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ORIGINAL ARTICLE

Effect of light stimuli on squat jump performance: Comparison of Japanese university male track and field athletes and football players

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ABSTRACT

We aimed to compare the effects of intentional jump conditions (IJC) and reactive jump conditions (RJC) using light stimuli on SJ performance, focusing on differences between track and field sports and football. Twenty-five university track and field athletes (TF group) and 25 male football players (F group) performed four SJs, receiving intentional or reactive jump verbal instructions. Reaction time (RT), jump height (JH), peak force (PF), peak rate of force development (PRFD), and average rate of force development (ARFD) during the SJ were recorded. Unpaired t-tests were used to evaluate differences in each variable between IJC and RJC, while two-way analysis of variance was used to assess differences between conditions and between sports. For all participants, JH and PF were significantly higher during IJC, whereas PRFD and ARFD were higher during RJC ($p < .05$). The TF group showed significantly higher JH and PF and significantly lower RT than the F group. In the F group, PRFD and ARFD increased significantly under RJC ($p < .05$), while PF did not decrease across conditions. These findings suggest that light stimulation affects SJ performance differently by sport. Notably, football players may enhance force development velocity under reactive conditions while maintaining force output.
Keywords: Performance analysis, Stretch-shortening cycle, Intentional jump, Reactive jump, Rate of force development, Kinetics.

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INTRODUCTION

The jump test is a primary method for evaluating explosive power generation capacity in the lower limbs (Bosco et al., 1983). The squat jump (SJ) is a jump test representing a standard technique for assessing lower limb strength and neuromuscular performance (Markovic et al., 2004), with its validity and reliability demonstrated by numerous studies (Fernandez-Santos et al., 2015; Markovic et al., 2004). The SJ eliminates the influence of the lower limb stretch-shortening cycle (SSC), enabling the evaluation of pure power generation capacity in the concentric phase (Markovic et al., 2004). Furthermore, SJ exhibits less kinematic and dynamic variability than do the other jump tests (Bosco et al., 1983). Additionally, SJ highly correlates with acceleration ability during sprinting (Gonzalez-Badillo et al., 2017), making it a useful indicator for evaluating an athlete's power production capacity (Meylan et al., 2009). Consequently, many strength and conditioning (S&C) coaches incorporate SJ into their assessment programs.

In team sports, the ability to react instantly to unpredictable external stimuli and execute optimal movements is crucial (Mackala et al., 2020). Football players repeatedly perform over 60 sprints (Taylor et al., 2017), more than 300 changes of direction (Bloomfield et al., 2007), and over 10 jumping movements (Nedelec et al., 2014) during a match. These actions are executed while reacting immediately to external stimuli such as the movements of the opponents and the ball. Therefore, football players require high-intensity motor performance capabilities for intentional and reactive movements (Stølen et al., 2005). In particular, reactive movements—where the direction and timing of actions are determined in response to external stimuli—may require a neuromuscular control pattern different from that under intentional movements. Consequently, examining motor control under time constraints in football is of practical and theoretical significance.

Football players make decisions while exerting considerable physical effort owing to the nature of the sport (Tenenbaum et al., 1993). Hence, they repeatedly perform actions such as sprinting, changing direction, and jumping under high cognitive load (Stølen et al., 2005). Conversely, in individual sports such as track and field events, explosive power output and movement efficiency using SSC are required under predictable conditions (Mero et al., 1992). Furthermore, the cognitive load during competition is lower in track and field sports than in ball sports (such as football), and the ability to perform simpler movements is demanded in the former. Track and field athletes demonstrate superior performance in intentional movements, while football players may exhibit their sport-specific characteristics more prominently in reactive movements (Little and Williams, 2005; Mero et al., 1992). However, the specific differences between these sports remain poorly understood.

Intentional and reactive actions using visual stimuli (light and partner's movements) may exhibit different sports performance and neuromuscular control patterns. Regarding single-joint movements (fingers), studies have shown that while intentional and reactive conditions share partially common central preparatory mechanisms, a reactive advantage has been confirmed, where the overall time from movement initiation to completion is shorter in the reactive condition than in the intentional condition (La Delfa et al., 2013; Welchman et al., 2010). Some of these studies indicate that reactive movements exhibit higher peak velocities than do intentional movements while showing increased variability at the end of the movement (La Delfa et al., 2013) and a reduction in movement time by approximately 10 % (Welchman et al., 2010).

In recent years, similar trends have been observed in single-joint and whole-body movements. Wakatsuki and Yamada (2020) demonstrated that the reactive condition using a single light stimulus resulted in earlier movement initiation than did the intentional condition; however, the reactive condition exhibited potentially limited velocity control. Furthermore, Vivar et al. (2025) reported that in football players, the time from movement initiation to force production was shorter in the reactive condition using light stimuli than in the intentional condition, and that jump height and reactive strength index-modified decreased depending on the task condition. These findings indicate that the reactive advantage exists in single-joint and whole-body movements, as well as in sports actions involving visual cognitive tasks. Thus, light stimulation may influence the timing and velocity control of force production in jump performance. However, studies on the differences in SJ performance between intentional and reactive (light-stimulated) conditions across different sports are lacking. Consequently, how movement characteristics in reactive conditions to light stimulation differ based on sport-specific characteristics remains unclear.

The rate of force development (RFD) has been used to evaluate explosive force production capacity. RFD reflects the ability to generate substantial forces within a remarkably short time (Aagaard et al., 2002; Suchomel et al., 2016; Thomas et al., 2015) and is a highly effective indicator for assessing explosive force production capacity under reactive conditions (Haff et al., 2015). Wakatsuki and Yamada (2020) reported that RFD was higher under reactive conditions than under voluntary conditions in a side-step task. However, no studies have been designed to calculate RFD during jump movements using external stimuli such as light signals. Moreover, the characteristics of RFD under reactive conditions remain unclear.

The purpose of study was to compare the effects of intentional and reactive conditions using light stimulation on SJ performance, focusing on differences between athletic disciplines (track and field versus football). Based on the differences in cognitive and motor characteristics between sports (Mero et al., 1992; Stølen et al., 2005) and prior research indicating that cognitive load affects motor control and performance under reactive conditions (Vivar et al., 2025; Wakatsuki and Yamada, 2020), we hypothesized that SJ performance and neuromuscular control patterns differ under reactive conditions, depending on the sport.

MATERIAL AND METHODS

Participants

Fifty male university-level athletes participated in this study. All participants were male university students (16 sprinters and 9 jumpers) in the university track and field clubs who had participated in regional-level competitions in Japan's Tokai region (TF group: mean ± standard deviation [SD] age, 19.76 ± 1.09 years; height, 1.72 ± 0.06 m; weight, 62.82 ± 5.03 kg; years of experience, 7.32 ± 2.64 years) or male university students (8 defenders, 13 midfielders, and 4 Forwards) in the university football clubs participating in the Tokai regional university football league (F group: mean ± SD age, 19.72 ± 1.02 years; height, 1.74 ± 0.05 m; weight, 67.72 ± 4.85 kg; years of experience, 13.16 ± 1.80 years). G-Power for Mac (Version 3.1.7) was used to calculate the required sample size. Analyses were based on a two-factor analysis of variance (ANOVA), assuming a moderate effect size (effect size f = 0.7), significance level α = .05, and statistical power of 80 %. The exclusion criteria were the use of drugs affecting athletic performance, orthopaedic limitations, or having a primary football position as a goalkeeper. No minors were included in this study; all participants were aged > 18 years. All track and field athletes and football players trained five times weekly, were proficient in SJ technique, and performed SJ regularly. Furthermore, the football players frequently performed jumping under various unexpected conditions during games and training and were accustomed to this movement. All participants had normal vision or vision corrected to normal. The consent form and all experimental methods were approved by the Gifu University Graduate School Medical Research Ethics Review Committee prior to this study (Certificate Number: 2025-062). After being informed of the benefits and risks of this study, the participants provided written informed consent per the institutional guidelines.

Design and procedures

Before the experiment— 1 week prior— all participants were invited to the laboratory for a familiarization session to minimize performance changes owing to learning effects during measurement, as well as suppress variations in jump technique (Markovic et al., 2004). During the familiarization session, the JH of the SJ had plateaued. All participants were instructed to refrain from resistance training the day before the experiment. On the experiment day, the participants reconverged in the laboratory and performed a 15-min individual warm-up, including dynamic stretching. Subsequently, they performed five SJs. All participants were given a 2-min rest after the warm-up. Each participant performed four SJs under two conditions. SJs under all conditions were performed following the experimental procedure described by Bosquet et al (Bosquet et al., 2009). Participants started from a standing position with feet shoulder-width apart. Upon a start signal, they transitioned to a squat position, held it statically for 2 s, and performed a maximal vertical jump (Bosquet et al., 2009). Landing was restricted to prevent lateral or anterior-posterior movement, ensuring participants landed in the same position as before the jump (Yamauchi and Ishii, 2007). To eliminate arm swing, participants initiated the jump with their hands on their hips (Magrini et al., 2018). Hip and knee joint angles were measured from the static initial posture, where the average hip angle for a smooth jump was 66° (0° being full extension), and the average knee angle was 77° (0° being neutral position) (Bobbert et al., 2006). Next, the participants performed a maximum effort jump (aiming for the maximum height) using the extension of the three lower limb joints without a counter movement. To ensure that the participants jumped from the same initial posture for all trials, they were instructed to visually track a marker placed at eye level in front of them. A photoelectric sensor (TC Timing Systems, Brower Timing System Inc., Draper, UT, USA) was positioned under the athlete's buttocks to emit a sound when predetermined hip and knee angles were reached, controlling the initial posture.

The experiment involved two conditions: the intentional jump condition (IJC) and the reactive Jump condition (RJC). In the IJC, each participant initiated the SJ at their own timing. In the RJC, the participants were instructed to visually track a light-emitting diode (LED) omnidirectional light presentation device (PH-145, DKH, Tokyo, Japan) placed 1 m in front of them and to jump quickly in response to the LED lamp lighting up (Figure 1). The participants performed the SJ in response to the light stimulus, which was presented at randomly set intervals of 2–5 s. Post-activation potentiation (PAP), where muscle contraction responses to specific stimuli are enhanced after spontaneous muscle contractions, peaks within seconds and halves in approximately 28 s (Blazevich and Babault, 2019). Therefore, the maximum waiting time was set to 5 s. However, the waiting time setting in this study primarily aimed to reduce the predictability of the light stimulus while considering the PAP duration. Exerted force and power are influenced by the temporal predictability of the stimulus (Mattes and Ulrich, 1997); thus, a random waiting time was implemented.

Participants performed two SJ trials per condition (four trials in total). To avoid habituation from performing the same condition consecutively, the two conditions were administered randomly. The athletes received verbal instructions about the next SJ condition before each trial. To eliminate fatigue effects, the participants were given at least a 2-min rest between trials (Markovic et al., 2004). Verbal instructions for both conditions required the athletes to jump maximally. Only for RJC, the participants were instructed to react quickly to the light stimulus and jump high. No feedback regarding SJ performance was provided to the participants.

The examiner monitored the vertical component of ground reaction forces from the force plate (PH-6210A, 0.9 × 0.9 m; DKH, Tokyo, Japan) and judged a trial as successful if no counter movements were observed. Trials were judged as failures if the SJ landing occurred outside the force plate, if the hands left the hips during the SJ, or if counter movements were observed. The trial was repeated after informing the participant of the reason for judging it as a failed attempt.

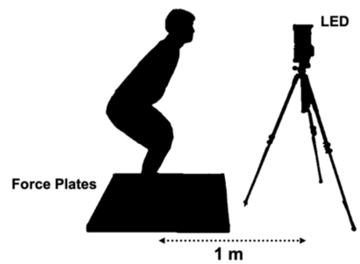

Figure 1. Schematic representation of the experimental design.

Measures

The following variables were used to evaluate SJ performance: RT, JH, PF, PRFD, and ARFD. Vertical ground reaction force was calculated at 1000 Hz using a force plate. The flight time (t) derived from the force plate data was used to estimate the height of the body's centre of mass (h) during the SJ. JH was defined as the flight time component and calculated using the equation JH = 9.81 × flight time2 / 8, as proposed by Bosco et al. (1983).

The data obtained from the force plate were smoothed using a five-point moving average method to create force-time curves. Based on the force-time curve, the maximum ground reaction force was calculated as PF. Differentiating this curve with a time step of 0.001 s produced the differential value-time curve. Additionally, using the ground reaction force-time curve, the point where the vertical ground reaction force on the force plate increased by > 10 % of body weight was defined as the force exertion onset time. The time between the onsets of the light stimulus and force exertion was calculated as RT. According to previous studies (Haff et al., 2015; Khamoui et al., 2011), RFD (the increase in force rate) was calculated using the formula Δground reaction force / Δtime. Average RFD was the PF during the jump divided by the elapsed time, and PRFD was the maximum value of its derivative. PF, PRFD, and ARFD were normalized by dividing by body weight. Furthermore, for each SJ performance evaluation variable, the change rate from IJC to RJC (IJC / RJC) * 100 was calculated. This variable was used to correct for differences in athletes' baseline abilities and capture relative performance changes between conditions (Cormack et al., 2008).

Statistical analysis

All statistical analyses were performed using IBM SPSS Version 25.0 (IBM, Armonk, New York, USA). The Kolmogorov–Smirnov test was conducted to verify normality. Intraclass correlation coefficients (ICCs) were calculated to assess the test-retest reliability of the measured variables. Independent t-tests were used to examine each SJ performance variable, RT, and the rate of change between IJC and RJC in the college athletes. Additionally, two-way ANOVA was used to test for significant differences in JH, PF, PRFD, and ARFD during SJ between sports. Furthermore, effect sizes (Cohen's d) were calculated to examine the magnitude of mean differences. Effect sizes were classified as small ($0.2 \le d < 0.5$), medium ($0.5 \le d < 0.8$), or large (≥ 0.8) (Cohen, 1988). The significance level was set to < 5 % for all tests. All data were presented as mean ± SD.

RESULTS

The Kolmogorov-Smirnov test revealed normality for all variables except RJC ARFD in all participants, all variables except RJC PRFD in the TF group, and all variables except IJC ARFD, RJC RT, and ARFD in the F group ($p > .05$).

Table 1 presents the ICCs for each variable between the first and second SJ performances under identical conditions, which were used to analyse IJC (JH, PF, PRFD, and ARFD) and RJC (RT, JH, PF, PRFD, and ARFD) data. High values (0.803–0.956) were observed for all calculated items in the university student athletes, TF group, and F group.

Table 1. ICC and 95 % CI for JH, PF, PRFD, and ARFD under each SJ condition for all university athletes, university track and field athletes, and football players.

			Jump height	Reaction time	Peak force	Peak RFD	Average RFD
All university athletes	IJC	ICC	0.939**	-	0.937**	0.884**	0.873**
		95 % CI	0.895-0.965	-	0.892-0.964	0.804-0.932	0.787-0.925
	RJC	ICC	0.939**	0.875**	0.956**	0.864**	0.910**
		95 % CI	0.896-0.965	0.791-0.927	0.924-0.975	0.773-0.920	0.847-0.948
Track and field athletes	IJC	ICC	0.922**	-	0.944**	0.916**	0.941**
		95 % CI	0.834-0.965	-	0.879-0.975	0.821-0.962	0.873-0.974
	RJC	ICC	0.899**	0.812**	0.956**	0.926**	0.941**
		95 % CI	0.786-0.954	0.623-0.912	0.903-0.980	0.841-0.967	0.872-0.973
Football players	IJC	ICC	0.866**	-	0.905**	0.855**	0.830**
		95 % CI	0.722-0.938	-	0.799-0.957	0.702-0.933	0.656-0.921
	RJC	ICC	0.915**	0.865**	0.951**	0.803**	0.885**
		95 % CI	0.819-0.962	0.720-0.938	0.894-0.978	0.606-0.908	0.760-0.947

*Note. ICC = intraclass correlation coefficient; CI = confidence interval; SJ = squat jump; JH = jump height; PF = peak force; PRFD = peak rate of force development; ARFD = average rate of force development. IJC = intentional jump condition; RJC = reactive jump condition. **p < .01; *p < .05.*

Table 2 presents the results for each SJ variable among all participants. The unpaired t-tests indicated that JH and PF were significantly higher in IJC than in RJC (JH: *d* = medium, PF: *d* = very small) ($p < .05$; $p < .01$). Furthermore, PRFD and ARFD were significantly higher in RJC than in IJC (PRFD: *d* = Small, ARFD: *d* = Small) ($p < .01$).

Table 2. Comparison of SJ performance between university athletes (mean ± SD).

	Intention (n = 50)			Reaction (n = 50)			*t* Value	*p*-Value	Effect size (*d*)
	Mean	±	Standard	Mean	±	Standard			
Jump height (m)	0.37	±	0.05	0.34	±	0.05	8.86	.000**	0.60
Peak force (N/kg)	25.12	±	2.22	24.76	±	2.16	2.32	.024*	0.16
Peak RFD (Ns^{-1}/kg)	169.20	±	49.50	197.42	±	67.65	4.59	.000**	0.48
Average RFD (Ns^{-1}/kg)	118.85	±	38.67	131.35	±	48.86	2.71	.009**	0.28

*Note. SJ = squat jump; RFD = rate of force development. Statistical significances of the difference between the two conditions: *p < .05; **p < .01.*

Table 3 summarizes the results for each SJ variable in the TF and F groups. The two-way ANOVA showed no interaction effect for JH; however, significant main effects were observed for condition and event type. Multiple comparison tests revealed that for both groups, JH was significantly higher in IJC than in RJC for the event type (Conditions: $F = 79.72$, $p = .000$; TF group: *d* = large; *F* group: *d* = medium). In addition, IJC and RJC exhibited significantly higher JH in the TF group than in the F group (Sports: $F = 34.41$, $p = .000$; IJC/RJC: *d* = large). Furthermore, no interaction effect was observed for PF; however, significant main effects were found for condition and sport type. Multiple comparison tests revealed that PF was significantly higher in IJC than in RJC in the TF group (Conditions: $F = 5.73$, $p = .021$; TF group: *d* = small). IJC exhibited significantly higher PF in the TF group than in the F group (Sports: $F = 6.48$, $p = .014$; IJC: *d* = medium).

PRFD showed no interaction effect; however, a significant main effect was observed for condition. Both groups showed significantly higher PRFD in RJC than in IJC (Conditions: F = 20.70, p = .000; TF group: d = Medium, F group: d = Small). No interaction was observed for ARFD; however, a significant main effect was observed for condition. Multiple comparison tests showed that ARFD was significantly higher in RJC than in IJC in the F group (Conditions: F = 7.23, p = .010; F group: d = Small).

Table 3. Performance variables in the SJ for track and field athletes and football players (mean ± SD).

	TF (n = 25)		**F (n = 25)**		**ANOVA**	
	IJC	**RJC**	**IJC**	**RJC**	**Difference**	
Jump height (m)	0.41 ± 0.05	0.37 ± 0.04	0.34 ± 0.04	0.31 ± 0.04	TF: IJC > RJC F: IJC > RJC	Intention: TF > F Reaction: TF > F
Peak force (N/kg)	25.99 ± 2.06	25.33 ± 2.04	24.24 ± 2.04	24.18 ± 2.16	TF: IJC > RJC	Intention: TF > F
PRFD (Ns^{-1}/kg)	174.97 ± 48.98	204.32 ± 65.47	163.43 ± 50.33	190.52 ± 70.41	TF: IJC < RJC F: IJC < RJC	n. s.
ARFD (Ns^{-1}/kg)	108.47 ± 30.40	119.30 ± 41.54	129.23 ± 43.63	143.40 ± 53.36	F: IJC < RJC	n. s.

*Note. SJ = squat jump; TF = track and field athletes; F = football players; IJC = intentional jump condition; RJC = reactive jump condition; PRFD = peak rate of force development; ARFD = average rate of force development. n.s. = not significant. Statistical significances of the difference between the two conditions: *p < .05; **p < .01.*

Table 4 presents the results comparing the mean RT values across groups. The independent t-test indicated that the TF group had significantly lower RTs than did the F group (d = medium) (p < .05).

Table 4. Comparison of reaction time between track and field athletes and football players (mean ± SD).

	Track and field athletes (n = 25)			**Football players (n = 25)**			***t* Value**	***p*-Value**	**Effect size (*d*)**
	Mean	±	Standard	Mean	±	Standard			
Reaction time (s)	0.19	±	0.03	0.23	±	0.09	2.43	.019*	0.69

*Note. Statistical significances of the difference between the two conditions: *p < .05.*

Table 5 summarizes the comparisons of the mean change rates in SJ performance across groups. The independent t-tests revealed no significant differences in the change rates for any SJ performance variables between the TF and F groups (p < .05).

Table 5. Comparison of rate of change between track and field athletes and football players (mean ± SD).

	Track and field athletes (n = 25)			**Football players (n = 25)**			***t* Value**	***p*-Value**	**Effect size (*d*)**
	Mean	±	Standard	Mean	±	Standard			
Jump height (%)	109.79	±	7.27	108.98	±	7.59	0.39	.700	0.11
Peak force (%)	102.66	±	3.27	100.39	±	4.97	1.90	.063	0.54
Peak RFD (%)	87.55	±	14.42	90.80	±	25.86	0.55	.586	0.15
Average RFD (%)	93.72	±	12.78	94.43	±	26.80	0.12	.906	0.03

*Note. RFD = rate of force development. Statistical significances of the difference between the two conditions: *p < .05.*

DISCUSSION

We aimed to compare the effects of intentional and reactive conditions using light stimulation on SJ performance, focusing on differences between sports (track and field events versus football). JH and PF were significantly higher in IJC than in RJC, while PRFD and ARFD exhibited an inverse trend (Table 2). Furthermore, the F group showed a tendency for higher PRFD and ARFD in RJC than did the TF group (Table 3). Only the F group exhibited a significantly higher ARFD in RJC, while PF showed no significant decrease between the conditions (Table 3). These results imply that the F group may increase the force production speed in response to light stimulation. These findings indicate that the presence or absence of light stimulation affects force production characteristics and that this effect varies across sports. Therefore, the findings support the hypothesis that differences in neuromuscular control patterns, tailored to sport-specific characteristics, are reflected in SJ performance. IJC enabled preparatory movement, facilitating maximal force production, whereas RJC demanded immediate response to light stimulation, potentially favouring short-duration explosive force development. This study highlights the significance of incorporating reaction elements into evaluation and training methods, considering sport-specific characteristics. In addition, it provides insights into conducting practical jump performance assessments in competitive settings.

PRFD and ARFD were significantly higher in RJC than in IJC (Table 2), suggesting that rapid neuromuscular responses were elicited in RJC. This aligns with a report (Wakatsuki and Yamada, 2020) indicating that in the side-step task, RJC significantly reduces the movement execution time compared with the effect of IJC. Furthermore, Bohr's law (Pinto et al., 2011) has been confirmed even in whole-body movements such as the side-step. Bohr's law describes the phenomenon where, when initiating movement reactively to an unexpected external stimulus, the movement execution time is shorter in simple reaction tasks than when movement is initiated intentionally, and a more abrupt force output occurs at an exceptionally early stage after movement initiation (Pinto et al., 2011). Wakatsuki and Yamada (2020) reported that the timing of the force increase, particularly during the initial phase of movement initiation, contributes to a shortened movement time. The significantly higher PRFD and ARFD in RJC may support Bohr's theory (Pinto et al., 2011).

Reactive conditions are characterized by an initial impulsive control strategy that promotes the rapid acquisition of PF. Such neuromuscular control strategies under reactive conditions involve a neuromuscular control pattern that enables highly rapid responses, albeit at the expense of planning and precision (Welchman et al., 2010). This aligns with the "*Fast and dirty*" strategy proposed by Pinto et al. (2011) They neuroscientifically demonstrates that reactive actions are faster than intentional actions but rely on crude processing strategies, reporting that this characteristic is particularly pronounced in immediate responses to external stimuli (Welchman et al., 2010).

Furthermore, PRFD is a specific indicator of the instantaneous onset of force production, reflecting explosive neuromuscular control capabilities in scenarios requiring immediate response to light stimuli (Maffiuletti et al., 2016). In addition, ARFD represents the time to reach PF and indicates the average force development rate over a broader time span, correlating with sustained output efficiency (Aagaard et al., 2002). In this study, the simultaneous elevation of PRFD and ARFD suggests that RJC enhances transient PRFD and neuromuscular activation during the initial phase of SJ. This background suggests that preparatory IJC optimizes voluntary and coordinated muscle activity, potentially favouring predictive control in neuromuscular function. Thus, our present results indicate that the temporal characteristics of neuromuscular function during RJC are evident even in the SJ task, suggesting a mechanism similar to that in the side-step task (Wakatsuki and Yamada, 2020).

IJC elicited higher force/power output and jump performance than did RJC (Tables 2 and 3). These results suggest that visual cognitive load induces specific changes in neuromuscular responses and motor output, providing theoretical evidence supporting the efficacy of cognitive-motor training (CMT) (Lucia et al., 2023), which has gained attention recently. Vivar et al. (2025) reported that jump performance significantly decreased with an increasing visual cognitive load. In addition, they reported that introducing CMT could improve movement accuracy and reaction time. Our results may indirectly support the effectiveness of CMT.

Furthermore, in the TF and F groups, the JH of IJC was higher than that of RJC, with the TF group demonstrating superior performance in JH, PF, and RT compared with those of the F group (Tables 3 and 4). Track and field events demand explosive power generation utilizing SSC and high reaction ability (Mero et al., 1992). These sport-specific characteristics contribute to the acquisition of high JH and rapid RT. In addition, Kobal et al. (2017) compared SJ, counter-movement jump, and depth jump performance among elite athletes of different sports. Their analysis revealed that track and field athletes demonstrated significantly higher JH in SJ, counter-movement jump, and depth jump than did football players, endurance athletes, and tennis players. This finding indicates that track and field athletes possess greater strength and power generation capabilities than do ball sport athletes. Football requires rapid decisions in complex environments involving high cognitive load situational judgment during matches (Roca et al., 2013). This may have limited the potential for improvement in simple light stimulus-based RT. In such cognitively demanding situations, cognitive functions such as, selective attention and predictive judgment, may take precedence over immediate responses to external stimuli. This may explain why football players did not show superiority in simple reaction tasks in this study. Team sport athletes (including football and basketball players) show RT values equivalent to or lower than those among non-athletes in simple tasks while demonstrating significantly higher performance in tasks with high cognitive load, such as selective reaction and visual search tasks (Voss et al., 2010). Therefore, the performance difference in RT between the track and field athletes and football players may stem from a mismatch between the task structure using a single-light stimulus condition and the sport-specific cognitive demands of football. Moreover, football players' training systems tend to emphasize adaptation to match situations, combining repetitive sprints, changes of direction, and high-intensity intermittent exercise with aerobic endurance loads. Training requiring single-effort vertical power output, such as the SJ, is relatively infrequent (Stølen et al., 2005). Hence, differences in neuromuscular adaptations resulting from training objectives and load structures may contribute to the lower JH among the football players than among the track and field athletes.

The differences between RT and JH across event types may reflect the involvement of feedback-based control, which responds immediately to changes in the external environment, and feedforward control, which anticipates situations and preadjusts actions, in human motor control. Winter et al. (1998) demonstrated that stable and efficient motor performance is achieved through the integrated application of these two control strategies. Therefore, posture maintenance and movement execution require the complementary functioning of anticipatory muscle activity based on feedforward control and immediate neuromuscular responses based on feedback-based control.

No significant differences were observed in the rate of change for any SJ performance variable (Table 5). This result indicates that the magnitudes of SJ performance variation in response to movement execution conditions are similar even when the specialized sport discipline differs. Track and field athletes, for whom the reproducibility of explosive force output in remarkably short durations using SSC is strongly demanded, have acquired neuromuscular adaptations that contribute to the consistency of motor output in response to changing conditions (Markovic and Mikulic, 2010). Conversely, football players experience intermittent and fluctuating play intensity and movement patterns during matches (Stølen et al., 2005). Consequently, the training of football players usually emphasizes cognitive-motor integration for immediate response to external stimuli, along with the ability to instantly select and switch movements (Stølen et al., 2005). These factors suggest that track and field sports and football differ in their force production characteristics and neuromuscular control strategies. Therefore, the lack of group differences observed in the present study suggests that force production variations in the SJ depended more on common neuromuscular control mechanisms than on sport-specific factors.

This study has some limitations. First, the football players included individuals from multiple positions and with diverse athletic backgrounds. Future comparisons by position may yield more detailed insights. Second, we considered a generic task design using a single light stimulus; thus, we could not replicate more practical reactive situations. Future research should consider reproducible experimental designs involving complex external stimuli to evaluate jump performance across different sports and league levels. Third, while the SJ aids in evaluating the concentric phase by isolating SSC motor performance, it does not fully reflect the stretch-load movements frequently observed in actual sports actions. Therefore, the SJ under reactive conditions may not necessarily align with the demands of actual football. Future research should explore sport-specific evaluation methods by incorporating jump movements involving SSC. Despite these limitations, our study revealed differences in jump performance under distinct movement conditions (IJC and RJC) and demonstrated neuromuscular control characteristics specific to different sports for the first time. These findings may inform S&C coaches substantially.

CONCLUSIONS

During SJ, IJC exhibited higher JH and PF, while RJC showed higher RFD. Although SJ performance differed between track and field athletes and football players, the two sports showed no significant differences in the rate of change in SJ performance accompanying the change in conditions. These results suggest that while the distinct sport characteristics of track and field and football are reflected in absolute performance, they do not influence the rate of change in force production across different movement execution conditions (IJC and RJC). This implies that neuromuscular control strategies differ based on sport characteristics; however, flexibility and adaptability to changing conditions are similar across sports. This indicates that while neuromuscular control in SJ demonstrates sport-specific adaptations, force production variability is constrained by universal neuromuscular control mechanisms. This study supports the significance of exercise evaluation and training design that considers intentional and reactive elements.

AUTHOR CONTRIBUTIONS

Conceptualization, Y.F. and R.H.; methodology, Y.F. and R.H.; formal analysis, Y.F.,K.I. and R.H.; writing — original draft preparation, Y.F. and R.H.; writing — review and editing, Y.F., K.I. and R.H. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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