**Title:** Kinetic responses to external cues are specific to both the type of cue and type of exercise in adolescent athletes

**Running Head**: Kinetic response to different external cues across different exercises in adolescent athletes

**Key Words:** Long Term Athlete Development; Plyometric; Coaching; Verbal Cues; External Attentional Focus;

## ABSTRACT

The purpose of this study was to examine how external cues influence kinetics during isometric and dynamic tasks in adolescent athletes. Fifteen adolescent male soccer players performed an isometric midthigh pull (IMTP), unloaded and loaded squat jumps (15 and 30% of body mass), countermovement jump (CMJ) and drop jump (DJ) using a neutral or external force- or velocity-specific cues. Cue type had limited effects on outcomes in the IMTP, or squat jumps, with mostly trivial ($g < 0.20$), non-significant differences ($p > 0.05$) across kinetic variables. In the CMJ and DJ, a force cue significantly ($p < 0.05$) increased jump height ($g = 0.43$ & 0.52) compared to a velocity cue; but, in the DJ, a force cue significantly increased jump height ($g = 0.52$) compared to both a neutral and velocity cue. However, a velocity cue significantly ($p < 0.05$) reduced ground contact time ($g = 0.73 – 1.52$) and time to peak force ($g = 0.50 – 1.29$) in both the CMJ and DJ when compared to a force and neutral cue, and, increased force and power-related measures ($g = 0.33 – 1.12$) in the CMJ and DJ when compared to a force cue. In adolescent athletes, the type of external cue had limited effects on kinetic measures in an IMTP and SJ but differential effects on both a CMJ and DJ, suggesting cues have more effect with increasing movement velocity. Consequently, practitioners working with adolescent athletes should consider both the type of exercise and the desired outcome when providing external cues.

## INTRODUCTION

Young athletes who engage in strength and conditioning may better develop the physical qualities needed to manage the demands of sport (29). Literature suggests that young athletes participating in structured training programs can develop their force, velocity, and power generating capacities to a greater extent than their non-trained counterparts (3, 4, 10, 16, 21, 22, 29). Consequently, young athletes will benefit from diverse training programs, inclusive of training stimuli that target different regions of the force-velocity relationship (3, 4, 8, 12, 21, 34). Practitioners will often manipulate variables such as load and volume during resistance and plyometric training to shift the focus of training to target specific areas of the force-velocity continuum (21). However, practitioners should also consider how an athlete's focus could influence the ability to produce force, velocity and power during different movements. Practitioners can direct an athlete's focus by the words used to teach technical models, describe task objectives, or for providing feedback during an exercise (1, 40, 41). When working with adolescent populations it is recommended that instructions (e.g. full sentences) be used primarily when first teaching an exercise and verbal cues (e.g., short phrases or action words) are used throughout a training program to reinforce key points (1, 20). Limited research has shown that using cues with young athletes during a drop jump (DJ) can influence jumping and kinetic performance (32). Thus, young athletes participating in structured training programs will likely have a greater advantage than their non-training counterparts, but the cues a practitioner uses may also positively or negatively affect an athlete's performance during an exercise task.

Neurologically, the efficacy of verbal feedback with young athletes is limited by their ability to process the information (19, 30). Thus, short verbal feedback (i.e. cues) providing relevant information may optimize the perceptual-motor and cognitive coordination required during an exercise task (1, 20); whereas, long verbal feedback (i.e. instructions) may provide too much information to focus on, with both relevant and non-relevant information given (19, 30). For the same reasons, practitioners are also recommended to not give too many cues at once, as it may provide an overload of information (1, 19, 20). It has also been demonstrated that young athletes may respond to cues differently than their adult counterparts, as young immature athletes may struggle with relevant information being delivered solely as verbal cues and may need additional visual demonstrations and physical manipulation, whereas, mature adolescent athletes may likely be able to interpret cues correctly (19). Cues can vary by the type of focus they elicit and include external-, internal- or a neutral-focus (1). An external cue focuses an athlete's attention towards components of the environment (e.g. reach for the ceiling), an internal cue towards a body part (e.g. extend through your legs), and a neutral cue is neither internal nor external (e.g. jump high) (1). Providing an external focus has been shown to elicit the greatest response when working with young athletes and may provide the most benefit by allowing the motor control system to operate automatically with fluent reflexive movements (1, 41).

Review work across a large body of literature supports that young athletes experience small to large improvements in strength, power and velocity following resistance training programs (3, 21, 34). However, practitioners should also consider how external cues may influence performance and kinetic outcomes within sessions. In adult populations, adopting an external focus in exercises across the force-velocity continuum has been reported to provide significant performance improvements when compared to an internal or neutral focus (7, 13, 17, 43). For instance, in adults, using an external cue has been shown to increase kinetic measures during an isometric mid-thigh pull (13), countermovement jump (42) and drop jump exercise (17). Of the limited available evidence in young athletic populations, research indicates that receiving external cues prior to a DJ results in small to large changes in force, velocity and power variables (32), similar to their adult counterparts (1). Although it could be hypothesized that mature adolescent athletes would likely respond to external cues similar to their adult counterparts in exercises across the force-velocity continuum as in the DJ, more research is needed to confirm this notion.

Interestingly, responses to cues may also be specific to the goal of the cue (1, 24). For example, during a jumping exercise, an external cue of "*get off the ground as fast as you can*" can be considered velocity-specific and may elicit greater changes in velocity and time-related variables than force variables (1). In contrast, *"reach high for the ceiling"*, while also an external cue, would theoretically be a more force-specific cue and may elicit greater changes in force-related variables than velocity and time-related variables (1). Literature supports that the specificity of a cue may result in specific outcomes in both adult and young populations (24, 31, 32, 44). In adult and youth literature, it has been shown that using a force cue to maximize jump height increased jump performance, whereas a velocity cue to minimize contact time results in shorter ground contact times (24, 31, 32, 44). A study of young soccer players reported that using a velocity-cue instead of a force-cue increased DJ reactive strength index by decreasing ground contact time albeit while also decreasing jump height (32). Although previous findings may be specific to the DJ, practitioners working with adolescent athletes will use a wide range of exercises across the force-velocity continuum and research is needed to understand how external force and velocity cues may affect performance and kinetic outcomes. Therefore, the aim of the current investigation is to compare the effects of external force and velocity cues on performance and kinetic outcomes in a range of tasks across the force-velocity continuum in adolescent athletes.

## METHODOLOGY

### Experimental Approach to the Problem

A within-group, repeated measures design was utilized to investigate the acute effects of using force-specific and velocity-specific external cues during an isometric mid-thigh pull (IMTP), squat jump (SJ), countermovement jump (CMJ) and drop jump (DJ). The SJ testing included conditions with no additional loading (SJ0) and an additional 15% (SJ15) and 30% (SJ30) of body mass. Testing was spread over three non-consecutive days separated by a week and at the same time of the day to minimize any diurnal or daily activity variation. Anthropometrics, optimized DJ height determination and familiarization for each test using a neutral cue were completed on the first testing day. The IMTP, CMJ and DJ tests were completed on the second testing day, followed by loaded and unloaded SJ tests on the third testing day. Participants performed two trials for each cue condition during each test, with cue conditions used in a counterbalanced manner.

### Subjects

Fifteen adolescent male academy soccer players (mean ± standard deviation (SD); age: 15.6 ± 0.6 years; maturity offset: 1.3 ± 0.7 years; body height: 170.1 ± 7.7 cm; mass: 60.5 ± 7.7 kg) volunteered to participate in the study. Maturity offset was assessed with a non-invasive method and all participants were classed as adolescents based on being either circa- or post-peak height velocity (27). The participants all had a minimum of six months of strength and conditioning training experience. None of the participants had any lower-body injuries during the testing period. Following ethical approval from the institutional research ethics board (approval number: PGR-1279), informed assent and consent were collected from each participant and parent or guardian, respectively.

## Procedures

All testing was conducted in a research laboratory and overseen by the same investigator. Data were collected using dual Kistler force plates sampling at a frequency of 1,000 Hz (type 9287BA; Kistler Instruments AG, Winterthur, Switzerland). Each participant was requested to maintain their normal daily habits, but to avoid any additional training 24 hours before testing and a heavy meal an hour before testing. In all sessions, participants performed a standardized warm-up and re-familiarized themselves with test procedures before completing testing. The standardized warm-up consisted of 10 glute bridges, 10 hamstring bridges, 12 split stance thoracic spine rotations (6 each side), 12 side lunges (6 each side), 10 air squats, 10 pogo jumps, and 5 inchworms. Each testing session followed the same routine, instructions relative to the start of each test (e.g. IMTP ready position or staying still during CMJ and SJ) were followed by a 5 second pause, then the cue condition (force-specific,velocity-specific, or neutral-control), an additional 2 second pause, then the verbal command *"ready, set, go".* Participants were instructed to only commence the test after hearing *"go"*. Table 1 includes the cues used on the familiarization and testing days. Cues used for the IMTP and dynamic tests were adapted from Halperin et al. (13) and Khuu et al. (17), respectively. The best trial based on peak force for the IMTP and peak power for the dynamic tests was taken forward to process. Exercise tests were performed in the same order on each testing day. Testing day 1 began with the IMTP followed by the DJ, then ended with the CMJ. Testing day 2 began with SJ0 followed by SJ15, then ended with SJ30. Previous literature has indicated the IMTP does not potentiate jump height (14), but SSC exercises may potentiate force and acceleration (25). Therefore, to reduce any differences in potentiation effect, exercise testing order was maintained for each participant.

**Table 1. Neutral cues and external force and velocity cues used during the Isometric Mid-Thigh Pull, Squat Jump, Countermovement Jump, and Drop Jump.**

| Exercises | Neutral Cue | External Force Cue | External Velocity Cue |
|---|---|---|---|
| IMTP† | *"pull as hard as you can, as fast as you can"* | *"push the ground away as hard as you can"* | *"push the ground away as fast as you can"* |
| Dynamic Tests*‡ | *"jump as fast as you can, getting as high as you can"* | *"try and touch the ceiling with your head"* | *"get off the ground as fast as you can"* |

*IMTP = Isometric Mid-Thigh Pull. †=Cues used during the IMTP are adapted from Halperin et al. (13). *=Dynamic Tests include the Squat Jump, Countermovement Jump, and Drop Jump. ‡=Cues used during the Dynamic Tests are adapted from Khuu et al. (17).*

### *Isometric Midthigh Pull*

The IMTP test was performed using a custom-built IMTP testing rack. The custom IMTP testing device allowed for increments in bar height of 1 cm, accommodating athletes of different leg lengths. During each trial of the IMTP, participants were instructed to step onto the force plates and were instructed into a desirable position (bar positioned at midthigh, knee angle ranged between 130˚ and 145˚, hip angle near 140 ˚ with an upright torso, and a neutral spine) (9, 13). They were asked to maintain their wrapped grip on the bar slightly loose and their gaze on a sign directly in front of them. Participants were not given any verbal encouragement to prevent an interaction with the efficacy of the verbal cues. Each trial was collected for a total of 8 seconds, inclusive of three seconds of passive baseline data collection during *"ready, set, go"* and five seconds of participants actively pulling on the bar with maximal effort. Participants received 90 seconds of rest between trials. Bar height used for the IMTP during the testing day was recorded during the familiarization day. All trials and data were analyzed on a custom-built IMTP LabView program.

### *Squat Jump*

Participants performed a SJ under three different loads, SJ0, SJ15, and SJ30. Participants were instructed to keep their hands on their hip throughout each trial. A weighted vest (20 kg Wolverson Weight Vest; Wolverson Fitness, Willenhall, United Kingdom) with 1 kg incremental weights were utilized to load the SJ. For testing, participants were instructed to step on to the force plates and assume a squat position with a 90° knee bend, which was visually assessed by the assessor (9). Cues were given as soon as the participant remained still in their squat position, followed by *"ready, set, go"*. Participants received 60 seconds of rest between trials. All trials and data were analyzed using a custom-built automated SJ Microsoft Excel spreadsheet.

### *Countermovement Jump*

Participants were instructed to step on to the force plates and keep their hands on their hips throughout each trial. In instances where the hands came off the hips, trials were discarded to minimize the influence of the upper body on CMJ performance (2). Instructions were followed by a 5 second pause, then the delivery of the cue condition, followed by *"ready, set, go"*. Participants were allowed to descend to a self-selected depth prior to jumping for maximal height (9). Participants received 60 seconds of rest between trials. All trials and data were analyzed using a custom-built automated CMJ Microsoft Excel spreadsheet (5).

### *Drop Jump*

During the familiarization of the DJ, participants performed the DJ protocol from four different heights, 15 cm, 30 cm, 45 cm and 60 cm to find the box height that optimized their reactive strength index (RSI) (37, 44). Participants were instructed to maintain their hands on their hips throughout the entire test. During the testing for the DJ, participants utilized the optimized box height and were given instructions as they got on to the box, then after a 5 second pause were given a cue condition followed by *"ready, set, go"*. Participants received 60 seconds of rest between trials. All trials and data were analyzed on a custom-built automated DJ Microsoft Excel spreadsheet.

*Force-Time Variables*

Table 2 includes descriptions and within-subject reliability (15, 39) of the performance and kinetic variables across all tests calculated from the customized software. Force-time variables were double-integrated to allow the measurement of velocity and displacement and the subsequent calculation of power output throughout the ground contact period. Performance variables included jump height, GCT, and RSI and the remaining variables were considered kinetic variables. The initiation of the pull in the IMTP was detected when force increased by > 20N above bodyweight and continued to rise rapidly. Thresholds indicating the beginning of the GCT during an SJ, CMJ and DJ were set differently due to differences in the exercises. The beginning of the unloaded and loaded SJ (i.e. propulsive phase) was set to the time point when a change greater than 20 N from body mass was observed and checked manually for accuracy. An absolute value was used to indicate the beginning of an unloaded and loaded SJ due to the variation of 5 SD of body mass being skewed in the two loaded SJ conditions (28). The beginning of a CMJ (i.e. unweighting phase) was set to the first force value less than 5 SD of body mass (5). The beginning of a DJ (i.e. braking phase) was set to the first force value greater than 5 SD of an empty force plate. Due to the rebound nature of the DJ potentially causing more noise, force data for the DJ was smoothed using a fourth-order recursive low-pass Butterworth filter with a cut-off of 30 Hz (33). All jumps included a propulsive phase, the CMJ and DJ also included a braking phase and only the CMJ also included an unweighting phase. The braking phase in the CMJ began when velocity was at its lowest value and force returned to body mass value. The end of the braking phase and the subsequent beginning of the propulsive phase in the CMJ and DJ was defined as the point velocity reached 0 m/s. Take-off was defined as the last force value greater than 5 SD of force during 100 ms of flight time during the loaded and unloaded SJ. Take-off was defined as the last force value greater than 5 SD of force during 300 ms of flight time during the CMJ and DJ (5). Take-off for the loaded and unloaded SJ used less flight time due to less flight time available to process as subjects progressed from unloaded into loaded SJs.

**Table 2. Within-session reliability of performance and kinetic variables measured during the Isometric Mid-Thigh Pull (IMTP), Squat Jump (SJ), Countermovement Jump (CMJ), and Drop Jump (DJ) exercise tests.**

| Variable | Abbreviation (unit) | Test | Description | CV (%)* | ICC† |
|---|---|---|---|---|---|
| Jump Height | Jump Height (cm) | SJ, CMJ, DJ | The maximum height achieved during the flight phase of a jump = flight time$^2$ x (gravitational force/8) | 3.9 - 8.0 | 0.90 - 0.96 |
| Ground Contact Time | GCT (ms) | SJ, CMJ | The contraction time interval developing force between the beginning of the exercise and take-off | 5.3 - 11.0 | 0.92 - 0.96 |
|  | GCT (ms) | DJ | The time interval developing force between the first landing and take-off | 8.1 | 0.98 |
| Reactive Strength Index | $\text{RSI}_{\text{mod}}$ | SJ, CMJ | The ratio of jump height (m) and contraction time (s) | 5.8 - 13.0 | 0.84 - 0.95 |
|  | RSI | DJ | The ratio of jump height (m) and ground contact time (s) | 6.3 | 0.94 |
| Peak Force | PF (N) | IMTP, SJ, CMJ | The maximum instantaneous force achieved during the IMTP and before take-off during the SJ and CMJ | 1.9 - 4.6 | 0.90 - 0.95 |

| | | | | | |
|---|---|---|---|---|---|
| | PF (N) | DJ | The maximum instantaneous force achieved during the propulsive phase of the ground contact period | 4.7 | 0.90 |
| Time to Peak Force | tPF (ms) | IMTP, SJ, CMJ | The time interval between beginning the exercise and peak force | 10.1 – 16.8 | 0.82 - 0.93 |
| | tPF (ms) | DJ | The time interval between the first landing and take-off peak force | 11.9 | 0.91 |
| Force at Time Epochs | PF$_{50}$, PF$_{90}$, PF$_{150}$, PF$_{200}$, PF$_{250}$ | IMTP | The maximum instantaneous force achieved between 0 ms and 50, 90, 150, 200, and 250 ms. | 3.2 - 12.2 | 0.94 - 0.96 |
| Peak Rate of Force Development | PRFD (N.s$^{-1}$) | IMTP, SJ, DJ | The maximum change of force over a 20 ms sampling window until peak force | 8.9 - 26.4 | 0.49 - 0.91 |
| | PRFD (N.s$^{-1}$) | DJ | The maximum instantaneous 20 ms change of force overtime between initial landing and peak force | 11.7 | 0.76 |
| Time to Peak Rate of Force Development | tPRFD (ms) | IMTP, SJ, CMJ | The time interval between beginning the exercise and peak rate of force development | 23.4 - 94.9 | 0.35 - 0.81 |
| | tPRFD (ms) | DJ | The time interval between the first landing and peak rate of force development | 20.5 | 0.99 |
| Rate of Force Development at Time Epochs | RFD$_{50}$, RFD$_{90}$, RFD$_{150}$, RFD$_{200}$, RFD$_{250}$ | IMTP | The maximum change of force between 0 ms and 50, 90, 150, 200, and 250 ms. | 17.7 - 41.4 | 0.91 - 0.96 |
| Braking Impulse | IMP$_{brake}$ (N.s) | CMJ, DJ | The amount of force produced over time in seconds during the braking phase | 1.6 - 5.2 | 0.95 |
| Propulsive Impulse | IMP$_{prop}$ (N.s) | SJ, CMJ, DJ | The amount of force produced over time in seconds during the propulsive phase | 2.5 - 4.1 | 0.92 - 0.95 |
| Peak Power | PP (W) | SJ, CMJ, DJ | The maximum instantaneous 1 ms power achieved during the propulsive phase | 2.0 - 5.0 | 0.89 - 0.92 |
| Mean Braking Power | MP$_{brake}$ (W) | CMJ, DJ | The mean power achieved during the braking phase | 5.3 - 5.8 | 0.92 |
| Mean Propulsive Power | MP$_{prop}$ (W) | SJ, CMJ, DJ | The mean power achieved during the propulsive phase | 3.8 - 14.7 | 0.88 - 0.93 |
| Peak Velocity | PV (m.s$^{-1}$) | SJ, CMJ, DJ | The maximum instantaneous 1 ms velocity achieved during the propulsive phase | 1.5 - 3.7 | 0.98-0.99 |

*= Within-subject reliability reported as a coefficient of variation (CV) (15) based on the adolescent soccer players of the current investigation.

†= Within-subject reliability reported as an intraclass correlation, equation 3,1 (39) based on the adolescent soccer players of the current investigation.

## Statistical Analyses

Descriptive statistics (mean ± SD) were calculated for all variables. To compare the main effects of the different external cues across all tests, a 3 (condition) x 1 (time) repeated measures ANOVA was used for each dependent variable. Significant main effects were followed up with a Bonferroni post-hoc test. All analyses were conducted using SPSS version 26 (SPSS, Inc., Chicago, IL, USA), with an alpha level of $p \leq 0.05$ used to determine statistical significance. Hedges' $g$ effect sizes were calculated to describe the magnitude of the difference between conditions. Thresholds were interpreted as ≤ 0.20 = trivial, 0.20 - 0.59 = small, 0.60 - 1.19 = moderate, 1.20 - 1.99 = large, and ≥ 2.00 = very large (15).

## RESULTS

Dynamic performance results are shown in Figure 1, with effect sizes ($g$) reported in Table 3. Data values for Figure 1 are included in Supplemental Digital Content 1. Using a force cue significantly increased jump height in the CMJ ($g = 0.43$ ; $p = 0.02$) and DJ ($g = 0.52$; $p = 0.03$) when compared to a velocity cue, and also when compared to a neutral cue in the CMJ ($g = 0.52$; $p = 0.01$). However, a neutral cue was also found to increase jump height in the CMJ ($g = 0.43$; $p = 0.02$) when compared to a velocity cue. Using a velocity cue significantly reduced GCT in the CMJ ($g = 1.12 – 1.52$; $p < 0.05$) and DJ ($g = 0.73 – 1.37$; $p < 0.05$) when compared to both other cues, while also significantly increasing RSI in CMJ ($g = 1.50$; $p < 0.01$) and DJ ($g = 0.55$; $p = 0.02$) when compared to a force cue. Using a neutral cue significantly reduced GCT in the DJ ($g = 0.95$; $p = 0.01$) when compared to a force cue. No other significant changes were observed in the performance variables across dynamic tests.

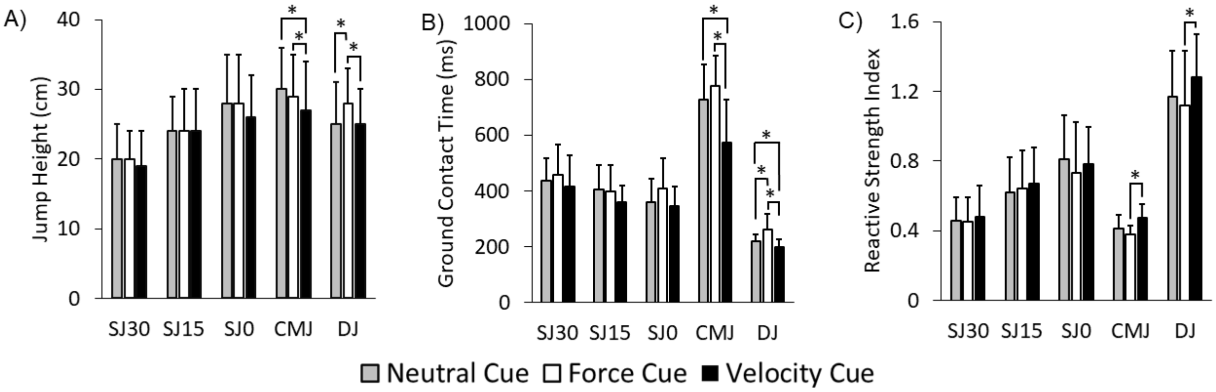

**Figure 1**. Bar graph of mean + SD and effect size data of comparable performance variables across dynamic tests. **A)** Jump Height, **B)** Ground Contact Time, and **C)** Reactive strength index. *Significantly different between cues (p<0.05).

**Table 3. Effect size (*g*) of kinetic measures across dynamic exercise tests for the comparisons between the neutral cue, force cue and velocity cue conditions.**

| Performance Measure | Cue Condition Comparisons | | | SJ30 | SJ15 | SJ0 | CMJ | DJ |
|---|---|---|---|---|---|---|---|---|
| Jump Height | Neutral | Vs | Force | $0.04^{N}$ | $0.06^{N}$ | $0.01^{N}$ | $0.06^{N}$ | $0.52^{F*}$ |
| | Neutral | Vs | Velocity | $0.19^{N}$ | $0.06^{N}$ | $0.21^{N}$ | $0.47^{N*}$ | $0.01^{N}$ |
| | Force | Vs | Velocity | $0.17^{F}$ | $0.11^{F}$ | $0.22^{F}$ | $0.43^{F*}$ | $0.53^{F*}$ |
| Ground Contact Time | Neutral | Vs | Force | $0.22^{N}$ | $0.09^{N}$ | $0.51^{N}$ | $0.41^{N}$ | $0.95^{N*}$ |
| | Neutral | Vs | Velocity | $0.23^{V}$ | $0.60^{V}$ | $0.15^{V}$ | $1.12^{V*}$ | $0.73^{V*}$ |
| | Force | Vs | Velocity | $0.39^{V}$ | $0.46^{V}$ | $0.67^{V}$ | $1.52^{V*}$ | $1.37^{V*}$ |
| Reactive Strength Index | Neutral | Vs | Force | $0.08^{N}$ | $0.10^{F}$ | $0.28^{N}$ | $0.50^{N}$ | $0.16^{N}$ |
| | Neutral | Vs | Velocity | $0.12^{V}$ | $0.25^{V}$ | $0.11^{N}$ | $0.85^{V}$ | $0.42^{V}$ |
| | Force | Vs | Velocity | $0.19^{V}$ | $0.14^{V}$ | $0.20^{V}$ | $1.50^{V*}$ | $0.55^{V*}$ |

**SJ30** = Squat jump loaded with 30% body mass; **SJ15** = Squat jump loaded with 15% of body mass; **SJ0** = Unloaded squat jump; **CMJ** = Countermovement jump; **DJ** = Drop Jump

Effect favors: **N** = Neutral cue; **F** = Force cue; **V** = Velocity cue

*=significantly different cue comparison (p<0.05)

Results of peak force-related variables across all tests are shown in Figure 2, with effect sizes (*g*) reported in Table 4. Data values for Figure 2 are included in Supplemental Digital Content 2. The type of cue had no signficant effect on PF, tPF, or PRFD during the IMTP and SJ, but significant effects were observed in both the CMJ ($g = 0.85 – 1.29$; $p < 0.05$) and DJ ($g = 0.50 – 1.17$; $p < 0.05$) in favor of the velocity cue compared to both other cue conitions. Using a velocity cue also significantly reduced tPRFD in the SJ15 ($g = 0.85$; $p = 0.04$) compared to a neutral cue. However, a neutral cue did provide favorable significant improvements on PF, tPF, and PRFD in the DJ ($g$ = 0.67 – 0.75; $p < 0.05$), but only when compared to a force cue. When investigating specific time epochs of the IMTP, using a neutral cue significantly increased $PF_{200}$ ($g$ = 0.51; $p$ = 0.03) and $RFD_{200}$ ($g$ = 0.90; $p < 0.01$) compared to a force cue; whereas, using a velocity cue significantly increased $RFD_{50}$ ($g$ = 0.78; $p$ = 0.045) and $RFD_{90}$ ($g$ = 0.85; $p$ = 0.049) compared to a force cue.. No other significant changes were observed in the IMTP time epochs or across exercise tests.

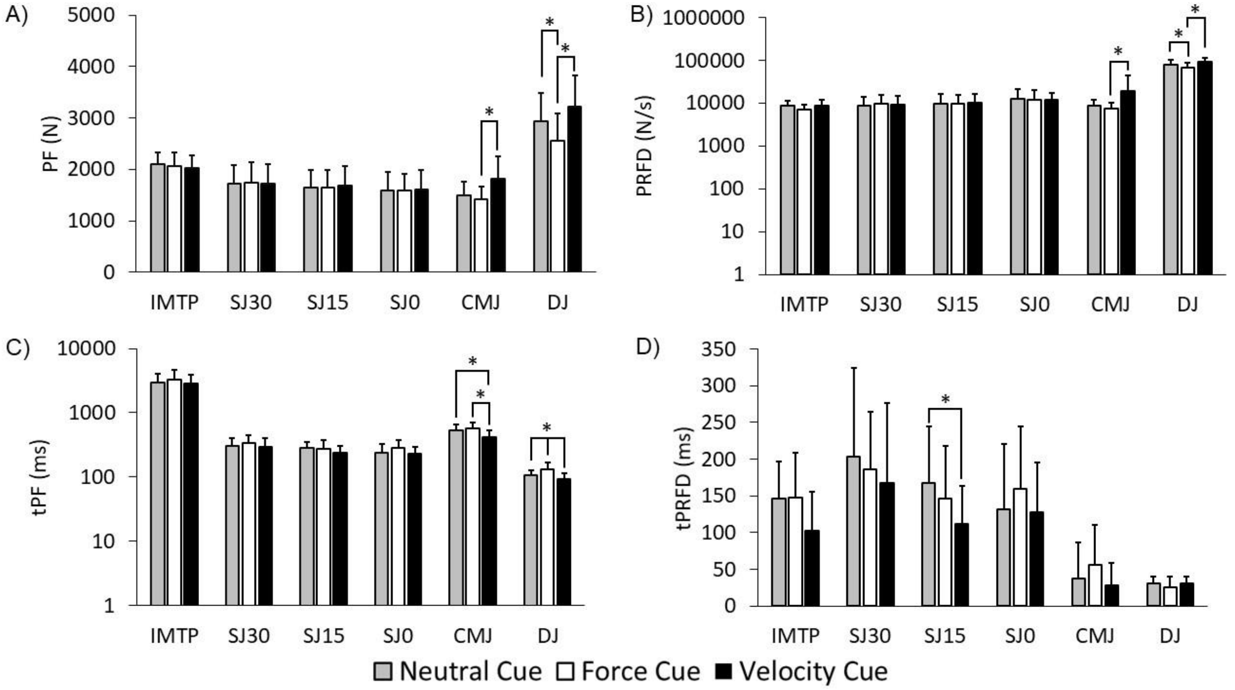

**Figure 2**. Bar graph of mean ± SD and effect size data of peak-force related variables across exercise tests. **A)** Peak force (PF), **B)** Peak rate of force development (PRFD), **C)** Time to peak force (tPF), **D)** Time to peak rate of force development (tPRFD). For graphs B and C, data is set to a base 10 logarithmic scale. *Significantly different between cues (p<0.05).

**Table 4. Effect size (*g*) of kinetic measures across isometric and dynamic exercise tests for the comparisons between the neutral cue, force cue and velocity cue conditions.**

| Performance Measure | Cue Condition Comparisons | | | IMTP | SJ30 | SJ15 | SJ0 | CMJ | DJ |
|---|---|---|---|---|---|---|---|---|---|
| Peak Force | Neutral | Vs | Force | $0.21^{N}$ | $0.06^{F}$ | $0.03^{F}$ | $0.00^{N}$ | $0.26^{N}$ | $0.72^{N}$* |
| | Neutral | Vs | Velocity | $0.32^{N}$ | $0.00^{V}$ | $0.11^{V}$ | $0.05^{V}$ | $0.85^{V}$* | $0.49^{V}$ |
| | Force | Vs | Velocity | $0.09^{F}$ | $0.06^{F}$ | $0.09^{V}$ | $0.05^{V}$ | $1.06^{V}$* | $1.17^{V}$* |
| Time to Peak Force | Neutral | Vs | Force | $0.35^{N}$ | $0.24^{N}$ | $0.03^{F}$ | $0.51^{N}$ | $0.41^{N}$ | $0.75^{N}$* |
| | Neutral | Vs | Velocity | $0.07^{V}$ | $0.16^{V}$ | $0.63^{V}$ | $0.12^{V}$ | $0.88^{V}$* | $0.50^{V}$* |
| | Force | Vs | Velocity | $0.40^{V}$ | $0.38^{V}$ | $0.48^{V}$ | $0.67^{V}$ | $1.29^{V}$* | $1.11^{V}$* |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Peak Rate of Force Development | Neutral | Vs | Force | $0.82^{N}$ | $0.16^{F}$ | $0.00^{N}$ | $0.10^{N}$ | $0.49^{N}$ | $0.67^{N*}$ |
| | Neutral | Vs | Velocity | $0.04^{N}$ | $0.06^{V}$ | $0.15^{V}$ | $0.11^{N}$ | $0.94^{V}$ | $0.44^{V}$ |
| | Force | Vs | Velocity | $0.71^{V}$ | $0.09^{F}$ | $0.16^{V}$ | $0.00^{V}$ | $1.07^{V*}$ | $1.12^{V*}$ |
| Time to Peak Rate of Force Development | Neutral | Vs | Force | $0.01^{N}$ | $0.17^{F}$ | $0.29^{F}$ | $0.31^{N}$ | $0.37^{N}$ | $0.52^{F}$ |
| | Neutral | Vs | Velocity | $0.84^{V}$ | $0.30^{V}$ | $0.85^{V*}$ | $0.05^{V}$ | $0.22^{V}$ | $0.07^{N}$ |
| | Force | Vs | Velocity | $0.77^{V}$ | $0.19^{V}$ | $0.54^{V}$ | $0.41^{V}$ | $0.63^{V}$ | $0.48^{F}$ |

**IMTP** = Isometric mid-thigh pull; **SJ30** = Squat jump loaded with 30% body mass; **SJ15** = Squat jump loaded with 15% of body mass; **SJ0** = Unloaded squat jump; **CMJ** = Countermovement jump; **DJ** = Drop Jump
Effect favors: **N** = Neutral cue; **F** = Force cue; **V** = Velocity cue
*=significantly different cue comparison (p<0.05)

Results for comparable kinetic variables across the different dynamic tests are shown in Figure 3, with effect sizes ($g$) reported in Table 5. Data values for Figure 3 are included in Supplemental Digital Content 3. Different cue types did not affect kinetic outcomes during the SJ30, SJ15 and SJ0. Conversely, different cue types had significant effects during the CMJ and DJ. Specifically, when comparing a force and velocity cue, using a velocity cue significantly increased $MP_{brak}$ and PP in the DJ ($g = 0.52 – 0.59$; $p < 0.01$) and $MP_{prop}$ in the CMJ ($g = 0.55$; $p < 0.01$) and DJ ($g = 0.33$; $p = 0.03$). Whereas, using a force cue significantly increased $IMP_{brak}$, $IMP_{prop}$, and PV in the DJ ($g = 0.46 – 0.66$; $p < 0.01$) when compared to both other cue conditions and also increased PV in the CMJ ($g = 0.51$; $p = 0.01$) when compared to a velocity cue. When comparing a neutral cue to a velocity cue, significant increases were observed using a neutral cue in PV and $IMP_{prop}$ during the CMJ ($g = 0.27 – 0.50$; $p = 0.01$); with, significant increases in $IMP_{prop}$ and $IMP_{brak}$ during the DJ ($g = 0.20$; $p < 0.05$) also observed. No other significant changes were observed in the kinetic measures across the jump protocols.

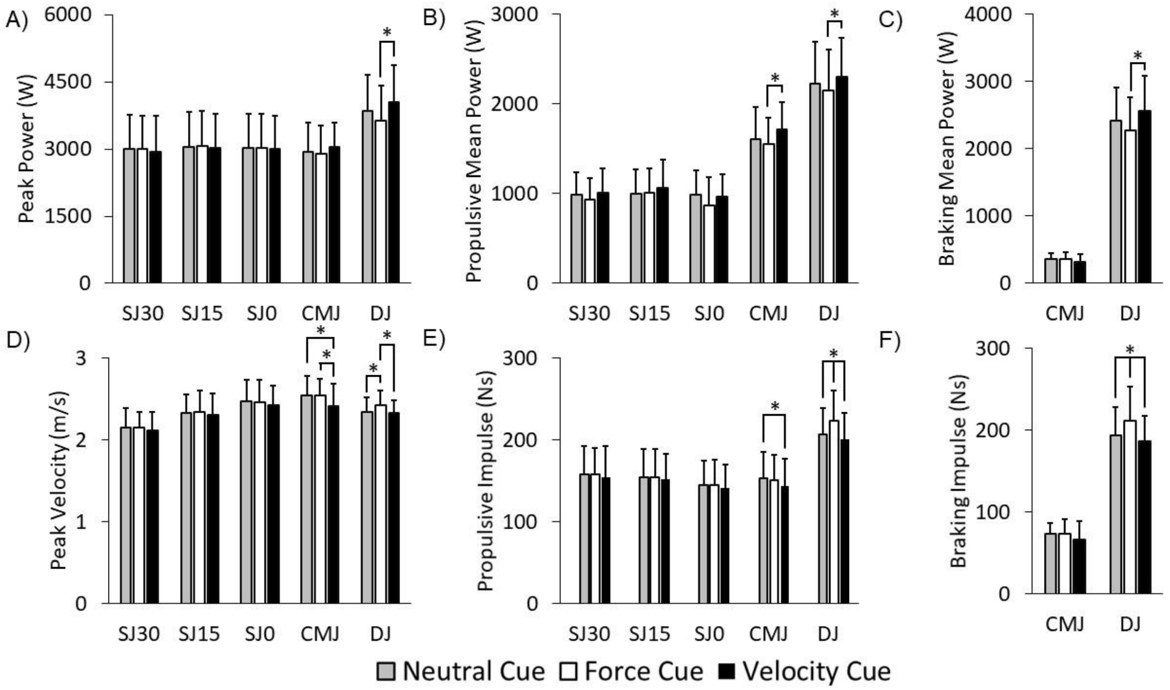

**Figure 3**. Bar graph of mean ± SD data of kinetic variables across dynamic exercise tests. **A)** Peak power (PP), **B)** Propulsive mean power ($MP_{prop}$), **C)** Braking mean power ($MP_{brak}$), **D)** Peak velocity ($V_{max}$), **E)** Propulsive impulse ($IMP_{prop}$), **F)** Braking impulse ($IMP_{brak}$). *Significantly different between cues ($p<0.05$).

**Table 5. Effect size (*g*) of kinetic measures across dynamic exercise tests for the comparisons between the neutral cue, force cue and velocity cue conditions.**

| Performance Measure | Cue Condition Comparisons | | | SJ30 | SJ15 | SJ0 | CMJ | DJ |
|---|---|---|---|---|---|---|---|---|
| Braking Impulse | Neutral | Vs | Force | - | - | - | $0.08^{N}$ | $0.46^{F}$* |
| | Neutral | Vs | Velocity | - | - | - | $0.39^{N}$ | $0.20^{N}$* |
| | Force | Vs | Velocity | - | - | - | $0.29^{F}$ | $0.66^{F}$* |
| Propulsive Impulse | Neutral | Vs | Force | $0.02^{F}$ | $0.01^{F}$ | $0.00^{F}$ | $0.07^{N}$ | $0.49^{F}$* |
| | Neutral | Vs | Velocity | $0.10^{N}$ | $0.07^{N}$ | $0.13^{N}$ | $0.27^{N}$* | $0.20^{N}$* |
| | Force | Vs | Velocity | $0.09^{F}$ | $0.08^{F}$ | $0.13^{F}$ | $0.20^{F}$ | $0.68^{F}$* |
| Peak Power | Neutral | Vs | Force | $0.00^{F}$ | $0.03^{F}$ | $0.01^{N}$ | $0.05^{N}$ | $0.28^{N}$ |
| | Neutral | Vs | Velocity | $0.08^{N}$ | $0.03^{N}$ | $0.04^{N}$ | $0.19^{V}$ | $0.25^{V}$ |
| | Force | Vs | Velocity | $0.09^{F}$ | $0.06^{F}$ | $0.03^{F}$ | $0.26^{V}$ | $0.52^{V}$* |
| Braking Mean Power | Neutral | Vs | Force | - | - | - | $0.06^{N}$ | $0.30^{N}$ |
| | Neutral | Vs | Velocity | - | - | - | $0.49^{N}$ | $0.29^{V}$ |
| | Force | Vs | Velocity | - | - | - | $0.40^{F}$ | $0.59^{V}$* |
| Propulsive Mean Power | Neutral | Vs | Force | $0.22^{N}$ | $0.06^{F}$ | $0.38^{N}$ | $0.18^{N}$ | $0.15^{N}$ |
| | Neutral | Vs | Velocity | $0.11^{V}$ | $0.23^{V}$ | $0.08^{N}$ | $0.32^{V}$ | $0.18^{V}$ |
| | Force | Vs | Velocity | $0.33^{V}$ | $0.17^{V}$ | $0.32^{V}$ | $0.55^{V}$* | $0.33^{V}$* |
| Peak Velocity | Neutral | Vs | Force | $0.02^{F}$ | $0.04^{F}$ | $0.02^{F}$ | $0.01^{F}$ | $0.50^{F}$* |
| | Neutral | Vs | Velocity | $0.19^{N}$ | $0.09^{N}$ | $0.20^{N}$ | $0.50^{N}$* | $0.08^{N}$ |
| | Force | Vs | Velocity | $0.19^{F}$ | $0.12^{F}$ | $0.18^{F}$ | $0.51^{F}$* | $0.61^{F}$* |

**SJ30** = Squat jump loaded with 30% body mass; **SJ15** = Squat jump loaded with 15% of body mass; **SJ0** = Unloaded squat jump; **CMJ** = Countermovement jump; **DJ** = Drop Jump

Effect favors: **N** = Neutral cue; **F** = Force cue; **V** = Velocity cue
*=significantly different cue comparison ($p<0.05$)

## DISCUSSION

The aim of the current investigation was to compare the effects of external force and velocity cues on performance and kinetic outcomes in a range of tasks across the force-velocity continuum in adolescent athletes. Few significant effects of cue conditions were observed across the IMTP, unloaded SJ or loaded SJ. Conversely, cue type frequently had a significant influence on CMJ and DJ outcomes. Using a velocity cue significantly reduced contact time, leading to improved RSI and tPF, greater PF, and increased power, but reduced movement velocity, with differences, often greatest when compared to a force cue. A neutral and force cue tended to increase contact time, leading to increased impulse and movement velocity, resulting in greater jump heights compared to a velocity cue in the CMJ, and greater jump heights with a force cue compared to both a neutral and velocity cue in the DJ. Therefore, practitioners should be mindful of their cueing strategies as using different external cues can result in different kinetic and performance outcomes, particularly in CMJ and DJ.

Providing direct comparisons between the current findings and previous research is difficult; to the author's knowledge, no previous study has reported the effects of external cues on kinetic outcomes in adolescent athletes. Previous literature indicates using an external cue during an IMTP can lead to greater peak force production compared to a neutral or internal cue in adults (13). However, when comparing differing external cues and a neutral cue in the current investigation, different cue types provided limited benefit during an IMTP in adolescent athletes, unless accounting for the specific time epochs between 0 ms and 250 ms. Typically, contraction times of 0-250 ms are associated with fast movements because it is not possible to develop maximal force within this period (12). Thus, brief contraction times may be required to show a difference when comparing different external cues, which is supported by observations from the CMJ and DJ in this study. Although GCT during unloaded and loaded squat jumps trended to be shorter when using a velocity cue, there were no significant changes to performance and kinetic variables, aside from tPRFD. However, tPRFD was also shown to be a variable with poor reliability and practitioners should be cautious when interpreting significant changes in tPRFD. Cues with an external focus may not be effective in eliciting changes in force, velocity or power during a SJ due to the absence of a braking phase. Possible explanations for the differences in jumps without (i.e. SJ) and with (i.e. CMJ and DJ) a braking phase could be attributed to better utilization of elastic energy and stretch-reflexes (26) or greater pre-activation (38) during the braking phase, and it may be that the use of external cues can influence these mechanisms to a greater degree than an isometric or concentric contraction.

Given the results for the CMJ and DJ, the use of force and velocity cues appear to have greater effects on movements involving the stretch-shortening cycle (SSC). Previous literature agrees that adopting an external focus results in greater CMJ and DJ performance compared to using an internal or neutral focus (11, 17, 42, 43), with DJ performance also being influenced by the specificity of a cue (24, 31, 32, 44). Results from the current investigation indicate that a velocity cue provided some desirable changes during a CMJ and DJ, which could reflect enhanced SSC function (33). Intuitively, the large reduction in GCT using a velocity cue allowed athletes to generate significantly greater rates of force development and propulsive force in order to achieve greater peak power compared to using a force and neutral cue. Using a velocity cue concomitantly reduced the time to achieve peak force and jump height in both a CMJ and DJ, indicating that athletes utilized longer contact times to develop greater propulsive impulse and subsequently jump height with a force and neutral cue. Although the CMJ and DJ demonstrated many changes with all cue types, the magnitude of change seems to be dependent on the performance or kinetic outcome. Specifically, it seems that large changes in GCT lead to small to moderate kinetic changes which then lead to small changes in CMJ and DJ jump height when comparing a force and velocity cue; however, when using a neutral compared to a velocity cue, moderate increases in GCT during the CMJ and DJ lead to small kinetic and jump height changes only in the CMJ.

The duration of the propulsive phase may influence the efficacy of external cueing, with a shorter movement duration likely associated with a greater response to cueing. The DJ had the shortest propulsive phase as the entire GCT of the DJ (200 – 262 ms) was shorter than the propulsive phase of the CMJ (207 – 279 ms) and nearly half the time of the GCT of the SJ0 (347 – 408 ms). Movements that are quick and reflexive (i.e. SSC exercises with short GCT) may be more responsive to the different types of external cues as adopting an external focus facilitates fluent and reflexive movements (1, 41). Stretch-shortening cycle movements will be controlled by both preactivation and stretch-reflex responses (18, 26, 38). Tentatively, the data in the current study infer that external cues can alter these control mechanisms during SSC movements. Given that preactivation and stretch-reflex control of plyometric exercise continues to develop throughout adolescence (23, 36), providing adolescent athletes with velocity cues during plyometric training may help to develop a more excitatory neural profile. However, research is needed to confirm this. During isometric (i.e. IMTP) or concentric only (i.e. SJ) contractions there is limited reflex control and the tasks are less constrained by the time to develop force. When quantifying exercises across the force-velocity continuum, the current findings indicate that external cues may have more effect on velocity-dominant exercises that utilize a SSC (i.e. CMJ and DJ), rather than force-dominant exercises (i.e. IMTP and SJ).

A limitation of the current investigation could be how the cues were labelled. The cues were considered as force and velocity specific based on previous suggestions in the literature (1). However, using a velocity cue resulted in peak velocity being unchanged or reduced and using a force cue did not increase force, but did increase jump heights. Furthermore, even when the cues specifically used force and velocity terminology (i.e*. “as fast as you can” or “as hard as you can”*) in the IMTP, the force cue resulted in a reduction of force and rate of force development at specific time epochs. Both outcomes from cue types are likely reflecting whole-body changes in movement strategies. Thus, considering cues to be force or velocity specific may be indicative of a time-specific change (e.g. a velocity cue reduces the time of a task, whereas a force cue would increase the time of the task) instead of how it improves force and velocity outcomes. Another limitation of the current study is all the exercises included produce force vertically and movements with a very high movement speed were not included, and it may be that even greater effects of cue type would have been observed in higher speed movements, but it is unclear how cue types would affect tasks producing force horizontally compared to the vertical tasks of the current study. However, the current study has provided novel insight regarding how performance and kinetic outcomes change in adolescent athletes performing several different tasks with different external cues. This adds to previous similar research in child (i.e. ≤ 12 years old) athletes (32) and non-athletes (6, 35) and adult moderately trained (11, 13, 17, 31, 44) and physically active populations (24, 42, 43).

The aim of the current investigation was to compare the effects of external force and velocity cues on performance and kinetic variables in a range of tasks across the force-velocity continuum in adolescent athletes. The results of the current investigation indicate that exercises containing SSC characteristics (i.e. CMJ and DJ) were responsive to the different types of external cues and a neutral cue, whereas, slow and less reflexive exercises (i.e. IMTP and SJ) were less responsive to either type of external or neutral cue. Trained adolescent athletes exhibited large changes in GCT during the CMJ and DJ in response to the different cues, and these changes were associated with small to moderate changes in kinetic outcomes and jump height. Although initially termed as “force” and “velocity” cues, the cues may be more specifically considered in terms of how they constrain time. An external cue requiring the adolescent athlete to get off the ground as fast as possible reduces GCT, increases RFD, PP and MP and also increase PF. Conversely, an external cue to jump to the ceiling increased GCT, IMP and jump height as well as increasing PV. However, when using a neutral cue, an observed increase in GCT compared to a velocity cue, in both the CMJ and DJ, lead to an increase in jump height during a CMJ and not a DJ. Practitioners should be aware that the cues they use with adolescent athletes can influence performance and kinetics, particularly during vertical movements involving the SSC. The use of cues may have implications regarding how adolescent athletes respond to training interventions, but more research is needed to examine this.

## PRACTICAL APPLICATION

Practitioners use many exercises across the force-velocity continuum to train young athletes and prepare them for the physical demands of sport. Cueing has emerged as another tool practitioners may use to influence the performance of young athletes during training. The findings from the current investigation indicate trained adolescent athletes respond to different types of external cues in dynamic, reflexive exercises. Specifically, using an external cue to get off the ground quickly results in short GCT compared to an external cue to reach for the ceiling and a neutral cue to jump high and fast. However, using an external cue to reach for the ceiling did result in greater jump heights in the CMJ and DJ; whereas, a neutral cue to jump high and fast only resulted in greater jump heights during the CMJ. Although practitioners tend to focus on GCT and jump height as common performance variables to signify better or worse CMJ or DJ performance, different external cues and a neutral cue resulted in different kinetic strategies utilized. Specifically, the external cue of quickly getting off the floor shortened GCT and the adolescent athletes were able to increase PRFD, PF, RSI, MP, and PP, but at the cost of a small to moderate reduction in jump height, in both the CMJ and DJ. Whereas, practitioners can use an external cue to reach for the ceiling to achieve greater jump height in both a CMJ and DJ by increasing GCT and subsequently increasing IMP and PV. These cue-induced changes in kinetics will be underpinned by alterations in neuromuscular control. Practitioners looking to develop the ability to produce force quickly in a CMJ and DJ should prioritize cues that minimize contact time, but practitioners should also be aware that they can also change the external cue to maximize impulse and jump height if needed.

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## Figure Legend

**Figure 1**. Bar graph of mean + SD and effect size data of comparable performance variables across dynamic tests. **A)** Jump Height, **B)** Ground Contact Time, and **C)** Reactive strength index. *Significantly different between cues ($p<0.05$).

**Figure 2**. Bar graph of mean ± SD and effect size data of peak-force related variables across exercise tests. **A)** Peak force (PF), **B)** Peak rate of force development (PRFD), **C)** Time to peak force (tPF), **D)** Time to peak rate of force development (tPRFD). For graphs B and C, data is set to a base 10 logarithmic scale. *Significantly different between cues ($p<0.05$).

**Figure 3**. Bar graph of mean ± SD data of kinetic variables across dynamic exercise tests. **A)** Peak power (PP), **B)** Propulsive mean power ($MP_{prop}$), **C)** Braking mean power ($MP_{brak}$), **D)** Peak velocity ($V_{max}$), **E)** Propulsive impulse ($IMP_{prop}$), **F)** Braking impulse ($IMP_{brak}$). *Significantly different between cues ($p<0.05$).

## List of Supplemental Digital Content

Supplemental Digital Content 1. pdf

Supplemental Digital Content 2. pdf

Supplemental Digital Content 3. pdf