Salazar NavarreteLA, Berral De La Rosa FJ. Comparison and association of acute physiological and posturographic effects in four exercises on stable and unstable surfaces with or without partial blood flow restriction. Hum Mov. 2021;22(2):78–86; doi: https://doi.org/10.5114/hm.2021.100016.

are contradictory [5, 6]. Muscular fatigue adversely affects postural control [7]. However, low-load strength exercises performed to a maximum effort under conditions of muscular fatigue promote protein synthesis and muscle hypertrophy in a way comparable with high-intensity overload exercise [8].

Training with partial blood flow restriction (PBFR) in combination with low-intensity training (20–30% of one-repetition maximum [1RM]) has been shown to generate muscle adaptations that are equivalent to those resulting from high-intensity strength stimuli [9] or of a greater magnitude when compared with low-intensity exercise without PBFR [10]. The primary mechanisms of action of PBFR start with the dominance of metabolic stress over mechanical stress, which, in turn, mediate other responses; together, they potentiate and induce muscular hypertrophy [11]. Evidence shows that training with PBFR can cause substantial muscle hypertrophy and strength gains in clinical populations, in groups of physically active people, and in competitive athletes [12].

Given the controversy over the effects described with unstable exercise regarding increased strength and power of the lower limb musculature, complementing this methodology with PBFR during its execution is proposed. This could potentially facilitate an increase in agonist muscle strength in actions such as squatting. Acute changes produced by unstable exercise on the neuromuscular system have been documented in the literature where the production of muscle strength and postural control are altered [4, 7]. Including exercises with PBFR would complement the evidence and develop future interventions that optimize the effects of unstable exercise. Nonetheless, given the limited information available on the parameters of postural stability, unstable exercise, muscle fatigue, and its relation to PBFR exercises, we believe it is necessary to recognize the acute responses and the potential associations between parameters of physiological load and postural stability. The aim of the present study was to compare the acute physiological and posturographic effects of 4 types of training under stable and unstable conditions in healthy and physically active subjects. The proposed hypothesis is that incorporating PBFR into exercise on unstable surfaces causes greater physiological stress and metabolic demand, without altering postural stability, thus promoting the effects of this type of exercise in conditions of instability.

Material and methods

Participants

Twelve male volunteers with at least 9-month experience in overload training were recruited, but not in exercise with unstable surfaces, and their health condition was evaluated. Individuals with blood pressure ≥ 140/90 mm Hg (1 subject), smokers (2 subjects), and those with musculoskeletal conditions in lower limbs (2 subjects) were excluded. Therefore, 7 participants were involved in the study (age: 22.3 ± 1.4 years; body mass: 72.8 ± 9.1 kg; height: 1.75 ± 0.05 m; body mass index: 23.8 ± 2.2 kg/m^2; resting heart rate: 76.1 ± 16.0 bpm; systolic and diastolic blood pressure: 120.3 ± 2.4 and 79.7 ± 8.0 mm Hg, respectively).

Design

Four protocols were applied in random order and on separate days (within 96 hours). At the beginning, the workloads of the overloaded protocols were established, so that each individual performed a half-squat maximum strength test in a Smith press, taking into account prior protocol recommendations and measurement reliability [13], thereby determining the maximum strength (1RM) (80.7 ± 13.0 kg) and maximum force relative to body mass (1RM/BM) (1.1 ± 0.2). Previously, the investigators performed 2 evaluations in a group of 13 men with similar characteristics with the same protocol, establishing a technical error of absolute measurement of 3.27 kg for 1RM, a relative error of 4.06%, and an intraclass correlation coefficient of 0.94. For the comparisons between the different protocols, the participants performed 2 familiarization sessions and then 4 different work sessions, where the variables of interest were measured. The evaluations were all performed under the same environmental conditions (temperature: 20–21°C; relative humidity: 60%), with the same clothing (shorts, T-shirt, and sneakers), and at the same time (16:00–18:00 hours). The protocols are as follows:

– HIST (high-intensity overload exercise in stable conditions): half-squat on a stable surface with overload at 70% 1RM, performed in a Smith press;

– SPBFR (low-intensity overload exercise with blood flow restriction in stable conditions): half-squat on a stable surface with overload at 30% 1RM and PBFR, performed in a Smith press;

– UNS (unstable exercise without blood flow restriction): half-squat on an unstable surface (without PBFR), performed on balance pneumatic discs (Dyna Disc®);

– UNS + PBFR (unstable exercise with blood flow restriction): half-squat on an unstable surface and PBFR, performed on balance pneumatic discs (Dyna Disc®).

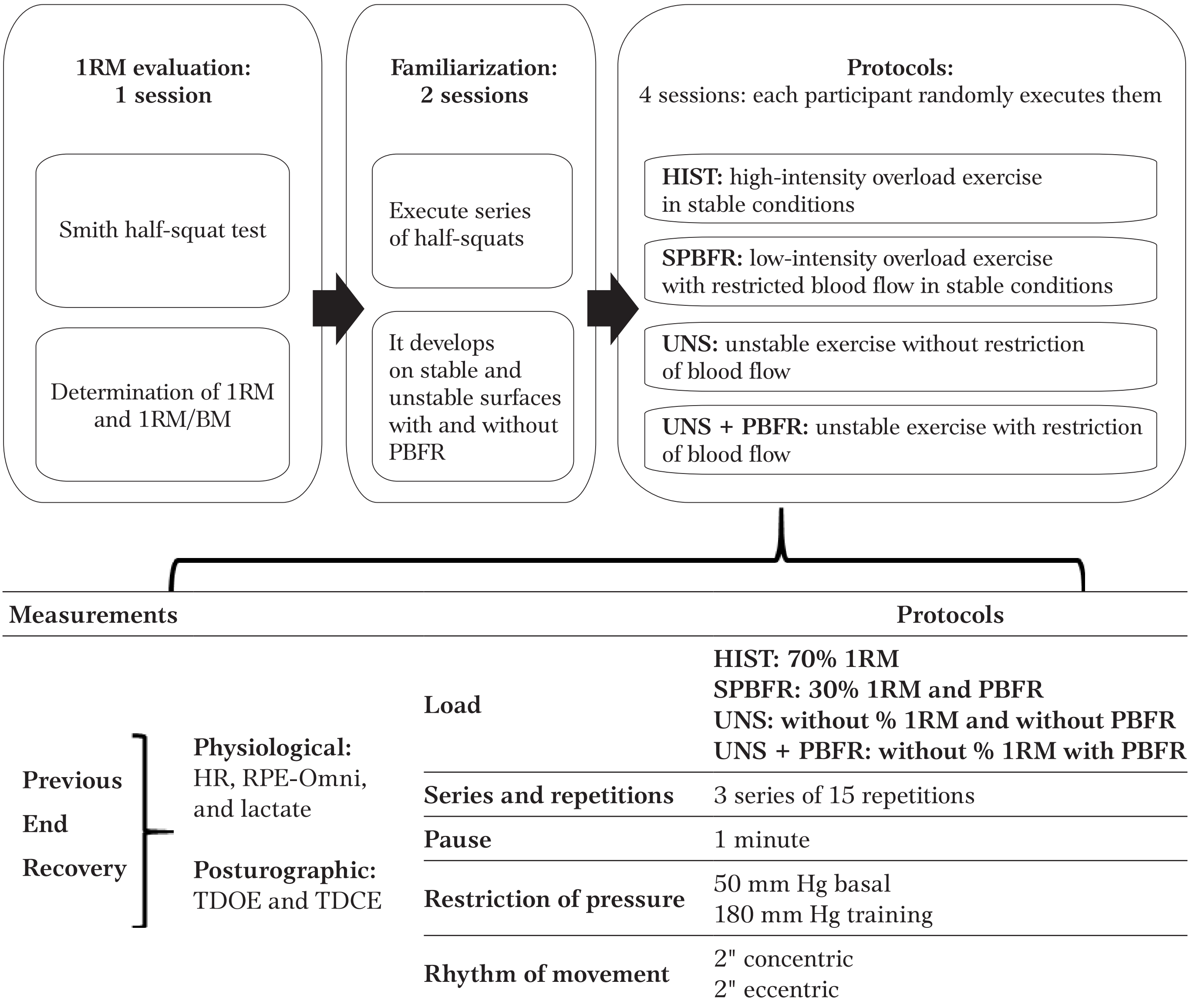
Within the training parameters, all participants had the same number of repetitions, distributed in 3 sets of 15 repetitions each, with pauses of 1 minute between the series in a work sequence of 2" in concentric and eccentric contraction, respectively. Protocols that used PBFR applied a basal restriction pressure of 50 mm Hg and a training restriction pressure of 180 mm Hg. The unstable surface protocols were carried out without overload, mobilizing only the body mass (Figure 1).

The variables of interest were recorded before, immediately at the end of, and 15 minutes after (recovery) each protocol. The recording sequence was as follows: heart rate (HR), subjective effort perception (RPE-Omni), blood lactate (LACT), total distance with open eyes (TDOE), and total distance with closed eyes (TDCE).

Instruments

The physiological variables were evaluated in the following way:

– HR: a Bioharness® was placed on each individual's chest, validated to record biometric signals [14], which are transmitted via Bluetooth to a computer and visualized and recorded in real time. The HR sample rate is 250 Hz and is expressed in beats per minute (bpm).



1RM – one-repetition maximum, BM – body mass, PBFR – partial restriction of blood flow, HR – heart rate, RPE-Omni – OMNI Perceived Exertion Scale for Resistance Exercise, TDOE – total distance with open eyes, TDCE – total distance with closed eyes

Figure 1. Diagram of the study procedures

– RPE-Omni: the OMNI Perceived Exertion Scale for Resistance Exercise was used, in which the evaluated individual is asked about their exercise condition and graded in values of 0–10, given the relationship of this type of scale with the number of repetitions or exercise intensity [15].

– LACT: an Accutrend® Plus portable device was used, which had been validated in studies linked to blood lactate kinetics [16].

In order to obtain the capillary blood samples and determine the blood lactate concentration, blood was collected from the fingertips. This was done after cleaning and removing the first drop of blood, to later analyse the second one. The equipment was calibrated with standard solutions before each series of tests, which provided values in mmol/l by reflectance photometry analysis.

The posturographic variables of TDOE and TDCE were evaluated with the Wii Balance Board platform (Nintendo, Kyoto, Japan), a portable, low-cost device that is useful and reliable in measuring the centre of pressure compared with the power platform [17]. The postural stability data provided by the Wii Balance Board platform were processed by a PowerLab computer extension of ADInstruments. The participants were instructed to remain in a bipodal support position for 2 minutes, with open eyes in the first minute and with closed eyes in the second minute [18]. The analysis considered the central 40 seconds of each minute, allowing to obtain TDOE and TDCE as positional indicators of the centre of pressure.

Statistical analysis

All data are presented as mean ± standard deviation. The normality of the data was verified by the Shapiro-Wilk test. To determine the effect of different types of training on the physiological and posturographic responses, a fixed 2-way model analysis with repeated measures (interactions group by time) was applied, including multigrade set tests of freedom and developing the interactions with simple effect tests further. To estimate the effect size of each intervention, the partial eta squared test (η_p^2) was used, classifying the effect as $\eta_p^2 \geq 0.01$: small; $\eta_p^2 \geq 0.06$: medium; $\eta_p^2 \geq 0.14$: large. Finally, to correlate the physiological and posturographic variables, the Pearson correlation coefficient (*r*) was used; this can range from –1.00 to +1.00. The magnitude of the correlation was interpreted, with positive (+) or negative (–) sign, as $r = 0.0$: no correlation; 0.0–0.10: very weak; 0.10–0.25: weak; 0.25–0.50: medium; 0.50–0.75: considerable; 0.75–0.90: very strong; and 1.0: perfect [19]. All statistical analyses were carried out with the Stata software, version 12.0. The statistical significance of the results was accepted at $p < 0.05$.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics Committee of the main author's university.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Physiological variables (see Table 1)

– HR: Significant interactions upon completion and recovery were presented in the 4 types of exercises ($p < 0.05$) (group, time, and group × time). These occurred upon completion vs. at the beginning and in recovery vs. at the end. The significant group × time interactions ($p < 0.05$) at the end were noted for HIST vs. UNS, HIST vs. UNS + PBFR, SPBFR vs. UNS, and SPBFR vs. UNS + PBFR; and in recovery for HIST vs. UNS + PBFR, SPBFR vs. UNS, and SPBFR vs. UNS + PBFR. The effect size was large for all exercise modalities ($\eta_p^2 \geq 0.14$).

– RPE-Omni: Significant interactions were observed upon completion and in recovery in the 4 types of exercises ($p < 0.05$) (group, time, and group × time). These occurred at the end vs. at the beginning and in recovery vs. upon completion. The significant group × time interactions ($p < 0.05$) were presented only at the end for HIST vs. SPBFR, HIST vs. UNS, and HIST vs. UNS + PBFR. The effect size was large for all exercise modalities ($\eta_p^2 \geq 0.14$).

– LACT: Significant interactions were shown at the end and in recovery in the 4 types of exercises ($p < 0.05$) (group, time, and group × time). These occurred at the end vs. at the beginning in HIST, SPBFR, and UNS + PBFR; and in recovery vs. at the beginning and in recovery vs. at the end in HIST and SPBFR. The significant group × time interactions ($p < 0.05$) at the end occurred for HIST vs. SPBFR, HIST vs. UNS, HIST vs. UNS + PBFR, SPBFR vs. UNS, and SPBFR vs. UNS + PBFR; and in recovery for HIST vs. SPBFR, HIST vs. UNS, HIST vs. UNS + PBFR, and SPBFR vs. UNS. The effect size was large for all exercise modalities ($\eta_p^2 \geq 0.14$).

Table 1. Changes in HR, RPE-Omni, and LACT obtained in the different training protocols

Variable	Type of training	Previous	End	Recovery	Group – time – group × time *p*	Time (end vs. previous) *p*	Time (recovery vs. previous) *p*	Time (recovery vs. end) *p*	Group × time interactions at the end	Group × time interactions in recovery	Effect size (η_p^2)
HR (bpm)	HIST	90.9 ± 11.8	160.7 ± 21.9	101.4 ± 15.6	0.01 – 0.01 – 0.01	< 0.01	0.15	< 0.01	HIST vs. UNS; HIST vs. UNS + PBFR; SPBFR vs. UNS; SPBFR vs. UNS + PBFR	HIST vs. UNS + PBFR; SPBFR vs. UNS; SPBFR vs. UNS + PBFR	0.97‡‡
	SPBFR	93.3 ± 10.5	147.1 ± 15.4	96.9 ± 11.3		< 0.01	0.67	< 0.01			0.82‡‡
	UNS	90.7 ± 14.1	121.4 ± 12.3	91.9 ± 11.1		< 0.01	0.88	< 0.01			0.60‡‡
	UNS + PBFR	90.7 ± 15.6	127.3 ± 14.4	86.4 ± 12.8		< 0.01	0.56	< 0.01			0.66‡‡
RPE-Omni (N°)	HIST	0.4 ± 0.5	8.6 ± 1.9	1.4 ± 0.8	0.01 – 0.01 – 0.01	< 0.01	0.07	< 0.01	HIST vs. SPBFR; HIST vs. UNS; HIST vs. UNS + PBFR	–	0.91‡‡
	SPBFR	0.4 ± 0.5	6.0 ± 1.3	0.9 ± 0.4		< 0.01	0.43	< 0.01			0.92‡‡
	UNS	0.4 ± 0.5	5.1 ± 1.8	0.7 ± 0.8		< 0.01	0.60	< 0.01			0.80‡‡
	UNS + PBFR	0.4 ± 0.5	5.9 ± 1.8	0.9 ± 0.7		< 0.01	0.43	< 0.01			0.85‡‡
LACT (mmol/l)	HIST	2.4 ± 0.6	9.8 ± 2.6	6.9 ± 3.4	0.01 – 0.01 – 0.01	< 0.01	0.01	< 0.01	HIST vs. SPBFR; HIST vs. UNS; HIST vs. UNS + PBFR; SPBFR vs. UNS; SPBFR vs. UNS + PBFR	HIST vs. SPBFR; HIST vs. UNS; HIST vs. UNS + PBFR; SPBFR vs. UNS	0.64‡‡
	SPBFR	2.7 ± 0.4	6.9 ± 0.6	4.6 ± 1.0		< 0.01	0.01	< 0.01			0.88‡‡
	UNS	2.8 ± 0.8	4.0 ± 1.3	2.7 ± 0.7		0.10	0.91	0.08			0.30‡‡
	UNS + PBFR	2.4 ± 0.5	4.5 ± 0.8	3.3 ± 0.9		0.01	0.17	0.12			0.61‡‡

HR – heart rate, RPE-Omni – subjective effort perception, LACT – blood lactate, HIST – high-intensity overload exercise in stable conditions, SPBFR – low-intensity overload exercise with blood flow restriction in stable conditions, UNS – unstable exercise without blood flow restriction, UNS + PBFR – unstable exercise with blood flow restriction

Data presented as mean ± standard deviation.
‡‡ large effect size

Table 2. Posturographic responses obtained in the different training protocols

Variable	Type of training	Previous	End	Recovery	Group – time – group × time *p*	Time (end vs. previous) *p*	Time (recovery vs. previous) *p*	Time (recovery vs. end) *p*	Group × time interactions at the end	Group × time interactions in recovery	Effect size (η_p^2)
TDOE (mm)	HIST	175.85 ± 57.74	200.24 ± 49.66	298.87 ± 300.06	0.40 – 0.16 – 0.52	0.60	0.01	0.05	–	HIST vs. UNS	0.09††
	SPBFR	191.26 ± 119.78	218.32 ± 75.40	214.27 ± 86.32		0.56	0.62	0.93			0.03†
	UNS	187.59 ± 64.24	169.07 ± 34.27	181.98 ± 49.55		0.69	0.91	0.78			0.02†
	UNS + PBFR	188.95 ± 44.44	191.14 ± 63.85	218.31 ± 94.72		0.96	0.53	0.56			0.04†
TDCE (mm)	HIST	457.86 ± 98.05	533.56 ± 135.82	659.44 ± 438.75	0.46 – 0.54 – 0.07	0.33	0.01	0.11	–	–	0.01†
	SPBFR	503.61 ± 228.38	641.88 ± 252.19	583.47 ± 265.72		0.08	0.31	0.46			0.004
	UNS	503.23 ± 145.59	499.96 ± 112.36	518.88 ± 164.07		0.97	0.84	0.81			0.06†
	UNS + PBFR	636.15 ± 459.24	538.53 ± 245.18	509.01 ± 187.77		0.21	0.10	0.71			0.03†

TDOE – total distance with open eyes, TDCE – total distance with closed eyes, HIST – high-intensity overload exercise in stable conditions, SPBFR – low-intensity overload exercise with blood flow restriction in stable conditions, UNS – unstable exercise without blood flow restriction, UNS + PBFR – unstable exercise with blood flow restriction

Data presented as mean ± standard deviation.
† small effect size, †† medium effect size

Table 3. Correlations (r) obtained between the physiological and posturographic variables at the end and in recovery in the different training protocols

Variable	Exercise type	End			Recovery		
		HR (bpm)	RPE-Omni (N°)	LACT (mmol/l)	HR (bpm)	RPE-Omni (N°)	LACT (mmol/l)
TDOE (mm)	HIST	0.386	0.596	–0.045	0.148	–0.240	0.524
	SPBFR	0.585	–0.232	–0.308	0.068	–0.934	–0.026
	UNS	0.108	0.596	0.206	–0.496	–0.209	0.664
	UNS + PBFR	–0.363	–0.648	–0.133	0.242	–0.292	0.017
TDCE (mm)	HIST	0.115	0.121	0.074	0.118	–0.221	0.373
	SPBFR	0.342	–0.338	–0.227	0.098	–0.900**	–0.019
	UNS	0.200	0.055	–0.048	–0.378	–0.308	0.432
	UNS + PBFR	–0.306	–0.841*	0.064	0.293	–0.608	0.120

HR – heart rate, RPE-Omni – subjective effort perception, LACT – blood lactate, TDOE – total distance with open eyes, TDCE – total distance with closed eyes, HIST – high-intensity overload exercise in stable conditions, SPBFR – low-intensity overload exercise with blood flow restriction in stable conditions, UNS – unstable exercise without blood flow restriction, UNS + PBFR – unstable exercise with blood flow restriction
* r significant at the 0.05 level, ** r significant at the 0.01 level

Posturographic variables (see Table 2)

– TDOE and TDCE: Significant interactions were only observed in recovery vs. at the beginning ($p = 0.01$) and in recovery vs. at the end ($p = 0.04$) in TDOE of HIST and in recovery vs. at the beginning ($p = 0.01$) in TDCE also of HIST. In the group × time analysis, a significant interaction ($p < 0.05$) was only observed in recovery for HIST vs. UNS. The effect size was medium only for HIST in TDCE ($\eta_p^2 = 0.09$). In the other exercise modalities, a small ($\eta_p^2 < 0.06$) or trivial ($\eta_p^2 < 0.01$) effect was observed.

Correlations (see Table 3)

At the end of the intervention, only a very strong negative correlation was found in TDCE with RPE-Omni in the UNS + PBFR protocol ($r = –0.841$, $p < 0.05$); in addition to other interactions of considerable magnitude: the UNS + PBFR protocol with RPE-Omni ($r = –0.648$) was negative, and the HIST ($r = 0.596$) and UNS ($r = 0.596$) protocols with RPE-Omni and the SPBFR protocol with HR ($r = 0.585$) all were positive. The strongest correlations were observed in recovery. In TDOE and TDCE, there were very strong negative interactions in the SPBFR protocol with RPE-Omni ($r = –0.934$ for TDOE and $r = –0.900$, $p < 0.01$, for TDCE). In addition, 3 correlations of considerable magnitude were presented: 2 positive for the UNS ($r = 0.664$) and HIST ($r = 0.524$) protocols with LACT in TDOE, and a negative in the UNS + PBFR protocol with RPE-Omni ($r = –0.608$) in TDCE.

Discussion

The aim of this study was to compare the acute physiological and posturographic effects of 4 types of exercise under stable and unstable conditions in healthy and physically active subjects, under an equal volume of repetition model during exercise. When comparing the 4 protocols, at the end of the exercise, a tendency to a higher physiological response was observed in the HIST and SPBFR trainings compared with both exercises on unstable surfaces, especially for HR and lactate. The highest physiological response from the HIST and SPBFR protocols is connected with the execution of exercises with weight (HIST: 70% 1RM; SPBFR: 30% 1RM) in conditions of instability. However, the evaluated parameters show higher energy demand in anaerobic metabolism in support of HIST [20]. This behaviour has also been observed when comparing knee extensions sitting in stable conditions, with the same volume and applied load, with and without PBFR induced with elastic bands, with a greater increase in HR, RPE-Omni, and lactate noted in the protocol with PBFR [21]; activity commanded by cardiac autonomic control [22], and increase in intramuscular metabolic stress and muscle fibre recruitment [23]. In addition, the use of PBFR on stable and unstable surfaces imposes a greater demand than just exercising under unstable conditions without PBFR. This condition has not been previously observed with the PBFR exercise modality; nonetheless, it follows the behaviour in traditional strength exercises, where the instability condition represents additional stress in the neuromuscular system [3] and a greater energy cost and metabolic impact [24] than the same exercise under stable conditions.

During the recovery phase, all parameters returned to near basal values, although again the HIST and SPBRF protocols showed a slower return of HR and lactate to basal values than exercises on unstable surfaces. A higher response in the PBFR protocol was also observed when comparing both exercises on unstable surfaces. This physiological environment must be taken into account, since in a regular training with PBFR, the metabolic condition of acidosis in the muscle would have a dominant role in the hypertrophic effects that support this type of training [11] or be an adjunct to the effects mainly observed in unstable exercises [1].

In our study, postural control was significantly affected only in the HIST modality. This coincides with various studies which indicate that acute exercise may deteriorate postural control, increase postural balance during unipodal support with open eyes [2], and increase the distance travelled and velocity of centre of pressure [4] at the end of the exercise. The results of our study can be explained in part by the fact that the HIST exercise is performed at the highest intensity, with a predominance of rapid fibres and a glycolytic metabolism. This is in agreement with what was demonstrated in the lactic anaerobic training, which worsens postural control immediately after and at 30 minutes, returning to baseline values 24 hours after exercise [4]. In absolute and relative values, the HIST exercise used in our study mobilized a higher volume of load (series × repetitions × kilograms) and was more intense when compared with the other protocols, especially with the unstable exercises. This is a condition observed during the recovery phase comparing HIST vs. UNS with open eyes, owing to the high total distance that the HIST maintained; in addition, having the same break for all the protocols also generates a greater density of stimuli in relation to the rest. The intensity, rest time, and density used in the protocols with unstable surfaces developed a lower metabolic stress (HR-LACT) compared with the exercises with overload. This could have been limited to the appearance of significant changes in the centre of pressure. Moreover, lower physiological stress was also observed in exercises with and without PBFR with pauses of 150 seconds, where there was probably an unnecessary recruitment of fast-contracting glycolytic fibres, given a complete recovery of these between the series [21]. In addition, unstable exercise predominantly induces muscle co-contraction activity [5], with a lower perception of effort for the same level of muscle activation in core when comparing squat exercises on an unstable vs. stable base. Likewise, low-intensity exercise tends to activate slow-twitch muscle fibres preferentially [3].

We only found one study associating PBFR with postural balance [25], in which it is compared with a displacement of the centre of pressure as a measure of change in balance ability after 8 weeks of training with knee-extension exercises in a sedentary position with or without PBFR. No differences between the groups were observed, even though the tendency in the group with PBFR was to decrease, which would indicate a higher balance ability. These results are not seen in other studies and would suggest that the incorporation of PBFR to stable or unstable exercise induces an increase in perceived effort, but scarce displacement of the centre of pressure. Most likely, the co-contraction of extensor and flexor knee muscles during squats (biarticular: hamstring and gastrocnemius muscles) allows a greater participation of the quadriceps in closed kinetic chain activities [26], including conditions of misalignment, which may occur with eyes closed or when exercising on unstable surfaces, where it increases the activation of the hamstrings and gastrocnemius in relation to a neutrally aligned squat [27]. This is in addition to specific features observed in PBFR exercises, such as a change in the pattern of muscle recruitment, increased electromyographic activity of the active muscles under restriction, and preferential or additional recruitment of fast-twitch muscle fibres [28], which would make it possible to perceive a greater effort, but without modifying the total distance of the centre of pressure.

Our study presents some limitations, for example, the small sample size, inclusion of young and heterogeneous adults, and the proportionality of the loads in relation to the participants' age, which condition the expected level of physiological stress. Taking this into account, we suggest incorporating these observations in future research, as well as variants in training variables, such as different constraint pressures or types of surfaces, changes in the density, speed of execution, or intensity of the stimuli, and inter-series pauses.

Conclusions

Stable surface overload exercises (HIST and SPBFR) generate greater physiological stress than exercises in unstable conditions (UNS and UNS + PBFR). Nonetheless, incorporating PBFR into unstable exercise also increases the physiological demand, although in a smaller amount. Moreover, only high-intensity exercise on a stable surface (HIST) significantly altered postural balance. Consequently, the benefits of training under unstable conditions and including PBFR are likely to favour the effects related to muscular strength and hypertrophy. These results facilitate the understanding of future interventions with exercise programs including PBFR on stable and unstable surfaces.

Acknowledgements

We would like to thank the authorities of the School of Kinesiology at the Universidad Mayor in Temuco, who provided us with the necessary facilities to perform this study, and the group of students who participated in the study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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