COGNITIVE-MOTOR TRAINING WITH UNSPECIFIC STIMULI IMPAIRS JUMP PERFORMANCE IN VOLLEYBALL PLAYERS

EL ENTRENAMIENTO COGNITIVO-MOTOR CON ESTÍMULOS VISUALES INESPECÍFICOS PERJUDICA EL RENDIMIENTO DEL SALTO EN JUGADORES DE VOLEIBOL

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CMT With Unspecific Stimuli in Volleyball Jumping

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Abstract

New training methodologies for team sports emphasize the concurrent development of cognitive and neuromuscular abilities to enhance motor execution and decision-making. However, research on performing high-intensity motor-actions with unspecific visual stimuli for neuromuscular optimization remains limited. This study evaluated the effects of four unspecific perceptual-cognitive dual-tasks on countermovement jump (CMJ) performance—used as an indicator of force application ability—in federated volleyball players (n = 11) and examined how these effects evolved over five sessions. Results showed a significant reduction in jump height across all conditions, with the largest effect in the divided-attention simple reaction-time task (JD-A/SRT, p < .001). The reactive strength index was higher in the simple reaction-time task (JSRT) and JD-A/SRT (p = .02 and p < .001). These results suggest that cognitive tasks affect the ability to apply force and the movement's biomechanics, a key factor to consider for strength andneuromuscular training. Reaction time showed notable improvements over the sessions in the complex-elective reaction-time task (JCERT, d = 0.64), the elective reaction-time task (JERT, d = 0.59), and the divided attention task (JD-A/SRT, d = 0.48). These findings highlight the need to investigate sport-specific perceptual-cognitive demands to integrate them effectively into training programs, thereby minimizing interference and maximizing the transfer to real-world sports contexts.

Keywords: Dual task, visual training, countermovement jump, reaction time, reactive strength.

Resumen

Las nuevas metodologías de entrenamiento para los deportes de equipo enfatizan el desarrollo simultáneo de las capacidades cognitivas y neuromusculares para la mejora de la ejecución motriz y la toma de decisiones. No obstante, la investigación sobre la inclusión de estímulos visuales inespecíficos en tareas orientadas a la optimización neuromuscular sigue siendo limitada. Este estudio tuvo como objetivo evaluar los efectos de cuatro tareas duales perceptivo-cognitivas inespecíficas, sobre el rendimiento del salto con contramovimiento (CMJ) en jugadores federados de voleibol (n = 11), y analizar cómo evolucionan estos efectos a lo largo de cinco sesiones de evaluación. Los resultados mostraron una reducción significativa en la altura del salto en todas las condiciones, especialmente en la tarea de atención dividida con tiempo de reacción simple (JD-A/SRT, p < .001). El índice de fuerza reactiva aumentó en las tareas de tiempo de reacción simple (JSRT, p = .02 y JD-A/SRT, p < .001). Estos resultados sugieren que las tareas cognitivas afectan la capacidad de aplicar fuerza y la biomecánica del movimiento, un factor clave a considerar para el entrenamiento neuromuscular. El tiempo de reacción mostró mejoras notables a lo largo de las sesiones en la tarea de tiempo de reacción electivo complejo (JCERT, d = 0.64), la tarea de tiempo de reacción electivo (JERT, d = 0.59) y la tarea de atención dividida y tiempo de reacción simple (JD-A/SRT, d = 0.48). Estos hallazgos subrayan la necesidad de investigar las demandas perceptivo-cognitivas específicas del deporte para integrarlas eficazmente en los programas de entrenamiento, minimizando así la interferencia motriz y maximizando la transferencia a contextos deportivos reales.

Palabras clave: Tarea dual, entrenamiento visual, salto con contramovimiento, tiempo de reacción, fuerza reactiva.

Introduction

In interactive team sports, athletes play in complex and dynamic environments where perceptual-cognitive demands must be processed concurrently with motor execution. In volleyball, physical efforts are combined with visual-tactical requirements, such as tracking ball and opponent trajectories, decision making in blocking or defensive actions, and determining optimal setting locations for counterattacks (Fleddermann & Zentgraf, 2018).

Cognitive-Motor Training (CMT) methods have been developed to simultaneously stimulate both cognitive and motor processes to enhance sports performance (Lucia et al., 2022). CMT is primarily based on the dual-task (DT) paradigm, in which specific multitasking training aims to induce performance changes within the practiced DT combination, enhancing the crucial subprocesses involved in the task (Wollesen et al., 2022). Scientific literature has revealed that, although DT training may initially lead to short-term performance decrements (also known as DT costs), it typically results in long-term improvements in DT performance (Moreira et al., 2021). These effects have been observed in contexts that differ significantly from the sports domain. For example, DT-based CMT has been extensively investigated as a method to improve physical functioning (walking, balance or postural control) in older adults or individuals with neurological impairments (Anderson-Hanley et al., 2017). For example, previous research has examined the effects of a CMT program on young and adult non-athletes, where the motor task involved postural control, and the cognitive task required memorizing symbols displayed on a screen (Doumas et al., 2009). The considerable heterogeneity in the design of studies regarding the influence of cognitive training programs on cognitive function has led to inconsistent experimental evidence (Sala & Gobet, 2019).

Regarding the use of Cognitive-Motor Dual-Task (CM-DT) training in sports, previous studies on DT paradigms have shown methodological differences related to task characteristics, DT costs, participant populations, and study designs. Notably, many studies have not incorporated DT conditions throughout entire training sessions, and this fact complicates the understanding of both acute and chronic effects on cognitive and motor performance. Additionally, the different characteristics among sports (e.g., individual vs. team-based, open vs. closed skill sports) makes it difficult to establish solid conclusions on this topic (Moreira et al., 2021). In a similar fashion to non-athletic populations, as previously mentioned, the motor tasks evaluated in most dual-task (DT) research in sports have focused on analyzing posture, balance, or low-intensity cyclical tasks such as walking and running (Moreira et al., 2021). For example, Laurin & Finez (2020) evaluated a motor task in soccer players of keeping a ball in the air while performing a numerical countdown.

We know that in sports, the decisive actions in matches are executed at maximum intensity. In that sense, with respect to the use of CM-DT for enhancing physical performance, only two studies have specifically evaluated how unspecific visual tasks affects the neuromuscular performance of a sport-specific action, such as vertical jumping. Vivar et al. (2025) investigated how different dual-task conditions influenced countermovement jump (CMJ) performance in a sample of 299 soccer players. Their findings indicated that even the simplest perceptual-cognitive tasks interfered with the ability to execute the movement at maximal intensity, and this adverse effect became more pronounced when task complexity increased.

Similarly, Fleddermann and Zentgraf (2018) examined how a visual information-processing task affected the motor performance of a jump block in a game-like and sport-specific situation among elite volleyball players. Their results demonstrated that motor performance (i.e., jumping height) decreased when additional visual-cognitive tasks were introduced, regardless of the specificity of the perceptual-cognitive stimulus (i.e., sport-specific video vs. static image).

Although the inclusion of a visual stimulus may initially appear to impair motor performance in high-intensity motor actions, to date, no studies have assessed how these effects may evolve over the long term.

In a study conducted with high-performance athletes, (Quevedo Junyent et al., 2015) observed positive adaptationsto a CM-DT training protocol after each training session, suggesting that improvements are possible with minimal practice. However, the measured output in this study was related to perceptual speed rather than motor performance. Additionally, the motor action performed during the DT condition was a sustained and low-intensity task rather than a high-intensity action as those performed in sport practice.

To date, we have been unable to conclusively determine the real impact of CM-DT in the context of neuromuscular performance training, despite the implementation of CM-DT using nonspecific visual stimuli appears to be increasingly adopted in strength and conditioning training sessions for team sports (gym sessions). New paradigms in team sport trainingadvocate for the inclusion of game contextual constraints in strength-oriented exercises (e.g., pressure, temporal uncertainty, disruptive stimuli), as well as the integrated—not isolated—training of the athlete's components (i.e., cognitive and physical structures) (Seirul·lo, 2017). Based on this author, for example, in a gym-based strength training context for a volleyball player, the inclusion of perturbations during a drop jump landing would constitute a type of motor constraint on the task that would benefit adaptation to game situations such as blocking, where the jump is performed in physical contact with teammates. Similarly, it is assumed that a jump excercise with a perceptual-cognitive (PC) task (jump in response to a visual signal given by the coach)would constitute a constraint at a cognitive level with which the athlete will also have to deal during the game (reacting to the ball during the block, for example). However, the type of stimulus (specific vs. unspecific) and its effects on motor actions in these types of tasks is something that has not yet been investigated.

The present study explores the adaptations to repeated exposure to CM-DT conditions involving a high-intensity motor task (i.e., countermovement jump [CMJ]) in trained athletes (i.e., federated volleyball players). To our knowledge, no previous study has examined the longitudinal effects of perceptual-cognitive dual-tasking using unspecific stimuli on high-intensity neuromuscular performance across multiple training exposures.

The objective of this study is to evaluate the effect of four unspecific PC dual tasks of varying complexity on CMJ jump performance as an expression of applied force ability in federated volleyball players. Additionally, we aim to investigate how these effects evolve over time across five consecutive sessions.

Given that the selected sample (volleyball players) is familiar with jumping actions in cognitively demanding situations, our hypothesis is that the dual-task cost on jump performance will only be evident under the most complex PC conditions due to the increased cognitive processing load (Wickens, 2008) for both jump height and RSImod, causing a decrease in both variables. Conversely, we believe that simple tasks may have a potentiating motor effect, likely due to a higher level of player pre-activation required to face the task. We suggest this effect may be primarily reflected in an increase in RSImod while maintaining jump height.

Finally, we hypothesize that, over successive training sessions, adaptations will occur in CMJ height and RSImod, demonstrating a decrease in the associated cost under the most complex PC conditions, and likely improvements in the RT variable.

Material and Methods

Participants

Eleven federated volleyball players participated in this study (age: 26.7 ± 0.6 years; height: 1.83 ± 0.08 m; body mass: 76.66 ± 3.6 kg). The subjects were recruited from a volleyball club in Alicante competing in the 5th division of the Spanish league and trained 4.5 hours per week plus the match.

The inclusion criteria required participating actively in a volleyball competition with an official license, not suffering any injury that could have hindered their ability to train or compete in the previous three months, and not reporting any visual impairment. Players in the libero position were excluded from the study, as their role on the court restricts them from jumping, which could result in differences in jumping experience compared to the rest of the team and introduce potential bias in study.

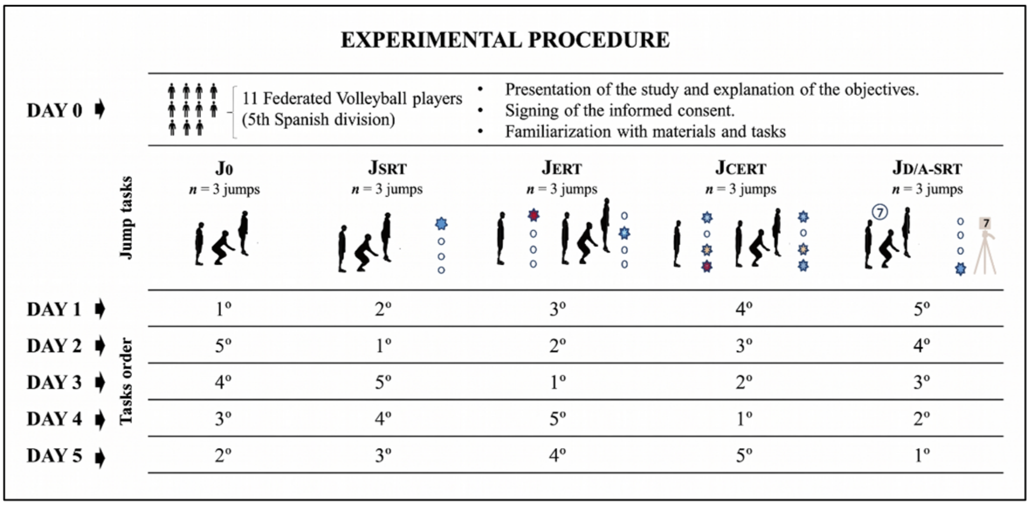
After receiving a detailed explanation of the study's objectives, methods, and potential risks, all participants voluntarily signed an informed consent, in accordance with the Declaration of Helsinki (Ebihara, 2000). The study protocol was approved by the Ethics Committee from the Polytechnic University of Madrid (INEF) (Code: LEDRAUEVEL-MSQ-DATOS-20200307).

Procedures

Participants were recruited over six different sessions conducted within two weeks (Figure 1). During the first session (day 0), they were introduced to the experiment and completed a questionnaire to collect general information, including health status, anthropometric data, and other individual characteristics.

Figure 1

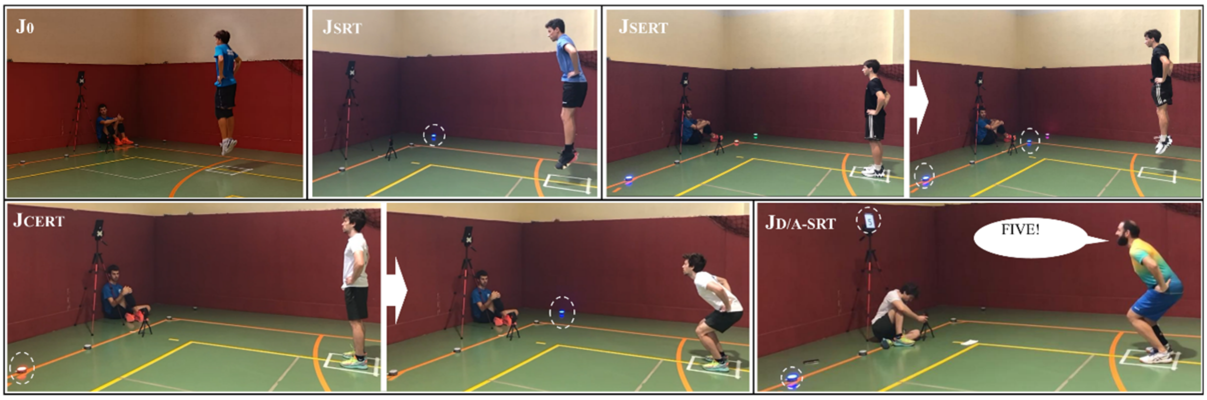
Schematic Representation of the Experimental Design and Sessions



Following this, the correct execution technique for the countermovement jump (CMJ) was explained, and any potential technical errors were identified and corrected. Subsequently, after completing a standardized warm-up, participants were given the opportunity to practice each experimental task (Figure 2) for approximately five minutes. This familiarization phase aimed to ensure proper execution of the tests and minimize errors or performance blockages during the subsequent data collection.

Figure 2

Illustration of the Different PC Conditions: J_0= Jump Control (video), J_{SRT}= Jump in a Simple Reaction Time Task (video), J_{ERT}= Jump in a Simple and Elective Reaction Time Task (video), J_{CERT}= Jump in a Complex and Elective Reaction Time Task (video) and $J_{D\text{-}A/SRT}$= Jump in a Divided Attention and Simple Reaction Time Task (video)



From the second session onward, and throughout the next five days, each participant performed four types of CM-DT and one single-task condition (CMJ jump).The order of the tasks was counterbalanced across the sessions following a Latin square design (Figure 1).

Testing Protocol for Each Experimental Session

All the subjects did the same standardized warm-up in each day, included 3 minutes of low-intensity running and 2 minutes of dynamic stretching in the arms and legs. They were required to complete 8 repetitions of squats with their own body weight, 5 squat jumps and 5 CMJ without recording the results.

After the warm-up, all participants performed the different tasks in the designated order for each day. The PC tasks in which the subjects participated are detailed in Table 1 and Figure 2, which includes a link to an example video for each condition.

Table 1

Characteristics of the Five Tasks

Jump	Common term	Number of stimuli	Number of responses	Attention processes required	Studied Variables
Jump Without Stimulus (J_0)	Pre-planned/ voluntary action	No visual stimulus	1 (Motor-related.)	No external attention required	Jump height (cm), RSI_{mod} (cm/ms)
Jump Simple Reaction Time ($_{JSRT}$)	Simple reaction time	1	1 (Motor-related.)	Preparedness for action	Jump height (cm), RSI_{mod} (cm/ms), RT (ms)
Jump Elective Reaction Time (J_{ERT})	Go/no go reaction time	2	2 (Both motor-related)	Selective attention	Jump height (cm), RSI_{mod} (cm/ms), RT (ms)
Jump Complex Elective Reaction Time (J_{CERT})	Go/no go reaction time	4	2 (Both motor-related).	Selective attention	Jump height (cm), RSI_{mod} (cm/ms), RT (ms)
Jump Divided Attention Simple Reaction Time ($J_{D-A/SRT}$)	Divided Attention	2	2 (Verbal + motor related)	Divided attention	Jump height (cm), RSI_{mod} (cm/ms), RT (ms)

Regardless of the task, the subject was always instructed to reach the maximum height of the jump (i.e., "Jump as high as you can") to prioritize the jumping task to the fast reaction task (Beurskens et al., 2020). The different PC tasks performed by subjects were:

1. Jump simple reaction time (JSRT): The subjects performed the jump in reaction to a randomly illuminated blue light.
2. Jump Elective reaction time (JERT): Subjects performed the jump in reaction to a randomly illuminated blue light, avoiding reaction to the red light.
3. Jump Complex Elective Reaction Time (JCERT): Subjects performed the jump in response to 3 of 4 lights that were illuminated simultaneously and randomly. The color of the light was also random and could be blue, red, or yellow. The subject only executed a jump when they perceived two lights of the same color. Therefore, three possible stimuli could initiate the execution of the action (two yellow lights, two blue lights, or two red lights from the three illuminated devices), while three lights of different colors indicated that the jump was not executed. Figure 3 illustrates the exact operation of the lights during the task.
4. Jump Divided Attention Simple Reaction Time (JD-A/SRT): The subjects performed the jump in response to a randomly appearing blue light appearing on one of the four devices of the setting, while attending to a screen and verbalizing various stimuli (colors, symbols, and numbers) that appeared on it. Correct identification of the stimuli ensured their attention on the screen and the appearance of the blue light in the entire visual field of the subject.

For each of the PC tasks, the player reacted to a nonspecific visual stimulus (light signal). As the force exerted in the CMJ can be related to the temporal predictability of the stimulus (Mattes & Ulrich, 1997), a random waiting time was established for each trial. Regardless of the condition, the stimulus was programmed to appear randomly in every condition, both in the interval appearance (between 3 and 15 seconds) and in the light sequences.

As shown in Figure 4, the setting consisted of four independent lights that were placed three meters away from a square of 40 x 60 cm painted on the floor, which determined the participants' position for both take-off and landing, avoiding any horizontal impulse that could bias the CMJ data (Petrigna et al., 2019). As a fixation point, a cross was marked on the wall in front of the participant position at a height of 1.5 meters. The participant stood behind a line located 3 meters away from the visual fixation point and the four units of the lighting system were located equidistantly from the vertical of the fixation point. The participants were instructed to keep their gaze fixed on this point. Two internal lights were placed equidistantly one meter away from the vertical of the fixation point line, while the external lights were positioned one meter away from the internal ones, totaling four meters between the two external lights. To see all the stimuli in the visual field, participant needed a visual field of 67.38°, corresponding to a mid-peripheral vision (Strasburger et al., 2011).

Figure 3

Visual Graph of the JCERT Condition

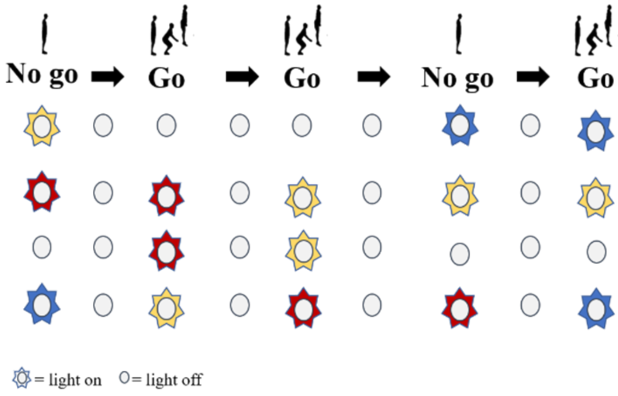
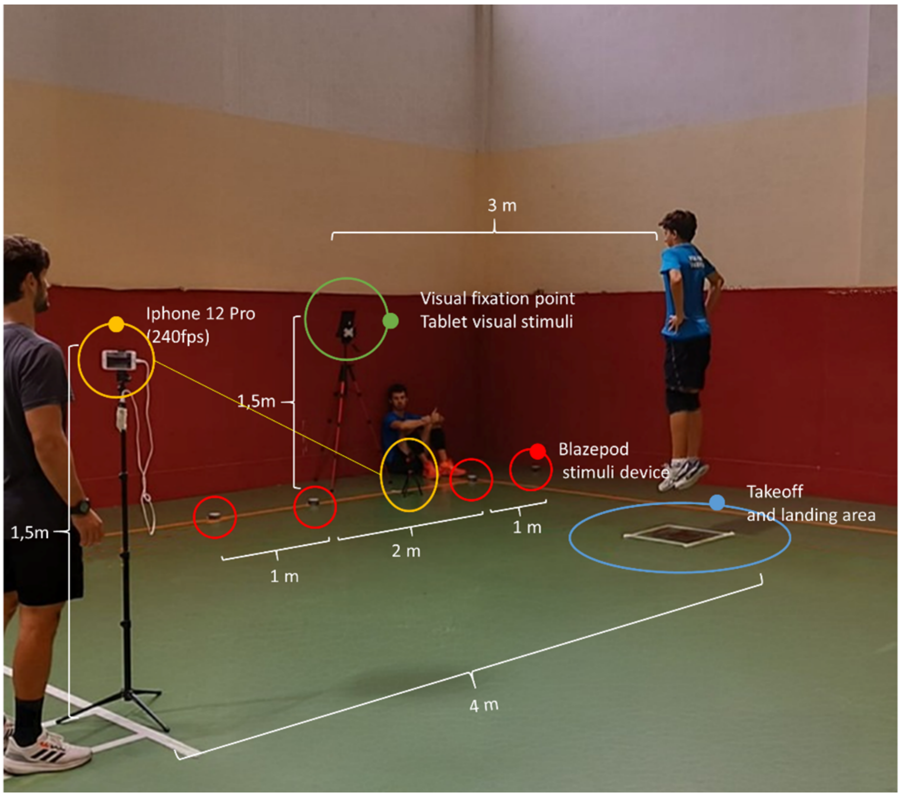


Figure 4

Visual Graph of the Experimental Setting



Jump Test

In the CMJ protocol, participants started from a standing position, with their feet positioned between the hip and shoulder width. Next, they descended into a counter-movement stance to a depth of their choosing, followed by performing a maximal vertical jump. The hands remained on the hips throughout the entire movement to prevent any impact from arm swinging. If the hands were lifted off the hips at any time, the trial would be repeated. After each jump, participants returned to the initial position (França et al., 2022).

The jump technique and contact with the ground on landing were checked to ensure that it was carried out in plantar flexion, to avoid registering longer flight times that would result in greater jumping height measurements (Morin & Samozino, 2018). Hands rested on the hips during the whole jump. To ensure verticality of the jump, subjects were required to take off and land within the delimited area on the ground (Petrigna et al., 2019)

Outcomes

The primary outcome of this study was CMJ height (cm), a reliable indicator of athletes' force application capacity and neuromuscular system state (Bosco et al., 1983; Markovic et al., 2004). CMJ height has been shown to strongly correlate with metrics associated with force application over short time periods, such as the rate of force development (RFD), as well as with metrics related to maximal force production capacity, such as peak force and net impulse. (Marques et al., 2015; McHugh et al., 2021) .

The other variable analyzed was the Reactive Strength Index modified (RSImod), an indicator of athletes' ability to rapidly and efficiently transition from an eccentric to a concentric muscle contraction within a stretch-shortening cycle movement. Activities such as jumping largely depend on the capacity to generate maximal force in the shortest possible time. RSImod quantifies this ability by measuring the ratio between jump height (cm) and the time elapsed from the initiation of movement to takeoff (ms) (Pleša et al., 2022).

Lastly, for each CM-DT, reaction time (RT) was measured. RT is the time recorded from the appearance of the stimulus until the initiation of movement. It has been frequently used as a measure of information processing, cognitive function, or simply as the ability to respond quickly to a given stimulus (Janicijevic & Garcia-Ramos, 2022). According to Gottsdanker & Shragg (1985) RT can provide insights into both visual information processing and motor response preparation. One of the gaps identified in most studies focusing on the effects of dual-tasking on performance out outcomes is the lack of information regarding information processing (Luan et al., 2021).

Materials

The light device used to provide the variable visual stimuli was the Blaze Pod (Tel Aviv, Israel). The lights were programmed through its mobile application, following the procedure described above for each of the experimental condition.

For the JD-A/SRT task, a Lenovo Android 13.0 tablet (Pekin, China) with an 11 inch screen and the Switched-on software was utilized to exhibit the attention task presenting randomly different elements, such as symbols, numbers, and colors, to focus the participants' central vision on them.

To determine the height of CMJ and the RSImod each jump was recorded in slow motion (240 fps) using an iPhone 12 Pro (Shenzhen, China), placed below the fixation point (Figure 4). To determine the reaction time, a lateral view of the jumps were recorded at slow motion (240 fps) with another iPhone 12 Pro (Shenzhen, China), positioned 4 meters away from the participant at a height of 1.5 meters.

In the subsequent analysis, the first frame displaying the stimulus and the first frame showing the start of the participants' movement were identified, and the time between these moments was calculated (Reaction Time). All videos were then analyzed using the "My Jump 2" app (2022), which is a valid and reliable method for calculating jump height and RSImod (Balsalobre-Fernández et al., 2015; Bishop et al., 2022), with a bias estimation of 0.001 meters for the different variable for the jump height, and 0.006 for the RSImod. Furthermore, My Jump 2 has shown high correlation with the results obtained by force platform: 0.98 for jump height and 0.85 for RSImod. The choice of this tool, in addition to its proven validity and reliability, was primarily due to its ease of transport to the data collection sites. This factor was crucial for its selection because multiple data collection sessions were planned at different times and outside of the laboratory.

Statistical Analysis

Data statistical analysis was performed using SPSS 19.0 statistical software. A 1-way random-effects model intraclass correlation coefficient (ICC) with absolute agreement was used to determine relative reliability of the average measures of each variable. The size of the correlation was evaluated as follows: negligible (< 0.1), weak (0.1–0.4), moderate (0.4–0.7), strong (0.7–0.9), and very strong (> 0.9) (Weir and Vincent, 2020). The coefficient of variation relative to the mean (%CV) was also established. The reliability of the researcher in data collection was reported using the technical error of measurement (TEM= $\sqrt{\frac{\sum(X1-X2)^2}{2n}}$). For that reason, each video was analyzed twice, with a 1-month interval between analyses.

COGNITIVE-MOTOR TRAINING WITH UNSPECIFIC STIMULI IMPAIRS JUMP PERFORMANCE IN VOLLEYBALL PLAYERS

In our study, we employed a linear mixed-effects model with repeated measures over time, incorporating subjects as random effects variables. Linear mixed models were chosen as they have successfully accounted for repeated-measures data in previous research (Delves et al., 2021), and have demonstrated great robustness even when the assumptions of normality and homoscedasticity are not maintained (Shieh, 2000). The dependent variables analyzed were jump height, RSImod, and RT values. We used the factors 'Conditions' (comprising JSRT, JERT, JCERT, and JD-A/SRT) and 'Time' (day 1 through day 5) to examine the effects of condition and time, as well as their interaction, using the maximum likelihood estimation method with an unstructured covariance matrix. Main effects and interactions were considered significant based on the Bonferroni correction method applied for multiple comparisons. For significant interactions within the mixed model, we calculated F-statistics and P-values for pairwise contrasts. The size of the condition effects was determined using Cohen's d, with thresholds set at 0.2 for a small effect, 0.5 for a medium effect, and greater than 0.8 for a large effect, as defined by (Cohen, 1988).

Results

All dependent variables exhibited strong to very strong ICC values, except for the RT variable in the JCERT condition, which showed a moderate ICC (ICC = 0.666). The coefficient of variation (CV) for CMJ height and RSImod was below 10%, indicating good data reliability. However, the CV for RT was slightly higher, around 15%. The technical error of measurement (TEM) for all variables remained below 5%. indicating a very good reliability of the investigator for data collection (Table 2).

Table 2

Reliability (ICC, CV, TEM) for all Dependent Variables

Variable	Condition	M ± SD	ICC (CI:95%)	CV(%)	TEM (%)
Jump Height (cm)	J0	34.46±4.37	0.937(0.90-0.96)	3,06	0.02
	JSRT	33.21±3.78	0.979(0.97-0.98)	2.96	0.02
	JERT	32.96±3.96	0.973(0.95-0.98)	3.01	0.02
	JCERT	32.40±3.97	0.957(0.93-0.97)	3.30	0.02
	JD-A/SRT	30.13±3.6	0.941(0.91-0.96)	4.10	0.02
RSImod (cm/ms)	J0	0.362±0.052	0.948(0.92-0.97)	5.19	0.65
	JSRT	0.377±0.059	0.801(0.69-0.88)	5.11	0.65
	JERT	0.366±0.054	0.922(0.88-0.95)	5.90	0.65
	JCERT	0.366±0.070	0.916(0.87-0.95)	7.6	0.65
	JD-A/SRT	0.378±0.061	0.933(0.89-0.96)	5.81	0.65
RT (ms)	JSRT	273.67±60.59	0.801(0.69-0.88)	15.32	4.3
	JERT	302.96±73.48	0.762(0.63-0.85)	15.8	4.3
	JCERT	436.58±117.86	0.666(0.48-0.79)	16.45	4.3
	JD-A/SRT	381.27±112.63	0.718(0.56-0.82)	17.29	4.3

Note. Abbreviations: ICC= Intraclass correlation coefficient; CI = confidence interval; CMJ = countermovement jump; CV = coefficient of variation (% related to mean); JCERT = jump complex elective reaction time; JD-A/ SRT = jump divided attention simple reaction time; JERT = jump elective reaction time; JSRT = jump simple reaction time, J0= Jump Control; RSImod = modified reactive strength index; RT = reaction time; TEM = technical error of measurement (% related to mean).

The analysis revealed a significant main effect of condition on jump height [$F(4,790) = 120.96$, $p \leq .001$], on RSImod [$F(4,790) = 6.731$, $p \leq .001$], and on RT [$F(3,630) = 125.407$, $p \leq .001$]. Table 3 presents the pairwise comparisons of conditions relative to the control condition for Jump Height and RSImod, and across all conditions for RT.

Table 3

Pairwise Condition Effect for Each Considered Dependent Variable

		Height (cm)				
		MD	P	Cohen's d		95% CI
J0	JSRT	1.25	<.001	0.33	*Small*	(0.681–1.831)
	JERT	1.51	<.001	0.40	*Small*	(0.932–2.082)
	JCERT	2.07	<.001	0.55	*Medium*	(1.496–2.646)
	JD-A/SRT	4.33	<.001	1.19	*Large*	(3.757–4.907)
RSImod						
J0	JSRT	-0.015	.002	-0.256	*Small*	[-0.026–(-0.004)]
	JERT	-0.004	1.00	-0.141	*Small*	(-0.015–0.007)
	JCERT	-0.004	1.00	-0.116	*Small*	(-0.016–0.007)
	JD-A/SRT	-0.016	<.001	-0.256	*Small*	[-0.027–(-0.005)]
RT(ms)						
JSRT	JERT	-29.29	.011	-0.43	*Small*	[-54.08–(-4.50)]
	JCERT	-162.90	<.001	-1.73	*Large*	[-187.70–(-138.11)]
	JD-A/SRT	-107.61	<.001	-1.19	*Large*	[-132.39–(-82.81)]
JERT	JSRT	29.29	.011	0.43	*Small*	(4.50-54.08)
	JCERT	-133.61	<.001	-1.36	*Large*	[-158.40–(-108.82)]
	JD-A/SRT	-78.31	<.001	-0.82	*Large*	[-103.11–(-53.52)]
JCERT	JSRT	162.90	<.001	-1.7	*Large*	(138.11–187.70)
	JERT	133.61	<.001	1.36	Large	(108.83–158.41)
	JD-A/SRT	55.30	<.001	0.48	*Medium*	(30.51-80.09)
JD-A/SRT	JSRT	107.60	<.001	1.19	*Large*	(82.81–132.39)
	JERT	78.31	<.001	0.82	*Large*	(53.52–103.11)
	JCERT	-55.30	<.001	-0.48	*Medium*	[-80.09–(-30.51)]

Note. Abbreviations: MD= mean difference, 95% IC = 95% difference confidence interval [lower–upper].

The analysis revealed a significant main effect of the condition × day interaction on jump height [F(16,790) = 1.884, p = .019]. These differences were only detected between conditions on each individual day, but not across days within each condition (see Table 4 and Figure 5).

Regarding RSImod, no significant effects were observed in the overall analysis of the condition × day interaction [F(16,790) = 1.597, p = .063]. These differences were only detected between conditions on each individual day, but not across days within each condition (see Table 4 and Figure 6).

The applied statistical model did not reveal a statistically significant condition-by-time (days) interaction for RT, although it showed a clear trend toward significance (F(12, 630) = 1.754, p = .052). In order to evaluate the practical relevance of the changes observed across the sessions (see Table 4 and Figure 7), the magnitude of the differences was analyzed using the effect size (Cohen's d). When comparing performance from Day 1 to Day 5, a progressive cognitive adaptation linked to task complexity was observed: conditions with higher demands showed moderate improvements (JCERT, d = 0.64; JERT, d = 0.59), whereas in simpler tasks, the changes reflected a smaller effect size (JD-A/SRT, d = 0.48; JSRT, d = 0.22).

Table 4

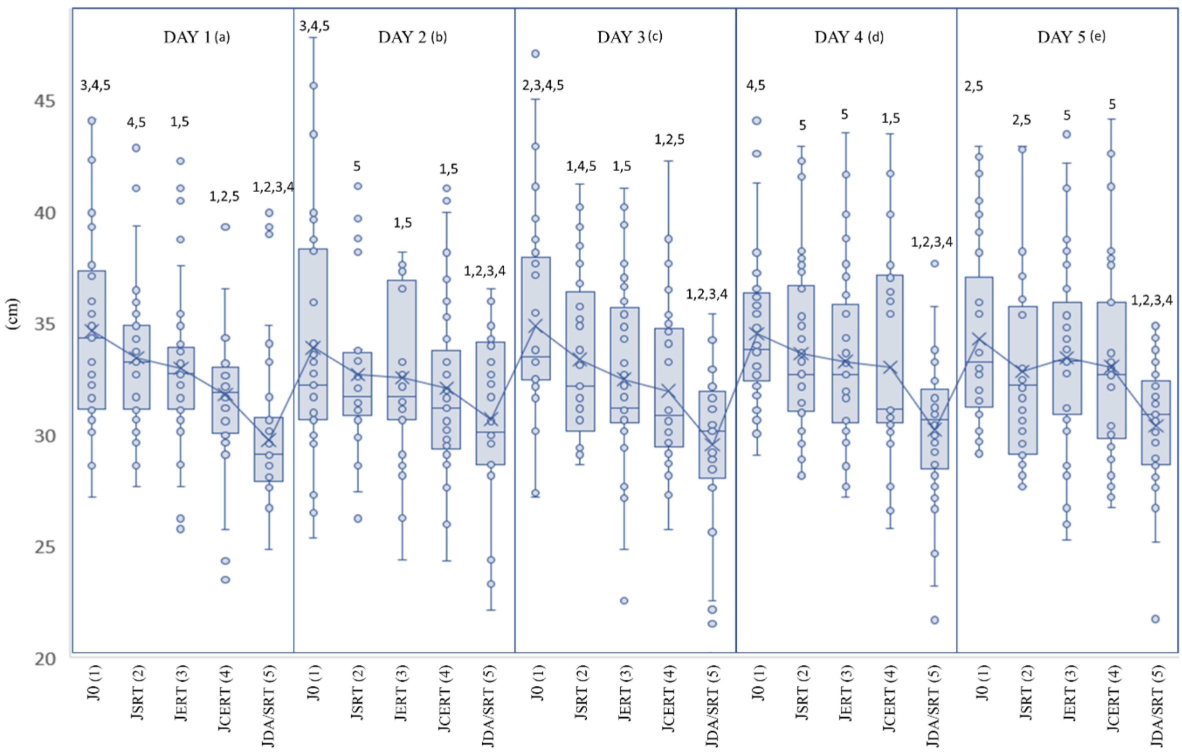
Pairwise Effect (Condition x day) for Each Considered Dependent Variable

			Jump height (cm)		
	DAY 1(a)	**DAY 2(b)**	**DAY 3(c)**	**DAY 4(d)**	**DAY 5(e)**
J0(1)	34.67±4.343,4,5	33.91±5.333,4,5	34.88±4.692,3,4,5	34.54±3.424,5	34.31±4.042,5
JSRT(2)	33.45±3.314,5	32.70±3.535	33.39±3.741,4,5	33.65±3.985	32.84±4.382,5
JERT(3)	32.98±3.771,5	32.57±3.591,5	32.49±4.151,5	33.29±4.005	33.45±4.405
JCERT(4)	31.80±3.571,2,5	32.08±3.941,5	31.98±3.601,2,5	33.04±4.331,5	33.05±4.375
JD-A/SRT(5)	29.76±4.471,2,3,4	30.70±3.551,2,3,4	29.55±3.741,2,3,4	30.23±3.301,2,3,4	30.40±2.831,2,3,4
RSImod (cm/ms)					
J0(1)	0.375±0.575	0.358±0.0524	0.369±0.054	0.350±0.0452,5	0.359±0.0485
JSRT(2)	0.385±0.051	0.379±0.060	0.376±0.053	0.374±0.0671	0.369±0.065
JERT(3)	0.376±0.048	0.379±0.053	0.353±0.051	0.361±0.061	0.366±0.054
JCERT(4)	0.376±0.069	0.383±0.0591	0.355±0.064	0.362±0.085	0.356±0.0705
JD-A/SRT(5)	0.379±0.064	0.377±0.060	0.371±0.053	0.381±0.0671	0.385±0.0631,4
			RT (ms)		
J0(1)	[redacted]				
JSRT(2)	265.76±44.833,4,5	283.82±74.224,5	282.30±59.294,5	282.52±57.844,5	253.94±60.854,5
JERT(3)	332.67±672,4,5	294.85±66.384,5	284.88±55.024,5	308.00±83.554,5	294.39±61.574,5
JCERT(4)	463.91±98.442,3,	470.33±116.542,3,5	439.97±126.142,3,5	412.42±121.902,3	396.24±113.192,3
JD-A/SRT(5)	415.85±126.282,3	378.15±126.152,3,4	351.85±95.692,3,4	396.94±115.602,3	363.58±88.982,3

Note. The superscript numbers correspond to the differences between groups ($p < 0.05$) according to the Bonferroni post hoc analysis (letters indicate differences between days and numbers differences between conditions in each day).

Figure 5

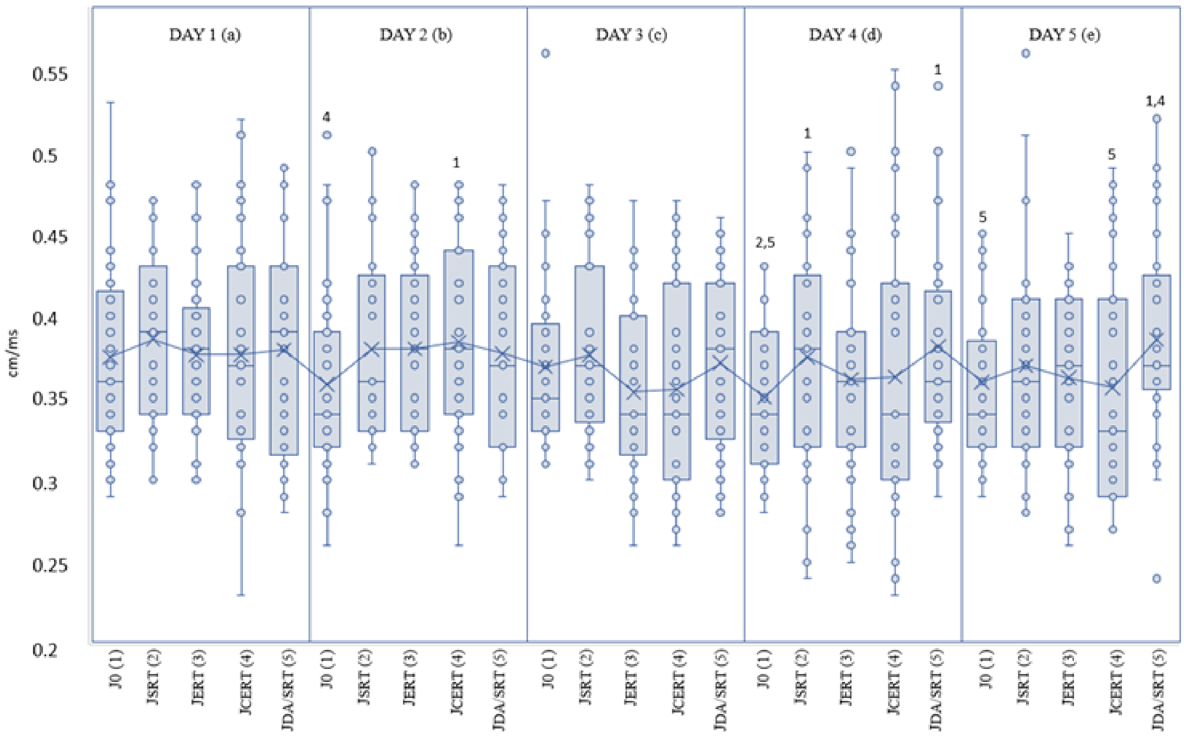
Mean and Standard Deviation of the CMJ Height of the Five Conditions Across the Different Sessions



Note. The superscript numbers correspond to the differences between groups ($p < 0.05$) according to the Bonferroni post hoc analysis.

Figure 6

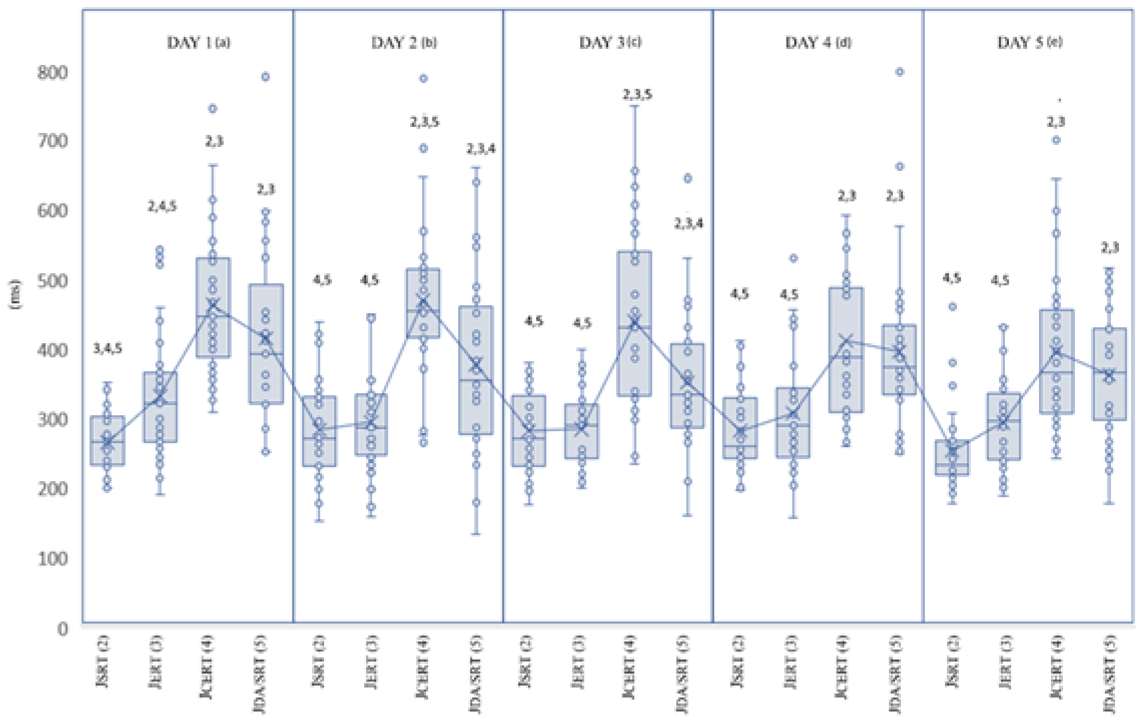
Mean and Standard Deviation of the RSImod of the Five Conditions Across the Different Sessions



Note. The superscript numbers correspond to the differences between groups (p < 0.05) according to the Bonferroni post hoc analysis.

Figure 7

Mean and Standard Deviation of the RT of the Five Conditions Across the Different Sessions



Note. The superscript numbers correspond to the differences between groups (p < 0.05) according to the Bonferroni post hoc analysis.

COGNITIVE-MOTOR TRAINING WITH UNSPECIFIC STIMULI IMPAIRS JUMP PERFORMANCE IN VOLLEYBALL PLAYERS

Discussion

This study aimed to examine the effects of reacting to different non-specific visual stimuli of varying complexity on neuromuscular performance in the countermovement jump (CMJ) among athletes trained in jump execution (e.g., federated volleyball players). Additionally, the study sought to evaluate how these tasks influenced jumping performance over five sessions, in order to assess time-acute adaptations to dual-task conditions. To achieve this, the dependent variables measured were jump height, the reactive strength index (RSImod), and reaction time (RT).

Jump Height

One of the most physically demanding actions in volleyball is vertical jumping. (Alcaraz et al., 2017) reported a jump volume ranging from 150 to 200 jumps per match in U16, U19, and senior national-level competitions, making it one of the most relevant scoring actions in the sport (Ramirez-Campillo et al., 2020). Although the selected sample in this study was from a lower competitive level (5th category of the Spanish federated league), the ICC analysis on the reproducibility and reliability of the CMJ jump showed very high values (>0.9) (Table 2). These findings indicate that the data must be considered as robust and feasible and the movement pattern is consolidated in the players.

Regarding the observed effects of the different PC tasks, even the simplest reaction-time task (JSRT) resulted in a significant 3.6% decrease in jump height compared to the control CMJ jump (J0) (Table 3 and Figure 5). On the other hand, the most complex task (JD/A-SRT) led to a 12.4% decrease compared to J0, which represents a substantial performance deterioration. At a practical level, both conditions exceeded the smallest worthwhile change (SWC) for our sample (the minimum reference value for detecting a practically relevant change). This value was 2.3% (0.8 cm), based on the mean value (34.67 cm) calculated from the between-subject standard deviation (SD = 4.34 cm) multiplied by 0.2 (Turner et al., 2015).

These results align with those reported by Vivar et al., (2025), where a similar trend was observed despite working with a sample of soccer players, who are less accustomed to jumping actions.This finding could be consistent with perceptual theories that emphasize the necessity of specificity in both stimuli and responses (Mann et al., 2007). In this context, the cited manuscript concludes that the expert advantage may be disguised or even masked by an inability to link stimulus characteristics to response selection and execution in contrived settings. For instance, a volleyball player reacting to an unspecific stimulus (e.g., a random light) may rely on a different perception-action coupling than when facing an actual game-specific situation.

As shown in Table 4 and Figure 5, no significant differences were observed between conditions across sessions, indicating no acute adaptation or change in motor response over time.

RSImod

The RSImod was selected as a variable because it is a useful method for evaluating the jumping characteristics of volleyball players, particularly for assessing vertical reactive strength and the efficiency of the fast stretch-shortening cycle (Pleša et al., 2022) Similarly to CMJ jump height, RSImod exhibited excellent reliability (>0.9) (Table 2).

Regarding the effects of the different PC tasks on RSImod, significant differences were observed only between JSRT and JD/A-SRT compared to the control condition. The reactive strength index was approximately 5% higher in the cognitive tasks than in the control condition. Interestingly, this effect was observed only in tasks that included simple reaction time components (JD/A-SRT and JSRT), whereas tasks requiring decision-making (i.e., Go/No-Go tasks) as JERT or JCERT did not show this enhancement (Table 3).

This increase in jump reactivity could represent a positive adaptation for improving athletic performance in sports such as volleyball, where players must execute motor actions under high time pressure, adapting to the physical and spatio-temporal parameters of the ball and other players (Récopé et al., 2019). Considering the 12.4% reduction in jump height caused by the most complex task (JD/A-SRT), simpler tasks such as JSRT could be a viable option to train when aiming to enhance a player's reactive strength without a significant reduction of the performance. An interesting result is that differences between conditions mainly emerge from sessions 4 and 5 (Table 4 and Figure 6). This indicates that an adaptation period to the stimulus is required before achieving an improvement in movement reactivity.

Reaction Time

In our study, RT reliability analysis showed moderate to strong ICC values (Table 3).

The Reaction time (RT) on different tasks was used as a measure of cognitive performance across conditions and sessions. It must be pointed out that each task (condition) had different cognitive requirements been the JSRT the simplest, and the JD/A-SRT the most complex. Previous research has established RT as an effective tool to assess the cognitive costs imposed by one task on the other.

Among the four PC tasks, the highest RT was observed in JCERT (436.58 ± 117.86 ms), followed by JD/A-SRT (381.27 ± 112.63 ms), JERT (302.96 ± 73.48 ms), and the lowest RT in JSRT (273.67 ± 60.59 ms). All conditions were significantly different from each other.

Notably, these results are almost identical to those reported by Vivar et al., (2025), in which an identical protocol was applied to soccer players.The single substantial difference was in the JD/A-SRT task, where RTs were significantly lower in the previous study (298.10 ± 107.02 ms). This discrepancy could be attributed to sport-specific perceptual functions and the primary attentional demands of different sports. In this regard, experts in team sports that require a broader horizontal distribution of attention (e.g., soccer) exhibit greater horizontal attentional breadth compared to athletes in sports with greater vertical attentional demands (e.g., volleyball), and vice versa (Hüttermann & Memmert, 2017).

The use of RT assumes that two tasks can share processing resources simultaneously, leading to a decrease in performance speed under dual-task conditions compared to single-task conditions (Strobach, 2024). The results obtained under the JD-A/SRT experimental condition are interesting because, although they probably had the highest attentional and cognitive demand, they did not show the highest RT (381.27 ± 112.63 ms); however, the JD-A/SRT task was the one that most affected jump performance. This finding suggests that two sources of visual information are processed in parallel (simultaneously) rather than in serial (one after the other) as proposed by classic information processing models (Czyż, 2021). These finding challenges traditional cognitive information processing models and aligns better with the ecological approach (Araújo et al., 2019; Ashford et al., 2021; Renshaw et al., 2019). The ecological approach emphasizes the perception-action coupling over internal mental processing (computational models). Perception is not based on mental associations or labels but on information detected directly by the observer. In this model, deciding involves simultaneously integrating intentions, actions, and perceptions, since decisions emerge continuously from the interaction between the individual and their performance environment, and not through sequential processes (Renshaw et al., 2019).

In our study, RT was the only variable that exhibited changes of a relevant magnitude across sessions (Table 4 and Figure 7). When comparing the first and last sessions, a notable RT reduction was observed, specifically decreasing by 14% in the JCERT condition (d = 0.64) and 12% in the JD-A/SRT condition (d = 0.48). Similarly, a moderate improvement was found in the JERT task with a decrease of 11.5% (d = 0.59), whereas the simplest condition (JSRT) exhibited a much smaller effect (d = 0.22). The magnitude of these effect sizes suggests a clear and progressive adaptation to the task over time in the cognitive domain, a finding that aligns with previous studies (Quevedo Junyent et al., 2015).

Implication

The Importance of Specific Practice Environments With Specific Visual Stimuli

Although it is generally assumed that training with dual tasks improves both motor and cognitive performance (Moreira et al., 2021), there is some controversy regarding the effectiveness and generalizability of non-specific cognitive training on tasks that are not directly related, such as specific sport performance (Sala & Gobet, 2019; Simons et al., 2016). The acute and chronic effects of cognitive-motor dual tasks (CMDT) have been insufficiently studied mainly in high-intensity motor tasks that rely on maximal neuromuscular system performance. The few studies that have assessed the acute effects of performing an intense physical action in the presence of cognitive-perceptual (CP) stimuli have shown a decrease in motor performance similar to our results, even in highly skilled athletes (Fleddermann & Zentgraf, 2018; Monz et al., 2023). This suggests that reducing the cost of a dual task may depend more on the ability to recognize CP scenarios than on mastering the motor action itself.

Our study highlights that even athletes trained in executing jumps under highly demanding CP conditions do not exhibit far transfer effects when performing dual tasks in different contexts, a phenomenon also demonstrated in cognitive training research (Sala & Gobet, 2019)

Our findings support ecological theories that emphasize the need for CP stimuli to closely match real sports environments and suggest that dual-task training promotes the development of new perceptual strategies, optimizing attentional focus on the relevant cues and improving decision-making (Bherer et al., 2008).

The ability to detect relevant cues and allocate attention relies on working memory (Friebe et al., 2024). In a sports context, this involves deliberate analysis of the situation, considering the abilities and positioning of teammates and opponents to devise a strategic and successful play. This type of processing is crucial for high-level decision-making in dynamic and complex game situations. The use of advanced perceptual cues has been shown to enhance sports performance by facilitating the anticipation of opponents' actions and reducing overall response time (Mann et al., 2007).

Designing specific practice environments with specific visual stimuli has implications not only for performance enhancement but also plays a crucial role in return-to-sport protocols after injury. Reintegrating athletes into an increasingly chaotic sport environment presents an even more demanding visual-cognitive dual-task challenge, increasing the likelihood of movement errors or a decline in movement quality for unprepared athletes (Taberner et al., 2025). These authors propose not only the integration of visual-cognitive dual-task challenges but also the importance of considering how players focus their attention on real game situations during the rehabilitation process. In this regard, having a deep understanding of the game can serve as an excellent injury prevention mechanism, as it allows athletes to anticipate potential traumatic events.

Some authors have tried to relate RT tasks to lower limb injuries in American football, reporting an increased risk when RT in computational tasks increased above 545 ms (Wilkerson, 2012). Although the causal relationship is not demonstrated in the study, in addition to not clarifying the type of PC tasks that should be used, nor how other factors (starting vs. non-starting role) were influencing the results, these findings emphasize the importance of the PC factor and its relationship with the risk of injury. Other investigations revealed deficits in reaction time, processing speed, and visual and verbal memory in ACL-injured athletes. It was demonstrated that either ACL-injured athletes sacrifice their cognitive performance to maintain sufficient postural control, or vice versa, postural stability declines with added cognitive load (Piskin et al., 2022). Based on our results, the costs in a CMJ task executed in a DT situation like the ones we have studied could be more appropriate to assess these deficits in injured players, since the sports context will have a greater relationship with this type of actions. Future studies could focus on how these variables evolve throughout an ACL recovery process to know how to interpret and manage these results in order to establish reference values for the return to performance of injured players.

The Importance of Seeking Maximum Output in Neuromuscular Training

It is still not clear whether extended practice would completely eliminate dual-task costs (Monz et al., 2023). Based on the results of our study, none of the variables related to neuromuscular jump performance showed significant changes across sessions. Therefore, it appears that if the concurrent exercise is too intense (i.e., maximum jump), motor performance is likely to decrease in a CMDT.

As previously discussed, one of the strategies that may protect athletes from the cost of a perceptual-cognitive (PC) task is the experience in specific complex scenarios. However, not all actions can be anticipated, and sports inevitably involve unpredictable scenarios in which rapid decisions must be taken due to time constraints (Souza et al., 2024). In these situations, we must assume the cost of the cognitive task on neuromuscular capacity, even for expert athletes in both the motor action and the PC stimulus (Fleddermann & Zentgraf, 2018). Studies in other sports, such as soccer, have demonstrated a 14.4% higher injury rate during matches compared to regular training (Romeas et al., 2016). The main difference between training and competition is the intensity of the game, rather than the complexity of PC stimuli, which can sometimes be even greater during training sessions.

From a practical standpoint, designing neuromuscular training programs aimed at maximizing force production could play a key role in preparing athletes for high perceptual-cognitive demand scenarios.

When is it Useful to Train With Non-Specific Visual Stimuli?

This work has focused on evaluating the use of Cognitive Motor Training (CMT) through non-specific stimuli from the perspective of neuromuscular performance (i.e CMJ). The results discussed above do not support the use of these methodologies when the main goal is performance enhancement. Perception and action are interdependent processes that continuously influence each other (Mann et al., 2007). Applying more representative paradigms, where tasks are performed in real-world scenarios, appears to be the most suitable approach for executing CMTs.

However, we believe that in other areas, CMT could be a useful tool for sports professionals. For instance, a type of CMT widely used is Exergames, which have proven to be effective in facilitating engagement in exercise within attractive, motivating, and interactive environments (Gallou-Guyot et al., 2023). In this sense, introducing tasks with non-specific visual stimuli could be useful in regenerative sessions or in other conditional settings to brake the monotony of training, thereby promoting the motivation of the players. Similarly, some authors propose coordinative exercises suitable for warm-ups, aiming to stimulate athletes' physical, coordinative, and cognitive structures (Dietz & Nelson, 2024)

Finally, other authors advocate for the use change of direction tasks (COD) in response to non-specific stimuli to expose athletes to worst-case scenarios (WCS) (Kadlec et al., 2023). As observed in our study, the conditions that athletes face when they are exposed to a non-specific stimulus (i.e., a light) cause a decrease in the capacity to apply force. Other studies have shown that biomechanical movements are altered in unexpected situations, both during COD (Lee et al., 2019) and jumps (Ren et al., 2022) . In this sense, designing drills that challenge athlete performance through CMT may help to prepare the musculoskeletal system to withstand the loads experienced in extreme conditions(Kadlec et al., 2023).

Implications

One of the main limitations of the study is related to the sample size. The calculation a priori using G*power, performing an approximation with the mixed ANOVA test of repeated intra-subject and between-group measures ($\alpha = 0.05$, $r = 0.8$, $f = 0.4$, $1 - \beta = 0.80$) for five conditions with five measurement occasions, indicated a size of 20 subjects; however, in our case, the volleyball team we had access to, had only 11 players who met the inclusion criteria. It is important to consider that other studies that have focused on the effects of reaction time (RT) tasks on motor performance across multiple sessions have reported significant results with sample sizes similar to our study (Sutter et al., 2021). Despite taking measurements from multiple jumps on multiple days, a larger number of participants would have allowed for more robust results to be drawn from the research.

Similarly, it would be interesting to investigate not only the adaptation to the testing protocol but also the adaptation to a specific training protocol over a greater number of sessions, although previous research has shown that significant changes can be achieved with minimal doses (Quevedo Junyent et al., 2015).

Conclusions

This study is the first to analyze the longitudinal effects of CMDT on maximal jump performance in volleyball.

The inclusion of a non-specific visual stimulus in a CMJ task significantly and negatively impacts action performance (jump height), even in athletes trained in jumping action (federated volleyball players). As the cognitive complexity of the task increases, the performance losses in the jump become greater.

Variables such as RSImod may benefit from tasks involving simple reaction times without causing a significant loss in jump height. This effect may require an adaptation period to the task.

Motor action interference in the jump is not reduced with practice over 5 sessions, while cognitive adaptation to the tasks can be observed through RT.

From a practical point of view, our results emphasize the importance of analyzing sport-specific attentional demands and investigating how perceptual-cognitive skills might be practiced in a sport-specific manner to minimize cognitive-motor interference and improve performance transfer to competition. Therefore, in a training context, it is recommended that coaches separate perceptual-cognitive tasks from jump training if the goal is to maximize physical outputs. Conversely, if the objective is to improve the athlete's decision-making skills in game-like situations, the training should prioritize realistic, sports-specific stimuli.

Ethics Committee Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Technical University of Madrid (MSQ-20200307, 22 March 2023).

Conflict of Interest

The authors declare that there are no conflicts of interest related to the content of this article.

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Author Contributions

Conceptualization G.M.V. & M.S.Q.; Methodology G.M.V & M.S.Q.; Software G.M.V. & M.S.Q.; Validation G.M.V. & M.S.Q.; Formal Analysis G.M.V. & M.S.Q.; Investigation G.M.V. & M.S.Q.; Resources G.M.V. & M.S.Q.; Data Curation G.M.V. & M.S.Q.; Writing – Original Draft G.M.V. & M.S.Q.; Writing – Review & Editing G.M.V. & M.S.Q.; Visualization G.M.V. & M.S.Q.; SupervisionM.S.Q.; Project Administration G.M.V. & M.S.Q.; Funding Acquisition, none. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are openly available in Figshare at: https://doi.org/10.6084/m9.figshare.28652201

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