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Effects of Adding Mechanical Vibration and a Stick on Acceleration and Movement Variability during a Slide-Board Skating Exercise: Differences between the Dominant and Non-Dominant Legs

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Abstract: The aim of the present study was to analyse differences in acceleration and movement variability caused by adding whole-body vibration (WBV) and an implement (stick) while performing a slide-board (SB) skating exercise. A total of 10 professional ice-hockey players (age 20.4 ± 2.07 years) participated in the study. Participants performed 30 s of lateral sliding on a slide vibration board (SVB). Four conditions were analysed: no vibration and no stick (NVNS), no vibration with a stick (NVS), vibration without a stick (VNS) and vibration with a stick (VS). Peak acceleration, mean acceleration and movement variability (MV) were analysed in the dominant and non-dominant legs in each condition. Peak acceleration was higher in the non-dominant leg ($p < 0.01$). However, MV was higher in the dominant leg ($p < 0.01$). Regarding differences between conditions, mean acceleration was higher in VNS and VS than in NVS ($p < 0.05$). Regarding MV (sample entropy), there were differences in NVNS compared to VNS and VS ($p < 0.01$) and in NVS compared to VNS and VS ($p < 0.01$), with the values being superior in VNS and VS. The addition of WBV during an SB skating exercise results in an increase in MV and mean acceleration. The dominant leg shows greater MV regardless of the addition of vibration and a stick during sliding on an SVB.

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

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1. Introduction

Ice hockey is a team sport characterised by short periods of fast skating alternated with extended periods of recovery [1,2]. Ice hockey requires well-developed aerobic and anaerobic energy pathways. In addition to the intense glycolytic activity associated with vigorous muscular actions, ice hockey demands substantial aerobic power and endurance [2,3]. The game actions are complex and multifaceted, requiring endurance, speed and strength along with highly developed technical, tactical and cognitive skills. These skills enable swift decision making and precise execution of specific movements and techniques during the game [4,5].

Ice-hockey training typically comprises a combination of both off-ice and on-ice components [6–8]. Off-ice training commonly emphasises strength and conditioning exercises to enhance explosive and maximum strength, repeated sprint ability, squat jumps and aerobic and anaerobic fitness [9,10]. However, a significant portion of these exercises are non-specific to the demands of ice hockey, such as running, jumps and cycling [11]. While these exercises have demonstrated positive effects on on-ice performance, the use of more specific off-ice exercises could potentially yield even greater benefits. In this context, slide-board (SB) exercises have emerged as a promising option, having been effectively employed in rehabilitation programs for ice-hockey injuries and validated as a specific off-ice testing exercise for speed skaters due to their sport-related demands [12]. For example, according to Bizzini [13], in the early stages of return to play, adapted SB exercises can be used to improve sport-specific reactive stabilisation. Additionally, SB exercise could be beneficial for increasing quadriceps strength after anterior cruciate ligament reconstruction [14]. As such, incorporating SB exercises into ice-hockey strength and conditioning programs could provide a more targeted and effective approach to enhancing performance.

Perturbed performance training, where performers are challenged with a variety of stimuli during task execution, has demonstrated enhanced effects in rehabilitation, sport, fitness and health [15–19]. This approach, based on constraint-induced training principles, increases the level of physical stress or stimulus without necessarily altering traditional training variables such as volume, intensity and density. Specifically, manipulating task unpredictability enhances exercises' technical difficulty, variability in movement patterns and uncertainty in the actions required [20,21]. By introducing task unpredictability, coaches and trainers can disrupt performers' stability and prevent plateaus in training adaptations, promoting continuous improvement and enhanced performance.

Various studies have demonstrated that implementing task constraints, such as incorporating a ball during rugby resistance training or wielding a stick in field-hockey sprinting tasks, can evoke unique patterns of variability in players' body acceleration across various time scales, particularly at higher-level or systemic scales [20,22,23]. While all players were found to be perturbed by these task constraints, several parameters were assessed to quantify the level of perturbation, including muscle activity [24,25], kinematics and movement variability (MV). MV can be assessed using sample entropy (SampEn), a computational algorithm that evaluates the overall temporal variability structure of a signal and quantifies signal reproducibility [26]. SampEn can be applied to a given data series such as the acceleration time series collected using an inertial measurement unit (IMU) and has gained prominence as an effective method for evaluating the level of perturbation experienced by athletes engaged in constrained tasks [20,27,28]. In the context of perturbation, lower SampEn values, indicating greater reproducibility of movement patterns, suggest a reduced level of perturbation, whereas higher SampEn values, indicating less reproducibility, suggest a greater level of perturbation [28].

While introducing task constraints inevitably perturbs performers [29], the specific nature of this perturbation depends on the dynamic interplay between the task, athlete and environment. Therefore, careful assessment is necessary to fully understand the effects of task constraints on MV. In this context, the development of a large vibrating SB has enabled the incorporation of vibration/surface constraints into sliding tasks [30]. Traditionally, whole-body vibration (WBV) exercise has been employed in resistance training, but its application as an unstable perturbation during displacement sliding tasks has been limited due to the absence of suitable platforms. However, WBV has been combined with unstable surfaces or shoes during squatting exercises and has been evaluated in terms of muscle activation [17], reaction time [18] and MV [19]. These studies have demonstrated that the interaction of task constraints can significantly impact MV, highlighting the need to consider the specific athlete–task–environment combination when evaluating the effects of constraint perturbation.

Recent studies have demonstrated that WBV training enhances MV [31]. This enhancement of MV is considered a crucial component of adaptability to the environment, which is essential for enhancing athletic performance [32]. Similarly, task constraints introduced by adding external implements, such as balls, have been shown to lead to increased MV, resulting in alterations in the coordination patterns of the system [33]. However, the investigation of MV in ice hockey remains limited. Therefore, this study aimed to identify differences in acceleration and MV when incorporating WBV and an implement (stick) during an SB skating exercise on a slide vibration board (SVB). We hypothesised that the combined effects of vibration stimuli and the stick as task constraints would enhance the variability structure of the players' body acceleration, which could be detected using a non-linear approach.

2. Materials and Methods

2.1. Participants

Ten professional ice hockey players gave written consent to participate in this study (mean ± SD: 20.4 ± 2.07 years; 1.79 ± 0.05 m; 75.97 ± 5.44 kg). All were part of a professional team from Spain. The inclusion criterion was to have at least ten years of ice-hockey experience. Participants were involved in five training sessions per week, which lasted ten hours per week. Exclusion criteria included a history of head trauma, cardiovascular diseases, joint implants and low back pain or a condition that would not allow WBV training (i.e., musculoskeletal and/or chronic disorders). Participants were instructed not to participate in any physical activity 24 h prior to the experiment. Participants were asked to report any discomfort or unusual symptoms immediately. If these occurred, then the experiment was stopped. The procedures of this study complied with the Declaration of Helsinki (2013) and were approved by the Ethics Committee for Clinical Sport Research of Catalonia (06/2018/CEICGC). Each participant was assigned a code for the collection and processing of samples to preserve their anonymity.

2.2. Instruments and Tasks

The ice-hockey players performed the analyses by sliding upon a slide vibration board (SVB; Vislide, Viequipment, Movilani System SCP, Sant Joan Despí, Barcelona, Spain). The characteristics of the SVB were as follows: frequencies (20, 25 and 30 Hz), amplitude (1.7 mm [peak-to-peak displacement]), total size (2.27 × 0.74 × 0.24 m) and sliding surface size (2.00 × 0.59 m). The SVB is a synchronously vibrating platform. Players wore a pair of nylon socks over their shoes to be able to slide on the polyethylene surface [30]. The acceleration of the ice-hockey players was registered using an IMU (WIMU, Realtrack Systems, Almería, Spain) with a 3D accelerometer (range: ± 100 G; sampling frequency: 1000 Hz). The rhythm of the skating exercise on the SVB was controlled using a metronome (Korg KDM-3, Tokyo, Japan) [31].

The task consisted of sliding from side to side upon the SVB according to the players' own technique for 30 s. The players performed the four tasks with different conditions in randomised order, constrained or not by the combinations of vibration and a stick. Carrying a stick meant successfully driving a puck with the stick while performing the task on the SVB. The conditions analysed are described below:

- No vibration and no stick (NVNS): the SB skating exercise was performed without WBV and without the stick implement.
- No vibration with a stick (NVS): the SB skating exercise was performed without WBV and with the stick implement driving a puck.
- Vibration without a stick (VNS): the SB skating exercise was performed with WBV and without the stick implement.
- Vibration with a stick (VS): the SB skating exercise was performed with WBV and with the stick implement driving a puck.

To determine the influence of the lateral dominance of the lower limbs, the dominant and non-dominant leg were analysed separately. Lateral dominance was determined by interviewing the athlete.

2.3. Experimental Design and Procedures

To investigate the effects of WBV and stick perturbations on acceleration and MV, a cross-over study design was employed, involving a single group of participants undergoing two testing sessions separated by a one-week interval. Participants were exposed to the four aforementioned conditions in a counterbalanced manner. Participants visited the laboratory three times in total: once for a familiarisation session to acclimate to the equipment and procedures, and twice for the actual testing sessions.

Each testing session commenced with a standardised warm-up consisting of 3 min of cycle ergometer exercise followed by one set of each experimental condition. This was followed by a 5-min rest period before the test. The test protocol involved four sets consisting of 30-s skating bouts, one for each condition, separated by 3-min rest intervals. The skating rhythm was maintained at 30 bpm, and the WBV stimulus was applied at 30 Hz and an amplitude of 1.7 mm (peak-to-peak displacement).

To minimise potential confounding factors and ensure the integrity of the experimental design, the order of the experimental conditions was randomised to control for cross-contamination effects. The different rhythms were controlled using a metronome (speed constraint). The test was finished when all four conditions were registered successfully. If a set was not completed under the study requirements (i.e., loss of skating balance or loss of control of the puck), the set was stopped and repeated after a 1-min rest period. No participant repeated the same condition more than once. The test protocol is described below (Figure 1):

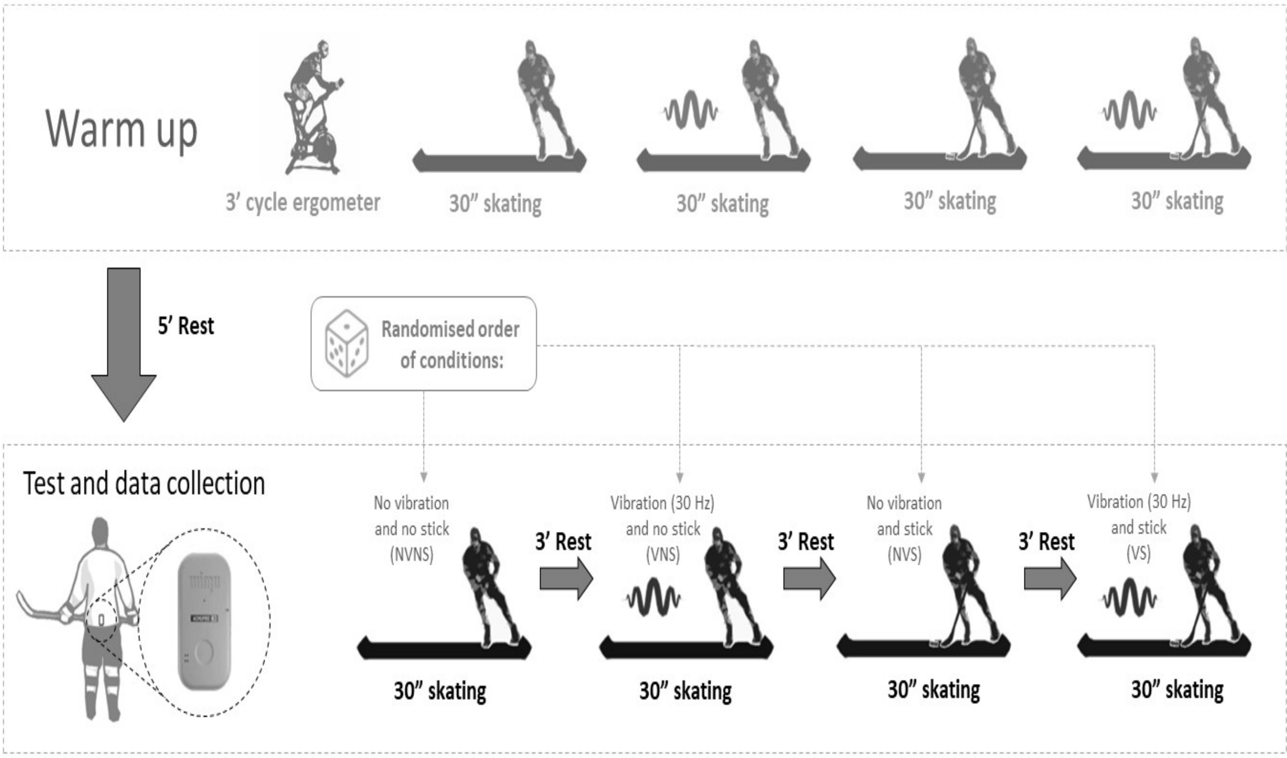

Figure 1. Study design; NVNS: no vibration and no stick; NVS: no vibration with stick; VNS: vibration without stick; VS: vibration with stick.

2.4. Data Collection and Processing

Players were instructed to synchronise their side-to-side movements with the tempo set by the metronome. The duration of lateral displacement was standardised to ensure consistent data collection. After a familiarisation period, data were collected by attaching an IMU to the lower back of each player at the L4-L5 level using an elastic belt (Figure 2). IMUs were configured to collect data at a sampling frequency of 1000 Hz and were calibrated on a flat surface, consistent with established protocols [20,22,31,33]. This placement was chosen to optimise the capture of whole-body movement data [34]. The IMUs employed in this study have demonstrated excellent accuracy and reliability in previous research [35–38].

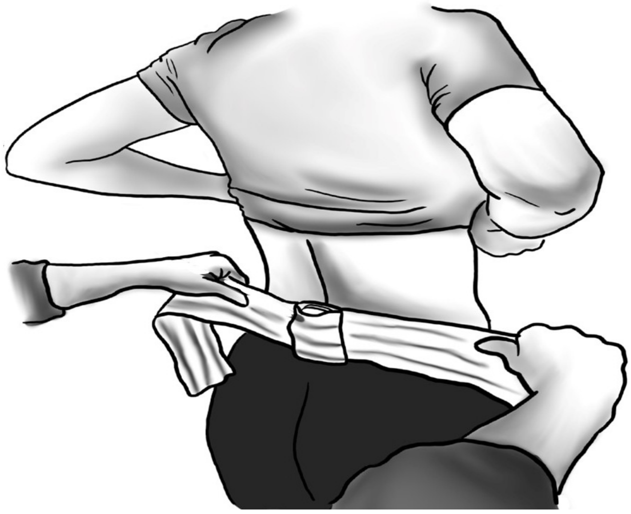

Figure 2. Placement of the accelerometer on the lower back.

For the analysis, 10 lateral slides (5 with the dominant leg and 5 with the non-dominant leg) characterised by push-off actions were extracted from each participant's time-series data to eliminate any potential influence from the initial and final phases of the movement. The first 10 s of push-offs were discarded to allow stabilisation of behaviour. Subsequently, the raw acceleration data collected from the IMUs were analysed using WIMU software (V1.0.0, SPRO, Realtrack Systems, Almería, Spain). The acceleration signals were processed using a summation of vectors (AcelT) in three axes, namely, vertical (x), mediolateral (y) and anteroposterior (z), following the method described by previous authors [36,39].

SampEn was calculated for the AcelT signals according to the algorithm described by Goldberger et al. [40], using custom-written Matlab® routines (version R2020a, The MathWorks, Natick, MA, USA). Additionally, the mean value (MeanAcelT) and peak value (PeakAcelT) of AcelT were calculated.

To establish the values for the dominant and non-dominant legs, the exercise always started by pushing off with the dominant leg. This was performed so that in the subsequent analysis, the first push-off was omitted, and from that point on, odd peaks corresponded to the non-dominant leg, and even peaks to the dominant leg.

2.5. Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics 22.0 for Windows (SPSS Inc., Chicago, IL, USA). Normality and homogeneity of variances were assessed using the Shapiro-Wilk test and Levene's test, respectively. The primary analysis involved a two-way ANOVA considering leg dominance, whole-body vibration (WBV) and stick conditions. Specific differences between conditions were determined using the Bonferroni post hoc test. The significance level was set at $p < 0.05$. Results were reported as the mean ± standard deviation. *F*-values; *p*-values; effect-size (ES) values, represented as the eta partial square (η_p^2); and the 95% CI were reported. The magnitude of ES was categorised as small ($\eta_p^2 = 0.01$), medium ($\eta_p^2 = 0.06$) or large ($\eta_p^2 = 0.14$) [41,42].

3. Results

The results of this study are presented in Figures 3 and 4, which depict the findings for peak AcelT, mean AcelT, SampEn and time for each lateral displacement. Peak AcelT was significantly higher in the non-dominant leg than in the dominant leg ($p < 0.001$). In contrast, SampEn was significantly greater in the dominant leg ($p < 0.001$).

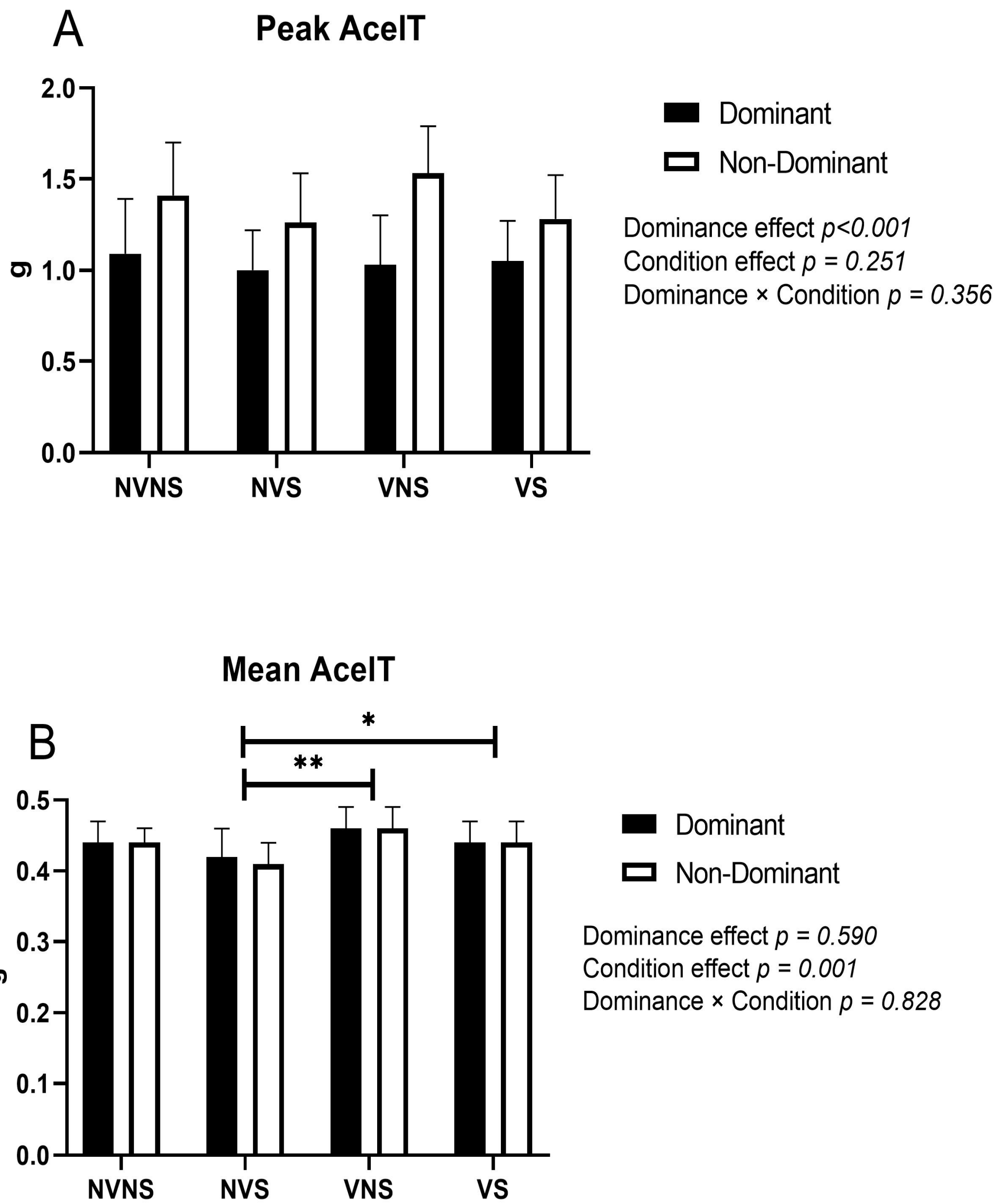

Figure 3. Peak and mean AcelT in different conditions. (**A**): Peak AcelT; (**B**): Mean AcelT; AcelT: acceleration; NVNS: no vibration and no stick; NVS: no vibration with stick; VNS: vibration without stick; VS: vibration with stick; * $p < 0.05$, ** $p < 0.01$ for differences between conditions.

Regarding mean AcelT, it was superior in VNS ($p < 0.01$) and VS ($p < 0.05$) compared to the NVS condition. For SampEn, the values were higher when vibration was added than with no vibration. Specifically, there were significant differences between NVNS and the VNS and VS conditions ($p < 0.01$), as well as between NVS and the VNS and VS conditions ($p < 0.01$).

No significant interactions were observed, and there were no differences in the time of the sliding action.

Table 1 shows the data corresponding to the differences between leg dominance (dominant and non-dominant) and conditions (NVNS, NVS, VNS and VS) in the sum of squares, F and $\eta_p{}^2$ for the different effects. Large effect sizes were reported on peak AcelT and SampEn for the dominance effect; in the condition effect, large effect sizes were reported on mean AcelT and SampEn.

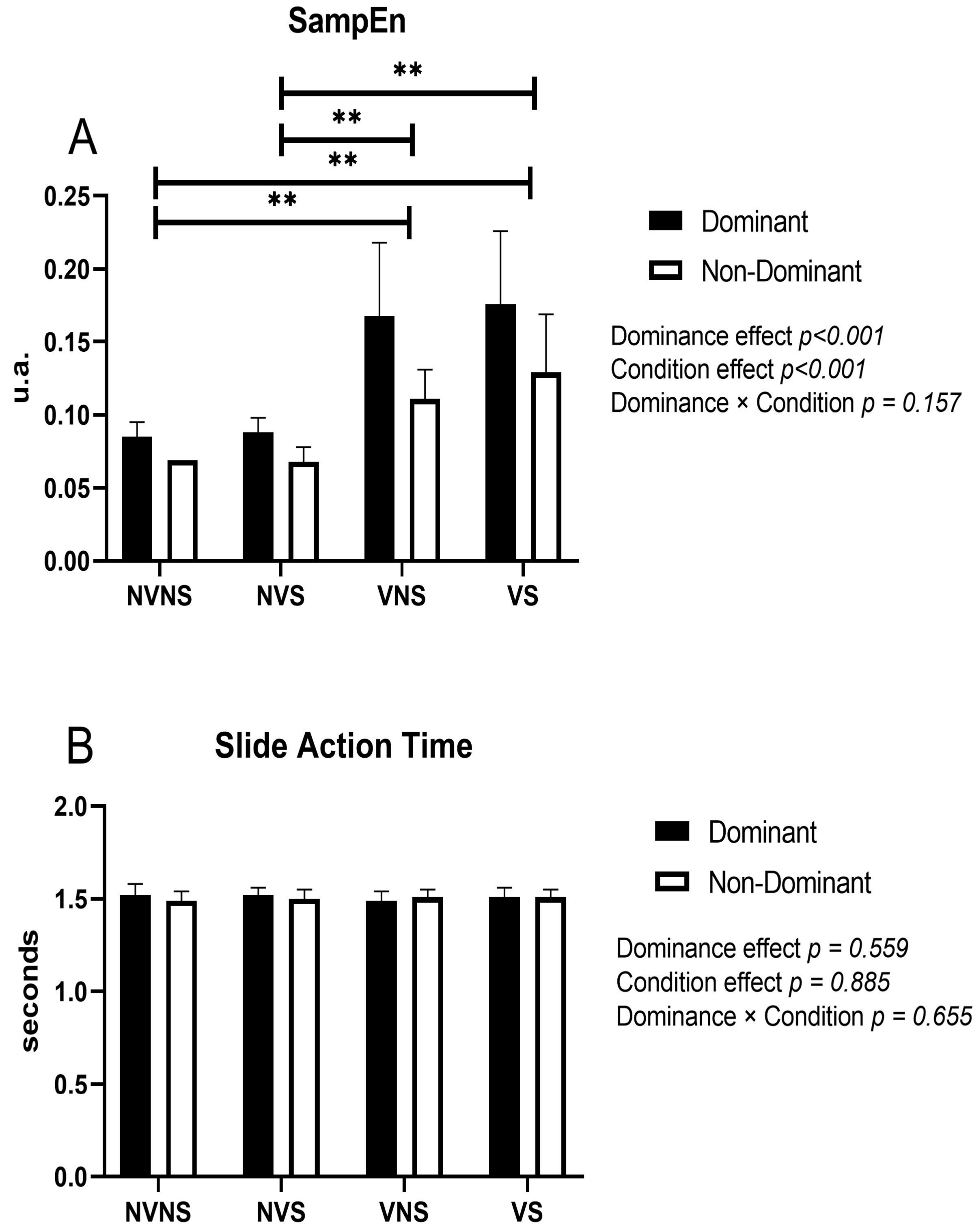

Figure 4. SampEn and sliding action time in different conditions. (**A**): SampEn; (**B**): Time; SampEn: sample entropy; NVNS: no vibration and no stick; NVS: no vibration with stick; VNS: vibration without stick; VS: vibration with stick; ** $p < 0.01$ for differences between conditions.

Table 1. Values of sum of squares, F and $\eta_p{}^2$ for the different effects analysed (dominance, condition and dominance × condition).

Parameters	Dominance Effect			Condition Effect			Dominance × Condition		
	Sum of Squares	F	$\eta_p{}^2$	Sum of Squares	F	$\eta_p{}^2$	Sum of Squares	F	$\eta_p{}^2$
Peak AcelT (g)	2.208	31.29	0.303	0.296	1.396	0.055	0.232	1.097	0.044
Mean AcelT (g)	0.000	0.293	0.004	0.020	6.017	0.200	0.001	0.296	0.012
SampEn (u.a.)	0.025	21.66	0.231	0.096	28.157	0.540	0.006	1.789	0.069
Sliding Action Time (s)	0.001	0.345	0.005	0.002	0.216	0.009	0.004	0.543	0.022

AcelT: acceleration; SampEn: sample entropy; $\eta_p{}^2$: partial eta squared.

Table 2 shows the data obtained in the Bonferroni post hoc analysis (multiple comparisons) between the analysed conditions. Significant differences were reported in mean AcelT, specifically in NVS vs. VNS and in NVS vs. VS ($p < 0.05$). Similarly, in SampEn, differences were found in NVNS vs. VNS, NVNS vs. VS, NVS vs. VNS and NVS vs. VS ($p < 0.001$).

Table 2. Analysis of differences between conditions (NVNS, NVS, VNS and VS).

Parameters	Condition I	Condition II	Mean Differences	*p*	CI (95%)	
					Lower	Upper
Peak AcelT (g)	NVNS	NVS	0.120	0.945	−0.10	0.34
		VNS	−0.030	1.000	−0.25	0.19
		VS	0.080	1.000	−0.14	0.31
	NVS	VNS	−0.150	0.464	−0.37	0.07
		VS	−0.037	1.000	−0.26	0.19
	VNS	VS	0.113	1.000	−0.11	0.34
Mean AcelT (g)	NVNS	NVS	0.021	0.259	−0.06	0.05
		VNS	−0.021	0.259	−0.05	0.00
		VS	−0.009	1.000	−0.03	0.01
	NVS	VNS	−0.043	0.001 **	−0.07	0.01
		VS	−0.030	0.028 *	0.05	0.00
	VNS	VS	0.012	1.000	0.01	0.04
SampEn (u.a.)	NVNS	NVS	−0.001	1.000	−0.02	0.02
		VNS	−0.062	<0.001 **	−0.09	0.03
		VS	−0.075	<0.001 **	−0.10	0.04
	NVS	VNS	−0.061	<0.001 **	−0.09	−0.03
		VS	−0.074	<0.001 **	−0.10	−0.04
	VNS	VS	−0.013	1.000	−0.04	0.01
Sliding Action Time (s)	NVNS	NVS	−0.003	1.000	−0.04	0.04
		VNS	0.006	1.000	−0.03	0.05
		VS	−0.006	1.000	−0.05	0.03
	NVS	VNS	0.009	1.000	−0.03	0.05
		VS	−0.003	1.000	−0.04	0.04
	VNS	VS	−0.012	1.000	−0.05	0.03

AcelT: acceleration; SampEn: sample entropy; NVNS: no vibration and no stick; NVS: no vibration with stick; VNS: vibration without stick; VS: vibration with stick; * $p < 0.05$, ** $p < 0.01$ for differences between conditions.

4. Discussion

The aim of the present study was to identify differences in acceleration and MV by adding WBV and a stick while players performed a skating exercise on an SVB. Significant differences were reported between the dominant and non-dominant legs in peak AcelT and SampEn. On the other hand, there were differences between conditions (NVNS, NVS, VNS and VS) in mean AcelT and SampEn. Specifically, in the mean AcelT, there were differences in the NVS vs. VNS and VS. conditions. On the other hand, there were differences in the NVNS vs. VNS and VS conditions, as well as between the NVS and VNS conditions. Considering the above, the inclusion of vibration produces an increase in MV, which would be in line with previous studies [31]. The time for each sliding action was similar in all conditions analysed. Thus, it could be an indicator that participants had enough experience to execute the task in the imposed rhythm with competence. In this way, it was intended to ensure that the time series exported from each condition had a similar length and quantity of data. In addition, this assured us that the changes found between conditions were not determined by the execution speed but by the variations in the conditions.

Some authors propose that off-ice tests have limited utility [11]. Test batteries are extensively described [43], but their weak predictive validity, particularly due to potential lack of specificity to on-ice demands, has been demonstrated [44]. Similarly, training protocols often involve running drills without stick carrying, forgetting potential technical adaptations resulting from equipment limitations in a real match scenario [45]. In the present study, WBV was used on an SVB with the aim of executing a gesture similar to constant gliding on ice. The addition of WBV during the execution of a specific gesture such as sliding could increase the stimulus at the coordinative level.

Recent literature on skill acquisition advocates the use of constraint-based approaches to improve specificity and develop challenging training environments that increase MV and adaptability [21]. Given that responding to different perturbations initiated through various unstable conditions increases the richness of task-specific perceptual–motor experience and therefore improves performance [46,47], it is considered that understanding MV during the training process may be a key factor for optimising it.

The results obtained for peak AcelT and SampEn show differences between leg dominance in all conditions analysed. These results are in line with those found by Promsri et al. [48], who reported higher SampEn in the dominant leg during single-leg balance on different surfaces. These results substantiate the hypothesis that the SampEn, a non-linear measure of complexity that measures the variability of a given time series, could reflect an inherent difference in neuromuscular control between the legs. The assessment of postural accelerations has the potential to identify a divergence in postural control between limbs [49,50], highlighting the bilateral asymmetry in the motor control circuits of the two hemispheres [51]. With regard to AcelT, several studies have shown that the non-dominant leg absorbs impacts worse and shows greater reactive forces in receptions or landings. Therefore, it is likely that in our case, despite the similar speed of both legs, given that the time was set by the metronome, the impact absorption was worse in the non-dominant leg [52,53].

When constraints are applied to resistance training, it seems that there are changes in the coordination patterns of the system [20,54]. In the present study, it was observed that the addition of mechanical vibration increased MV. As mentioned above, this is in line with previous authors [31]. However, the addition of the implement (stick) did not produce significant changes, which is contrary to what was found by Moras et al. [20] and Fernández-Valdés et al. [33]. Mechanical vibration has been demonstrated to disturb postural regulation by engaging mechanisms that involve supraspinal structures, resulting in increased phasic muscle activation [55]. Consequently, the increase in MV induced by mechanical vibration can be explained by the acute neuronal modulation triggered by the vibratory stimulus within the central nervous system. It is known that a change in the motor command enhances excitability at the supraspinal level, in a similar way to inhibition at the spinal level. Therefore, there is an increase in cortical activity to control the body’s position [56]. Such behaviour implies a modification in the configuration of postural responses concerning external perturbations [57].

Regarding the influence of the stick, no significant differences were reported in the present study when this implement was incorporated, unlike vibration. Previous research suggests that MV can be reduced by a number of factors, including experience and technical gesture control [58–60]. Considering that they were professional players, the addition of the stick during gliding did not represent an additional stimulus, unlike WBV. Players may be accustomed to using this implement, as it is a common item in their training.

One of the main limitations of the present study was the small sample size (n = 10). However, due to the type of sport and the number of federation licenses, we consider the sample to be representative. In addition, all the players belonged to the same club, and there was no representation of players from different categories and sexes.

5. Conclusions

The addition of WBV during the sliding action on an SVB generated an increase in MV and mean AcelT. In addition, the dominant leg showed higher MV regardless of vibration and the addition of the implement during sliding on an SVB. However, the peak AcelT in the non-dominant leg was higher in all conditions analysed.

The inclusion of WBV in an ice-hockey-specific exercise such as a skating exercise on the SVB would increase the training potential and improve the adaptive capacity of the athletes.

Understanding MV during the training process seems to be a suitable tool to analyse the destabilising effect of constraints such as WBV. Furthermore, analysing it unilaterally in the dominant and non-dominant legs can help us to understand the inter-limb asymmetries in motor control and shock absorption in athletes.

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Data Availability Statement: The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding author.

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