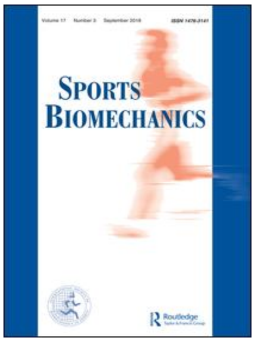


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# Verbal instructions affect reactive strength index modified and time-series waveforms in basketball players

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# Verbal instructions affect reactive strength index modified and time-series waveforms in basketball players

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**ABSTRACT**

This study aimed to determine the effects of different verbal instructions, intended to affect the countermovement jump (CMJ) execution time, on the reactive strength index modified ($RSI_{Mod}$) and the time-series waveforms. Thirteen male basketball players performed six CMJs on a force plate with two different verbal instructions: 'jump as high as possible' (CMJhigh) and 'jump as high and as fast as possible' (CMJfast). Force-, power-, velocity-, and displacement-series waveforms, $RSI_{Mod}$ and jump height were compared between conditions using statistical parametric mapping procedures. CMJfast showed greater values in $RSI_{Mod}$ ($p = 0.002$) despite no differences in jump height ($p = 0.345$). Unweighting force (between 18% and 33% of total time) was lower in the CMJfast compared to CMJhigh. Larger force (between 53% and 63% of total time), velocity (between 31% and 48% of total time) and power (between 43% and 56% of total time) were found in the CMJfast compared to CMJhigh. These findings suggest that commanding athletes to jump as high and fast as possible increases rapid force production. Additionally, the results highlight the relevance of the countermovement phase in jumping and show that $RSI_{Mod}$ could increase without power output modifications during propulsion, despite previous studies having reported positive associations between $RSI_{Mod}$ propulsion power.

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**KEYWORDS**
Biomechanics; force plate; jumping

## Introduction

A high number of vertical jumps occur in each basketball game in order to reach a ball before the opponent or jump up to the basket to score. For this reason, it is common among physical trainers and researchers to use vertical jump tests to assess the physical condition of basketball players (McInnes et al., 1995). The countermovement jump (CMJ) is a common test utilised in the literature (Van Hooren & Zolotarjova, 2017). The performance criteria accepted by strength and conditioning professionals are to reach the highest jump height (Casserly et al., 2020; Jlid et al., 2019). However, there are many sports where the time to jump is limited by game circumstances (Domire & Challis, 2015). In this sense, it seems necessary to incorporate parameters which take into account both the jump height and jump execution time, such as the Reactive Strength Index Modified ($RSI_{Mod}$) (Heishman et al., 2019).

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The $RSI_{Mod}$ is defined as the vertical jump height divided by time to take-off (time from the start of the countermovement phase to the take-off instant) (McMahon et al., 2018). Several investigations showed the $RSI_{Mod}$ as a valid measure of rapid force production (sometimes referred to as 'explosiveness') in different sports (Heishman et al., 2019; Kipp et al., 2016). The $RSI_{Mod}$ is measured when athletes perform a CMJ test. During this test, participants receive different instructions from coaches and researchers which may (Cormie et al., 2009; Hassani et al., 2014) or may not restrict (Hunter & Marshall, 2002; Young et al., 1995) the execution of the CMJ. The absence of standardised instructions could have an influence on the test results. Previous investigation showed that the instruction given to the participants affected the CMJ performance and the biomechanical variables analysed (Kirby et al., 2011; Pérez-Castilla et al., in press; Salles et al., 2011; Sánchez-Sixto et al., 2018; Talpey et al., 2016). When athletes were instructed to 'just concentrate on jumping for maximum height' the jump height, peak velocity and countermovement depth were higher in comparison with the instruction 'just concentrate on extending the legs as fast as possible to maximise explosive force' where higher peak force values were achieved (Talpey et al., 2016). When athletes were instructed to increase the countermovement depth, their jump height increased and the force applied parameters decreased (Kirby et al., 2011; Salles et al., 2011). Other investigations showed that higher countermovement velocities were reached when participants were instructed to start the propulsion phase from a deeper position (Pérez-Castilla et al., in press; Sánchez-Sixto et al., 2018). In the recent literature, it is possible to find discrepancies between the instructions given to athletes when executing a CMJ in order to evaluate the $RSI_{Mod}$, with the most common being 'jump as high as possible' (Heishman et al., 2019; James et al., 2020) and 'jump as high and as fast as possible' (Barker et al., 2018; McMahon et al., in press, 2018). Due to the differences observed with the different instruction utilised, it is possible that the given verbal instructions influence the magnitude of the $RSI_{Mod}$. Pérez-Castilla et al. (in press) found higher $RSI_{Mod}$ values when athletes were instructed to perform a faster countermovement in comparison to a self-selected speed during the CMJ. The authors suggested that these differences could be appreciable in the force-time curve shape, although they did not reach conclusive results when the countermovement depth was self-selected. The researchers of this study categorised each vertical jump based on whether one or two distinct force peaks appeared during the propulsion phase. This type of visual analysis does not allow for a deep analysis of the effect of verbal instructions on the force-time curve shape; consequently, accurate statistical analysis is necessary to understand how the given verbal instruction influences the CMJ biomechanics.

Most of the previous investigations that assessed the effects of jump strategy modification used discrete variables (Kirby et al., 2011; Salles et al., 2011). The data reduction from a continuous series to a discrete measure discards a large amount of data which could provide relevant information for understanding CMJ performance (Deluzio et al., 2014; Preatoni et al., 2013). The analysis of continuous biomechanical variables based on time-series data could facilitate the evaluation of differences in the shape or pattern of the waveform without severe loss the important information (Deluzio et al., 2014; Preatoni et al., 2013). Several studies demonstrated how useful the analysis of continuous biomechanical variables is, based on time-series data, to identify differences in the waveform patterns between groups of different performance levels or changes in response to training

(Cormie et al., 2009; Floría et al., 2016, 2019). However, few investigations focused on analysing how waveform patterns change based on slight technical modifications or instructions within the same session (Pérez-Castilla et al., in press).

Statistical Parametric Mapping (SPM) is an appropriate method for the analysis of time-series waveforms as it reduces the probability of false positives (Pataky et al., 2015, 2016). Several movement patterns have been evaluated by SPM to analyse movement patterns (Kipp et al., in press; Whyte et al., 2018). However, few investigations used the SPM method to analyse the CMJ (James et al., 2020; Kipp et al., in press). The SPM could help to identify the time instant where the difference of each parameter is statistically significant in an accurate way (Pataky et al., 2015, 2016). Therefore, the purpose of this study was to determine the effects of different verbal instructions, intended to affect the countermovement jump execution time, on the $RSI_{Mod}$ and the time-series waveforms. An SPM analysis was used to compare the shape of the force-, velocity-, power- and displacement-time profiles between verbal instructions. We hypothesised that instructions emphasising fast movements produce a higher $RSI_{Mod}$ and results in phase-specific kinematic and kinetic changes throughout the CMJ performance.

## Methods

### *Participants*

Thirteen competitive male basketball players volunteered to participate in this investigation (mean ± SD: age = 20.9 ± 3.0 years; height = 1.80 ± 0.05 m; weight = 76.5 ± 10.9 kg). All the participants were part of an amateur basketball club which trained at least twice a week and compete in a local league (IMD Seville League). The players had a minimum basketball experience of 5 years and they incorporate CMJs during their training sessions. None of them had any musculoskeletal injury within 6 months before participation in this study. The study was approved by the CEU Cardenal Spinola University Institutional Review Board, all participants provided informed consent and the study protocol adhered to the Declaration of Helsinki principles.

### *Design*

The design proposed was a repeated measures study to evaluate the effect of different verbal instructions that were intended to affect the execution time had on the $RSI_{Mod}$ and time-series curves. The participants performed 6 CMJ during a single session with two different instructions: ‘jump as high as possible’ (CMJhigh) or ‘jump as high and as fast as possible’ (CMJfast). All of the participants were informed before the testing session and the same researcher gave the instructions to the participants. The testing session took place in-season. All the jumps were performed on a force plate (Accupower; AMTI, Watertown, MA, USA) sampling at 1000 Hz.

### *Procedures*

All the participants were used to performing CMJs with the instruction given in this investigation during the season, so six jump attempts were enough to ensure correct execution. Previous to the CMJ test, participants carried out a 10-min standardised warm-up consisting of 2-min running, dynamic stretching exercises and one set of 6 sub-maximal jump (Vetter, 2007). After the warm-up, each participant performed 3 CMJhigh and 3 CMJfast in random order. In all CMJs, participants retained the arms akimbo from the start of the jump until the finish of the landing phase and they self-selected the countermovement depth. Each participant stood upright and stationary for at least 2 s before the jump began. Three successful jumps were recorded for each jump type and the jump selected for the SPM analysis was the jump where participants achieved the higher jump height for each jump condition.

## Data analysis

The force-time data of the CMJs were analysed by the impulse method (Linthorne, 2001). We calculated the net vertical impulse by integrating the net vertical force with respect to time from 2 s prior to the start of the jump (Street et al., 2001). The vertical velocity of the centre of mass was calculated by dividing the net vertical impulse and the mass of the participants. Then, the vertical displacement of the centre of mass was obtained by integrating the vertical velocity of the centre of mass. Finally, we calculated the vertical power during the CMJ by multiplying the force-velocity data along the time series.

The countermovement phase was considered from the start of the movement to the maximal countermovement displacement of the centre of mass and the propulsion phase was considered from the maximal countermovement depth to the take-off instant. We determined the start of the countermovement and the take-off instant following the recommendations of Street et al. (2001). The start of movement was detected by searching forwards from the first intersection of vertical ground reaction force, within a pre-defined threshold of 1.75 times the peak residual force, during the 2-s BW averaging period. A backward search was then performed until the ground reaction force passed through body weight. The moment of take-off was defined as the instant in which the first intersection of vertical ground reaction force occurred, within an offset threshold. This threshold was determined by adding the average flight time (i.e., 0.4 s) and the peak residual of the offset. Total time of the CMJ, time of the countermovement phase and time of the propulsion phase were calculated according to the phases described. The maximum countermovement velocity of the centre of mass was found in the velocity-time series as the highest negative value. The maximal negative value in the displacement-time series was considered the countermovement displacement of the centre of mass. Finally, $RSI_{Mod}$ was calculated as jump height divided by the total time of each jump (McMahon et al., 2018).

## Statistical analysis

Statistical analysis of the discrete variables was conducted using SPSS 18.0 software (IBM, Armonk, NY, USA). To check the effect of verbal instructions on $RSI_{Mod}$ and CMJ discrete values, a difference test was conducted between conditions. Means and standard deviations (SD) of each participant were computed for the extracted discrete variables (jump height, countermovement, propulsion and total time of the CMJ, maximal countermovement velocity and displacement of the CMJ and $RSI_{Mod}$). A Shapiro–Wilk test was conducted, when data were normally distributed a paired t-test was applied. If data were not normally distributed, a Wilcoxon test was used. Post-hoc power analysis was performed for statistically significant results using a power analysis program, G*Power 3 (Faul et al., 2007). The significant level was set at $p < 0.05$ for all tests. The magnitude of the differences between jumps was expressed as a standardised mean effect size (ES). The criteria to interpret the magnitude of the ES were: trivial = 0.00–0.19, small = 0.20–0.59, moderate = 0.60–1.20, and high >1.20 (Hopkins et al., 2009).

Additionally, force-, velocity-, displacement-, and power-time data were normalised to 101 points using a piecewise linear length normalisation procedure. To ensure the data alignment, the normalisation process was developed for the countermovement and propulsion phase separately (Floría et al., 2019; Helwig et al., 2011). Data normality was verified by the SPM1D normality test for paired t-test data (v.0.4, http://www.spm1d.org) in MATLAB software (R2015a, MathWorks Inc., USA). The effect of the different verbal instructions given on the kinematic and kinetic waveforms was evaluated with the SPM1D, equivalent to a paired t-test of their difference (v.0.4, http://www.spm1d.org) in MATLAB software (Pataky, 2012; Pataky et al., 2013).

## Results

Table 1 shows means, SD and ES of the discrete variables. The results showed that the type of instruction given affected the values of $RSI_{Mod}$. Higher $RSI_{Mod}$ values were reached in the CMJfast compared to the CMJhigh (t = −3.810; $p$ = 0.002; ES = 0.79, moderate, power = 0.85) condition. The total time and the countermovement time were shorter in the CMJfast than in the CMJhigh (t = 3.187; $p$ = 0.008; ES = −0.88, moderate, power = 0.91 and t = −2.621; $p$ = 0.009; ES = −1.00, moderate, power = 0.96, respectively) condition, but no differences were found in the jump height (t = −1.103; $p$ = 0.292). This shorter countermovement phase time was accompanied by changes in speed but not in countermovement displacement (t = 0.570; $p$ = 0.579). Higher countermovement velocity was achieved in the CMJfast in comparison with the CMJhigh (t = 6.058; $p$ < 0.001; ES = −1.18, moderate, power = 0.99) condition.

**Table 1.** Results (Mean ± SD) of discrete variables of the different CMJ conditions.

| Variables | CMJ | CMJfast | ES (90% CI) |
|---|---|---|---|
| $H_{max}$ (m) | 0.41 ± 0.06 | 0.42 ± 0.06 | 0.21 (−0.13; 0.55) |
| $T_{Tot}$ (s) | 0.85 ± 0.11* | 0.75 ± 0.09 | −0.88 (−1.37; −0.39) |
| $T_{Countermovement}$ (s) | 0.58 ± 0.09* | 0.48 ± 0.06 | −1.00 (−1.50; −0.50) |
| $T_{Propulsion}$ (s) | 0.28 ± 0.03 | 0.27 ± 0.04 | −0.18 (−0.54; 0.18) |
| $V_{maxneg}$ (m/s) | −1.15 ± 0.19* | −1.40 ± 0.19 | −1.18 (−1.53; −0.83) |
| $D_{Countermovement}$ (m) | −0.32 ± 0.05 | −0.32 ± 0.07 | −0.13 (−0.53; 0.27) |
| $RSI_{Mod}$ | 0.49 ± 0.10* | 0.57 ± 0.12 | 0.79 (0.42; 1.16) |

ES = Effect size, $H_{max}$ = jump height, $T_{Tot}$ = total time, $T_{Downward}$ = countermovement phase time, $T_{Upward}$ = propulsion phase time, $V_{maxneg}$ = maximal countermovement velocity, $D_{Downward}$ = countermovement displacement. * denotes a significant difference between CMJ-CMJfast ($P$ < 0.05).

The SPM analysis revealed differences between verbal instructions for all waveforms analysed, except in the displacement-time series data (Figure 1). All of the differences appeared during the countermovement phase. Vertical ground reaction force was lower in CMJfast, compared with CMJhigh, from 18% to 33% of total time when the minimum force value was reached during the unweighting phase. Additionally, the CMJfast showed a higher vertical force, compared with CMJhigh, during the final part of the countermovement phase (i.e. braking) between 53% and 63% of total time. Higher countermovement velocity was observed in CMJfast, compared with CMJhigh, from 31% to 48% of total time, when the negative peak velocity was reached as the participants transitioned from the unweighting to the braking portions of the countermovement phase. Finally, larger power values were observed in the CMJfast compared with the CMJhigh during the early braking phase, between 43% and 56% of total time.

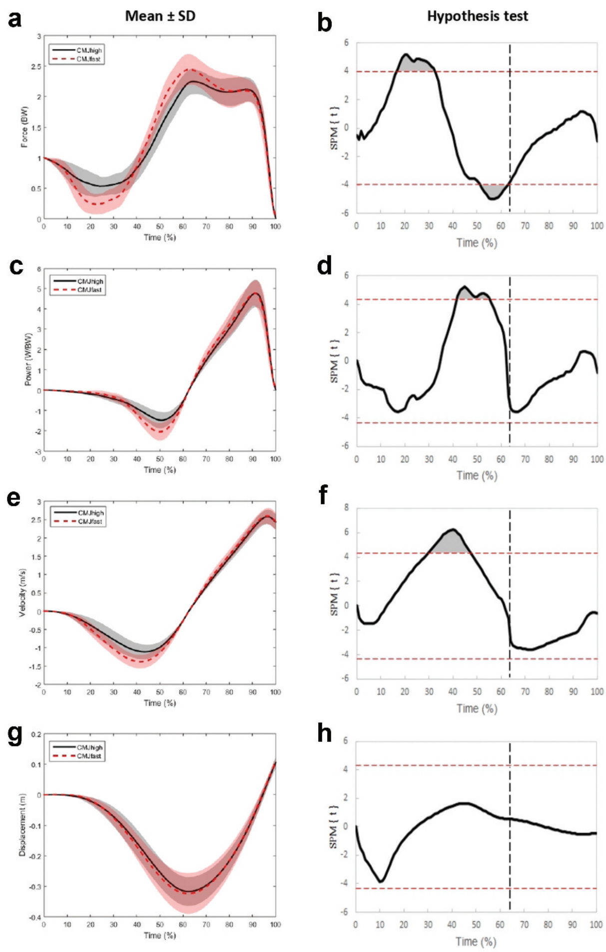


**Figure 1.** The countermovement jump force-time (a), power-time (c), velocity-time (e) and displacement-time (G) curves for CMJhigh (black line) and CMJfast (red dashed line). (b, d, f and h) The statistical parametric mapping results for the force-, power-, velocity-, and displacement-time curves. The black vertical dashed lines on b, d, f and h represent the end of the countermovement phase. The red horizontal dashed lines on b, d, f and h represent the critical thresholds and the shaded area above and below the thresholds indicate a significant difference between CMJhigh and CMJfast ($p < 0.05$). SPM, statistical parametric mapping.

## Discussion and implications

The purpose of this study was to determine the effects of different verbal instructions, intended to affect the jump execution time, on the $RSI_{Mod}$ and the time-series profile. The principal findings of the present investigation were that verbal instructions which were intended to modify the movement time influenced $RSI_{Mod}$ scores and patterns of force-, velocity- and power-time series without altering the jump height. The $RSI_{Mod}$ value was higher when an instruction that emphasised to increase the movement velocity was given to the participants in comparison to the instruction that only emphasised to jump as high as possible. High $RSI_{Mod}$ value can be achieved by increasing the jump height or shortening the jump time. This study showed no differences between the jump height when the two instructions were proposed but significant differences appeared in the jump time. Similar findings were found in an investigation that compared the $RSI_{Mod}$ across different rugby level players, where the jump height was similar but the jump time was lower in the high-level players (McMahon et al., in press). This information highlights the importance of the time it takes to execute the jump over the $RSI_{Mod}$. The present study showed that the instruction 'jump as high and as fast as possible' reduced the jump time by decreasing the countermovement time while the propulsion time remained stable. Previous investigations have used different instructions when evaluated the $RSI_{Mod}$, some of them instructed the participant to jump as high as possible (Heishman et al., 2019; James et al., 2020) and other investigations gave the instruction to jump as fast and as high as possible (Barker et al., 2018; McMahon et al., in press, 2018). The results of this study suggest the need to establish a consensus regarding the instruction given, aiming $RSI_{Mod}$ values can be compared. Since the $RSI_{Mod}$ is a measure of lower limb rapid force production during the CMJ (Kipp et al., 2016) and it has been shown that $RSI_{Mod}$ values increased when the countermovement time decreased, an instruction that emphasised a fast and high jump could be more appropriate in comparison to other instructions when the purpose is to reach the higher $RSI_{Mod}$ value. If the objective is to reach a higher value of another CMJ variable, such as jump height, then other more appropriate cues might be used. In addition, this information shows the necessity to instruct the players to jump as fast as possible, because the rapid force production characteristics of their jump will increase.

The waveform profile changes appeared during the countermovement phase and no differences were found during the propulsion phase between the CMJfast and the CMJhigh. The instructions' effects were observed during the early countermovement phase (i.e. unweighting), where CMJfast execution showed lower force values compared to the CMJhigh. This lower force led to an increase in negative impulse resulting in a higher negative velocity which was braked with higher force later in the jump. Modifications during the propulsion phase could be expected when changes during the countermovement phase occur. Contrary to this expectation, no change was observed during the propulsion phase between instructions. Previous investigations have observed that different execution instructions had an effect on both the countermovement and propulsion phases of the CMJ (Kirby et al., 2011; Pérez-Castilla et al., in press; Salles et al., 2011; Sánchez-Sixto et al., 2018). The contradictory results of this investigation could be explained because the centre of mass displacement of our participants remained constant between the two verbal instructions, unlike in previous studies. Larger displacement of the centre of mass during the countermovement phase brings on higher net vertical impulse values in the subsequent phase (Kirby et al., 2011; Sánchez-Sixto et al., 2018). A deeper countermovement position increases the distance over which the athlete can apply force during the propulsion phase. If the levels of force are maintained, the work outputs will increase, resulting in increased height jumped. The results of the present study suggest that in order to increase the jump height within the same session, changes in force and velocity outputs during countermovement phase must take place with changes in the displacement of the centre of mass. Further studies are needed to determine the role of the centre of mass displacement on vertical jump performance as well as the optimal displacement range where the highest jump height and $RSI_{Mod}$ values are reached.

The power curve shape during the countermovement phase showed a similar behaviour between the two instructions but, the CMJfast showed higher power values in the negative direction compared to the CMJhigh. It should be explained that the power data-series of this investigation could be analysed without weight and displacement limitations because force was normalised to athlete's bodyweight and no differences in the centre of mass displacement appeared (Markovic et al., 2014). In that sense, differences in the power curve values during the countermovement phase could be explained by the higher negative velocity and force values achieved in the CMJfast. Conversely, no difference was found between the two jump instructions in the power curve shape during the propulsion phase, despite $RSI_{Mod}$ being altered. Previous investigations showed a relationship between $RSI_{Mod}$ and peak power of the propulsion phase (James et al., 2020; McMahon et al., 2018). These contradictory results can be explained because these two investigations improved $RSI_{Mod}$ as a consequence of a reduction in execution time and an increase in jump height while our participants did not increase the latter. This information reveals that the relationship between $RSI_{Mod}$ and power during the propulsion phase may be more dependent on jump height than total time execution when the time reduction is a consequence of a decrease in the countermovement time. Nevertheless, future investigations should evaluate the relationship between the $RSI_{Mod}$ and power in order to clarify this aspect.

Finally, limitations should be acknowledged. Though every participant received the same verbal instruction, the modification between each jump was not the same in all of them. So, the effect of the verbal instruction did not improve the $RSI_{Mod}$ or modify each individual's time-curves profile in the same way. However, this investigation tried to evaluate the athletes in the same condition that they are frequently exposed to when coaches or researchers try to evaluate their $RSI_{Mod}$ performance. For that reason, the only instructions given were the ones already explained. In addition, our results showed a similar standard deviation in the variables analysed to previous investigations that compared the effect of different instructions on CMJ performance (Mandic et al., 2016; Pérez-Castilla et al., in press).

## Conclusion

This investigation suggests the need to establish a consensus regarding the verbal instruction given to athletes when coaches and researcher try to evaluate the $RSI_{Mod}$. We propose the instruction 'jump as high and as fast as possible' is the most appropriate because increases in rapid force production characteristics (i.e. the 'explosiveness' capacity) were found when that instruction was given. Moreover, this study contributed to highlight the relevance of the countermovement phase in jumping tasks, clarifying how the curve shape modifications could be altered by verbal instructions and could produce increases in the athlete's performance when the time of key athletic actions in their sports is limited. Finally, caution is needed when coaches and researchers associate a higher $RSI_{Mod}$ value with a higher power since the $RSI_{Mod}$ could be increased without power output modification during the propulsion phase.

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