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Vibration effect on ball score test in international vs. national level table tennis

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ABSTRACT: In table tennis, motor skills are crucial for discriminating player level. However, there is a dearth of studies exploring the impact of a vibrational stimulus on performance. Thirty-four male players (age 25±2 years; body mass index, BMI 23.4±1.2 kg·m^{-2}) participated in the study. Seventeen played at international level (IL), while the remaining 17 played at national level (NL). The participants underwent a ball-handling test, the ball score, before (PRE) and after (POST) a vibrational stimulus. Intra-class correlation (ICC) for the ball score result showed good reliability (ICC 0.87 for IL and 0.80 for NL). Repeated measures ANOVA showed differences between groups for ball score (p=0.000) and a significant group×time interaction (p=0.004). Better performances were observed for the IL group than for the NL group, significantly only for POST. Vibration produced positive and negative effects in IL and NL groups, respectively.

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INTRODUCTION

In table tennis (TT), motor skills are crucial for discriminating a player's level: a high skill level is characterized by accurate, fast movements [1]. Better players exhibit higher general physiological outcomes, such as higher maximal oxygen consumption, and performance indicators, such as maximal accumulated oxygen deficit and total amount of anaerobic work [2], hence achieving better scores. A low level athlete can compete with a high level athlete for only a few minutes, then he/she fails to keep up with the opponent's pace, due to his/her poorer timing capability [3]. In fact, the TT ball travels at ~27 m·s^{-1} and TT players have only ~1 s to get ready for the return after the opponent hits the ball [3]. The athlete's overall ability emerges especially under fatigued conditions [4], mainly in terms of fewer errors made.

The ability to be accurate and fast requires superior neuromuscular control of movement, especially of the upper limbs, given the 100-200-ms visuomotor delay [5]. However, there are no studies on TT investigating the factors discriminating the elite athlete from the amateur one. Furthermore, there are no studies concerning simple and practical tests that are reliable and ecologically valid and enable to evaluate TT players during game play.

It is well known that there exists a strong relationship between neuromuscular response and peak force and rate of force development [6]. A vibration of the upper limb, which is a mechanical stimulus characterized by oscillatory motion [7], may affect the neuromuscular response and, consequently, have an impact on performance in terms of muscle activation, force, and power [8]. In more detail, vibration is believed to act via neurogenic potentiation involving spinal reflexes and stretch-reflex muscle-spindle activity, which is based on the tonic vibration reflex [9]. For instance, in the young population, increased surface electromyography (sEMG) and voluntary activation, following a mechanical vibration, can be observed [10]. Therefore, vibration could enable one to discriminate subjects with a high nerve transmission potential from those with a low one.

Despite a dearth of studies on the matter, a mechanical vibration of the upper limb has already been shown to increase muscle activation acutely, especially in international-level TT players [11]. Padulo et al. investigated muscle activation by recording sEMG root mean square from upper arm muscles during vibration and maximal voluntary contraction (for normalization purposes [11]). Increased muscle activation is a clear requirement for performance improvement.

Therefore, given the already proven relationship between mechanical vibration and muscle activation, the aim of this study was to investigate with a ball-handling test (ball score) – as a proxy for real game play – the effect on TT performance of a vibrational stimulus in international and national TT players. Ball handling is clearly an essential skill for TT players, and both TT players and their coaches could take great advantage from an ecologically reliable ball-handling test. A ball score measure was assessed for reliability, as well.

MATERIALS AND METHODS

Subjects

For sample size calculation purposes, a pilot study that included a sample of 17 subjects was performed *a priori* and gave a statistical power greater than 0.81. Thirty-four male TT players participated in this study (age 25±2 years; body mass 70.3±4.4 kg, height 174±6 cm, and body mass index (BMI) 23.4±1.2 kg·m^{-2}). Seventeen players with international competition experience were allocated to the international-level group (all within the world top 50, training six days per week, five hours per day, training experience 12.2±4.8 years; IL), while the remaining 17 without international competition experience were allocated to the national-level group (ranked within regional rank, training three days per week, maximum two hours per day, training experience 6.6±4.9 years; NL; Table 1). Group-shared inclusion criteria were: 1) having competed during the previous season, and 2) possession of a valid medical clearance for competition. The participants were healthy, without any muscular, neurological and/or tendinous injuries, and were not taking any drug.

TABLE 1. Anthropometric characteristics.

Group	Age (yrs)	Height (cm)	Mass (kg)	BMI (kg·m^{-2})
IL	24.4±2.3	172±8	63.1±4.5*	21.4±1.5*
NL	25.9±1.6	175±4	77.5±4.3	25.3±0.8

Data (means±SD) for all subjects broken down for international (IL=17) and national (NL=17) levels. BMI=body mass index, * = statistically significant with p<0.05.

The participants refrained from drinking alcohol or caffeine for 24 hours, and fasted for at least 4 hours before testing, to reduce any interference with results. Each participant completed all trials on the testing days at the same time to eliminate any circadian variation. Both groups were homogeneous with regard to training status. None of the participants underwent any strenuous endurance activity or resistance training outside the training protocol.

After being informed of procedures, methods, benefits and possible risks of the study, each participant read and signed an informed consent form, in accordance with the requirements of the Declaration of Helsinki. The university human ethics committee followed the ethical standards for human studies and approved all experimental procedures.

Procedures

This experimental study was approached through a “cross-over” observational design. We used vibrational stimulus and group as the independent variables and ball score result as the dependent variable. Data were acquired over two different days, from 9:00 a.m. until 1:00 p.m., at average temperature of 23°C (range 22-24°C). Four participants (1 IL and 3 NL) were left-handed. Each participant wore typical TT sportswear. All experiments were done at the “Table Tennis International Centre” in Cagliari (Italy). Assessment was done over three different steps (Table 2, day 1) and repeated one week later (Table 2, day 2), to assess the reliability of the measures.

A standardized protocol was used to weigh the participants [12]: body mass was measured twice to the nearest 0.1 kg on an electronic scale (Personal Line, Filizola, Campo Grande, MS, Brazil) and the mean value was taken. Height was measured twice to the nearest 0.01 m using a portable stadiometer (67310, Country Technology, Gays Mills, WI, USA) and the mean value was taken.

Ball score

The ball score result was measured as the number of ball contacts with the racket (i.e., with frequent low vertical bounces) in 15 s. In the authors’ opinion, managing to achieve with the racket a high number of ball contacts per time unit reasonably testifies to a player’s great ball-handling capacity. Each participant attended a whole 1-hour preliminary learning session and was tested on an official TT table after performing a standardized warm-up (7 min with an opponent throwing the ball to the participant and the participant freely returning the ball with both forehand and backhand strokes). The experiment started with the participant standing with a 90° elbow angle and the ball lying on the racket. The test was performed three times, and the mean score was used for further analysis. The procedure was never interrupted during the tests and no injuries were reported.

This test session was performed within a 2×1-m area, used as acquisition volume, and recorded with a high-speed camera (Exilim FH20, Casio, Japan) located on a 1.5-m high tripod at 3 m from the participant, so as to be perpendicular to the sagittal plane of the ball trajectory.

TABLE 2. Experimental design.

		day 1		
ball score	3' pause	upper limb vibration	3' pause	ball score
		day 2		
ball score	3' pause	upper limb vibration	3' pause	ball score

Athletes were taught to perform the technical task by means of a video reproducing the test, with instructions provided by a qualified coach. The camera-sampling rate was fixed at 420 Hz (1 frame=420 Hz, i.e., lasting ~0.0024") and the resolution at 224×168 for a spatial precision of ±5 pixels. All the movies were analyzed off-line by the same operator and by using motion analysis software (Dartfish 5.5Pro, Dartfish, Fribourg, Switzerland). The measured variable was the number of ball contacts in 15 s.

Upper limb vibration

The vibrating equipment used was the Nemes Arms (nemeS HandleMed, Bosco System, Norway), with the frequency set at 40 Hz, a peak-to-peak displacement of about 2.2 mm and an acceleration of about 7.7 g for 30 s [8]. During the vibrational stimulus, the participants assumed a standing position, with the dominant arm flexed at 90° and the hand in a neutral position while gripping the handlebar (Figure 1).

Statistical analysis

Data were reported as mean±standard deviation (SD). The assumption of normality was verified with the Shapiro-Wilk test. To assess the reliability of the ball score measures the intra-class correlation coefficient (ICC) was performed [13]. The ICC represents a measure of relative reliability showing the degree to which the sample's individual measures keep their value with repeated measurements. An ICC higher than 0.75 generally exhibits excellent reliability [14]. Also, the coefficient of variation (CV) was computed.

ANOVA with a grouping factor and with time as a repeated measure was used to assess the effect of vibration on the ball score result. The normality of distribution, the homogeneity of covariance matrices, the independence and the sphericity assumptions were verified. Mauchly's test was used to check for sphericity. If the sphericity assumption was violated, the Greenhouse-Geisser correction was applied to adjust for the degrees of freedom of the interaction effect between different time points and different sample groups. If the value was less than 0.75, the Huynh-Feldt correction was used. Post-hoc tests were performed using Bonferroni correction. The effect size (ES) was classified as small ($0.01<\eta^2<0.06$), medium ($0.06<\eta^2<0.14$) or large ($\eta^2>0.14$ [15]). The significance level was set at $p<0.05$ and all the statistical analyses were performed with the commercial software SPSS for Windows (version 23.00, IBM, Chicago, IL, USA).

Receiver operating characteristics (ROC) is a technique that allows the visualization of test performance in terms of sensitivity and specificity [16]. ROC analysis is mostly used to evaluate a classifier based on data collected under similar conditions, but can be used as a binary classifier system in different conditions, as well, in that their discrimination thresholds are varied [17]. We computed ROC analysis calculating the area under the curve (AUC), in order to obtain stimulus-specific (PRE vs. POST) or group-specific (IL vs. NL) cut-off values. All pairwise comparisons (namely between IL and NL athletes,

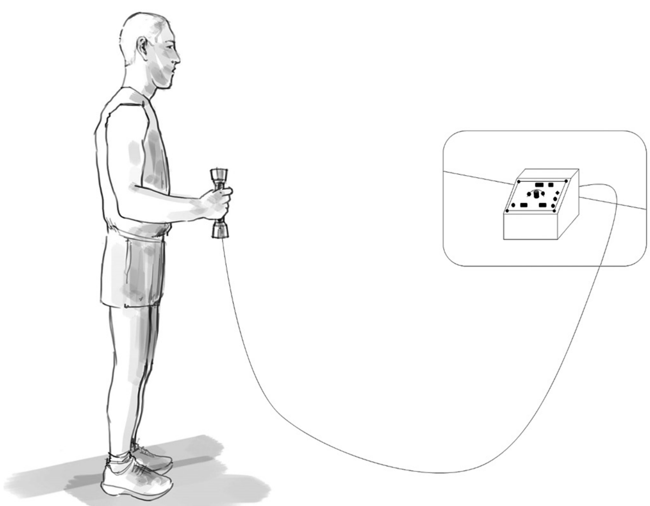

Figure 1. Schematic sketch of the subject's posture for maximal isometric voluntary contraction and vibration interventions [11].

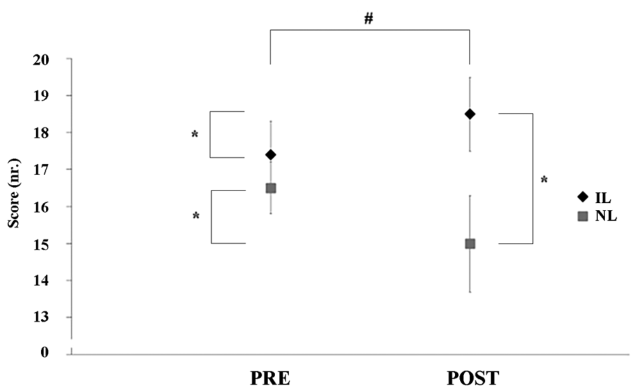

Figure 2. Mean±standard deviation ball score results before and after vibrational stimulus in the international-level group (IL) and national-level group (NL). "#" $p<0.01$ between post- and pre-vibrational stimulus. "*" $p<0.05$ between post- and pre-vibrational stimulus for each group and between groups in post-vibrational stimulus as well.

PRE and POST) were computed to approximate the multi-class ROC, correcting for multiple comparisons. The Youden J index was calculated to separate the different groups for each pairwise comparison with acceptable sensitivity and specificity, using commercial software, namely MedCalc Statistical Software version 16.4.3 (MedCalc Software bvba, Ostend, Belgium). Finally, multi-class ROC analysis was performed using the pROC package run in the R environment.

RESULTS

No significant differences were found between the two groups for age (p=0.09) and body height (p=0.42), while NL players had higher values for body mass and BMI (p=0.000; Table 1).

Ball score measures' ICC showed good reliability in both groups (ICC 0.87 and 0.80 for IL and NL, respectively). The CV values were 17% and 14%, respectively. Repeated measures ANOVA showed differences between groups for ball score ($F_{(1,32)}$=24.27, p=0.000, η^2=0.45, ES=large, Figure 2) and a significant group×time interaction ($F_{(1,32)}$=9.54, p=0.004, η^2=0.24, ES=large), both during the first and the second bouts.

Correcting for multiple comparisons, the comparison between IL and NL groups after vibration (POST) showed a statistically significant difference. Vibration had a significant effect on the ball score result in both groups. Vibration significantly improved the IL ball score result, while it significantly worsened the NL ball score result, making the POST inter-group difference significant. These findings were confirmed by the multi-ROC analysis (overall multi-AUC=0.69, Figure 3).

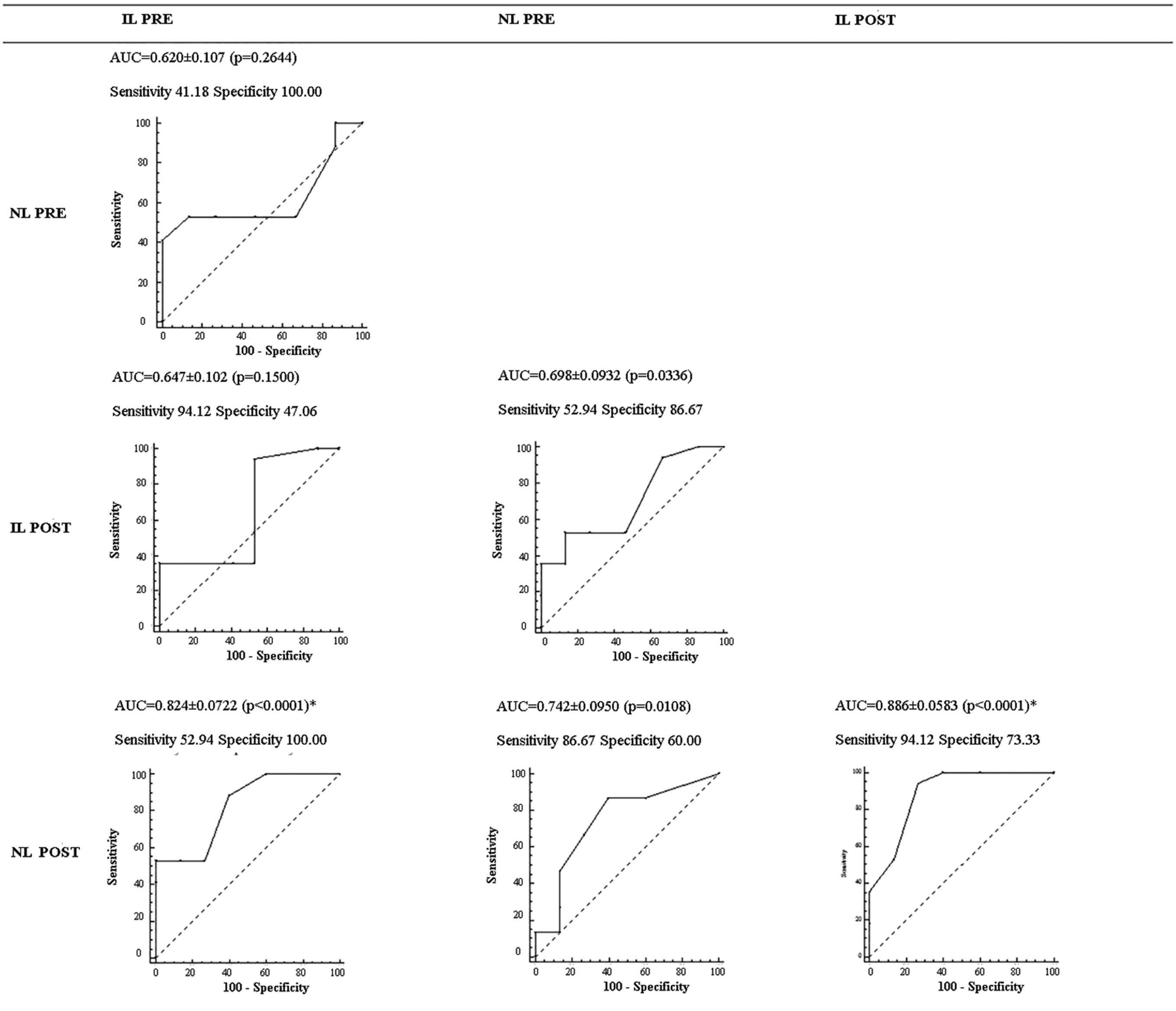

Figure 3. Multiclass receiver operating characteristic (ROC) analysis for evaluating the potential of the ball-handling test in distinguishing between before (PRE) and after (POST) vibration and between the international-level group (IL) and national-level group (NL). "*" p<0.05, correcting for multiple comparisons.

DISCUSSION

The main findings were that: (1) IL resulted in better performances compared to NL, at both PRE (not significantly, p=0.24) and POST (significantly) time points; and (2) the vibrational stimulus produced positive and negative effects on the ball score results of IL and NL groups, respectively.

One point should be made regarding the non-significant PRE ball score result difference between IL and NL groups before proceeding with the discussion of the results. As a matter for further research, a TT ball-handling test more demanding than ball score may better highlight performance differences between different players' levels. It was found that motor efficiency produces athletic skills characterized by automaticity, speed, and accuracy [1]. Our study demonstrates that the ability to achieve a high ball score result was mostly related to the athlete's level of expertise. Experts in highly reactive sports such as TT move rapidly, effortlessly, and smoothly [1,18]. In the context of athletic performance, elite karate athletes require proportionally less brain activation in task-relevant brain areas (i.e., cortical dorsal and "mirror" pathways) compared to amateur athletes or non-athletes (the "neural efficiency" hypothesis, as postulated from the electroencephalographic investigation carried out by Babiloni et al. [19]). Motor efficiency can be achieved through intensive training, leading to improved perception, focus, anticipation, planning, and fast responses [18]. The relationship between the ball score results and the level of expertise is, therefore, logical, considering that the task consisted of finely structured movements of the upper extremities, with minimal variations of the complex hand-racket movement and the ball trajectory. Due to the high accuracy required, even small deviations from an ideal ball trajectory can disrupt the course of action, requiring corrections that may have detrimental effects on the task. In addition, optimal intra-limb coordination patterns are promoted in the acquisition of expertise [20]. An "ideal motor pattern" should minimize intra-cyclic speed variations and stability of the demanded tasks. Accordingly, IL players, both at PRE and POST, presented less variability compared to the NL group (Figure 4). The more stable, less variable performance in the IL group highlights the superior ability in using a more efficient motor control pattern in relation to the interacting constraints related to the (technical) task, (physiological) organism, and (vibration) conditioning stimulus.

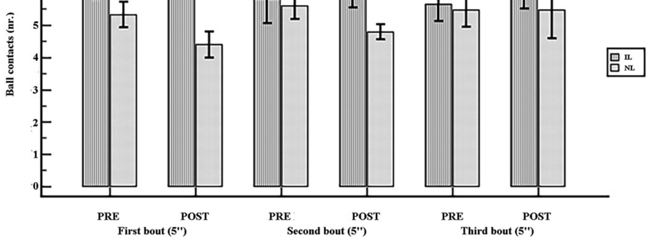

Figure 4. Scores of the ball-handling test in the international-level group (IL) and national-level group (NL) of table tennis players, broken down for the test's three different 5-s bouts.

Another possible explanation could be related to the different capacities in the learning process of the task among the subjects. Learning a movement skill implies an information transfer from teachers to learners, commonly carried out via observation (observational learning [21,22]). Previous studies have reported differences between elite and non-elite athletes in exploiting observational learning, with the elite athletes using this function more than the non-elite athletes. Observational learning functions have a cognitive aspect and the performance function (one of the three factors of the Functions of Observational Learning Questionnaire [23]) has a motivational aspect. Since the cognitive functions are correlated with psychological factors, such as athletic self-confidence [24], this is one of the reasons for the supremacy of these athletes and their success in reaching an elite level. Elite athletes also use performance function to a much greater extent. This could depend on their previous experiences in using observational learning as a factor for motivational enhancement [25].

The second finding was that the local vibrational stimulus produced opposite outcomes in the task, with positive and negative effects on the ball score results of IL and NL players, respectively. Padulo et al. [11], investigating the effects of local muscle vibration on the sEMG responses of the forearm and hand muscles among TT athletes of different competition levels, found that larger muscle activation could be skill-level related. Indeed, the application of local muscle vibration may be crucial for individualizing the vibration load relative to the skill level of athletes. The specific nature of the vibratory effect could be dependent on the specificity of the stimulus of the skill training [26]. In fact, the designed experimental exercise, matching similar biodynamic responses in the kinetic chain system (wrist-metacarpal and finger joint kinematics) commonly involved in TT skills, resulted in positive effects on the ball score performance. As reported by Padulo et al. [11], the application of local muscle vibration during a hand-racket complex configuration, similar to that used in our study, resulted in higher activation of most of the target muscles in IL compared to NL athletes [27]. From a functional perspective, higher activation of muscle groups may result in the greater ability of high-skilled athletes to apply transfer processes, leading to better performance. Moreover, the pattern activation acquired during skill learning processes or isolated conditioning exercises could be refined, leading to changes in the connectivity between these peripheral effectors and the neural structures and in the motor cortex plasticity. The motor cortex plasticity results in an alteration of the cortical synapse number, synaptic strength, and topography of stimulation-evoked movement representations. In fact, the discrete movements of TT players across different joints are controlled by the primary motor cortex [28]. Therefore, the concurrent application of local muscle vibration during skill learning processes or conditioning exercises may produce a potentiation effect for functional/structural adaptations of both the peripheral effectors and the central neural structures. However, we acknowledge that the vibration worsening effect on NL performance remains still surprising. One hypothesis for that might be related to some still undisclosed nervous conduction difference between IL and NL athletes. Such a relevant issue may be worth further electrophysiological investigation going beyond the methods of the present study.

CONCLUSIONS

The aim of this research was to investigate the effect of a vibrational stimulus on a table tennis test result. IL players' results showed better performances compared to those of NL players after vibration. Vibration produced positive and negative effects in IL and NL players, respectively.

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Conflict of interest

The authors declare that they do not have any conflict of interest.

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