Effect of mechanical vibration applied in the direction of the resultant muscle forces' vector addition on maximal isometric force production in judo athletes

Authors' Contribution:
A Study Design
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Received: 24 October 2017; **Accepted:** 07 December 2017; **Published online:** 27 December 2017

AoBID: 11802

Abstract

Background and Study Aim: Judo can be characterised as an intermittent and high-intensity sport, which demands motor actions like pushing, pulling, dominating and throwing the opponent. The combat requires a combination of different expressions of muscle strength, such as maximal and submaximal strength efforts in the upper limbs during the gripping combat (*kumi-kata*), to control the distance between the opponent and preparation of the throws. The aim of the present study was the effects of mechanical vibrations applied in the direction of the resultant muscle forces produced on the maximal isometric strength of the upper limbs muscles in judo athletes.

Material and Methods: The sample consisted of 10 male national-level judo athletes (20.0 ±1.5 years old,1.7 ±0.6 m body height, 55.4 ±7.6 kg total body mass). The intervention session consisted of three steps: pre-test; *kumi-kata* maximal volunteer contraction MVC with local vibration (LV); post-test. Pre-test (all the volunteers performed three *kumi-kata* MVCs with a duration of 6 seconds and 5-minute intervals between the repetitions). *Kumi-kata* MVC with LV (after 30 minutes recovery from the pre-test, athletes performed three MVCs with LV exposure during 6 seconds, and a 3-minutes rest interval between MVCs was adopted; the flexion angle of the knees was set at 10° and elbow flexion at 90°; the LV was only applied after the volunteers reached the peak strength). Post-test (was performed in three different moments: immediately, 5-minutes and 10-minutes after; all the procedures of pre-test were repeated).

Results: A significant increase in maximal strength during vibration was found compared to pre-test ($p = 0.006$) and post-test in all moments: immediately ($p = 0.021$), 5-minutes ($p = 0.005$) and 10-minutes ($p = 0.008$) values. Regarding intra-repeated measures, immediately after was higher than 5-minutes ($p = 0.018$) and 10-minutes ($p = 0.008$). Impulse did not differ between situations (with and without vibration).

Conclusions: The application of mechanical vibration in the direction of the resultant muscle forces of upper limbs superimposed during maximal isometric actions could generate acute and residual increases in the maximal strength of judo athletes.

Keywords: kumi kata • maximal volunteer contraction • tonic vibration reflex • whole body vibration

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The study was approved by the Ethical Committee for Research at the Federal University of Minas Gerais, Brazil (49553815.4.0000.5149)

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: Departmental sources

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Kumi kata – gripping methods (is one of the most important elements of modern judo, establishing a good grip and negating your opponent's grip can be what wins or loses you a match).

Kumi-uchi – grappling [32].

Muscle strength – essential and basic physical capacity in combat sports by which the body is moving status is modified [33].

Strength training – *noun* training that aims to build muscle strength, usually resistance training [34].

Concentric strength – noun the force exerted by a muscle while it is contracting [34].

Technique – *noun* a way of performing an action [34].

Technique – specific procedures to move one's body to perform the task that needs to be accomplished [35].

Chronic – *adjective* **1.** used for describing a disease or condition that lasts for a long time. Compare **acute 2.** used for describing severe pain [34].

Capacity – *noun* **1.** the ability to do something easily **2.** the amount of something that a container or organ can hold **3.** the amount of something that can be produced or the amount of work that can be done [34].

Muscle spindle – *noun* any of the sensory receptors that lie along striated muscle fibres [34].

Muscle fibre – *noun* a component fibre of muscles (NOTE: there are two types of fibre, one forming striated muscles and one forming smooth muscles) [34].

INTRODUCTION

Judo can be characterised as an intermittent and high-intensity sport [1], which demands motor actions like pushing, pulling, dominating and throwing the opponent [2]. The combat requires a combination of different expressions of muscle strength, such as maximal and submaximal strength efforts in the upper limbs during the gripping combat (*kumi-kata*), to control the distance between the opponent and preparation of the throws [3]. It is well documented that the development of muscular strength capacity in this modality in specific actions can be determinant for the competitive success.

Concerning the importance to develop muscle strength, studies [4-6] have been conducted with the objective to verify the acute, residual and chronic effects of the application of mechanical vibration on force capacity.

During the application of mechanical vibrations, the muscle may produce a contraction reflex referred to as tonic vibration reflex (TVR) [7]power and balance although contradictory findings have been reported. Prolonged exposure may result in adverse effects. We investigated the effects of high (5.5 mm, which occurs through a sequence of fast muscle stretching actions due to the application of mechanical vibration [8]. According to the theoretical model, TVR involves the stimulation of the muscle spindle and the activation of neural signs and muscle fibers through large alpha motor neurones [9]. According to Cardinale and Bosco [10], an increase in muscle strength mediated by mechanical vibrations is expected to occur because of the TVR. The contractile response produces an involuntary component of force production. As seen, the TVR refers an acute response to a vibration stimulus. However, this is not the only mechanism proposed in the literature to explain the positive effects of vibration training. There is also evidence related to residual or transient responses, which can explain the positives effects on human performance after the application of different vibration stimuli, such as increased muscle temperature as a result of the friction caused by vibration in body tissues [11] as well as increased blood flow [12, 13]; and the effects of post-activation potentiation (PAP) mechanisms [14].

Previous studies have examined the effects of vibration in two different ways: by vibration applied in the direction of the resultant muscle forces' vector addition (VDF) or by whole body vibration (WBV). In the sports context, the WBV has been broadly used. However, during this type of exposure a significant dissipation of vibration energy during transmission by the body tissues can be observed and, consequently, the target muscle or member may not suffer the desired effects [15]. Rubin et al. [16]o reported that when standing (20° knee flexion) on a vibratory platform, transmission is dampened by the hip and spine (~30%). Similarly, Tankisheva et al. [17] showed a significantly lower transmission to the upper limb when WBV was applied. Based on this premise, it is possible that using the VDF during maximal isometric strength, the vibration magnitude that reaches the target muscles is optimised [18].

However, the effect of this type of intervention on performance in specific sports techniques is still a controversial matter [19], especially regarding the use of VDF superimposed during maximal volunteer contraction (MVC). A recent study showed the possibility of optimising the kick speed performance and maximal isometric strength through the application of mechanical vibrations [6]. These authors found no significant differences between pre-test and post-test (immediately: 3-, 5- and 8 minutes after intervention) for kick speed. However, force recorded during MVC with local vibration (LV) significantly increased during MVC compared to the moment after vibration. According to Rittweiger [20], the complexity of the task may reflect in vibration effects, because other factors – which are not eminently influenced by vibration stimulus – are involved, such as reaction time, motor patterns and tendon force transmission. Premise ascertained by previous studies, Cochrane et al. [21] and Delecluse et al. [22] found no vibration effects to improve sprinting ability.

In addition to the fact that the majority of the vibration studies are performed with the application of WBV and usually employing non-specific exercise conditions, VDF can be applied during the *kumi-kata* MVC position (posture). Thus, in agreement with previous studies, vibration exposure prior to the specific sports action are believed to enhance strength performance [4–6] and one of the main mechanisms proposed to explain this is PAP phenomenon [14]. Therefore, it was hypothesised that the specificity of muscle action during vibration exercise, performed as a trigger to PAP, can optimise the transient response to specific sports-related muscle action.

The aim of the present study was the effects of mechanical vibrations applied in the direction of the resultant muscle forces produced on the maximal isometric strength of the upper limbs muscles in judo athletes.

It is expected that the major benefit related to the application of vibration compared to conventional strength training is the possibility of inducing higher improvements in muscle strength without increasing muscle effort. The hypotheses formulated was that the vibration stimulus applied during the *kumi-kata* initial posture would induce an increase in force performance during and immediately after the vibration exposure.

MATERIAL AND METHODS

Participants

The sample consisted of 10 male national-level judo athletes (20.0 ±1.5 years old,1.7 ±0.6 m body height, 55.4 ±7.6 kg total body mass). The inclusion criteria were: 1) participate in a systematic training program for at least 2 years; 2) absence of a history of upper limb injuries; 3). Do not use any ergogenic aids.

The study was approved by the Ethics Committee of the Federal University of Minas Gerais (approval reference number: 0472.0.203.000-10).

Proceedings

All volunteers participated in two experimental sessions, one familiarisation and one intervention session with vibration application. There was a 48 hours interval for recovery between sessions.

Familiarization Procedure

During familiarisation, anthropometric data (height and body mass) were obtained, and subjects were familiarised with the *kumi-kata* MVC position (posture) with LV exposure. A minimum of two days separated the familiarisation and the intervention session; the subjects were also instructed not to perform any physical activity 24 hours prior to each intervention. The interventions involved 5 MVCs, in which the subjects attempted to sustain the maximal force for 6 seconds. The rest interval between MVCs was 5 minutes.

Intervention session

The intervention session consisted of three steps: pre-test, *kumi-kata* MVC with vibration and post-test.

Pre-test

All the volunteers performed three *kumi-kata* MVCs with a duration of 6 seconds and 5-minute intervals between the repetitions.

Kumi-kata MVC with vibration

After 30 minutes recovery from the pre-test, athletes performed three MVCs with vibration exposure during 6 seconds, and a 3-minutes rest interval between MVCs was adopted. All MVCs were performed with upper limbs positioned similarly to the initial *kumi-kata* posture used in combat, which the dominant limb performed an isometric contraction of shoulder extension with the flexed elbow joint (Figure 1). The flexion angle of the knees was set at 10° and elbow flexion at 90°. During the MVCs with vibration, the vibration was only applied after the volunteers reached the peak strength [6, 18]. The vibration stimulus was sinusoidal and applied using a steel cable in the direction of the resultant muscle forces (Figure 1). The vibration frequency was set at 26Hz, and peak-to-peak amplitude was 6mm.

Motor neuron, **motor neurone** – *noun* a neuron that is part of a nerve pathway transmitting impulses from the brain to a muscle or gland [34].

Tissue – *noun* a type of substance that the body is made up of, e.g. skin, muscle or nerves [34].

Friction – *noun* deliberate rubbing of a body part as a way of stimulating blood circulation, warming or relieving pain [34].

Isometric – *adjective* **1.** involving equal measurement **2.** used for describing muscle contraction in which tension occurs with very little shortening of muscle fibres **3.** used for describing exercises in which the muscles are put under tension but not contracted [34].

Acute – *adjective* used for describing the pain that is sharp and intense [34].

Judogi – is the formal Japanese name for the traditional uniform used for judo practice and competition [36].

Eccentric action – *noun* an action performed by extending a muscle [34].

Post-test

After the vibration application, the post-test was performed in three different moments: immediately, 5-minutes and 10-minutes after. All the procedures of pre-test were repeated in the post-test.

Instruments

The application of VDF used a three-phase induction motor (WEG IP55 model, 2CV power, 60 Hz frequency and 1740 rpm velocity; Jaraguá do Sul, Santa Catarina, Brazil) provided with an eccentric shaft, which transmitted vibration to the athlete's upper limb (Figure 1). A frequency inverter (WEG, CFW model 09, Jaraguá do Sul, Santa Catarina, Brazil) was used to control the vibration frequency of the cable (26Hz). Values of maximal force were obtained using a force cell by JBA (Zb Staniak, Poland) connected to an amplifier of signals (WTM 005–2T/2P, Jaroslaw Dolinski Systemy Mikroprocesorowe, Poland). The amplifier itself was connected to a computer with a MAX (ver.5.1, JBA) interface that enables analysis of the force curve as a function of time (frequency of data input: 1000 Hz).

The analysed area of the force versus time curve corresponded to the 6 seconds immediately after the start of the vibration exposure [23]. The measurements obtained in this study were a maximal force: 1st moment – pre-test (without vibration); 2nd moment – with vibration; 3rd moment – pre-test (without vibration) and impulse (pre-test and during vibration). The obtained values of force were calculated using Dasylab software ver.11.

Statistical Analysis

The Shapiro-Wilk test verified the data normality. In addition to inferential statistics, descriptive statistics of the data were calculated (mean and standard deviation). One-way ANOVA with repeated measures and *posthoc* analysis were used to compare the force results obtained in the different situations. A paired Student's *t*-test was conducted to compare the impulse pre-test and during vibration (without and with vibration). The level of significance was set at 0.05. Statistical analysis was performed using the SPSS ver. 20 (SPSS, Inc., Chicago,USA.).

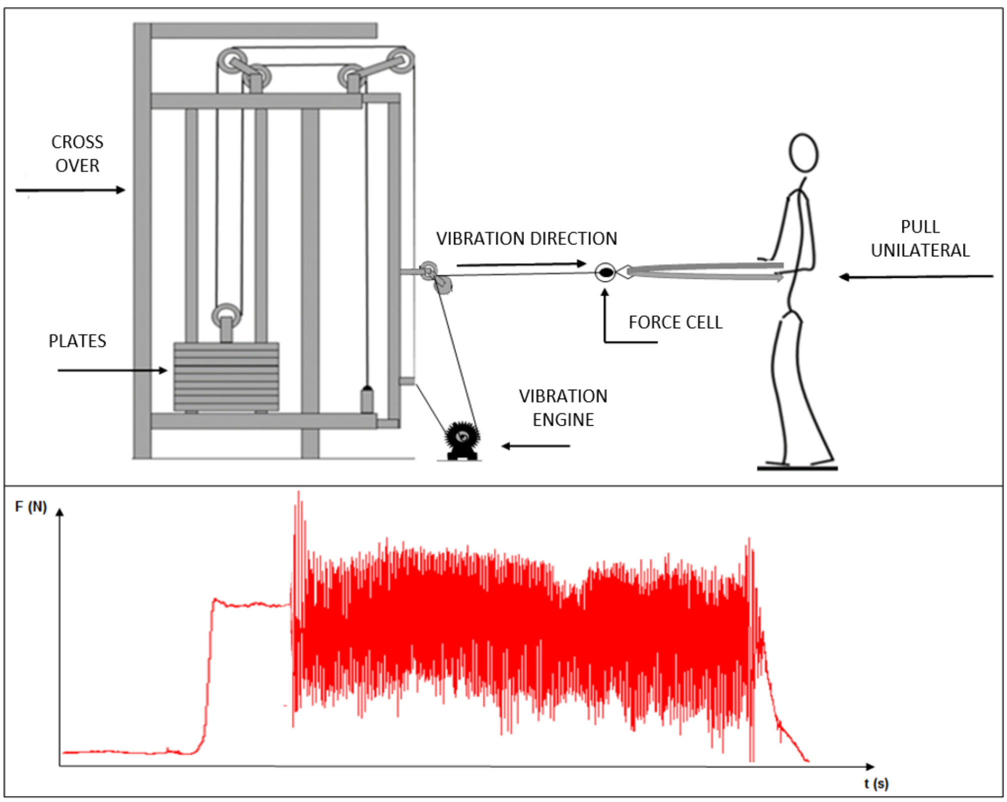

Figure 1. Positioning of the volunteer during CVM with and without vibration and force time curve with LV application at 26Hz.

RESULTS

A significant increase in maximal strength during vibration was found compared to pre-test ($F_{(1,4)}$ = 3,784, p = 0.006, η^2 = 0.684 observed power = 0.604) and repeated measures – immediately ($F_{(1,4)}$ = 3,784, p = 0.021, η^2 = 0.684 observed power = 0.604), 5-minutes ($F_{(1,4)}$ = 3,784, p = 0.005, η^2 = 0.684 observed power = 0.604) and 10-minutes ($F_{(1,4)}$ = 3,784, p = 0.008, η^2 = 0.684 observed power = 0.604) values and between repeated measures, immediately after was higher than 5-minutes ($F_{(1,4)}$ = 3,784, p = 0.018, η^2 = 0.684 observed power = 0.604) and 10-minutes ($F_{(1,4)}$ = 3,784, p = 0.008, η^2 = 0.684 observed power = 0.604) (Table 1).

Regarding impulse (Ns) values, no significant differences were found between the situation without (53.42 ±1.37) and with vibration (54.19 ±1.29) (p = 0.787).

DISCUSSION

The hypothesis tested was that subjects during and after the MVC performed with vibration, would generate a greater acute and transient increase in strength and acute increase in impulse performance, when compared to the pre-test. No significant differences were observed between the impulse values with and without the application of vibration. For the maximal force values comparing the three moments (pre-test, during and the three moments after), maximal strength values registered during vibration was significantly higher, when compared to maximal force pre- and post-vibration exposure. Based on these results, the hypothesis was not fully confirmed.

The precise mechanisms underlying the acute and transient increases in strength performance after the application of mechanical vibrations are still not fully understood. The acute increase in force observed during the application of vibration in the present study can be explained by TVR [24, 25]. The vibratory stimulus is transmitted by the activation of afferents, which activate – via alpha motor neurones – mainly type II muscle fibres that cause a reflex response to muscle contraction and consequently, may increase performance in explosive activities. Regarding transient responses, some authors have reported an increase in peripheral circulation, blood flow and skin temperature [26, 27] nerve conduction velocity [28], PAP effects, such as increasing the intracellular sensitivity Ca^{2}+ due to prior muscle activation [14] and TVR, as well. As described above, the postulated mechanisms that may explain the transient effects of vibration are similar to those observed after PAP protocols. Thus, the vibration stimulus can represent an effective conditioning PAP activity.

The maximal strength performance increased significantly after vibration exposure compared to pre-test. For this reason, it may be of relevance to apply VDF (26Hz and 6mm) during judokas strength training, because it allows athletes training with higher strength intensities than those intensities normally used on conventional strength training. For future studies, it would be interesting to investigate the chronic effects of two types of training on judokas force production: with and without VDF.

According to Ogiso et al. [29], the mechanical response of stretch reflex depends on functional aspects relating to the motor task. In this way, probably the exercise performed during vibration exposure influences the response to this vibration stimulus. In addition, Rittweger [20] suggest that the complexity of the motor action may be influenced by the results of vibration exposure.

Table 1. Maximal strength (N) in different moments of investigations: data are presented as mean (X) and standard deviation (SD).

Indicator	Pre-test	During	After investigations		
			Immediately	5 minutes	10 minutes
X	21.57	**36.65***	24.51	20.77	21.92
SD	2.10	5.41	2.61	2.07	2.19

*p<0.05

The more complex the action, the smaller the effect of vibration to optimise performance. Therefore, it is still necessary to verify the effects of vibratory stimulation on the performance of specific techniques, such as *kumi-kata*, considering that, even in a complex sport action, positive effects are observed; and, perhaps, if the vibration stimulus is applied during dynamic action of even higher complexity, these results might not be identified.

The PAP phenomenon consists in increased strength produced as a result of a previous muscle contractile activity (CA) [30]. The results of the present study confirm this hypothesis partially. The effectiveness in which a CA can stimulate PAP mechanisms and improve muscle performance is related to the balance between fatigue and potentiation. This balance is affected by many factors, including training experience, recovery period and intensity of the CA [31]. In the present study, it seems that the magnitude of the stimulus was sufficient to produce potentiation immediately after the exposure. Furthermore, if one´s aim is to train the strength of *kumi-kata* specific muscles in a "potentiated" status, this procedure [e.g. VDF (26Hz frequency and 6mm amplitude) applied on *kumi-kata* MVC] designed in this present study, is useful to enhance *kumi-kata* specific performance only immediately after vibration.

The use of single or multiple series with short-time exposure protocols to mechanical vibrations has generated positive results because of TVR and consequent increase in strength and power performance [4]. However, compared to studies using WBV, the number of studies using direct vibration is still limited, especially investigations involving specific performance techniques. When an athlete is holding the opponent's kimono (judogi) and try to increase the opponent's distance, it is necessary to extend the elbow joint. On the other hand, to reduce the opponent's distance, it is necessary to flex the elbow joint. Differences in maximal strength and resistance strength to perform these movements more effectively may influence MOTOR performance in judo [3].

Therefore, the present study demonstrated that the vibration applied in the direction of the resultant muscle forces on maximal isometric strength using a specific action of *kumi-kata* can be a useful tool to develop the maximal specific strength in judokas and can lead to a better sports performance. It was hypothesised that the stimulus produced by vibration equipment was higher than the voluntary capacity to produce maximal strength by the muscles. It is possible that this kind of mechanical vibration could have overpassed the voluntary limit of strength production and could have contributed to the activation of the involuntary components of muscular strength production, characterised by the eccentric action, in this case, in supramaximal values (sufficiently higher than values obtained during MVC). Based on this fact, in sports training programs, this acute effect can be an interesting stimulus and, chronically, may provide a higher strength increase when compared with conventional training methods which do not employ vibration exposure, because "supramaximal force" produced by application of vibration increases training intensity.

In this study also investigated the effects of vibration on impulse. For this variable, there was no significant difference between moments (pre- and during vibration). Postural instability caused by the application of vibration, combined with the low experience of volunteers with vibration training, may have contributed to the fact that exposure to vibration did not increase the impulse as expected. Consequently, volunteers may have had to create strategies to maintain stability during MVC, which eventually favoured the reduction in force values. Moreover, during the concentric phase of return to the isometric position (posture), the force production tends to reduce. During the application of vibration, there are successive eccentric-concentric actions, and these sequences of muscular actions cause cycles of increased (eccentric) force production and subsequent abrupt (concentric) force decline, which generate, on average, lower values of force. The concentric force decreases because of the external resistance decreases (cable laxity). Future studies may investigate if this type of training (VDF applied by a steel cable) can produce a higher increase in the maximal isometric and/or concentric force.

In strength training for judokas, it is important to produce greater maximal force and higher impulse (strength resistance). However, even for trained individuals, maintaining a maximal force for a long period can be a very difficult task. Our results showed that this type of stimulation does not produce enhancements in the impulse. Therefore, if the coach aims to develop the impulse (submaximal strength training), this stimulus may not be optimal.

The influence of vibration stimulus on sports performance depends on many factors such as characteristics of the sample (trained, non-trained), vibration protocol (intensity, exercise, duration) [20]. According to Luo et al. [15], trained individuals have higher acute effects on vibration training compared to untrained subjects. The volunteers recruited for this present study were national judo athletes, so it was expected that they respond acutely and transiently to the vibration stimulus. Therefore, for future studies, it is necessary to investigate the effects of different vibrations training protocols on specific actions in judokas.

CONCLUSIONS

The application of mechanical vibration in the direction of the resultant muscle forces of upper limbs during maximal isometric actions could generate acute and transient increases in the maximal strength of judo athletes. The principal issue discussed in the present study is the importance of understanding the stimulus performed. The stimulus proposed here can be adequate if the objective of the training is: A) to produce acute increases in strength training intensity; and/or B) generate PAP effects and to train with PAP effects. Nevertheless, if the intention is to use the mechanical vibration as an additional resource to conventional strength training, the coach needs to define clearly what kind of stimulus he intends to apply. If the objective is to diversify the stimulus for maximal force, impulse and increase force acutely, eventually, the application of this type of vibration becomes an interesting training resource. However, if impulse increasements (resistance strength or strength resistance) is important, the use this type of vibration protocol may not be optimal.

ACKNOWLEDGEMENT

The authors are grateful to the National Council of Technological and Scientific Development (CNPQ), the Coordination of Improvement of Higher Education Personnel (CAPES), the Research Support Foundation of the State of Minas Gerais (FAPEMIG) and the Ministry of Sport for financial support.

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Cite this article as: Oliveira MP, Teobaldo B, Albuquerque MR et al. Effect of mechanical vibration applied in the direction of the resultant muscle forces' vector addition on maximal isometric force production in judo athletes. Arch Budo Sci Martial Art Extreme Sport 2017; 13: 127-134