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Article

Effects of Mechanical Vibration during an Incremental Slide Board Skating Test on Physiological and Movement Variability Parameters

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Abstract: The physiological, kinematic, and performance benefits of slide board (SB) training are well established. However, there is limited research investigating the potential effects offered by combining SB training with whole-body vibration (WBV). This study aimed to evaluate the impact of WBV on movement variability (MV) and physiological parameters during an incremental SB skating test. Ten elite ice hockey players (20.4 ± 2.07 years; 1.79 ± 0.05 m; 75.97 ± 5.44 kg; 23.64 ± 1.64 body mass index) participated in this study. An incremental test was conducted on the SB under two conditions, randomized in order: WBV (30 Hz) and non-WBV (0 Hz). The incremental test rhythms were established at 30, 35, 40, and 45 Hz. Participants performed the exercise on the SB at each rhythm for four minutes, for a total of 16 mins. MV, subjective perception of effort (RPE), heart rate (HR), and ergospirometric parameters were assessed. Differences were observed between rhythms in ergospirometric parameters and HR, increasing directly with rhythm ($p < 0.05$). Regarding differences between conditions, MV was higher when the incremental test was performed with WBV ($p < 0.01$). The addition of WBV during SB training resulted in a rise in MV without affecting physiological parameters.

Keywords: entropy; whole-body vibration; cardiorespiratory; metabolic; slide training; skating; ice hockey; off-ice training

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1. Introduction

In the 1950s, wooden slide boards (SBs) served as a valuable off-ice sport-specific training tool for Olympic skating athletes [1]. Since then, SB exercise has increased in popularity among skating athletes (i.e., speed skating, figure skating). Unlike traditional aerobic exercises that primarily engage sagittal plane movements, skating on an SB places skaters in a frontal plane, thereby emphasizing lateral movements and replicating the sport-specific physiological demands of figure skating. This exercise can serve as an effective sport-specific alternative to conventional off-ice training strategies for competitive figure skaters [2]. Studies have shown that SB off-ice tests are powerful predictors of both on-ice speed and acceleration in figure skating [3]. Additionally, SBs have been validated as a valuable tool to assess maximal and submaximal aerobic indices, providing a valid, specific, and practical off-ice exercise for evaluating performance, prescribing exercise training, and monitoring training adaptations in speed skaters [4].

Off-ice testing and training are prevalent in professional ice hockey leagues like the National Hockey League [5]. While some studies advocate for movement-specific off-ice performance evaluations to optimize training adaptations, due to the unique physiological and neuromuscular demands of ice hockey [4,6,7] nonspecific practices remain the norm [8,9]. Track skating tests are more challenging to conduct due to the difficulties in controlling test conditions. Similarly, the use of skate-specific treadmills often poses accessibility and cost-related limitations for monitoring training and performance during the competitive season [10].

Previous research on SB exercise has primarily focussed on analysing physiological, kinematic, and performance parameters [4,11]. However, the investigation of constraints during SB skating has been overlooked. In recent years, the application of instability in training has gained popularity as a means of destabilizing the body and increasing muscle demands, leading to enhanced neuromuscular adaptations. Different devices, including mechanical vibration platforms, have been used for this purpose. These platforms generate mechanical vibration, which is then incorporated into exercises. The most popular vibration modality applied to lower extremity exercise is whole-body vibration (WBV) [12]. WBV is known to improve various aspects of neuromuscular performance, including strength [13], stability [14], and muscle activity [15]. While studies have analysed physiological and performance parameters associated with WBV and its adaptive and training effects [12], nonlinear analyses of movement variability (MV) are relatively scarce [16]. From a constraint-led approach, skating across a WBV environment on an SB can be considered an environmental constraint since the performer must adapt to successfully performing the exercise while navigating the unstable surface. This approach could potentially enhance specificity and develop challenging training environments that increase MV and adaptability [17].

The importance of evaluating the effect of constraints in nonlinear terms is widely recognized, as these components can unveil insights into the underlying dynamics of the system [18]. Various methodologies exist for analysing human motion and evaluating variability in order to detect changes in spatiotemporal characteristics and patterns [19–21]. It is recognized that linear methods possess certain limitations, especially in ascertaining the complexity of motion and the temporal structure inherent in a time series [22]. To overcome these constraints, a nonlinear approach, such as entropy measures, can be utilized [19,23].

In MV analysis, entropy stands out as one of the most promising metrics for evaluating the complexity of biological signals [24]. Within this context, sample entropy (SampEn) analysis has emerged as a widely accepted method for quantifying system complexity. This approach has been effectively employed to characterize alterations resulting from various interventions in resistance training [19,25] and to assess running performance [26]. However, entropy analysis has been limited in its application to evaluate the amount of complexity induced by vibration environments [16]. Therefore, using tools like entropy, the functional variability of athletes during movement performance must be considered a key element in identifying the extent to which constraints cause perturbation [27].

The increase in MV during WBV exercise could be considered as a promoter of environmental adaptability, which is a crucial aspect of enhancing athletic performance [28]. The integration of WBV into training exercises provides a promising avenue for eliciting adaptations at various levels of the neuromuscular system, thereby approaching the reality faced by athletes [29]. Additionally, the increased stretch–shortening cycle of skeletal muscles, a characteristic of WBV training, can elicit sufficient muscular activity to elevate whole-body oxygen consumption (VO_2) [30,31]. By building upon these premises, we hypothesize that combining SB training with WBV could induce profound alterations in physiological parameters and MV. Therefore, this study aimed to evaluate the impact of WBV on MV and physiological parameters during an incremental SB skating test.

2. Materials and Methods

2.1. Participants

For this study, ten elite male ice hockey players from a professional team in the Spanish National League volunteered to participate in this study. The assessment was scheduled at the conclusion of the ice hockey season, coinciding with the transition period marked by ongoing training activities. The procedures of this study were in strict accordance with the Declaration of Helsinki (2013) and approval was obtained from the Ethics Committee for Clinical Sport Research of Catalonia (Study Approval Number: 06/2018/CEICGC). To maintain anonymity, a code was assigned to each participant. Table 1 shows the characteristics of the participants (age and anthropometric parameters).

Table 1. Participants' characteristics.

Parameters	n = 10
Age (years)	20.4 ± 2.07
Height (m)	1.79 ± 0.04
Leg height (m)	0.92 ± 0.03
Weight (kg)	75.97 ± 5.43
BMI	23.64 ± 1.64

BMI: body mass index.

Participants were included in this study if they met the following criteria: (i) not suffering from any type of illness, stroke, injury, pain, or a condition that would preclude WBV training (i.e., musculoskeletal and/or chronic disorders); (ii) not taking medication or supplementation during the study period; (iii) not smoking or consuming drugs or stimulant drinks (i.e., caffeine; alcohol) in the 24 h prior to each test; (iv) have trained regularly during the previous 30 days; and (v) have not performed intense exercise (any physical activity beyond their activities of daily living) in the 24 h prior to each test. In addition, the researchers informed the participants about nutritional and rest guidelines prior to the assessments. To homogenize conditions, study participants had no previous experience in SB training with or without WBV.

2.2. Study Design

A crossover design was conducted where each participant performed an incremental SB skating test under WBV and non-WBV conditions in two different sessions separated by 6 to 8 days. The order of testing was randomized and counterbalanced. Ice-hockey players performed a familiarization session one week before the start of the incremental tests. The familiarisation period was carried out, as the participants had no experience of conducting SB training and it provided a learning-by-doing period prior to the assessments.

2.3. Equipment

The study was conducted on a slide vibration board (SVB) (Patent, P201630075, Vislide; Viequipment, Movilani System SCP, Sant Joan Despí, Barcelona, Spain (Frequencies: 20, 25 and 30 Hz; Amplitude: 2 mm; Total size: 2.27 × 0.74 × 0.24 m; sliding surface size: 2.00 × 0.59 m). Players wore a pair of nylon socks over their shoes to be able to slide on the polyethylene surface of the SVB. The different intensities of the incremental test were controlled through different rhythms using a metronome (Korg KDM-3 Digital Metronome; Tokyo, Japan) to help the player keep the rhythm by providing auditory feedback and synchronizing the beep with the end of the slide action [16]. For the WBV condition, the frequency selected was 30 Hz [32,33].

Throughout each test, the trunk acceleration of the ice hockey players was measured using a wireless inertial measurement unit (IMU) (WIMU; Realtrack Systems, Almeria, Spain). Signals from the 3-axial accelerometer (range: ±100 G; sampling frequency: 1000 Hz) were used.

The IMU was securely attached near the players' sacrum using an elastic waist belt. This specific placement was chosen as it provides the most accurate representation of whole-body movement, given its proximity to the players' centre of mass [34]. SampEn was quantified in arbitrary units (a.u.) from the module of the acceleration signal [19] using specific routines written in MATLAB® (version R2020a, The MathWorks, Natick, MA, USA). The physiological parameters monitored included expired volume (VE), respiratory exchange ratio (RER), carbon dioxide production (VCO_2), and oxygen uptake (VO_2). These were measured on a breath-by-breath basis using a K4b2 (Cosmed®; Rome, Italy) portable gas exchange analyser, which was calibrated as per the manufacturer's guidelines before each testing session. Heart rate (HR) data were gathered via radiotelemetry using a SP0180 Polar Transmitter (Polar Electro INC., Kempele, Finland). The subjective perception of exertion was assessed by means of the rating of perceived exertion (RPE) questionnaire with the Borg scale [35]. When participants finished each series the evaluators asked, "How hard did you find the set you performed?". The scale consisted of 15 items in a range of scores from 6 to 20 (6 = very, very light; 20 = very, very difficult).

2.4. Incremental Test

The experimental protocol consisted of a 16 min incremental skating test performed on an SVB (Figure 1) [4,10]. Before the test, a standardized warm-up was performed consisting of 5 min of general joint mobility, 5 min of cycling, and 2 min of gliding on the SVB without WBV at a low-intensity rhythm (<30 bpm). After the warm-up, the participants rested for 5 min. During the rest, the IMU, the pulsometer, and the gas analyser were put in place. After knowing the condition chosen for that day (WBV or non-WBV), participants performed 4 min of continuous sliding at each rhythm of 30, 35, 40, and 45 bpm. The rhythms were progressively increased, with a 1 min pause between them. RPE was assessed between rhythms and at the end of the test. Approximately 6–8 days later, participants repeated the test with the other condition (WBV or non-WBV).

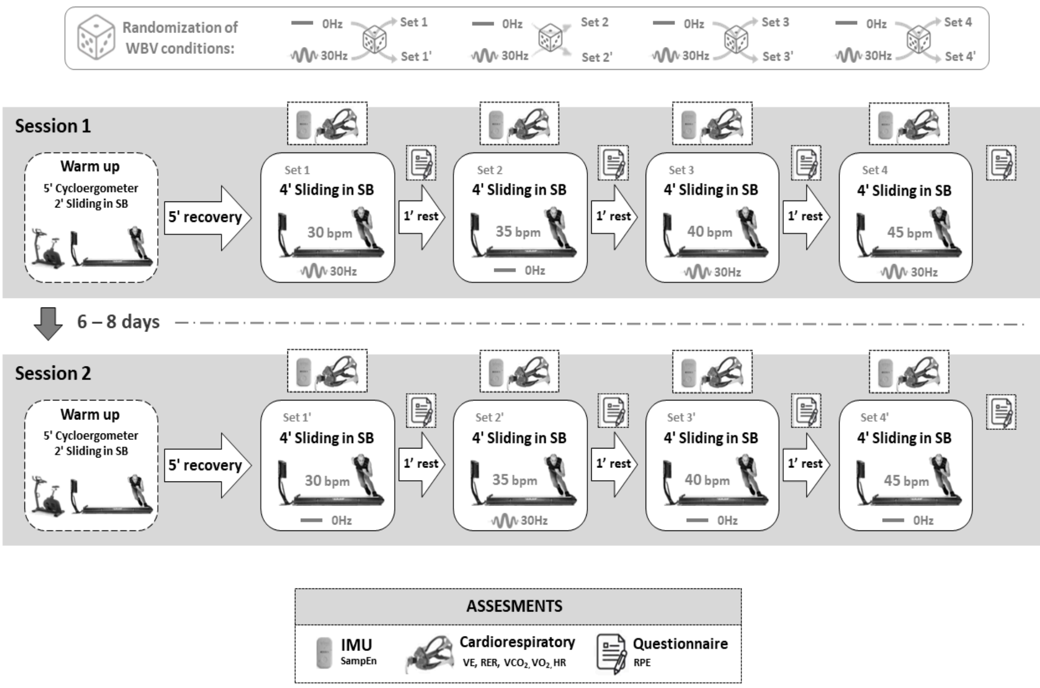

Figure 1. Study design. SB: slide board; WBV: whole-body vibration; RPE: rating of perceived exertion; VE: expired volume; RER: respiratory exchange ratio; VCO_2: carbon dioxide; VO_2: oxygen uptake; HR: heart rate.

2.5. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics 22.0 for Windows (SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk normality test and Levene's test were employed to assess normality of data distribution and homogeneity of variances, respectively. The main analysis was conducted by applying a two-way (rhythms and WBV conditions) analysis of variance (ANOVA). The Bonferroni post hoc test was used to determine specific differences between conditions. The level of statistical significance was set at $p < 0.05$ and the results were expressed as mean ± standard deviation. F values, p values, effect size values (η_p^2; partial eta squared), and the confidence interval (CI) at 95% were determined. The magnitude of effect size (ES) was established as small ($\eta_p^2 = 0.01$), medium ($\eta_p^2 = 0.06$), and large ($\eta_p^2 = 0.14$) [36,37]. A simple linear regression model was used to determine associations between SampEn and the physiological parameters analysed. The R^2 values were obtained.

3. Results

The results obtained in this study are shown below. Figures 2 and 3 show the data obtained in SampEn and the physiological parameters throughout the incremental test in both conditions (WBV and non-WBV). Significant differences were reported between rhythms in the physiological parameters and RPE, which increased directly in relation to the rhythm ($p < 0.001$). On the other hand, differences between groups were observed in SampEn; they were higher when WBV was applied ($p < 0.001$).

Table 2 shows the results obtained in the differences between rhythms (30, 35, 40, 45 bpm) and conditions (WBV and non-WBV). The ES on the rhythm effect was large ($\eta_p^2 > 0.14$) for all parameters except SampEn. On the other hand, the ES of SampEn on the condition effect was large. However, for the rest of the parameters analysed, the ES was small or insignificant. Finally, the ES of the parameters in the interaction between rhythm and conditions was small or insignificant.

Table 3 represents the intra-group differences in the analysed rhythm effect. Significant differences were reported in all the parameters analysed except SampEn. The most predominant differences were between 30 Hz vs. 40 Hz and 45 Hz ($p < 0.01$).

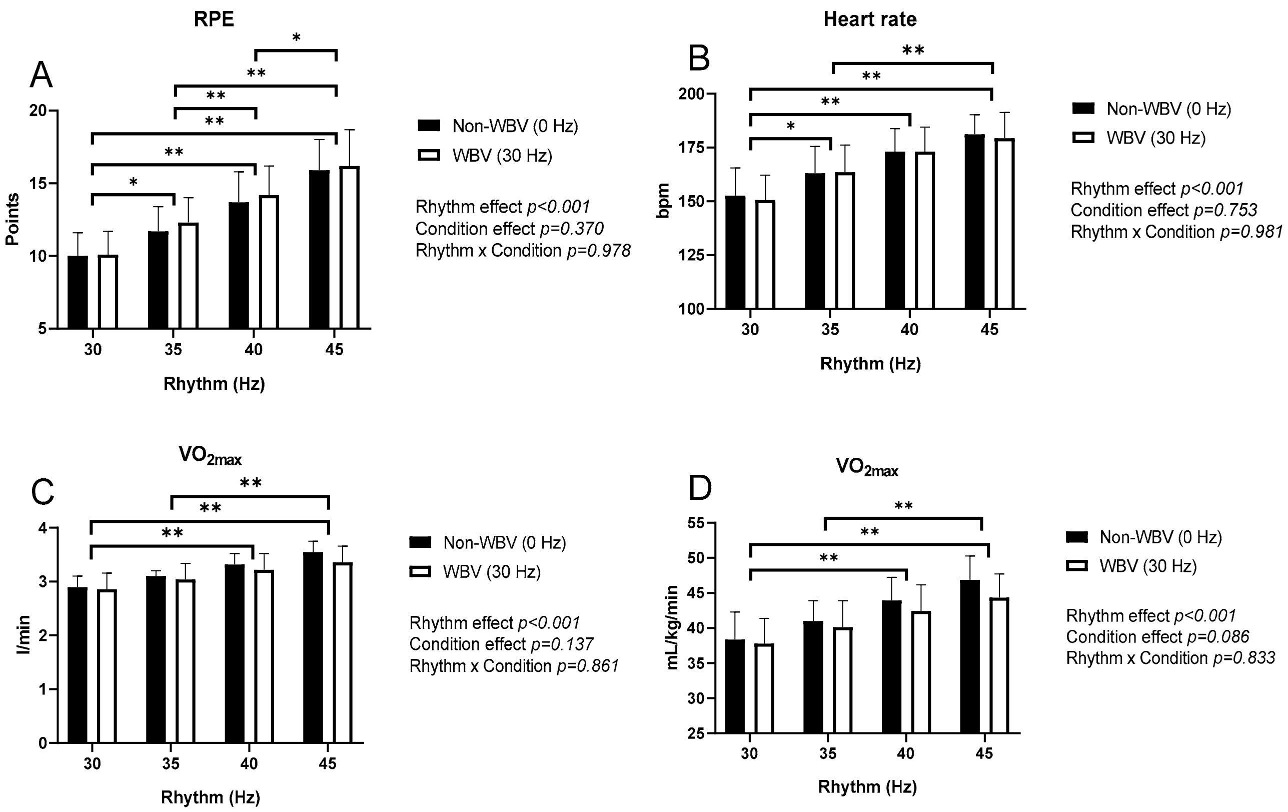

Figure 2. Evolution of RPE, HR, and VO_{2max} during the incremental test with and without vibration. (**A**) RPE: rating of perceived exertion; (**B**) HR: heart rate; (**C**) VO_{2max}: maximal oxygen uptake (absolute); (**D**) VO_{2max} (relative to body weight); WBV: whole-body vibration; * $p < 0.05$; ** $p < 0.01$ differences between rhythms.

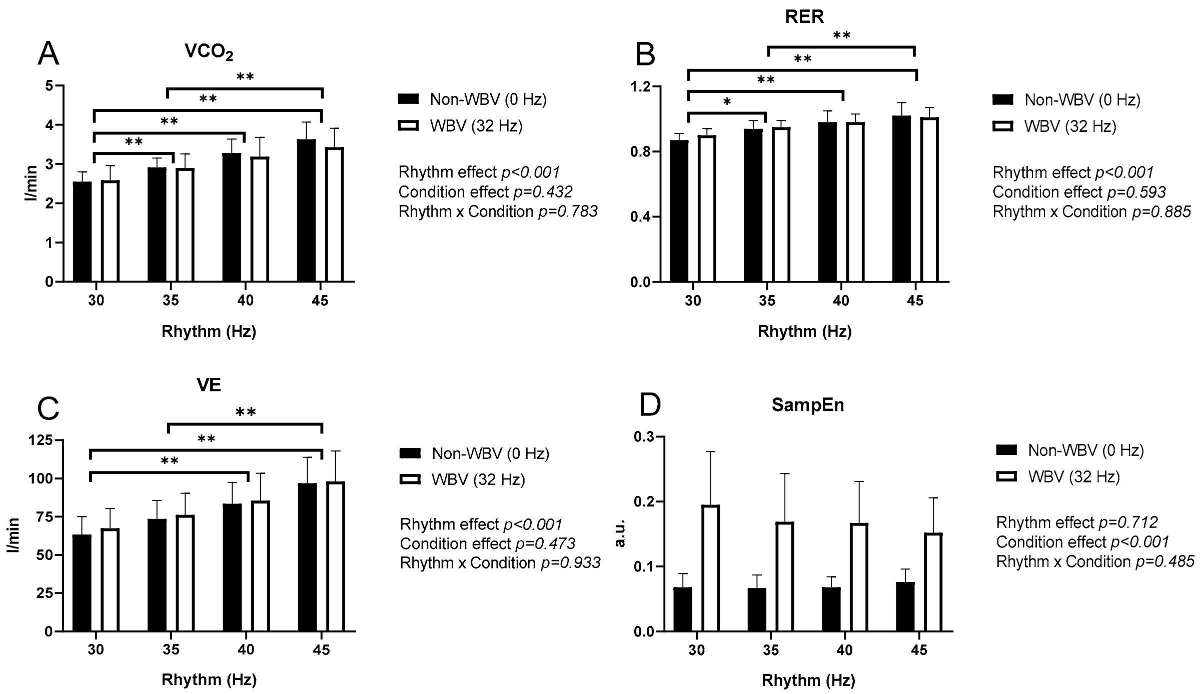

Figure 3. VCO_2, RER, VE, and SampEn evolution during incremental testing with and without vibration. (**A**) VCO_{2max}: maximal carbon dioxide; (**B**) RER: respiratory exchange ratio; (**C**) VE: expired volume; (**D**) SampEn: sample entropy; WBV: whole-body vibration; * $p < 0.05$; ** $p < 0.01$ differences between rhythms.

Table 2. Sum of squares, F, and η_p^2 values for the different effects analysed.

	Rhythm Effect			**Condition Effect**			**Rhythm × Condition**		
Parameters	**Sum of Squares**	***F***	η_p^2	**Sum of Square**	***F***	η_p^2	**Sum of Square**	***F***	η_p^2
RPE (point)	400.11	33.89	0.585	3.20	0.81	0.011	0.77	0.25	0.003
HR (bpm)	3082.94	22.66	0.486	13.61	0.10	0.001	24.13	8.04	0.002
VO_{2max} (L/min)	3.67	14.57	0.378	0.19	2.25	0.030	0.06	0.02	0.010
VO_{2max} (mL/kg/min)	637.42	17.12	0.416	37.65	3.03	0.040	10.78	3.59	0.012
VCO_{2max} (L/min)	10.32	22.78	0.487	0.09	0.62	0.009	0.16	0.05	0.015
RER	0.18	16.94	0.414	0.00	0.28	0.004	0.00	0.00	0.009
VE (L/min)	11,246.67	16.20	0.403	120.54	0.52	0.007	20.74	6.91	0.001
SampEn (a.u.)	0.00	0.459	0.019	0.20	77.71	0.519	0.00	0.00	0.033

η_p^2: partial eta squared; RPE: rating of perceived exertion; HR: heart rate; VO_{2max}: maximal oxygen uptake; VCO_{2max}: peak carbon dioxide; RER: respiratory exchange ratio; VE: expired volume; SampEn: sample entropy.

Table 3. Differences between rhythms in the analysed physiological and MV parameters.

Parameters	**Condition I (Hz)**	**Condition II (Hz)**	**Mean Differences**	***p***	**CI (95%)**	
					Lower	**Upper**
RPE (point)	30	35	−2.00	0.013	−3.70	−0.29
		40	−3.92	<0.001	−5.62	−2.22
		45	−6.02	<0.001	−7.72	−4.32
	35	40	−1.92	0.018	−3.62	−0.22
		45	−4.02	<0.001	−5.72	−2.32
	40	45	−2.10	0.008	−3.80	−0.39

Table 3. *Cont.*

Parameters	Condition I (Hz)	Condition II (Hz)	Mean Differences	*p*	CI (95%)	
					Lower	Upper
HR (bpm)	30	35	−11.60	0.014	−21.60	−1.59
		40	−21.45	<0.001	31.45	−11.44
		45	−28.60	<0.001	−38.60	−18.59
	35	40	−9.85	0.056	−19.85	0.15
		45	−17.00	<0.001	27.00	−6.99
	40	45	−7.15	0.339	−17.15	2.85
VO_{2max} (L/min)	30	35	−0.18	0.275	−0.43	0.06
		40	−0.38	<0.001	−0.63	−0.13
		45	−0.57	<0.001	−0.82	−0.32
	35	40	−0.20	0.187	−0.45	0.04
		45	−0.38	<0.001	−0.63	−0.13
	40	45	−0.18	0.291	−0.43	0.06
VO_{2max} (mL/kg/min)	30	35	−2.47	0.177	−5.49	0.54
		40	−5.10	<0.001	−8.12	−2.07
		45	−7.54	<0.001	−10.56	−4.51
	35	40	−2.62	0.127	−5.64	0.39
		45	−5.06	<0.001	−8.08	−2.04
	40	45	−2.44	0.190	−5.46	0.58
VCO_{2max} (L/min)	30	35	−0.34	0.039 *	−0.67	−0.01
		40	−0.66	<0.001	−0.99	−0.33
		45	−0.96	<0.001	−1.29	−0.63
	35	40	−0.32	0.066	−0.65	0.01
		45	−0.61	<0.001	−0.95	−0.28
	40	45	−0.29	0.106	−0.63	0.03
RER	30	35	−0.05	0.018	−0.11	−0.006
		40	−0.03	<0.001	−0.14	−0.04
		45	−0.12	<0.001	−0.18	−0.07
	35	40	−0.03	0.302	−0.08	0.01
		45	−0.07	0.002	−0.12	−0.01
	40	45	−0.03	0.530	−0.08	0.01
VE (L/min)	30	35	−9.47	0.316	−22.52	3.57
		40	−19.13	0.001 *	−32.17	−0.60
		45	−32.02	<0.001 *	−45.07	−18.97
	35	40	−9.65	0.291	−22.70	3.39
		45	−22.55	<0.001 *	−35.59	−9.50
	40	45	−12.89	0.055	−25.94	0.15
SampEn (a.u.)	30	35	0.013	1.000	−0.03	0.05
		40	0.014	1.000	−0.02	0.05
		45	0.017	1.000	−0.02	0.06
	35	40	0.000	1.000	−0.04	0.04
		45	0.004	1.000	−0.03	0.04
	40	45	0.003	1.000	−0.04	0.04

η_p^2: partial eta squared; RPE: rating of perceived exertion; HR: heart rate; VO_{2max}: maximal oxygen uptake; VCO_{2max}: peak carbon dioxide; RER: respiratory exchange ratio; VE: expired volume; SampEn: sample entropy; * $p < 0.05$ differences between rhythms (conditions).

Finally, Figure 4 shows the linear regressions between the physiological parameters analysed and MV. Significance was observed in the relationships between SampEn and HR ($p = 0.02$) and between SampEn and VO_{2max} absolute and relative to body weight ($p = 0.02$; $p = 0.04$). In the rest of the figures, the p value was greater than 0.05.

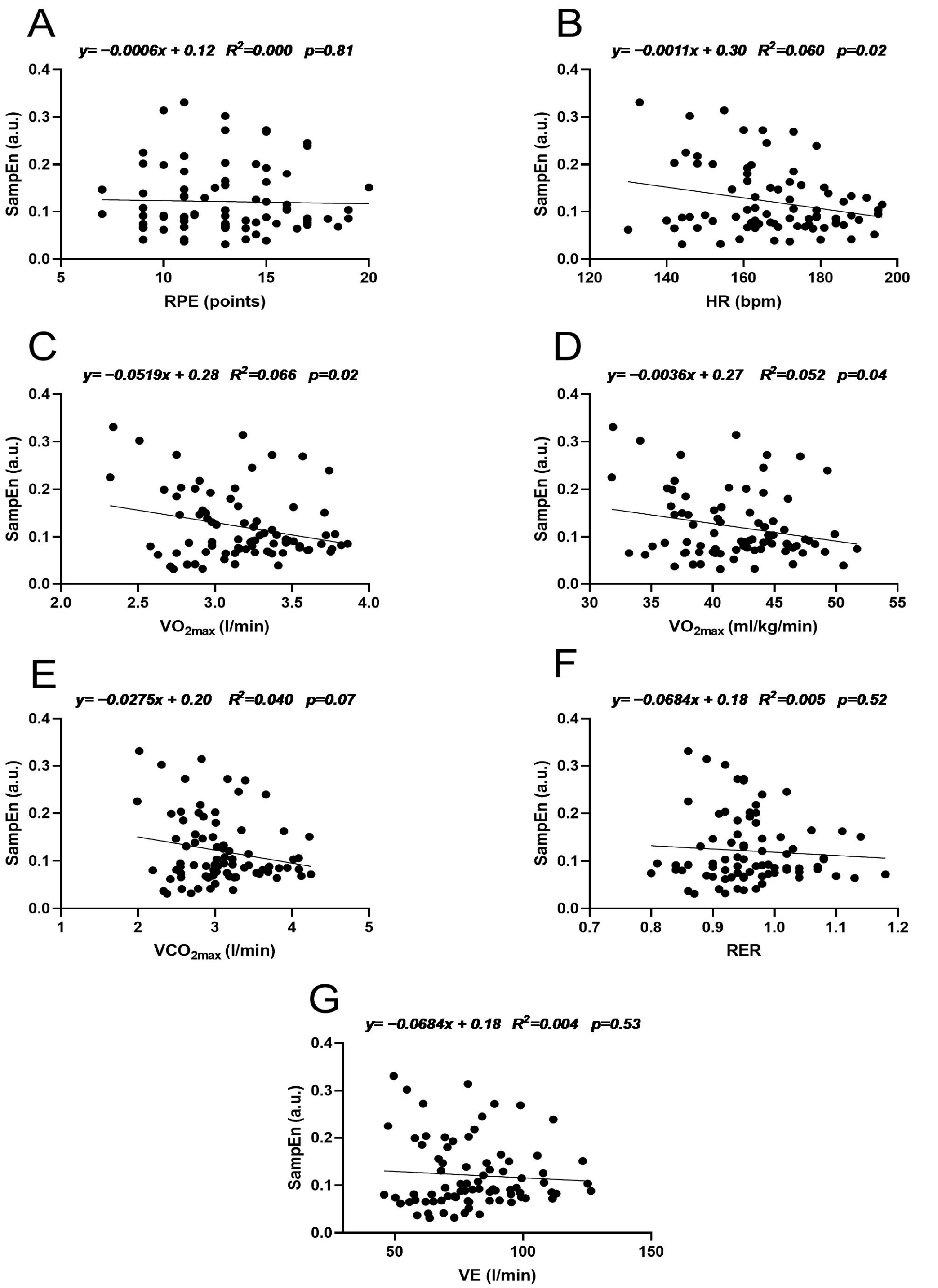

Figure 4. Linear regressions between physiological parameters analysed and SampEn. (**A**) RPE: rating of perceived exertion; (**B**) HR: heart rate; (**C**,**D**) VO_{2max}: maximal oxygen uptake; (**E**) VCO_{2max}: peak carbon dioxide; (**F**) RER: respiratory exchange ratio; (**G**) VE: expired volume; SampEn: sample entropy.

4. Discussion

The aim of the present investigation was to evaluate the effects of WBV on MV and physiological parameters during an incremental SB skating test. The results reported changes in ergospirometric parameters and RPE in relation to the rhythm (intensity) of the incremental test in SVB. However, the novelty of this study is its focus on the difference in MV between the conditions in which the incremental test was performed. SampEn was higher when the incremental test was performed with WBV in all the rhythms analysed. In addition, it should be noted that there were no differences between conditions (WBV and non-WBV) in physiological parameters. An increase in training support by exploiting different configurations of information movement within different levels of variability has gained significant traction in recent years. While this study represents the first exploration of MV in a constrained skating environment, several investigations have explored the impact of constraints on MV in human sports performance using entropy analysis [38] (i.e., by analysing video recordings of various sports, including golf and tennis, these studies have revealed changes in variability patterns associated with different constraint conditions). Similarly, more recently, SampEn was validated for MV analysis of running complexity [26]. Moreover, previous studies have indicated an increase in SampEn in the structure of body acceleration patterns when specific ball constraints were introduced for elite rugby players [19,25,39]. Our findings align with these previous investigations, which supports the notion that human performance variability is susceptible to environment constraints. Thus, SampEn measures could be a valuable tool for analysing perturbations caused by added constraints.

The SampEn values increased in the WBV condition for all players. The results obtained in the present study agree with those reported by Tuya-Viñas et al. [16] who reported that adding mechanical vibration to a half-squat exercise resulted in increased MV. These results suggest that the constraint applied to the SVB exercise induced a change in the coordination patterns of the system or establishes some combination of stability and adaptability of the movement [28,40]. These findings provide evidence that specific constraints can enhance the adaptive aspects of MV. The relationship between the degree of MV and skill and health is evolving [41]. Some degree of motor variability has been shown to be advantageous as it enables a system more adaptable to internal and external perturbations that constantly affect the body [16,29]. Therefore, the introduction of a vibration constraint during the SVB exercise impacts the athletes' sliding performance, potentially indicating compromised movement control or coordination in the presence of vibrational constraints. The perturbation observed under WBV could be attributed to the body's transient loss of contact with the SVB surface, leading to a state of being momentarily airborne due to the lack of a firm attachment [12]. Mechanical vibration interferes with postural control through complex integrations involving supraspinal structures, which leads to an increase in phasic muscle activation [42]. As a result, the escalation in MV associated with mechanical vibration could be attributed to the immediate neural modulation triggered by the vibratory stimulus within the central nervous system.

It is noteworthy that as the rhythm of the incremental test increased, SampEn decreased when exercise was performed with WBV. This observation was corroborated by linear regression analysis, which revealed an inverse relationships between SampEn vs. HR and VO_{2max}. Fatigue is known to decrease movement complexity [43]. Some studies have proposed that complexity loss is triggered, or at least influenced, by an increase in metabolic rate [44–46]. Prior researchers have suggested that peripheral fatigue may cause changes in motor unit discharge, which may be responsible for changes in complexity [46]. Similar to the current study, Tuya-Viñas et al. [16] reported a similar trend in their investigation. According to them, this fact could be explained by the relationship between the athlete's movement rhythm and the vibration frequency of the SVB. At slower rhythms, the athlete experiences more vibration cycles than at faster rhythms. Each vibration cycle generates a vertical force that tends to separate the body from the SVB, resulting in a noncontact phase that reduces grip and heightens the challenge of maintaining control [12]. Hence, it is not surprising that athletes face greater demands for rebalancing at the slower rhythm.

WBV exercise has been used as an adjunct to physical training for athletes and untrained individuals alike who seek to improve strength and power or facilitate recovery [32,47,48]. At the metabolic and cardiac level, previous studies that have combined WBV simultaneously with exercise have reported increases in HR, VE, and VO_{2max} [31,49–51]. Previous research focuses on exercises such as dynamic squat, isometric squat, push-ups, or lunges. In addition, some of this research has employed WBV frequencies and amplitudes that exceed those used in the present study, reaching up to 50 Hz. At that frequency, the only significant differences were observed in VO_{2max} [49]. On the other hand, because lateral gliding is considered a unilateral action, the muscle demand could be lower compared to a bilateral exercise, which could generate higher energy demands and thus an increase in VO_{2max} [31].

In the present study, although it was not statistically significant, the performance of the test in non-WBV conditions showed a tendency towards a higher VO_{2max} (see Figure 2D). This could be due to different reasons. On the one hand, it should be taken into consideration that the combination of the crouched position, the relatively long gliding phase, and high intramuscular forces can lead to reduced blood flow to the working muscles [52]. In addition, WBV combined with physical exercise could further decrease muscle oxygenation. A decrease in tissue oxygenation has been observed during squatting exercises that was further aggravated in the presence of WBV [53]. Consequently, exercise combined with WBV could induce muscle deoxygenation and, therefore, a decrease in VO_{2max}.

On the other hand, in WBV platforms, there is no firm grip and the only downward force acting on the body is gravity [12]. The application of vibration to individual muscles causes an illusion of movement in the opposite direction to reflex contraction [54]. Consequently, the rigid body will lose contact and become airborne. This effect together with the sliding action could decrease the resistance and, therefore, the metabolic muscle demand.

The present study is not without limitations, including (i) a small sample size (n = 10), (ii) an absence of female players, and (iii) an absence of sample-size analysis to determine whether the sample was representative.

5. Conclusions

In conclusion, adding WBV in an SB skating test for elite ice hockey players resulted in a distinct pattern of variability in body acceleration without inducing changes in physiological and perceived exertion parameters.

This suggests that WBV can be an effective tool for eliciting adaptations at different levels of the neuromuscular system without directly affecting the metabolic system.

Understanding the constraints imposed by WBV and the resulting motor adaptations can assist coaches and trainers in optimizing training efficiency.

By incorporating WBV into training programs, coaches can target specific neuromuscular adaptations, thereby enhancing the training potential of the exercises and improving the adaptive capacity of the athletes.

Given that responding to different perturbations initiated through various unstable conditions increases task-specific perceptual-motor responses and hence improves performance [55,56], we believe that understanding MV during the training process may be a key factor in improving athletic performance.

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References

1. Diener, M. The art, science, and business of the slide. *Fit. Manag.* **1994**, *10*, 26–30.
2. Pies, N.A.; Provost-Craig, M.A.; Neeves, R.E.; Richards, J.G. Cardioplmonary Responses to Slideboard Exercise in Competitive Female Ice Skaters. *Natl. Strength Cond. Assoc.* **1998**, *12*, 7–11.
3. Bower, M.E.; Kraemer, W.J.; Potteiger, J.A.; Volek, J.S.; Hatfield, D.A.; Vingren, J.L.; Spiering, B.A.; Fragala, M.S.; Ho, J.-Y.; Thomas, G.A.; et al. Relationship Between Off-Ice Testing Variables and on-Ice speed in women's collegiate synchronized figure skaters: Implications for training. *J. Strength Cond. Res.* **2010**, *24*, 831–839. [CrossRef]
4. Piucco, T.; Diefenthaeler, F.; Soares, R.; Murias, J.; Millet, G. Validation of a Maximal Incremental Skating Test Performed on a Slide Board: Comparison with Treadmill Skating. *Int. J. Sport Nutr. Exerc. Metab.* **2017**, *32*, 1363–1369. [CrossRef]
5. Vescovi, J.D.; Murray, T.M.; Fiala, K.A.; VanHeest, J.L. Off-ice performance and draft status of elite ice hockey players. *Int. J. Sports Physiol. Perform.* **2006**, *1*, 207–221. [CrossRef] [PubMed]
6. Peterson, B.J.; Fitzgerald, J.S.; Dietz, C.C.; Ziegler, K.S.; Baker, S.E.; Snyder, E.M. Off-ice anaerobic power does not predict on-ice repeated shift performance in hockey. *J. Strength Cond. Res.* **2016**, *30*, 2375–2381. [CrossRef]
7. de Boer, R.W.; Vos, E.; Hutter, W.; de Groot, G.; van Ingen Schenau, G.J. Physiological and biomechanical comparison of roller skating and speed skating on ice. *Eur. J. Appl. Physiol. Occup. Physiol.* **1987**, *56*, 562–569. [CrossRef] [PubMed]
8. Boland, M.; Miele, E.M.; Delude, K. Relationship between Physiological Off-Ice Testing, On-Ice Skating, and Game Performance in Division I Women's Ice Hockey Players. *J. Strength Cond. Res.* **2017**, *33*, 1619–1628. [CrossRef]
9. Boucher, V.G.; Parent, A.-A.; St-Jean Miron, F.; Leone, M.; Comtois, A.S. Comparison Between Power Off-Ice Test and Performance on-Ice Anaerobic Testing. *J. Strength Cond. Res.* **2017**, *34*, 3498–3505. [CrossRef]
10. Piucco, T.; O'Connell, J.; Stefanyshyn, D.; de Lucas, R.D. Incremental testing design on slide board for speed skaters: Comparison between two different protocols. *J. Strength Cond. Res.* **2016**, *30*, 3116–3121. [CrossRef]
11. Leirdal, S.; Sætran, L.; Roeleveld, K.; Vereijken, B.; Bråten, S.; Løset, S.; Holtermann, A.; Ettema, G. Effects of body position on slide boarding performance by cross-country skiers. *Med. Sci. Sports Exerc.* **2006**, *38*, 1462–1469. [CrossRef]
12. Rittweger, J. Vibration as an exercise modality: How it may work, and what its potential might be. *Eur. J. Appl. Physiol.* **2010**, *108*, 877–904. [CrossRef]
13. Colson, S.S.; Pensini, M.; Espinosa, J.; Garrandes, F.; Legros, P. Whole-body vibration training effects on the physical performance of basketball players. *J. Strength Cond. Res.* **2010**, *24*, 999–1006. [CrossRef]
14. Sierra-Guzmán, R.; Jiménez, J.F.; Ramírez, C.; Esteban, P.; Abián-Vicén, J. Effects of Synchronous Whole Body Vibration Training on a Soft, Unstable Surface in Athletes with Chronic Ankle Instability. *Int. J. Sports Med.* **2017**, *38*, 447–455. [CrossRef]
15. Roelants, M.; Verschueren, S.M.P.; Delecluse, C.; Levin, O.; Stijnen, V. Whole-Body-Vibration--Induced Increase in Leg Muscle Activity During Different Squat Exercises. *J. Strength Cond. Res.* **2006**, *20*, 124–129.
16. Tuyà Viñas, S.; Fernández-Valdés Villa, B.; Pérez-Chirinos Buxadé, C.; Morral-Yepes, M.; del Campo Montoliu, L.; Moras Feliu, G. Adding mechanical vibration to a half squat with different ballasts and rhythms increases movement variability. *PLoS ONE* **2023**, *18*, e0284863. [CrossRef]
17. Rienhoff, R.; Tirp, J.; Strauß, B.; Baker, J.; Schorer, J. The 'Quiet Eye' and Motor Performance: A Systematic Review Based on Newell's Constraints-Led Model. *Sport. Med.* **2016**, *46*, 589–603. [CrossRef]
18. McGregor, S.J.; Bollt, E. Control Entropy: What Is It and What Does It Tell Us? *Clin. Kinesiol.* **2012**, *66*, 7–12.
19. Moras, G.; Fernández-Valdés, B.; Vázquez-Guerrero, J.; Tous-Fajardo, J.; Exel, J.; Sampaio, J. Entropy measures detect increased movement variability in resistance training when elite rugby players use the ball. *J. Sci. Med. Sport* **2018**, *21*, 1286–1292. [CrossRef] [PubMed]
20. Stergiou, N.; Harbourne, R.T.; Cavanaugh, J.T. Optimal movement variability: A new theoretical perspective for neurologic physical therapy. *J. Neurol. Phys. Ther.* **2006**, *30*, 120–129. [CrossRef] [PubMed]
21. Dhawale, A.K.; Smith, M.A.; Ölveczky, B.P. The role of variability in motor learning. *Annu. Rev. Neurosci.* **2017**, *40*, 479–498. [CrossRef] [PubMed]
22. Lipsitz, L.A.; Goldberger, A.L. Loss of'complexity'and aging: Potential applications of fractals and chaos theory to senescence. *Jama* **1992**, *267*, 1806–1809. [CrossRef] [PubMed]
23. Busa, M.A.; van Emmerik, R.E.A. Multiscale entropy: A tool for understanding the complexity of postural control. *J. Sport Health Sci.* **2016**, *5*, 44–51. [CrossRef] [PubMed]
24. Gao, J.; Hu, J.; Tung, W.W. Entropy measures for biological signal analyses. *Nonlinear Dyn.* **2012**, *68*, 431–444. [CrossRef]

25. Fernández-Valdés, B.; Sampaio, J.; Exel, J.; González, J.; Tous-Fajardo, J.; Jones, B.; Moras, G. The influence of functional flywheel resistance training on movement variability and movement velocity in elite rugby players. *Front. Psychol.* **2020**, *11*, 1205. [CrossRef]
26. Murray, A.M.; Ryu, J.H.; Sproule, J.; Turner, A.P.; Graham-Smith, P.; Cardinale, M. A Pilot Study Using Entropy as a Non-Invasive Assessment of Running. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 1119–1122. [CrossRef]
27. Couceiro, M.S.; Dias, G.; Mendes, R.; Araújo, D. Accuracy of pattern detection methods in the performance of golf putting. *J. Mot. Behav.* **2013**, *45*, 37–53. [CrossRef]
28. Schöllhorn, W.I. Applications of systems dynamic principles to technique and strength training. *Acta Acad. Olymp. Est.* **2000**, *8*, 67–85.
29. Suarez, D.G.; Wagle, J.P.; Cunanan, A.J.; Sausaman, R.W.; Stone, M.H. Dynamic correspondence of resistance training to sport: A brief review. *Strength Cond. J.* **2019**, *41*, 80–88. [CrossRef]
30. Cardinale, M.; Lim, J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J. Strength Cond. Res.* **2003**, *17*, 621–624.
31. Kang, J.; Ratamess, N.A.; Kuper, J.; O'Grady, E.; Nicole, E.; Vought, I.; Bush-Wallace, J.A.; Faigenbaum, A.D. Cardiometabolic responses of body-weight exercises with and without vibration. *Kinesiology* **2019**, *51*, 83–91. [CrossRef]
32. Luo, J.; McNamara, B.; Moran, K. The use of vibration training to enhance muscle strength and power. *Sport. Med.* **2005**, *35*, 23–41. [CrossRef] [PubMed]
33. Chen, C.-H.; Liu, C.; Chuang, L.-R.; Chung, P.-H.; Shiang, T.-Y. Chronic effects of whole-body vibration on jumping performance and body balance using different frequencies and amplitudes with identical acceleration load. *J. Sci. Med. Sport* **2014**, *17*, 107–112. [CrossRef] [PubMed]
34. Montgomery, P.; Pyne, D.; Minahan, C. The Physical and Physiological Demands of Basketball Training and Competition. *Int. J. Sports Physiol. Perform.* **2010**, *5*, 75–86. [CrossRef] [PubMed]
35. Borg, G. Psychophysical bases of perceived exertion. *Med. Sci. Sport. Exerc.* **1982**, *14*, 377–381. [CrossRef]
36. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Routledge Academic: New York, NY, USA, 1988.
37. Lakens, D. Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Front. Psychol.* **2013**, *4*, 863. [CrossRef] [PubMed]
38. Couceiro, M.S.; Clemente, F.M.; Dias, G.; Mendes, P.; Fernando, M.L. On an Entropy-based Performance Analysis in Sports. In Proceedings of the 1st International Electronic Conference on Entropy and Its Applications, Internet, 3–21 November 2014; pp. 1–20. [CrossRef]
39. Moras, G.; Vázquez-Guerrero, J.; Fernández-Valdés, B.; Rosas-Casals, M.; Weakley, J.; Jones, B.; Sampaio, J. Structure of force variability during squats performed with an inertial flywheel device under stable versus unstable surfaces. *Hum. Mov. Sci.* **2019**, *66*, 497–503. [CrossRef]
40. van Emmerik, R.E.A.; van Wegen, E.E.H. On the functional aspects of variability in postural control. *Exerc. Sport Sci. Rev.* **2002**, *30*, 177–183. [CrossRef] [PubMed]
41. Hamill, J.; van Emmerik, R.E.A.; Heiderscheit, B.C.; Li, L. A dynamical systems approach to lower extremity running injuries. *Clin. Biomech.* **1999**, *14*, 297–308. [CrossRef]
42. Zaidell, L.N.; Mileva, K.N.; Sumners, D.P.; Bowtell, J.L. Experimental evidence of the tonic vibration reflex during whole-body vibration of the loaded and unloaded leg. *PLoS ONE* **2013**, *8*, e85247. [CrossRef]
43. García-Aguilar, F.; Caballero, C.; Sabido, R.; Moreno, F.J. The use of non-linear tools to analyze the variability of force production as an index of fatigue: A systematic review. *Front. Physiol.* **2022**, *13*, 1074652. [CrossRef] [PubMed]
44. Pethick, J.; Winter, S.L.; Burnley, M. Loss of knee extensor torque complexity during fatiguing isometric muscle contractions occurs exclusively above the critical torque. *Am. J. Physiol. Integr. Comp. Physiol.* **2016**, *310*, R1144–R1153. [CrossRef] [PubMed]
45. Pethick, J.; Winter, S.L.; Burnley, M. Physiological complexity: Influence of ageing, disease and neuromuscular fatigue on muscle force and torque fluctuations. *Exp. Physiol.* **2021**, *106*, 2046–2059. [CrossRef]
46. Pethick, J.; Casselton, C.; Winter, S.L.; Burnley, M. Ischemic preconditioning blunts loss of knee extensor torque complexity with fatigue. *Med. Sci. Sports Exerc.* **2021**, *53*, 306. [CrossRef] [PubMed]
47. Giombini, A.; Macaluso, A.; Laudani, L.; Di Cesare, A.; Piccinini, A.; Pigozzi, F.; Saraceni, V.M. Acute effect of whole-body vibration at optimal frequency on muscle power output of the lower limbs in older women. *Am. J. Phys. Med. Rehabil.* **2013**, *92*, 797–804. [CrossRef] [PubMed]
48. Marín, P.J.; Rhea, M.R. Effects of vibration training on muscle power: A meta-analysis. *J. Strength Cond. Res.* **2010**, *24*, 871–878. [CrossRef] [PubMed]
49. Kang, J.; Porfido, T.; Ismaili, C.; Selamie, S.; Kuper, J.; Bush, J.A.; Ratamess, N.A.; Faigenbaum, A.D. Metabolic responses to whole-body vibration: Effect of frequency and amplitude. *Eur. J. Appl. Physiol.* **2016**, *116*, 1829–1839. [CrossRef] [PubMed]
50. Hazell, T.J.; Lemon, P.W.R. Synchronous whole-body vibration increases VO_2 during and following acute exercise. *Eur. J. Appl. Physiol.* **2012**, *112*, 413–420. [CrossRef]
51. Gojanovic, B.; Feihl, F.; Gremion, G.; Waeber, B. Physiological response to whole-body vibration in athletes and sedentary subjects. *Physiol. Res.* **2014**, *63*, 779–792. [CrossRef]
52. Konings, M.J.; Elferink-Gemser, M.T.; Stoter, I.K.; Van der Meer, D.; Otten, E.; Hettinga, F.J. Performance characteristics of long-track speed skaters: A literature review. *Sport. Med.* **2015**, *45*, 505–516. [CrossRef]

53. Yamada, E.; Kusaka, T.; Miyamoto, K.; Tanaka, S.; Morita, S.; Tanaka, S.; Tsuji, S.; Mori, S.; Norimatsu, H.; Itoh, S. Vastus lateralis oxygenation and blood volume measured by near-infrared spectroscopy during whole body vibration. *Clin. Physiol. Funct. Imaging* **2005**, *25*, 203–208. [CrossRef] [PubMed]
54. Goodwin, G.M.; McCloskey, D.I.; Matthews, P.B.C. The contribution of muscle afferents to keslesthesia shown by vibration induced illusionsof movement and by the effects of paralysing joint afferents. *Brain* **1972**, *95*, 705–748. [CrossRef] [PubMed]
55. Birklbauer, J. *Optimal Variability for Effective Motor Learning: A Theoretical Review and Empirical Work on Movement Variability*, 1st ed.; Müller, E., Ed.; Meyer & Meyer: Aachen, Germany, 2019.
56. Wulf, G.; Shea, C.H. Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychon. Bull. Rev.* **2002**, *9*, 185–211. [CrossRef] [PubMed]