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Research article

Acute Neuromuscular Fatigue of a Random Vs Constant Session of Repeated Standing Long Jumps

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Abstract

There is little evidence of the acute effect of random practice, performed by solely varying the intensity but not the task itself, as compared to block practice, i.e. when one task is repeated in a constant manner. This study aimed to examine the acute neuromuscular effects of physical exercise consisting of repeated jumps of randomized length. Fifteen healthy young participants completed 2 separate sessions of 90 minutes. They did 20 minutes of fatiguing exercise, consisting of 100 repeated standing long jumps (SLJ), in two different manners: one session with targeted jump length kept constant (CO), and one with targeted jump length being varied and unpredictable (RA). Pre- and post-tests were conducted before and immediately after, including measurements of Countermovement Jump (CMJ), SLJ, leg extension maximal voluntary isometric contractions (MViC), EMG activities of leg muscles and patellar tendon reflex amplitude (T-reflex: strike force and evoked force). Results showed that performances decreased after the repeated SLJs, independently of the condition (MViC decreased from 448 ± 118 N to 399 ± 122 N; CMJ decreased from 36.7 ± 7.2 cm to 34.6 ± 6.6 cm). EMG during MViC decreased by 21 ± 28 % from pre- to post-intervention. T-reflex decreased after both conditions ([Force/Strike] ratio decreased by 38 ± 69 % from pre to post). Subjective measures showed a greater sense of personal performance and enjoyment after the RA session. Results suggest that a randomly organized intensity of effort led to a similar decrease in physical performance compared to constant intensity when the session loads were matched. It also led to similar fatigue of the neuromuscular system as shown by T-reflexes and EMG measures. Nonetheless, random practice presents the benefit of being markedly more appreciated by participants.

Key words: Random practice, T-reflex, force, countermovement jump, electromyography.

Introduction

Among various methods used to increase sport performance or motor learning more generally, there exists one that has proven to lead to better performance, especially in the long term (Horbacewicz, 2018), namely "random practice", or "random training". As opposed to "block" practice, which consists in repeating one task in the same manner, "random" practice is varied and non-organized (Lelis-Torres et al., 2017). To be more specific, in the context of sports training, random practice can consist in practicing several tasks at once, in an undefined order, or practicing only one task but with some of the parameters being randomized, for example the number of sets and repetitions, the intensity, the resting duration, or others.

Among all sporting activities, some are considered to involve closed skills, such as track and field, and gymnastics, while some others require open skills, such as rock climbing or parkour (Grosprêtre and Gabriel, 2021). In this context, closed and open skills refer to the degree of stability of the environment in which the sport is practiced; open skill sports being the ones that necessitate a higher adaptation capacity of athletes. For instance, Parkour is an open skill discipline, because athletes have to run and jump across an urban environment, overcoming an infinite variety of obstacles (Pagnon et al., 2022). According to the common definition of randomness, parkour could be considered as a sport that mostly involves random practice. According to the definition of the Oxford English dictionary, randomness is the apparent or actual lack of definite pattern or predictability in information. Following this logic, team sports such as soccer, handball, basketball, and others would also be considered random, as matches imply displacement and efforts that also are varied and unpredictable. The difference is that randomness in that case originates from the variations in the run of the match, guided by other athletes' actions, whereas in the case of parkour, the randomness stems directly from the environment.

An element closely related to randomization that has already been widely studied is the concept of Contextual Interference (CI), introduced in the 1960s. To give a definition, according to Schmidt and Lee, in 2005: "Contextual interference is defined as the interference in performance and learning that arises from practicing one task in the context of other tasks". CI resembles randomness in practice, in that it brings variability during the phase of learning or practice. The main effect that many studies have reported (Ammar et al., 2023; Barreiros et al., 2007; Shea and Kohl, 1990; Shea and Morgan, 1979) is the beneficial impact on retention and transfer test that high levels of CI yield, compared to low levels of CI. Furthermore, in most studies, the randomized parameters were the type of task (i.e. adding different task variations) (Aiken and Genter, 2018), or the order of practice of these tasks' variations (Porter et al., 2020). Nonetheless, there is arguably still a need to demonstrate that CI has beneficial effects when the only parameter that is randomized is the intensity of a given task.

To understand better the mechanisms responsible for this beneficial effect of CI, many studies tried to identify which factors modulate the most this effect. As an example, a study (Cheong et al., 2016) supports the fact that task difficulty is one of the most important factors impact-

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ing the effect of random practice. On this topic, an interesting review by Farrow and Buszard in 2017 brought clarifications on three key aspects related to random practice, that are 1) the link between task complexity and the level of CI required to benefit learning, 2) the possible mechanisms responsible for the beneficial CI effect, from a neurophysiological angle and 3) the typical measures of learning and their relevance to the transfer from theory to practice. One of their most important findings may be how the complexity of the task being learned, and/or the level of contextual interference impacts the cognitive effort. Knowing that positive changes are reported when cognitive effort is increased in a learning situation, it is important to know how to manipulate optimally these 2 factors (task complexity and level of CI) in order to maximize motor learning. Additionally, two other factors impacting the level of cognitive effort should be taken into account. These are the conditions of experiment in which the CI is implemented -i.e. in a laboratory setting, or in the applied setting- and the skill level of participants, relative to the task to be learnt. The authors explain that for simple motor tasks, the implementation of CI has consequent chances to lead to better learning, thanks to the increase of cognitive effort, whereas for a complex motor task, for which cognitive effort is already high, CI has little or no chances to increase its level further, and thus there might be little or no improvement of learning.

Another factor that could potentially impact the effectiveness of random practice is the intensity of a given motor task. Few studies examined specifically this factor or tried to isolate it to verify its effect. For example, one study (Horbacewicz, 2018) examined how randomizing intensity during a simple manual force production task impacted accuracy. Surprisingly, the author found out that blocked practice led to more accurate force application at the posttest and retention test than random practice. It was concluded that a block design seemed more appropriate for performing specific experimental tasks. Important factors to consider for the absence of positive effect of random practice, in this context, were the nature of the task, the learners' skill level, and practice time. This absence of positive effect could have been due to the low level of cognitive effort implied by the implementation of a single other level of force production. That is why, complementary to this study, we aimed to explore the effects of a higher degree of contextual interference, by increasing the number of different intensities (the different jump lengths participants had to aim for) in the acquisition phase.

There is certainly less data on the effects of randomization of the intensity of one single task, than data of the effects of task variation or task interference, more common when CI effects are investigated. Consequently, we aimed to explore randomization of intensity per se, to show its potential benefits, it terms of motor learning, performance at a given time, or even the mental effect. This would help clarify the benefits of incorporating randomness into training and offer insights into effective methods for doing so. By examining the model of parkour practice and the variability in long jumps, these findings could have a broad impact on sports science as a whole, providing an initial foundation for a more extensive integration of randomness into training programs.

The goal of this study was therefore to determine whether a randomly organized intensity of a repeated motor task would have a different effect on physical performance and on the neuromuscular system than the traditional "blocked" practice, with constant intensity.

The chosen exercise was the standing long jump, for two main reasons: firstly, it is widely practiced in the discipline of parkour, in the form of what practitioners call the "precision jump" (Marcora et al., 2009), and secondly because standing long jump (SLJ) is actually performed at different lengths by parkour practitioners in order to jump from one obstacle to another, with these obstacles separated by variable distances. The specific session design in the present experiment consisting of 4 different jump lengths and a complete randomization of the order in which they are done in the session, was created in the image of a classical parkour session. This would help to understand the interest of such randomness in parkour physical conditioning, as well as in all disciplines that involve plyometric capacities (track and field, etc.). The benefits of this approach, which utilizes variability in jumping distance, would extend beyond just enhancing muscle capacity. Indeed, targeting a given distance, especially if it randomly changes from one trial to another, is particularly solicitant for the action-perception couple. Therefore, this type of training may have greater interest in modifying distance perception and power gradation to reach the desired distance. This is of great interest for parkour practitioners who need a great ability to jump accurately between obstacles spaced at various distances, as for many other sports and daily life activities. The accuracy of jumping was analyzed as a complementary analysis of random practice effects.

As previously demonstrated, physical activity can greatly influence neuronal plasticity in the spinal cord (Behrman et al., 2006). We hypothesized that this long-term effect would be present even after a single session of intense exercise, if the demand for modulations of the neuromuscular system is increased by high variability in the intensity of effort, i.e. a single session of random jump intensities. The spinal reflex pathway would be particularly affected by repetitive jumps and random intensities, as this task involves the constant readjustment of plyometric muscle power, involving the myotatic reflex pathway. Assessment of the T-reflex would then give different results after exercise of high or low variable intensity.

In the end, the hypothesis was that when training loads in both conditions are matched, the impact on maximal performance is identical, but there would be differences on the spinal reflex system, as well as on the perception of the effort by participants. Indeed, we hypothesized that performing different required efforts (i.e. jumps) in a random manner would provide a different perception of effort and fatigue compared with performing a repetition of the same effort. An important point to consider is that, during the present experiment, randomization of the effort means that the intensity is randomized, but not that it is self-chosen (as it is the case for team sports matches for example). Rather, it is planned in advance by the experimenter. Randomization of the intensities of effort was computer generated in the present study.

Methods

Experimental approach to the problem

The experimental design involved a within-subjects' cross-over study, where participants underwent two different jump sessions—one with random intensity (RA) and another with constant intensity (CO)—on separate days in a randomized order. Neuromuscular measurements were taken immediately before and after each session to assess the acute effects of the interventions.

Each session lasted approximately 1.5 hours, with 7 days' rest between sessions. In CO, participants had to perform 100 Standing Long Jumps (SLJ) of constant length. In RA, they had to do 100 SLJ, aiming for different percentages of their maximal jump length at each jump. The maximal horizontal distance (in cm) that each participant could reach was measured during PRE and POST tests and is hereafter referred to as "SLJmax".

In RA, there were 25 SLJ at 65% of SLJ max length, 25 SLJ at 75% of SLJ max, 25 at 85% of SLJ max, and 25 SLJ at 95% of SLJ max. The order in which they did these percentages was randomized. Consequently, the average overall percentage was 80% of max length. In CO, there were 100 SLJ at 80% of SLJ max. In the end, the total distance covered in SLJ was identical in the RA and CO conditions.

PRE and POST tests were carried out before and after each bout of repeated SLJs, consisting of different neuromuscular-related measures, as well as effort perception questionnaires.

In order to randomize the order in which the percentages of jump length appeared, was used the "RANDOM" formula in Excel software. It uses the Mersenne Twister algorithm (MT19937).

Participants

Fifteen participants (13 men and 2 women) were recruited from a sport university, by means of email contacts as well as direct recruitment of acquaintances. They were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study (age: 23.7 ± 3.6 years; height: 174.7 ± 8 cm; weight: 70.8 ± 10.3 Kg; weekly training volume: 8.6 ± 5.3 hours; experience in sport practice: 13.4 ± 4.9 years).

They all practiced sports of various kinds for at least 3 years, (street workout, football, gymnastics, amongst others), for a minimum average training volume of 2 h per week.

Inclusion criteria were as follows: participants must not have any musculoskeletal disorder; they had to be free of any injury; they were required not to partake of any intense training 48 h prior to the tests; they were required to have at least 6 hours sleep in the night prior to the tests; and were required to abstain from ingestion of any stimulating substances such as caffeine in the 3 h prior to the tests.

The study protocol was conducted in accordance with the ethical principles of the Declaration of Helsinki (1983) and approved by the regional ethics committee (Comité d'Ethique pour la Recherche de l'Université Bourgogne Franche-Comté no. CERUBFC-2024-09-03-034).

Procedures

The procedure followed by the participants, as well as the various performance tests and neuromuscular measurements, are detailed in the paragraphs below.

Standing Long Jump (SLJ)

SLJ consisted in performing a horizontal jump; the starting position was standing still.

Jump lengths were measured by a 5-meter Optojump photocell system (Microgate, Bolzano, Italy). This device demonstrated strong concurrent validity and excellent test-retest reliability for the estimation of vertical jump height (Glatthorn et al., 2011). In this study, authors showed high intraclass correlation coefficients (ICCs) (0.997 to 0.998) for validity, and high ICC (0.982 to 0.989) for reliability. Another study showed a satisfactory reliability ICC of 0.93 for the estimation of the SLJ (Mackala et al., 2019). Horizontal distance covered, from ankle position at the start to ankle position at the end of the jump, as well as vertical jump height were measured by this system at each jump.

The starting position was done with the feet aligned, spaced hip width apart, with the arms straightened in front of the body, and horizontal. Then the movement begins with the hips, knees and ankles bending to create a forward imbalance, as the arms swing behind the trunk. Then the pushing phase begins, with the legs pushing the floor down and behind, and the arms accompanying the movement. During the flying phase, the feet catch up to the body and perform the landing.

Participants were asked to jump as far as possible, using a slight forward imbalance and the momentum of their arms.

Countermovement Jump (CMJ)

CMJ consisted in doing a vertical jump, with the starting position being standing still. The starting position was with the feet aligned, spaced hip width apart, and the hands placed on the hips. Then, the movement begins with the hips, knees and ankles bending at the same time, until the legs are parallel to the ground, then without interruption, the legs extend, with the goal of reaching the maximal vertical height. The landing is done with the tip of the feet touching the ground first. Flight time was measured by the optojump system at each attempt, and the height of the jump was directly determined by the software from this value.

Surface Electromyography

During the whole phase of repeated SLJs, as well as during PRE and POST tests, surface electromyography (sEMG) was recorded. Three wireless electromyographic sensors were placed on 3 knee extensor muscles of the right leg: vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF) after dry-shaving the skin and cleaning with alcohol. EMG signals from these 3 knee extensor muscles were continuously recorded throughout the experiment.

The skin was first shaved and rubbed with alcohol to ensure a low impedance (<5 kΩ). EMG signals were recorded with Trigno sensors (Delsys, Natick, Massachusetts, USA), firmly strapped to the leg with a skin adhesive. Sensors were placed according to SENIAM recommendations (Hermens et al., 2000). EMG signals were amplified with a bandwidth frequency ranging from 0.3 Hz to 2 kHz (gain: 1000) and digitized on-line (sampling frequency: 2 kHz) with Labchart software (LabChart 8, AD Instruments, Sydney, Australia).

Maximal Voluntary Isometric Contraction

Determination of maximal voluntary isometric contraction (MViC) in knee extension was carried out before (PRE) and after (POST) the effort of repeated SLJs, on an isometric chair (Leg Control, Mtraining, France). Participants had to perform 2 MViC PRE, and 2 MViC POST, lasting 5 seconds each, with 1 minute rest in between. Continuous verbal encouragement was given during each MViC. Surface EMG of the leg extensor muscles and maximal force production were recorded during MViC. Force signal was continuously recorded at a sampling rate of 2 kHz and stored in Labchart software (LabChart 8, AD Instruments, Sydney, Australia).

Tendinous reflex

The deep tendon reflex, or “T reflex”, was assessed by stimulating the patellar ligament with an instrumented reflex hammer (AD Instruments, Sydney, Australia). This hammer is equipped with a force sensor at its tip, which made it possible to know at which force each tap was carried out. Ten tendon taps were performed, inter-spaced by 10 seconds, and with intensities of the strikes randomly varied between 1 and 12 N in order to draw a relationship between tap force and neuromuscular response. The base of the hammer was fixed on a home-made structure in a “pendulum” fashion, so that movement of the hammer head was identical between each tendon strike. All stimulations of the T reflex were done by the experimenter, initiating the pendulum movement manually.

Testing procedure

First, participants had to complete a short questionnaire about general information. They had to give their rating on a rating of perception scale, the Borg centiMax scale (CR100), (Borg and Borg, 2002) (Fanchini et al., 2016). It was a scale going from 0 to 100, corresponding to “nothing at all”, and “maximal effort”, respectively. Then, they had to do a general warm-up, consisting of: 3 minutes of low intensity running, articular rotations of the lower body joints, 2 sets of 5 repetitions of bodyweight squats executed slowly, and 2 sets of 5 repetitions of bodyweight CMJ (CounterMovement Jump). Then, they did a specific warm up consisting of SLJ and CMJ familiarization.

After the warm-up, the PRE-TEST were conducted: participants were tested on their maximal SLJ length and CMJ height. They had to do at least 2 trials for SLJ and CMJ, inter-spaced by 1 min rest. If necessary, more trials were performed until the difference in performance was stable (less than 3% difference). Thereafter, they had to sit on an isometric chair, and T reflex was assessed on their right patellar tendon, with an instrumented reflex hammer as described above. Ten patellar tendon strikes were performed, inter-spaced by 10 seconds, with different strike forces and performed in a random order. Then, they had to perform 2 MViC of the quadriceps muscle of the right leg, lasting 5 seconds, spaced one minute apart.

After this PRE-TEST phase, participants did the fatiguing SLJ effort, lasting approximately 20 minutes. The participant had to perform 100 SLJs, successively, with a rest time between each repetition of approximately 10 seconds. In the random (RA) condition, the percentage jump length to be achieved was verbally indicated to the participant before each repetition. Four visual cues were placed on the ground, at percentages adapted to the participant's maximum performance: 65%, 75%, 85%, 95%. In the constant (CO) condition, a sound signal indicated to the participant to perform the jump, which was always 80%. This effort was performed in 10 sets of 10 repetitions, with 10 seconds of recovery between each set.

After this 20-minutes effort, the POST-TESTS were conducted, identically as it was for the PRE tests. Then, participants had to answer a short questionnaire on their perception of the session, consisting of 2 visual analogue scales (VAS) constructed specifically for this experiment, and a questionnaire of mental and physical effort perception (NASA-TLX) (Hart and Staveland, 1988). VAS n°1 was as follows: “On the line below, please indicate how difficult it was to jump precisely on the marks.” Participants had to draw a line on a 10cm non-graduated horizontal line, ranging from “very easy” the left, to “very hard” on the right. VAS n°2 was as follows: “On the line below, please indicate how you perceived the jumping session overall.” Participants had to draw a line on a 10cm non-graduated horizontal line, ranging from “very boring” on the left, to “very entertaining” on the right. Finally, participants were asked to rate their muscle soreness using a French version of the 7-point Likert scale of muscle soreness (Impellizzeri et al., 2007; Vickers, 2001), with 0 being the “complete absence of muscle soreness”, and 6 being “a severe pain that limits my ability to move”. They were asked to record their muscle soreness level each of the 7 days following both sessions, on 7 different muscle groups (Quadriceps, hamstrings, calves, anterior tibialis, glutes, abdominals, lower back). Only the highest value for each muscle group was then used to calculate the mean for each condition (regardless of the day that the individual peak muscle soreness occurred).

Data analysis

The raw surface EMG data of the knee extensor muscles were processed using the Root Mean Square (RMS) calculated over a moving window of 200 ms in the Labchart - ADinstruments software. The reflex hammer strike force data, as well as leg extension force data were also recorded on this software and synchronized with EMG signals. The reflex stimulation force was obtained with the peak force given by the force transducer in the head of the hammer at each tendon strike. The reflex reaction force of the quadriceps was measured by taking the peak-to-peak amplitude (maximum -minimum) of the force signal. Only the highest of the two MViCs was analyzed. The value for each MViC was taken as the mean value of the force produced over the 5 second contraction.

For the evaluation of the deep tendon reflex profile, two different calculations were carried out: 1) The ratio of surface EMG activity in relation to the force of reflex stimulation (= [(peak of the RMS of the EMG signal/maximal amplitude of RMS signal during MViC) / striking force of the patellar tendon * 100], referred to as "RMS/strike"). 2) The ratio of the reaction force to the reflex stimulation force (= [peak force of the quadriceps / striking force of the patellar tendon * 100], referred to as "force/strike"). For each participant, the average of the ratio for each of the 10 tendon stimulations was calculated.

All jump length and height data were recorded in the Optojump software, for PRE and POST measurements and for each of the 100 jumps of each session. Mean jump height in cm for each percentage of jump length targeted and for each participant was calculated. The coefficient of variation of the jumping height was calculated for each percentage of jump length targeted, for each participant, as follows: [(standard deviation of jump height in cm / mean jump height in cm) * 100]. The relative error of jump length was calculated for the first 20 SLJs and last 20 SLJs during the repetition of jumps, as follows: [(error of jump length in cm / jump length targeted in cm) * 100].

Statistical analysis

Normality of data and homogeneity of variances were confirmed using the Shapiro-Wilk and Levene tests, respectively. Separate analyses were performed for jump parameters, EMG data, perception of effort, and force production data.

Independent samples t-tests were conducted to compare the random vs constant condition, on the Δ of jump performance, on the VAS scores, and on the muscle soreness ratings. Pearson's correlation was conducted to examine the relation between the patellar ligament strike force and the EMG response, on each participant.

One-way repeated measures ANOVA was performed, with the factor Condition (Random and Constant), on the mean jump height in SLJ, and on the CV of the jump height in SLJ. Two-way repeated measures ANOVA was performed, with the factor Condition (Random and Constant) and the factor Time (PRE and POST), on the mean jump height in CMJ, on the mean jump length in SLJ, on the MviCs, on the ratio of Force/strike, on the ratio of EMG/strike, on the relative error of jump length on SLJ, on the 6 items NASA-TLX questionnaire, and on the RPE.

For every ANOVA conducted, sphericity of data was confirmed through Maulchy's test. Greenhouse-Geisser correction was performed when sphericity of data was not verified. The significance threshold was established for a p value <0.05. Both one-way and two-way repeated measures ANOVA were followed by the Bonferroni post hoc test for multiple comparisons. The eta squared statistic is reported as an effect size to describe the magnitude of significant differences (small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$) effects). Post hoc effect size (ES) was calculated through the standardized mean difference (Cohen's d) and interpreted as follows: trivial: <0.35; small: 0.35 - 0.80; moderate: 0.80 - 1.5; and large effect: >1.5. (Rhea, 2004)

Statistical analysis was performed using JASP Team software (2022), JASP (Version 0.16.3).

Results

Jump performance

SLJ

Two-way repeated measures ANOVA conducted on SLJ length showed no significant effect of time [$F(1,14) = 0.251$, $p = 0.624$, $\eta^2 = 0.005$] but no effect of condition [$F(1,14) = 3.101$, $p = 0.100$, $\eta^2 = 0.072$] and no interaction effect between time and condition [$F(1,14) = 1.460$, $p = 0.247$, $\eta^2 = 0.028$] (Figure 1).

CMJ

CMJ height significantly decreased after both conditions. Two -way repeated measures ANOVA conducted on CMJ height, showed an effect of time [$F(1,13) = 21.797$, $p < 0.001$, $\eta^2 = 0.626$] but no effect of condition [$F(1,13) = 0.503$, $p = 0.491$, $\eta^2 = 0.012$] and no interaction effect between time and condition [$F(1,13) = 3.809$, $p = 0.073$, $\eta^2 = 0.042$] (Figure 1).

MVIC

MViC decreased after both conditions. Two-way repeated measures ANOVA showed an effect of time [$F(1,14) = 22.097$ $p < 0.001$, $\eta^2 = 0.387$] but no effect of condition [$F(1,14) = 0.398$, $p = 0.538$, $\eta^2 = 0.007$] and no interaction effect between time and condition [$F(1,14) = 0.808$, $p = 0.384$, $\eta^2 = 0.006$] (Figure 1).

Deep tendon reflex

Two-way repeated measures ANOVA conducted on the RMS/Strike ratios, showed no significant effect of time [$F(1,11) = 3.736$ $p = 0.079$, $\eta^2 = 0.043$], no effect of condition [$F(1,11) = 1.106$, $p = 0.316$, $\eta^2 = 0.029$] and no interaction effect between time and condition [$F(1,11) = 0.408$, $p = 0.536$, $\eta^2 = 0.018$] (Figure 2).

The ratio of [Force/Strike] decreased overall from Pre to Post. Two-way repeated measures ANOVA conducted showed an effect of time [$F(1,13) = 5.735$ $p = 0.032$, $\eta^2 = 0.206$] but no effect of condition [$F(1,13) = 0.938$, $p = 0.351$, $\eta^2 = 0.014$] and no interaction effect between time and condition [$F(1,13) = 0.491$, $p = 0.496$, $\eta^2 = 0.004$] (Figure 2).

EMG during MViC significantly decreased overall from Pre to Post. Two-way repeated measures ANOVA showed a significant effect of time [$F(1,14) = 9.991$ $p = 0.007$, $\eta^2 = 0.160$], no effect of condition [$F(1,14) = 0.036$, $p = 0.852$, $\eta^2 = 0.001$] and no interaction effect between time and condition [$F(1,14) = 0.054$, $p = 0.820$, $\eta^2 < 0.001$] (Figure 2).

As shown in Figure 3 on one representative participant, Pearson's correlation test conducted on reflex data showed that there was a significant linear correlation between patellar ligament stimulation force and maximal RMS of EMG response of the vastus medialis muscle ($r = 0.947$; $p < 0.001$).

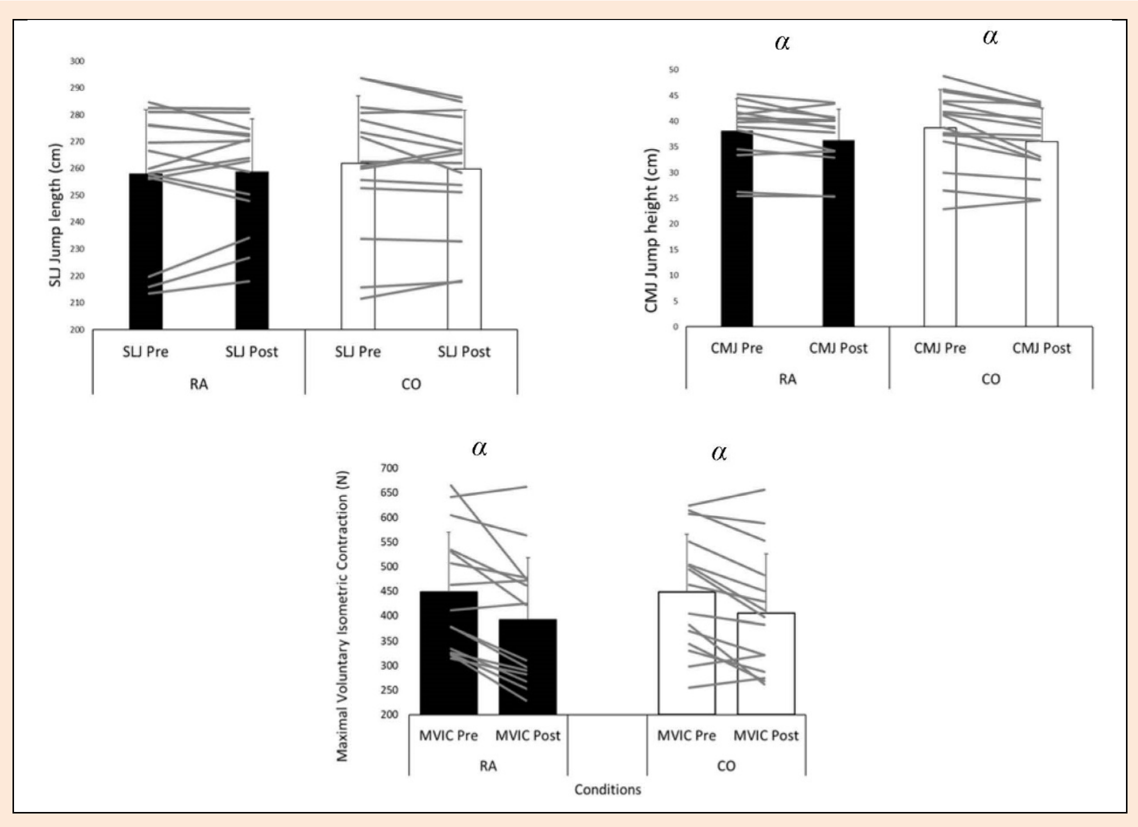

Figure 1. Performance results. Standing long jump length (top left). Countermovement jump height (top right). Leg extension MViC (bottom). RA: Random condition. CO: Constant condition. Pre: Pre-test. Post: Post-test. Lines on the graphs represent individual data. SLJ: Standing Long Jump. CMJ: Countermovement jump. α: main effect of time ($p<0.05$). β: main effect of condition ($p<0.05$). ω: interaction effect (time*condition) ($p<0.05$). Error bars represent standard deviations.

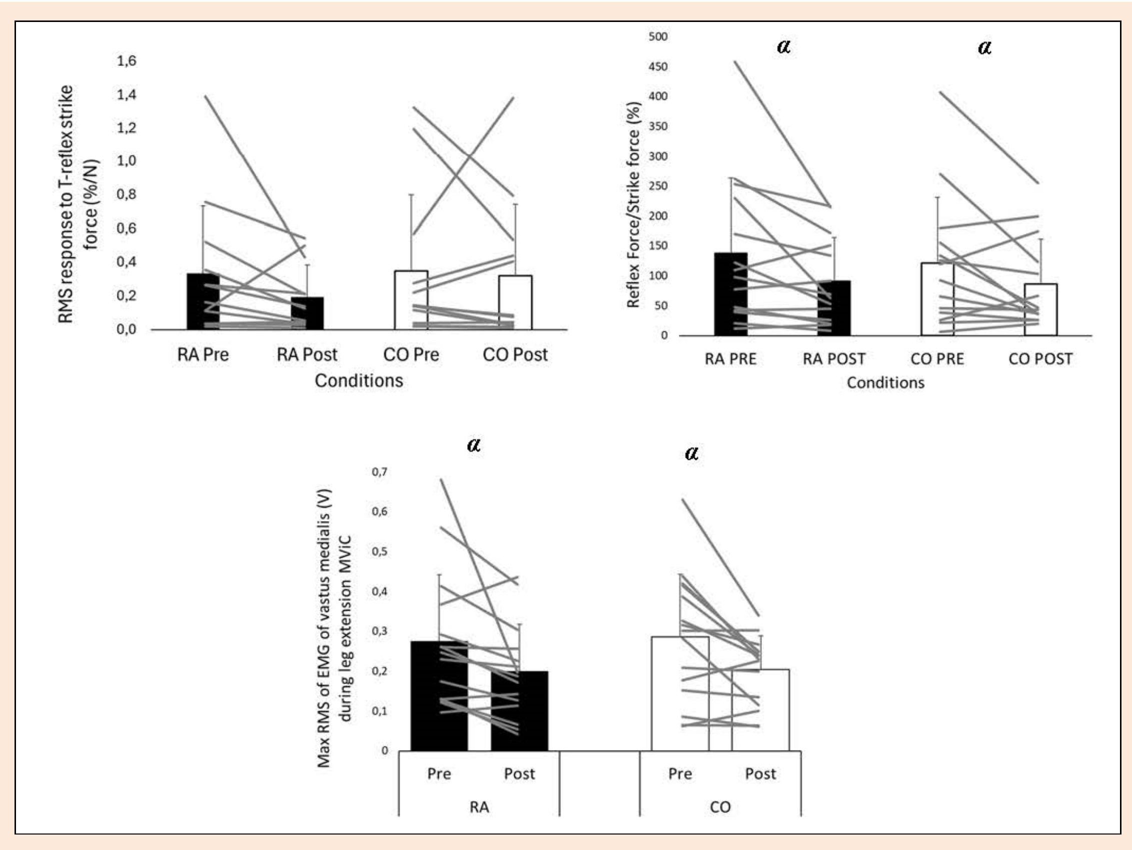

Figure 2. T reflex and EMG results. RMS response to T-reflex (top left). Knee extension force in reaction to T-reflex (top right). EMG during leg extension MViC (bottom). RA: Random condition. CO: Constant condition. Pre: Pre-test. Post: Post-test. RMS: Root Mean Squared. EMG: Electromyography. Lines on the graphs represent individual data. α: main effect of time ($p<0.05$). Error bars represent standard deviations.

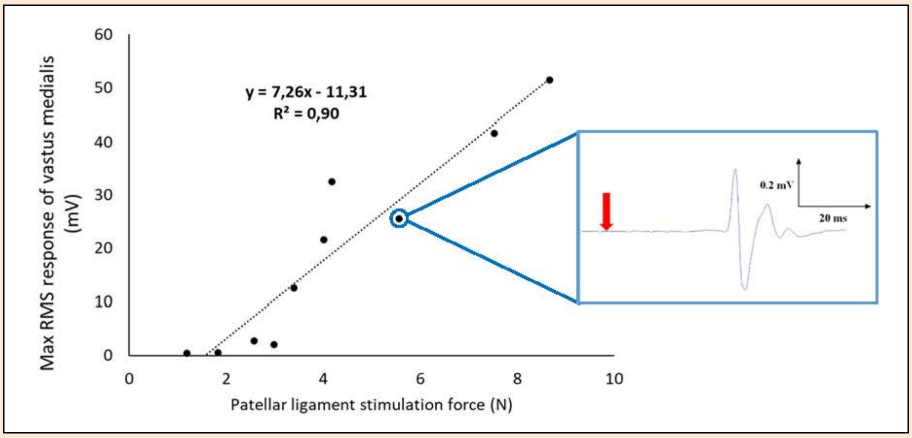

Figure 3. Representative data from 1 participant. Dotted line: linear model of the relation. On the right: an example of the EMG wave of the m. vastus medialis during T reflex testing. The red arrow represents the moment of patellar ligament stimulation.

Jump variability

Jump height during SLJ increased with increasing targeted length. One-way repeated measures ANOVA showed a significant effect of the relative jump length on the jump height adopted by the participants [F (1.538; 42) = 82.903, p < 0.001, η2 = 0.856] (Figure 4). Post-hoc tests showed that differences in jump height were significant between all jump lengths (for 65%, 75%, 85% and 95%: p<0,001). (with the following Cohen's d effect sizes: 65 - 75: -0.449; 65 - 85: -0.895; 65 - 95: -1.375; 75 - 85: -0.446; 75 - 95: -0.926; 85 - 95: -0.480)

The CV of the jump height decreased with increasing targeted length. One-way repeated measures ANOVA showed a significant effect of the relative jump length on the coefficient of variation of the jump height [F (4; 52) = 7.262, p < 0.001, η2 = 0.358] (Figure 4). Post-hoc tests showed the following significant differences: 65% from 85%: p = 0.028; 65% from 95 %: p < 0.001; 75% from 95%: p = 0.016; and 80% from 95%: p = 0.017 (with the following Cohen's *d* effect sizes respectively: 0.826, 1.356, 0.877, 0.873).

Two-way repeated measures ANOVA carried out on the relative jump length errors showed no significant effect of condition [F (1,13) = 0.018, p = 0.896, η2 < 0.001], no effect of time [F (1.13) = 1.455, p = 0.251, η2 = 0.030], and no interaction effect between time and condition [F (1,13) = 0.783, p = 0.393, η2 < 0.028] (Figure 4).

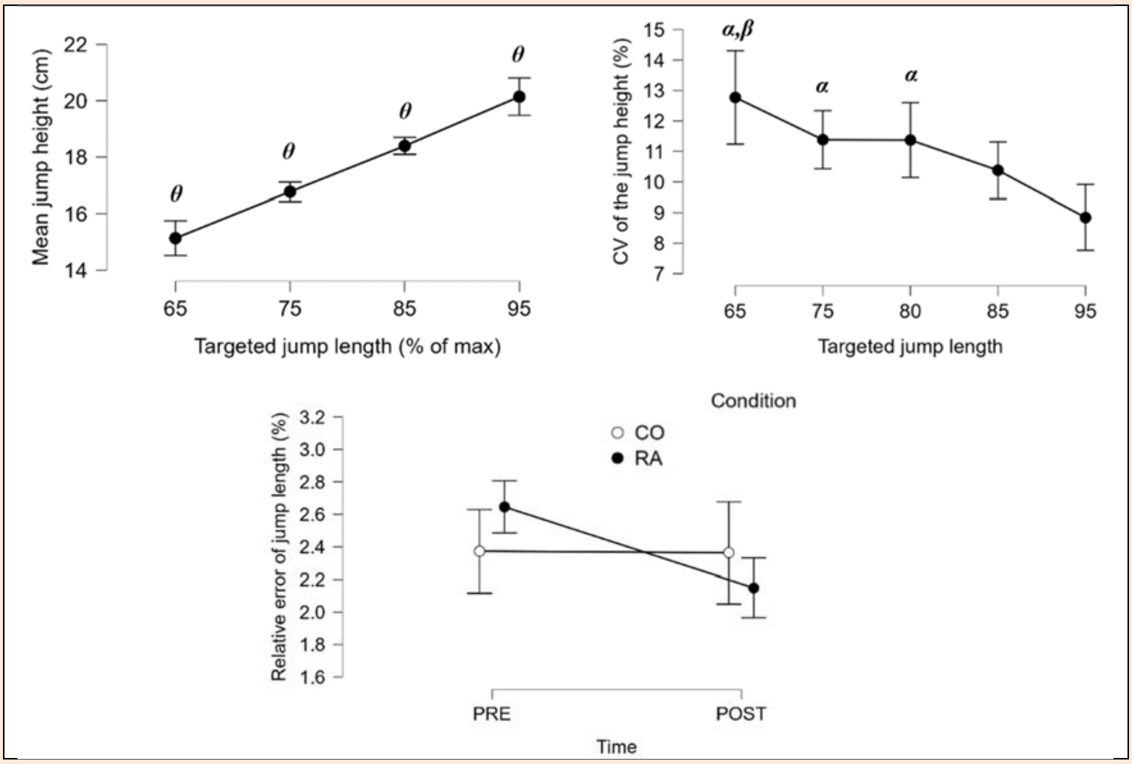

Figure 4. Jump parameter results over the 100 jumps. Jump height during standing long jumps (top left). Variations in jump height during standing long jumps (top right). Jump accuracy during standing long jumps (bottom). RA: Random condition. CO: Constant condition. Pre: Pre-test. Post: Post-test. α: different from 95% of jumping length (p <0.05). β: different from 85% of jumping length (p<0.05). θ: different from all other percentages of jumping length (p<0.05). Error bars represent standard deviations.

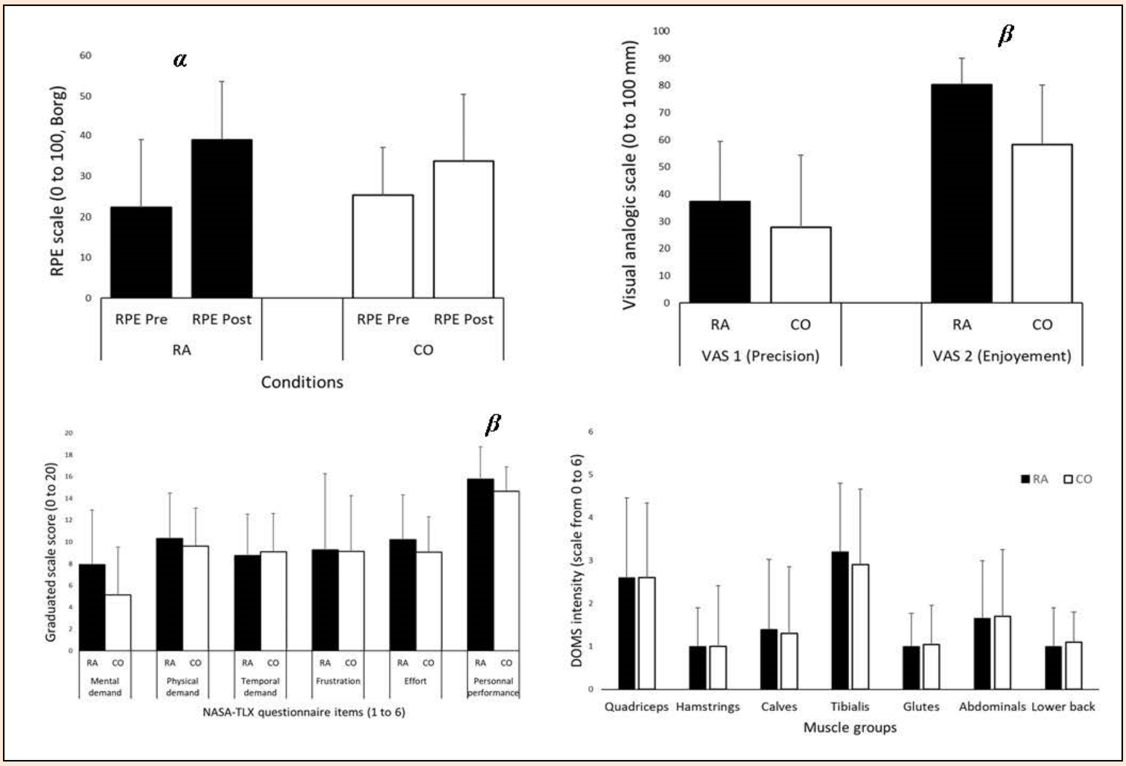

Figure 5. Subjective results. General perception of fatigue (top left). Perceived precision required and enjoyment (top right). NASA-TLX questionnaire scores (bottom left). Muscle soreness intensity (bottom right). RA: Random condition. CO: Constant condition. Pre: Pre-test. Post: Post-test. DOMS: Delayed Onset Muscle Soreness. RPE: Rate of Perceived Exertion. VAS: Visual Analogic Scale. α : Main effect of time (p<0,05). β: Significant difference between RA and CO (p<0,05). Error bars represent standard deviations.

Perceptual results

RPE increased only after the RA effort. Two-way repeated measures ANOVA carried out showed a significant effect of time [F (1.13) = 6.924, p = 0.021, η2 = 0.225], but no significant effect of condition [F (1,13) =0.137, p = 0.717, η2 = 0.002], and no significant interaction between time and condition [F (1,13) = 2.073, p = 0.174, η2 = 0.020] (Figure 5).

On the visual analogue scale (VAS) n°2 (measuring the perceived difficulty of the required precision), the T test did not show a significant difference between CO and AL. On VAS n°2; (measuring the boring/amusing nature of the activity), the T test showed that the RA condition was perceived to be more entertaining than the CO condition (p = 0.003) (Figure 5).

Concerning the NASA-TLX test, the T tests only showed a difference between the conditions for question no. 6 (“How successfully do you think you carried out this work?”), the participants having perceived greater success in the RA condition (p = 0.032). The first question (“What degree of mental and/or perceptible activity was required?”) was rated higher in the RA condition, but it was a nonsignificant difference. (p = 0.069) (Figure 5).

The paired sample T-tests performed on the peak muscle soreness ratings (DOMS) revealed no significant differences between conditions, regardless of the muscle group.

Discussion

The aim of this study was to determine whether randomizing the intensity of a repeated motor task would have an impact on physical performance and on neuromuscular and perceived fatigue, as compared to a more traditional approach with fixed intensity.

The results of this study show that acute sessions of random (RA) practice and constant (CO) practice have similar effects in terms of physical fatigue and neuromuscular system behavior. However, RA appeared to benefit participants mentally, as greater enjoyment was reported during random sessions.

Physical performance

First, the performance of participants on the CMJ max test decreased significantly overall, regardless of the condition. Our goal was to propose a jumping session that would be fatiguing enough to decrease the performance of participants on this particular test, which we believe mostly reflects the neuromuscular and peripheral fatigue. In the present experiment, on average, considering both conditions, jump height in CMJ decreased by 5%. This result is similar to a study (Raeder et al., 2016) that examined neuromuscular fatigue after five different dynamic squat protocols and found that the decrease in CMJ performance varied between 6% and 10%, independently of the fatigue inducing protocol.

Secondly, the performance decrease occurring in POST did not differ between the CO and RA conditions in CMJ max, SLJ max, or MViC of the leg extension. In order to examine the impact of the organization of the exercise session alone, the training load was equalized in the random and constant conditions. Thus, we can speculate that with matched training loads, the design of the fatiguing session does not affect the muscular fatigue induced, even if this hypothesis can be challenged by results of previous studies. One investigation (Gorostiaga et al., 2014) showed that different organizations of sets and repetitions, even with matched training load, led to different states of fatigue, as assessed by measures of blood lactate, power output and others. More precisely, there was a decrease of 37 % in power output, and in muscle ATP content of 24 %, as well as high levels of muscle lactate, blood lactate and blood ammonia. It is important to note, however, that the session durations were not matched. Conversely, other studies have shown that training design had little or no effect on power output, as measured by CMJ maximal height (Johnston et al., 2017; Raeder et al., 2016). Taken together, previous and present results suggest that randomizing the intensity of effort, when training loads and session duration are matched, does not seem to significantly change the athlete's physical state of fatigue.

Nevertheless, there was a difference in the decrease in performance between the 2 maximal jumps assessed in PRE and POST: there was a significant decrease in the maximal height reached in CMJ, resulting from the fatigue induced by repeated jumps, but no significant decrease in the maximal jump length reached in SLJ. Similarly, another study (Watkins et al., 2024) showed a decrease in the jump height (in CMJ) of approximately 0% to -7%, and an increase in jump length of approximately 2% to 5% (in SLJ), after a short bout of 40 repetitions of specific jumping exercises. In the present study, this could be explained by motor adaptations in the execution of the SLJ, enabled by the long repetition of 100 SLJs that the participants performed. As an example, according to a review of SLJ performance (Zhou et al., 2020), SLJ is a complex motor skill that requires adequate coordination of the upper and lower limb muscles. One of the aspects that could have been responsible for the performance increase is the use of the upper limb swing (Ashby and Heegaard, 2002).

The neuromuscular system

Surface EMG data was recorded during MViC to detect whether the neuromuscular factor would be responsible for the fatigue induced. Indeed, according to a recent meta-analysis (Hou et al., 2021), different indicators of myoelectrical activity can be used to effectively assess neuromuscular fatigue induced by exercise, including the RMS (Root Mean Squared). This study showed that a wide range of different physical activities can induce neuromuscular fatigue, via measures of different indicators of sEMG signals. Additionally, another study (Puce et al., 2021) investigated the validity of using 4 different spectral parameters of sEMG to assess mechanical fatigue in swimming. They showed that 2 of them, namely median frequency and mean frequency, were valid and stable indicators.

We also sought to verify whether the induced fatigue would be more pronounced after a random session, as the neuromuscular demand would be greater when the participants are exposed to greater variability. It turns out that there is indeed a decrease in peak RMS of EMG during the MViCs after the repeated jumps, but it is not different after the random condition. This suggests that central fatigue occurred because of the repeated jumps, regardless of the condition, and possibly originating from spinal and/or supraspinal levels (Gandevia, 2001).

Results on the T-reflex test showed a possible involvement of spinal adaptation to the observed fatigue. Indeed, a decrease in the ratio of [reflex force/strike force] could suggest decreased spinal excitability with fatigue. However, no significant change in the [RMS/strike force] ratio was found ($p = 0.079$). The absence of interaction effect signifies that the decrease in reflex intensity was similar after constant and random effort. As the random intensity of effort during repeated SLJ does not imply greater fatigue of the spinal reflex, this questions a previous hypothesis on the effect of random practice on the neuromuscular system. Either the present results are incomplete and were unable to reveal the actual effects of random practice, or the random intensity of effort is no different to constant intensity in terms of acute fatigue of the neuromuscular system. Deeper investigations of the spinal loops after random exercises are warranted at this stage, using H-reflex techniques for instance.

Variations in performance

It has been demonstrated that random practice is beneficial for performance in the long term, i.e. as assessed with retention tests, in the context of basketball (Porter and Magill, 2010), golf (Aiken and Genter, 2018) and baseball (Sharp et al., s. d.). Our results on the accuracy of jump length suggest that random practice does not have any acute beneficial effect. Indeed, the error of jump length did not decrease significantly in the RA condition, between the first 20 SLJs and the last 20 SLJs. It can therefore be supposed that, in order to see a beneficial effect of random practice on SLJs, the repetition of jumps in the present experiment should be regularly implemented into a training program, long enough for the random design to be beneficial for the athletes' accuracy. A single session of random practice is certainly not sufficient to improve the precision during jumps. More generally, aiming at varied distances enables one to be more precise on a given distance, compared to aiming at only one distance. A possible explanation for this phenomenon has already been proposed (Lee and Magill, 1985); whereby, when participants forget the specificity of a task, by increasing the resting time, or by placing other tasks in between a single task, then they are forced to realize a "reconstruction of the action plan" (Lee and Magill, 1985; Rey et al., 1994). This leads to an immediate decreased performance, but a greater performance on retention and transfer tests, which require cognitive analysis of the task to be learnt.

The coefficient of variation of the jump height (CV) was significantly lower for the 95% SLJ distance than in 65%, 75% and 80% ($p<0.05$). This result can be interpreted as a change in the jumping strategy, which depends on the percentage of SLJ distance to cover. The study by Grosprêtre et al. in 2018 showed that expert parkour practitioners were able to jump further than beginners on the SLJ, and that for higher percentages of maximal distance, they adopted a jumping strategy where they slightly diminished the jump height (by a decrease of the angle of take-off), thus increasing the jumping length. Consequently, the CV of the jump height necessarily decreases, as there are fewer options in the angle at take-off to reach the near maximal SLJ distances.

Subjective markers of fatigue

Overall, results related to perception of fatigue showed that there were differences between the conditions, and between pre and post effort.

Firstly, the CR100 (Borg) scale results showed that the general state of subjective fatigue increased significantly only after the random effort. Although randomization of the jumping session may be responsible for a greater state of fatigue at the end, this higher rating could also be due to the increased mental demand in the random condition, as the question they were asked was: "what is your general state of fatigue right now", including both physical and mental fatigue.

Interestingly, the physical demand seems to be identical, based on the various performance tests carried out. Thus, the greater mental demand of the random condition could be attributed to the near maximal jumping percentages, especially the 95% maximal jumping length. Indeed, even though, on average, the jumping length to achieve was 80% overall in the constant and in random conditions, that does not necessarily mean that average intensities were identical. Perhaps there is a nonlinear relation between the percentage of jump length and the actual intensity required. This hypothesis is supported by the results of a similar study (Grosprêtre et al., 2018) examining the differences in ground reaction forces (GRF) in standing long jump between different jump lengths. That study showed that unexperienced athletes presented higher antero-posterior GRF only in the 100% of SLJ length, compared to other, lower percentages of jump lengths (70, 80 and 90%). Thus, it is possible that in the present experiment, the near maximal intensity jumps (95%) are the ones that are responsible for the increased overall perception of effort in the RA condition, even though the training loads were matched in both conditions.

In a meta-analysis (Habay et al., 2021) the authors showed that mental fatigue can negatively affect sport-specific psychomotor performance. In the present study, despite higher perceived fatigue after the random effort, we did not observe a greater decrease in physical performance, which is congruent with existing literature. Indeed, in a study investigating the effect of mental fatigue on physical performance (Marcora et al., 2009), it was shown that a mentally demanding task can reduce physical performance, without the participation of cardiorespiratory and musculoenergetic factors. Thus, it is possible to speculate that in the present study, greater mental fatigue in the random condition, due to an additional cognitive load, was not sufficient to cause a larger decrease in physical performance.

The better appreciation of the random condition compared to the blocked condition, as shown by the differences in ratings on the NASA-TLX, and the adapted VAS, is in line with previous research on the effect of variability on the rating of perceived exertion (Streder, 2013). According to this research, implementing variability within a strength training program can decrease the stress imposed on the neuromuscular system. The author proposed that increased variability was responsible for a decrease in the RPE that participants reported. It is reasonable to speculate that in the present experiment, participants preferred the random condition because of the specific distribution of the jump percentages. It remains unclear whether the randomization, or more generally the variability, was responsible for the observed difference.

From a more general point of view, random practice, when compared to blocked practice with similar training load, seems to produce very similar physical stress, but is concomitantly better appreciated by participants. Thus, it is an interesting result, as this could encourage sports practitioners to implement this kind of training organization, especially during a phase where the monotony of training would be high.

The present study has some limitations. Firstly, there was no comparison of a variable and organized session to a variable and non-organized session. Thus, the effect of the random condition in the present study, which can be considered as variable and non-organized, cannot be attributed solely to one of these two components (variability or disorganization) but rather, only to both of them together. Moreover, it would be of interest to consider motor strategy adaptations throughout the 100 jumps, by means of kinematic analysis. Indeed, a different use of the arm swing, for instance, could interfere with jumping performance, and could be quantified by means of motion capture.

Conclusion

In conclusion, the results of the present experiment suggest that between random practice and blocked practice, the differences lie mostly in the perceptual aspect. The physical performance, as assessed by maximal strength testing, as well as the jump height and length, do not show any significant differences. Interestingly, very little changes in terms of the movement variation (only the jump length from 65 to 95% of maximum) leads to markedly higher practice enjoyment. Specifically, within a given, monotonous session of 100 repeated and identical standing long jumps, randomization of the practice design seems to make the session clearly more tolerable and more entertaining for the participants. The training load calculation was simple, in order to be as applicable to the field as possible and was chosen basically as the sum of all the distances covered over the 100 repeated SLJs. According to our results, coaches may utilize this simple method to implement random sessions of exercise instead of the traditional sessions, with equivalent training load. The benefit of this particular random design is to be more positively perceived by athletes, and it could be implemented during monotonous phases of training, with the intent on boosting the progression. Future research should investigate the effect of random and regularly varied intensities of jumps, for example, by intermittent training. More generally, there is a need to examine the effects of a randomly organized intensity of effort during specific movement associated with a sporting discipline. Researchers should also be aware of the clear distinction between effort of randomized intensity, established in advance, and effort with unpredicted intensity, because chosen by the participants or the athletes, and must design future research accordingly.

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The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request, who was an organizer of the study.

References

Aiken, C. A. and Genter, A. M. (2018) The effects of blocked and random practice on the learning of three variations of the golf chip shot. *International Journal of Performance Analysis in Sport* **18(2)**, 339-349. https://doi.org/10.1080/24748668.2018.1475199

Ammar, A., Trabelsi, K., Boujelbane, M. A., Boukhris, O., Glenn, J. M., Chtourou, H. and Schöllhorn, W. I. (2023) The myth of contextual interference learning benefit in sports practice: A systematic review and meta-analysis. *Educational Research Review* **39**, 100537. https://doi.org/10.1016/j.edurev.2023.100537

Ashby, B. M. and Heegaard, J. H. (2002) Role of arm motion in the standing long jump. *Journal of Biomechanics* **35(12)**, 1631-1637. https://doi.org/10.1016/S0021-9290(02)00239-7

Barreiros, J., Figueiredo, T. and Godinho, M. (2007) The contextual interference effect in applied settings. *European Physical Education Review* **13(2)**, 195-208. https://doi.org/10.1177/1356336X07076876

Behrman, A. L., Bowden, M. G. and Nair, P. M. (2006) Neuroplasticity After Spinal Cord Injury and Training: An Emerging Paradigm Shift in Rehabilitation and Walking Recovery. *Physical Therapy* **86(10)**, 1406-1425. https://doi.org/10.2522/ptj.20050212

Borg, E. and Borg, G. (2002) A comparison of AME and CR100 for scaling perceived exertion. Acta Psychologica **109(2)**, 157-175. https://doi.org/10.1016/S0001-6918(01)00055-5

Cheong, J. P. G., Lay, B. and Razman, R. (2016) *Investigating the Contextual Interference Effect Using Combination Sports Skills in Open and Closed Skill Environments*.

Fanchini, M., Ferraresi, I., Modena, R., Schena, F., Coutts, A. J. and Impellizzeri, F. M. (2016) Use of the CR100 Scale for Session Rating of Perceived Exertion in Soccer and Its Interchangeability With the CR10. *International Journal of Sports Physiology and Performance* **11(3)**, 388-392. https://doi.org/10.1123/ijspp.2015-0273

Farrow, D. and Buszard, T. (2017) Exploring the applicability of the contextual interference effect in sports practice. In *Progress in Brain Research* **234**, 69-83. Elsevier. https://doi.org/10.1016/bs.pbr.2017.07.002

Gandevia, S. C. (2001) Spinal and Supraspinal Factors in Human Muscle Fatigue. *Physiological Reviews* **81(4)**, 1725-1789. https://doi.org/10.1152/physrev.2001.81.4.1725

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M. and Maffiuletti, N. A. (2011) Validity and Reliability of Optojump Photoelectric Cells for Estimating Vertical Jump Height. Journal of Strength and Conditioning Research **25(2)**, 556-560. https://doi.org/10.1519/JSC.0b013e3181ccb18d

Gorostiaga, E. M., Navarro-Amézqueta, I., Calbet, J. A. L., Sánchez-Medina, L., Cusso, R., Guerrero, M., Granados, C., González-Izal, M., Ibáñez, J. and Izquierdo, M. (2014) Blood Ammonia and Lactate as Markers of Muscle Metabolites During Leg Press Exercise. *Journal of Strength and Conditioning Research* ***28*(10)**, 2775-2785. https://doi.org/10.1519/JSC.0000000000000496

Grosprêtre, S. and Gabriel, D. (2021) Sport Practice Enhances Athletes' Observation Capacity: Comparing Scenic Change Detection in Open and Closed Sports. *Perceptual and Motor Skills* **128(1)**, 96-114. https://doi.org/10.1177/0031512520958232

Grosprêtre, S., Ufland, P. and Jecker, D. (2018) The adaptation to standing long jump distance in parkour is performed by the modulation of specific variables prior and during take-off. *Movement & Sport Sciences - Science & Motricité* **100**, 27-37. https://doi.org/10.1051/sm/2017022

Habay, J., Van Cutsem, J., Verschueren, J., De Bock, S., Proost, M., De Wachter, J., Tassignon, B., Meeusen, R. and Roelands, B. (2021) Mental Fatigue and Sport-Specific Psychomotor Performance: A Systematic Review. *Sports Medicine* **51(7)**, 1527-1548. https://doi.org/10.1007/s40279-021-01429-6

Hart, S. G. and Staveland, L. E. (1988) Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Advances in Psychology* **52**, 139-183) Elsevier. https://doi.org/10.1016/S0166-4115(08)62386-9

Hermens, H. J., Freriks, B., Disselhorst-Klug, C. and Rau, G. (2000) Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology* **10(5)**, 361-374. https://doi.org/10.1016/S1050-6411(00)00027-4

Horbacewicz, J. (2018) Effect of Blocked Versus Random Practice on Physical Therapy Students' Manual Force Modulation. *Perceptual and Motor Skills* **125(6)**, 1173-1185. https://doi.org/10.1177/0031512518797845

Hou, X., Liu, J., Weng, K., Griffin, L., Rice, L. A. and Jan, Y.-K. (2021) Effects of Various Physical Interventions on Reducing Neuromuscular Fatigue Assessed by Electromyography: A Systematic Review and Meta-Analysis. *Frontiers in Bioengineering and Biotechnology* **9**, 659138. https://doi.org/10.3389/fbioe.2021.659138

Impellizzeri, F. M., Rampinini, E., Castagna, C., Martino, F., Fiorini, S. and Wisloff, U. (2007) Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine* **42(1)**, 42-46. https://doi.org/10.1136/bjsm.2007.038497

Johnston, M., Johnston, J., Cook, C. J., Costley, L., Kilgallon, M. and Kilduff, L. P. (2017) The effect of session order on the physiological, neuromuscular, and endocrine responses to maximal speed and weight training sessions over a 24-h period. *Journal of Science and Medicine in Sport* **20(5)**, 502-506. https://doi.org/10.1016/j.jsams.2016.03.007

Lee, T. D. and Magill, R. A. (1985) Can Forgetting Facilitate Skill Acquisition? In *Advances in Psychology* **27**, 3-22) Elsevier. https://doi.org/10.1016/S0166-4115(08)62528-5

Lelis-Torres, N., Ugrinowitsch, H., Apolinário-Souza, T., Benda, R. N. and Lage, G. M. (2017) Task engagement and mental workload involved in variation and repetition of a motor skill. *Scientific Reports* **7(1)**, 14764. https://doi.org/10.1038/s41598-017-15343-3

Mackala, K., Fostiak, M., Schweyen, B., Osik, T. and Coch, M. (2019) Acute Effects of a Speed Training Program on Sprinting Step Kinematics and Performance. *International Journal of Environmental Research and Public Health* **16(17)**, 3138. https://doi.org/10.3390/ijerph16173138

Marcora, S. M., Staiano, W. and Manning, V. (2009) Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology* **106**, 8. https://doi.org/10.1152/japplphysiol.91324.2008

Pagnon, D., Faity, G., Maldonado, G., Daout, Y. and Grosprêtre, S. (2022) What Makes Parkour Unique? A Narrative Review Across Miscellaneous Academic Fields. *Sports Medicine* **52(5)**, 1029-1042. https://doi.org/10.1007/s40279-022-01642-x

Porter, C., Greenwood, D., Panchuk, D. and Pepping, G.-J. (2020) Learner-adapted practice promotes skill transfer in unskilled adults learning the basketball set shot. *European Journal of Sport Science* **20(1)**, 61-71. https://doi.org/10.1080/17461391.2019.1611931

Porter, J. M. and Magill, R. A. (2010) Systematically increasing contextual interference is beneficial for learning sport skills. *Journal of Sports Sciences* **28(12)**, 1277-1285. https://doi.org/10.1080/02640414.2010.502946

Puce, L., Pallecchi, I., Marinelli, L., Mori, L., Bove, M., Diotti, D., Ruggeri, P., Faelli, E., Cotellessa, F. and Trompetto, C. (2021) Surface Electromyography Spectral Parameters for the Study of Muscle Fatigue in Swimming. *Frontiers in Sports and Active Living* **3**, 644765. https://doi.org/10.3389/fspor.2021.644765

Raeder, C., Wiewelhove, T., Westphal-Martinez, M. P., Fernandez-Fernandez, J., De Paula Simola, R. A., Kellmann, M., Meyer, T., Pfeiffer, M. and Ferrauti, A. (2016) Neuromuscular Fatigue and Physiological Responses After Five Dynamic Squat Exercise Protocols. *Journal of Strength and Conditioning Research* **30(4)**, 953-965. https://doi.org/10.1519/JSC.0000000000001181

Rey, P. D., Liu, X. and Simpson, K. J. (1994) Does Retroactive Inhibition Influence Contextual Interference Effects? *Research Quarterly for Exercise and Sport* **65(2)**, 120-126. https://doi.org/10.1080/02701367.1994.10607606

Rhea, M. R. (2004) Determining the magnitude of treatment effects in strength training research through the use of effect size. https://doi.org/10.1519/14403.1

Schmidt, R. A. and Lee, T. D. (2005) *Motor control and learning: A behavioral emphasis* (4th ed.) Human Kinetics.

Sharp, M. H., Gheith, R. H., Reber, D. A., Stefan, M. W., Lowery, R. P. and Wilson, J. M. (2020) The effect of blocked versus random practice on dominant and non-dominant baseball swing. *Journal of Sport and Human Performance,* **8(1).** https://doi.org/10.12922/jshp.v8i1.163

Shea, C. H. and Kohl, R. M. (1990) Specificity and Variability of Practice. *Research Quarterly for Exercise and Sport* **61(2)**, 169-177. https://doi.org/10.1080/02701367.1990.10608671

Shea, J. B. and Morgan, R. L. (1979) Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory* **5(2)**, 179-187. https://doi.org/10.1037/0278-7393.5.2.179

Streder, K. L. (2013) *Variability of Practice and Strength Training Periodization: When Theories Collide* [California Polytechnic State University]. https://doi.org/10.15368/theses.2013.192

Vickers, A. J. (2001) Time course of muscle soreness following different types of exercise. *BMC Musculoskeletal Disorders* **2(1)**, 5. https://doi.org/10.1186/1471-2474-2-5

Watkins, C. M., Gill, N. D., McGuigan, M. R., Maunder, E., Spence, A.-J., Downes, P., Neville, J. and Storey, A. G. (2024) Kinetic Analysis, Potentiation, and Fatigue During Vertical and Horizontal Plyometric Training: An In-Depth Investigation Into Session Volume. *International Journal of Sports Physiology and Performance* **19(2)**, 195-206. https://doi.org/10.1123/ijspp.2022-0220

Zhou, H., Yu, P., Thirupathi, A. and Liang, M. (2020) How to Improve the Standing Long Jump Performance? A Mininarrative Review. *Applied Bionics and Biomechanics* **2020**, 1-5. https://doi.org/10.1155/2020/4345723

Key points

- This was the first study to investigate the acute effects of randomizing the intensity of an exercise, -the standing long jump- on the neuromuscular system and several performance parameters.
- T reflex assessment in the present experiment showed for some participants a very clear linear relationship between hammer strike force and quadriceps force response.
- Despite major differences in terms of session intensity structuring, there are no notable differences in performance or neuromuscular system parameters between random and continuous, although the random sessions were better appreciated.
- These results highlight the potential benefit of using random intensity during training phases that present a high degree of monotony, in order to make training more tolerable for athletes.

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