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Development and reproducibility of a perceptual-cognitive test to assess upper-extremity visuomotor response time using the SwitchedOn® smartphone app: a study with young female volleyball players

Desarrollo y reproducibilidad de una prueba perceptual-cognitiva para evaluar el tiempo de respuesta visuomotora de los miembros superiores utilizando la aplicación SwitchedOn®: un estudio con jóvenes jugadoras de voleibol

Desenvolvimento e reprodutibilidade de um teste perceptual-cognitivo para avaliar o tempo de resposta visuomotora de membros superiores utilizando o aplicativo SwitchedOn®: um estudo com jovens jugadoras de voleibol

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ABSTRACT

This study aimed to develop and assess the test-retest reproducibility of an upper-extremity perceptual-cognitive test using the SwitchedOn® smartphone application in young female volleyball players. Twenty-one young female volleyball players were assessed three times at 7-day intervals at their usual training facilities. The participants made three attempts, during which they were presented with 20 color visual stimuli. Performance indicators based in response time (RT) were calculated (i.e., best attempt (BETT); mean of the three attempts (MTA); and mean of the last two attempts (MLA). The ICC for BETT, MTA, and MLA were 0.774 (SEM = 0.045; MDC95% = 0.126), 0.748 (SEM = 0.051; MDC95% = 0.143), and 0.776 (SEM = 0.051; MDC95% = 0.141), respectively. The perceptual-cognitive test using the SwitchedOn® app for assessing upper-extremity visuomotor RT showed acceptable reproducibility in young female volleyball players. These findings support the use of this test as a reliable tool for evaluating perceptual-cognitive performance.

Keywords: reaction time, injury, athlete performance, sports neuroscience.

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RESUMEN

Este estudio tuvo como objetivo desarrollar y evaluar la reproducibilidad test-retest de una prueba perceptual-cognitiva de miembros superiores utilizando la aplicación SwitchedOn® en jugadoras jóvenes de voleibol. Veintiún atletas fueron evaluadas tres veces, con intervalos de 7 días, en sus instalaciones habituales de entrenamiento. Las participantes realizaron tres intentos, durante los cuales se presentaron 20 estímulos visuales de color. Se calcularon indicadores de rendimiento basados en el tiempo de respuesta (RT), incluyendo: mejor intento (BETT), promedio de los tres intentos (MTA) y promedio de los dos últimos intentos (MLA). Los ICC para BETT, MTA y MLA fueron 0,774 (SEM = 0,045; MDC95% = 0,126), 0,748 (SEM = 0,051; MDC95% = 0,143) y 0,776 (SEM = 0,051; MDC95% = 0,141), respectivamente. La prueba perceptual-cognitiva utilizando la aplicación SwitchedOn® para evaluar el RT visomotor de miembros superiores mostró una reproducibilidad aceptable en jóvenes jugadoras de voleibol. Estos hallazgos respaldan el uso de esta prueba como una herramienta confiable para evaluar el rendimiento perceptual-cognitivo.

Palabras-chave: tiempo de reacción, lesión, rendimiento del deportista, neurociencia deportiva.

RESUMO

Este estudo teve como objetivo desenvolver e avaliar a reprodutibilidade teste-reteste de um teste perceptual-cognitivo de membros superiores utilizando o aplicativo SwitchedOn® em jovens jogadoras de voleibol. Vinte e uma atletas foram avaliadas três vezes com intervalos de 7 dias, em seus locais habituais de treino. As participantes realizaram três tentativas, durante as quais foram apresentados 20 estímulos visuais coloridas. Foram calculados indicadores de desempenho baseados no tempo de resposta (TR), incluindo: melhor tentativa (BETT), média das três tentativas (MTA) e média das duas últimas tentativas (MLA). Os ICCs para BETT, MTA e MLA foram de 0,774 (SEM = 0,045; MDC95% = 0,126), 0,748 (SEM = 0,051; MDC95% = 0,143) e 0,776 (SEM = 0,051; MDC95% = 0,141), respectivamente. O teste perceptual-cognitivo utilizando o aplicativo SwitchedOn® para avaliar o RT visuomotor de membros superiores apresentou reprodutibilidade aceitável em jovens jogadoras de voleibol. Esses achados apoiam o uso desse teste como uma ferramenta confiável para avaliar o desempenho perceptual-cognitivo.

Palavras-chave: tempo de reação, lesão, desempenho atlético, neurociência do esporte.

INTRODUCTION

Volleyball is a team sport that requires players to possess physical abilities, particularly muscular power and the capacity to recover following short-duration maximal efforts (Costa et al., 2018; Ziv & Lidor, 2010). However, as a sport predominantly characterized by open motor skills in a dynamic environment, perceptual-cognitive skills are crucial for performance (Trecroci et al., 2021; Wang et al., 2013). Briefly, perceptual-cognitive skills pertain to an athlete's ability to perceive environmental information, process it, and utilize it to produce appropriate motor responses during gameplay (Hodges et al., 2021; Williams & Ericsson, 2005). Similar to many other sports, volleyball relies heavily on visual stimuli to obtain the information necessary for executing game actions.

In this context, peripheral and central neural pathways are essential for converting visual stimuli into appropriate motor responses. Visual processing begins with the photoreceptor cells in the retina (i.e., rods and cones) capturing environmental information, which is relayed to the lateral geniculate nucleus and subsequently transmitted to the primary visual cortex (Hülsdünker et al., 2018). From there, the nerve impulse then travels through the posterior parietal cortex to the pre- and supplementary motor cortices (i.e., regions responsible for movement planning), and finally, a nerve impulse is sent from the primary motor cortex to the skeletal muscles to perform the movement (Hülsdünker et al., 2018).

To assess this cognitive process, the response time (i.e., the interval between the presentation of a visual stimulus and the completion of a motor response) is typically measured (Erickson, 2021; Hülsdünker et al., 2017). In this sense, simple tasks that require only a single motor response or choice tasks that necessitate selecting the correct response can be valuable tools for assessing perceptual-cognitive skills (Pojskic et al., 2019). Nevertheless, choice tasks appear to be more closely associated with team sports, as they often require decision-making skills (Afonso et al., 2012; Castro et al., 2016). Furthermore, the presence of color differentiation and visual search processes enhances the complexity of visuomotor tasks (Nagy & Sanchez, 1990; Vishteh et al., 2019). In practical terms, response time has been linked to sports performance (Hülsdünker et al., 2019; Laby et al., 2018; Zwierko et al., 2010), injury prevention (Wilkerson et al., 2017), and serves as a tool to assess the neurological impact of concussive injury (Lempke et al., 2020).

The current trend involves designing visuomotor assessment tasks that require broader and more specific movements than merely pressing a button. In this regard, researchers have utilized the FitLight system, which comprises touch-sensitive sensors that emit visual stimuli via LED lights, as an assessment tool (Brinkman et al., 2021; Pojskic et al., 2019) and for training visual skills (Badau et al., 2023). In such wise, tests measuring response time in visuomotor tasks using such devices have shown good reproducibility (Brinkman et al., 2021; Pojskic et al., 2019), defined as the test's stability (i.e., where variations in results are attributed to the test taker's performance rather than inconsistencies in the test itself), and the ability to maintain similar results over time under the same conditions (Bédard et al., 2000).

However, the FitLight system is not widely accessible and requires a substantial financial investment. In other direction, most coaches have access to smartphones for daily use. In recent years, smartphone applications have been employed to assess physical abilities, such as vertical jumping performance (Medeiros et al., 2024), and cognitive skills, such as inhibitory control (Solon-Júnior et al., 2024). For perceptual-cognitive skills, a viable alternative involves using smartphones and apps capable of emitting visual stimuli and measuring response times. In this circumstance, SwitchedOn® is an app available for Android® and IOS® systems that, in its free version, allows users to configure color visual stimulus tasks and utilize the device's touch screen to measure response time.

Although reaction time to colored visual stimuli does not directly replicate game situations, the stimulus-response dynamic simulates key aspects of the perception and visual processing required in sport (Hülsdünker et al., 2018; Montuori et al., 2019). For example, the visuomotor stimulus-response component is present in tactical scenarios in which players must react to visual cues to identify the opponent's actions and the trajectory of the ball. Moreover, studies have shown that basic cognitive functions (e.g., reaction time, inhibitory control, and perceptual speed) are directly associated with technical and physical performance in sports (Formenti et al., 2022; Trecroci et al., 2021).

In this regard, Trecroci et al. (2021) reported significant correlations between composite cognitive scores (reaction time, executive control, and visual search) and volleyball-specific motor skills, while Formenti et al. (2022) found that players at higher competitive levels performed better in inhibitory control and visual search tasks. Furthermore, visuomotor tests involving visual stimuli recruit neural circuits similar to those activated during actual sports actions (Hülsdünker et al., 2018; Montuori et al., 2019). Nevertheless, as these aspects are difficult to measure in real matches, alternative cognitive tasks can provide valuable insights (Alves et al., 2013).

To date, it remains unclear whether smartphone applications can reliably assess response times in visuomotor tasks involving the upper limbs. Therefore, this study aimed to develop and evaluate the test-retest reproducibility of an upper-extremity perceptual-cognitive test using the SwitchedOn® smartphone application. Additionally, the study examined participants' affective responses to the test (i.e., pleasure and displeasure). It was hypothesized that the test would demonstrate good reproducibility across sessions and that participants would report positive affective responses following test performance.

MATERIAL AND METHODS

Research design

The present research is characterized as an instrumental study, as it analyzes a psychometric property, test-retest reproducibility, of a perceptual-cognitive test aimed at assessing motor response time to visual stimuli (Ato et al., 2013). Thus, the research was divided into two phases: a) test design; and b) reproducibility testing.

Participants

Based on the sample size calculation to reproducibility study proposed by Walter et al., (1998), considering three attempts per participant, an α level of 0.05, statistical power of 0.80, a minimum acceptable ICC of 0.40, and an expected ICC of 0.80, the estimated required sample size ranged from approximately 20 to 25 participants. The study included twenty-one female volleyball players aged 10 to 16 years [Age (years): 13.90 (±1.17); Body Mass (Kg): 53.80 (±10.60); Height (m): 1.61 (±0.046); BMI (Kg/m2): 20.90 (±4.23); Neurological disease: none]. All players were regularly engaged in structured volleyball training programs there days per week. Moreover, players were recruited by convenience sampling from a volleyball team.

The inclusion criteria were as follows: a) age between 10 and 17 years; b) at least one year of volleyball training for competitive purposes; and c) absence of color blindness or any other neurological disease. These criteria were adopted to ensure a relatively homogeneous sample regarding age and sport-specific experience, as well as a minimum level of perceptual-motor and coordinative development relevant to the task. In addition, athletes with color blindness were not included, since the test involved visual perception of colors. The exclusion criteria were as follows: a) sustaining any injury during the study period, b) withdrawing from participation for any reason, and c) missing any data collection sessions.

Regarding ethical considerations, this study adhered to the Declaration of Helsinki (Bosnjak, 2001; WMA, 2001) and ethical standards for research in sport and exercise science (Harriss et al., 2022). Previously, all procedures were approved by the local ethics committee [Human Research Ethics Committee, Health Sciences Center, Federal University of Paraíba (opinion 6,729,120)]. Participation was voluntary, and all participants provided written informed consent, with additional authorization obtained from their legal guardians when applicable. Furthermore, all participants were guaranteed the protection of sensitive data, anonymity, and confidentiality, with their information processed in accordance with international data protection principles.

Materials/Instruments

Perceptual-cognitive performance indicators. Using a smartphone (iPhone 13, Apple, Brazil) and the SwitchedOn® app (SwitchedOn Training Inc., United States, Free Version), participants were presented with 20 randomized color visual stimuli, constituting a single attempt (i.e., one attempt = 20 color visual stimuli). The app settings were as follows: a) sync mode: all at once (same), b) stimuli: visual (red, blue, green, and yellow), c) transition: touch (0.9 delays between stimulus, anticipation off), d) duration: 20 rounds, and 1 set. The number of stimuli was defined based on previous perceptual-cognitive protocols (e.g., Van Cutsem et al., 2019). Additionally, the interval between stimuli was set to allow participants to return to the initial position, minimizing potential interference from motor execution and ensuring consistency across trials.

The participants were instructed to place their hands on designated spots on the response mat (100 × 70 cm, placed on a table at a height of 70 cm; see Supplementary File 1 for details), touch the corresponding color as quickly as possible according to the color presented on the smartphone screen, and then tap the screen (see Figure 1). After each stimulus, the participants returned their hands to the designated spot until the next visual stimulus appeared. Cross-armed responses were not allowed. If the researchers identified an error, the test was terminated, and a new attempt was initiated. This strategy was adopted to ensure that performance results were primarily influenced by visuomotor response time, and not by differences in movement patterns. The application automatically recorded the elapsed time between stimulus presentation and the participant's touch response on the screen, expressed in seconds. Each participant completed three trials, with a two-minute rest interval between attempts to minimize potential fatigue effects.

Performance was evaluated based on the following response time efficiency indicators measured by the SwitchedOn® app: a) Best attempt (BATT): the lowest average response time across 20 stimuli; b) Mean of three attempts (MTA): the average response time of three attempts; and c) Mean of the last two attempts (MLA): the average response time of the final two attempts. These metrics were adopted to explore which outcome would be most appropriate for assessing visuomotor response time. The inclusion of multiple indicators (best attempt, mean of three attempts, and mean of the last two attempts) allows for a more comprehensive analysis of performance. Additionally, the use of mean values increases the likelihood of estimating the true score and contributes to the identification of meaningful changes in performance, whether due to fatigue or positive training adaptations (Claudino et al., 2017).

State of readiness. The physical recovery status and mood were used to assess the participants' state of readiness. The athletes were instructed to report their quality of recovery using the Total Quality of Recovery Scale (TQR), validated for the Brazilian context(Osiecki et al., 2015), anchored at 6 ("extremely poorly recovered") to 20 ("extremely well recovered"). Additionally, mood was assessed using the Brunel Mood Scale (Rohlfs et al., 2008) (Brums). The participant was instructed to answer to the question "How do you feel now?" based on 24 simple mood indicators using a Likert scale anchored at 0 (not at all) to 4 (extremely). Mood dimensions, including tension, depression, anger, vigor, fatigue, and mental confusion, were calculated, with scores ranging from 0 to 16. Total mood disturbance (TMD) was calculated using the following equation: TMD = tension + depression + anger + fatigue + confusion - vigor.

Pleasure or displeasure sensation (PDS). The Feeling Scale (FS) (Alves et al., 2019) was used to assess the degree of pleasure or displeasure experienced by the participants during the test. The participants were instructed to rate their level of pleasure or displeasure on a scale ranging from -5 (very bad) to +5 (very good).

Procedures

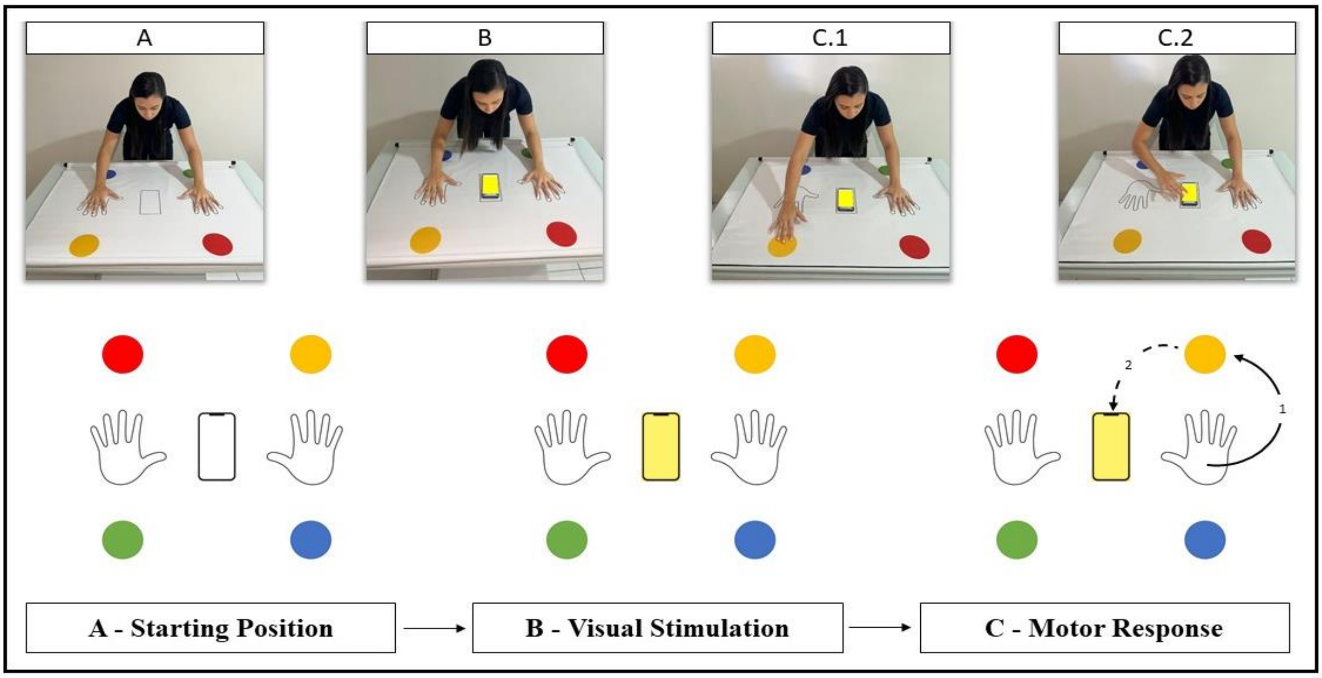
Phase 1 - Test design

The test format and configuration were developed by a researcher with expertise in both volleyball (i.e., a volleyball coach) and neuroscience (i.e., a PhD in cognitive neuroscience and behavior). Figure 1 and 2 illustrates the test setup. The objective was to assess perceptual-cognitive skills by measuring the response time (i.e., the time required for a visuomotor response) of the hands (i.e., upper extremities) using multiple-color stimuli.

Prior to advancing to the next phase, a pilot test was conducted with five physical education students to evaluate the clarity, functionality, and feasibility of the procedures. They were given detailed instructions, completed the test, and provided feedback on the overall functionality, any errors encountered, and potential improvements. This feedback was carefully analyzed and used to refine the protocols. As no operational issues were identified, the study proceeded to the next phase.

Figure 1

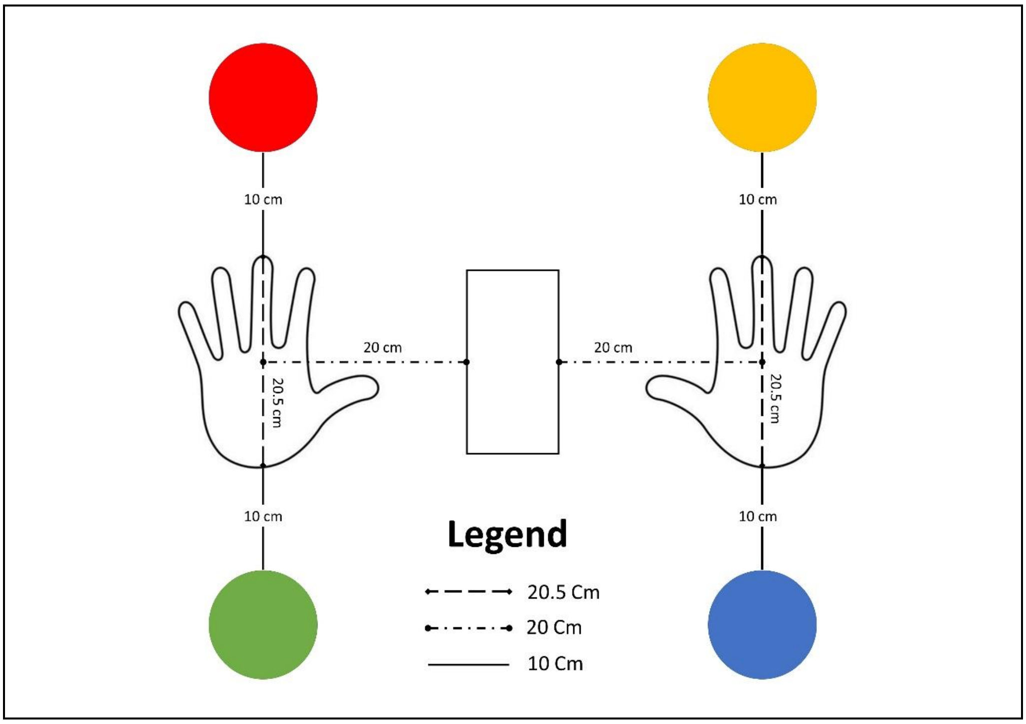
Test setup and procedure for assessing perceptual-cognitive performance by upper extremity visuomotor response time.



A - Starting Position**:** the participant begins with both hands placed on the designated starting points; B - Visual Stimulation: a visual stimulus (e.g., yellow) appears on the smartphone screen, signaling the participant to the circle that must be touched with a motor response; C - Motor response: C.1 - the participant responds to the visual stimulus by moving the hand to the circle, then C.2 - the participant moves the hand to the smartphone screen, completing the motor response sequence.

Figure 2

Hand positioning and distance to colored targets (100 x 70 centimeters).



Phase 2 - Test-retest reproducibility

Reproducibility was assessed using a test-retest protocol over three days, with a seven-day interval between sessions (Figure 3). Thus, reproducibility was checked on the "1st day Vs. 2nd day" and "2nd day Vs. 3rd day". This procedure allows for the verification of reproducibility at similar time intervals.

Participants were instructed to refrain from training or any physical exercise for 24 hours prior to testing, to obtain at least eight hours of sleep, and to avoid the consumption of stimulating substances (e.g., coffee, soda, and energy drinks). Prior to testing, participants' readiness was assessed using the Total Quality of Recovery scale - TQR (Osiecki et al., 2015) and Brunel Mood Scale - BRUMS (Rohlfs et al., 2008) instruments. Subsequently, participants performed a perceptual-cognitive test designed to assess upper-extremity visuomotor response time using the SwitchedOn® smartphone application. After completing the test, participants reported their perceived pleasure or displeasure using the Feeling Scale - FS (Alves et al., 2019)]. All measurements were conducted at the participants' usual training facilities in a private and quiet environment, at the same time of day (6:30 p.m.), under thermoneutral conditions (~20 °C, 50–60% relative humidity).

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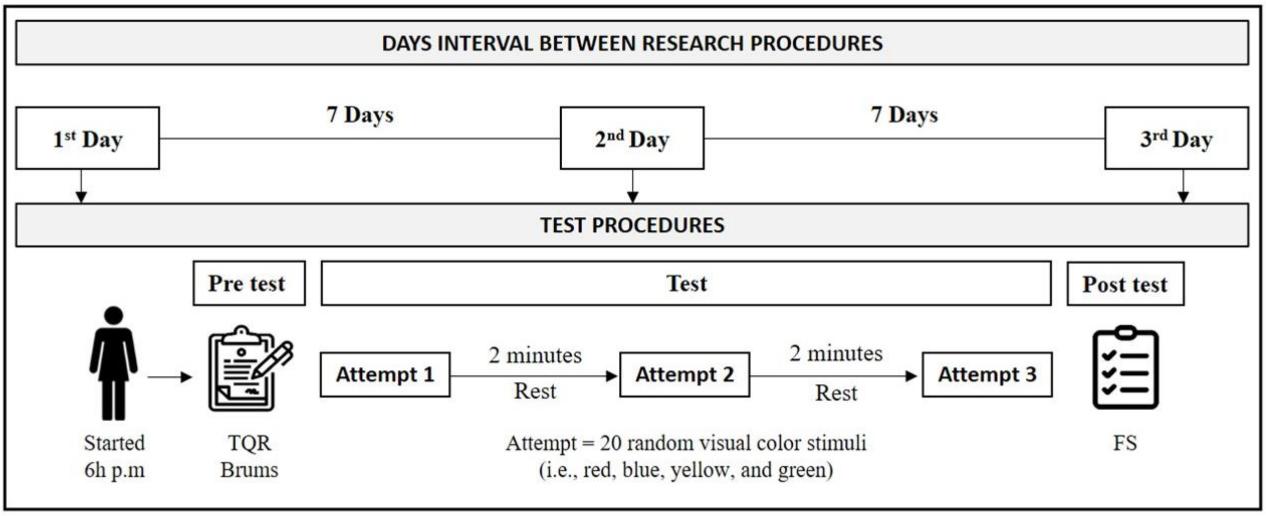
Figure 3

Study design, schedule, and procedures of perceptual-cognitive test.



TQR: Total Quality of Recovery; Brums: Brunel Mood Scale; FS: Feeling Scale.

Statistics analyses

Data are presented as mean and standard deviation (±SD). Table 1 presents skewness, kurtosis, and Shapiro–Wilk test results for all variables across testing days. Some variables did not follow a normal distribution. Thus, a generalized linear model (GLM) with a one-way repeated measures design (within-subjects) was used to compare the readiness state, PDS, and perceptual-cognitive performance indicators across different days. When necessary, Bonferroni post-hoc tests were applied for paired comparisons. Partial eta squared was employed as the effect size, with magnitudes interpreted as small (0.01), moderate (0.09), and large (0.25), as previously adopted by other researchers (Costa et al., 2024). Cohen's d was calculated to verify the magnitude of difference between performance indicators in paired comparisons, using Hopkins et al.'s interpretation (Hopkins et al., 2009): trivial: < 0.2; small: ≥ 0.2 to 0.6; moderate: > 0.6 to 1.2; large: >1.2 to 2.0; and very large >2.0.

The test-retest reproducibility of performance indicators was evaluated using the Intraclass Correlation Coefficient (ICC; two-way random effects, mean of k measurements, consistency). The reliability magnitude was classified following Koo & Li (2016): > 0.5 (poor reliability), 0.50 - 0.75 (moderate reliability), > 0.75 - 0.9 (good reliability), and > 0.9 (excellent reliability). For each ICC, the standard error of measurement [$SEM = SD * \sqrt{1 - ICC}$] and the minimal detectable change at the 95% confidence level ($MDC_{95\%} = SEM * 1.96 * \sqrt{2}$) were calculated. Additionally, the mean of coefficient of variation [CV% = standard deviation/mean) * 100] and coefficient of variation standardized [$CV\%^{standardized}$ = (participant CV - mean of CV) / standard deviation of CV] were calculated for the MTA and MLA performance indicators. Statistical analyses were performed using Jamovi Software (version 2.3.21 for Windows, AGPL3 license), with statistical significance set at 5%.

Table 1

Normality analysis (skewness, kurtosis, and Shapiro-Wilk test).

Variable	Day	Skewness	Kurtosis	Shapiro–Wilk (p)
BATT	1	1.07	0.599	0.035
	2	1.20	0.446	0.005
	3	0.787	1.43	0.253
MTA	1	1.28	1.40	0.021
	2	1.02	0.116	0.012
	3	0.419	0.872	0.830
MLA	1	1.06	0.345	0.019
	2	1.12	0.248	0.007
	3	0.330	0.312	0.929
TQR	1	-0.428	-1.10	0.033
	2	-1.64	2.63	<0.001
	3	-1.18	0.024	<0.001
Pleasure/Displeasure	1	-0.766	-0.757	<0.001
	2	-1.51	1.19	<0.001
	3	-2.41	7.15	<0.001
Anger	1	0.687	-1.33	<0.001
	2	1.41	1.14	<0.001
	3	2.01	4.77	<0.001
Confusion	1	1.40	1.37	0.001
	2	2.02	3.39	<0.001
	3	2.46	5.59	<0.001
Depression	1	1.19	0.533	<0.001
	2	2.47	5.48	<0.001
	3	2.21	4.61	<0.001
Fatigue	1	1.76	3.44	<0.001
	2	0.849	-0.306	0.004
	3	1.09	0.018	<0.001
Tension	1	0.863	0.516	0.137
	2	0.661	-1.03	0.002
	3	1.51	1.89	<0.001
Vigor	1	0.086	-0.754	0.348
	2	0.353	-0.601	0.204
	3	0.261	-0.771	0.354
TMD	1	0.858	0.588	0.126
	2	0.633	-0.709	0.058
	3	0.876	0.018	0.042

a) Best attempt (BATT): the lowest average response time across 20 stimuli; b) Mean of three attempts (MTA): the average response time of three attempts; and c) Mean of the last two attempts (MLA): the average response time of the final two attempts; TQR: Total Quality of Recovery Scale; TMD: Total mood disturbance.

RESULT

State of readiness

The state of readiness was similar between the data collection days (Table 2). No differences were observed in the TQR scores [$F_{(2.00 - 60.00)} = 0.370$; $p = 0.692$; $\eta_p^2 = 0.012$]. Moreover, a significant difference was observed only in the confusion [$F_{(2.00 - 60.00)} = 6.28$; $p = 0.003$; $\eta_p^2 = 0.173$] and tension [$F_{(2.00 - 60.00)} = 7.93$; $p < .001$; $\eta_p^2 = 0.209$] mood dimensions. Specifically, tension and confusion scores on 1st day were higher than those on the 2nd day (p = 0.003; p = 0.014, respectively) and the 3rd day (p = 0.003; p = 0.007, respectively).

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Table 2

Comparison of state of readiness between days.

	1st day	2nd day	3rd day	GLM
TQR	17.6 (±1.88)	18.2 (±1.86)	17.9 (±2.65)	$F_{(2.00-60.00)} = 0.370$; $p = 0.692$; $\eta_p^2 = 0.012$
Anger	1.05 (±1.28)	1.14 (±1.53)	0.90 (±1.26)	$F_{(2.00-60.00)} = 0.163$; $p = 0.850$; $\eta_p^2 = 0.005$
Confusion	2.90 (±2.55)	1.00 (±1.97)[a]	0.85 (±1.65)[a]	$F_{(2.00-60.00)} = 6.28$; $p = 0.003$; $\eta_p^2 = 0.173$
Depression	0.66 (±0.913)	0.61 (±1.40)	0.71 (±1.35)	$F_{(2.00-60.00)} = 0.0311$; $p = 0.969$; $\eta_p^2 = 0.001$
Fatigue	2.19 (±2.54)	2.24 (±2.45)	1.76 (±2.19)	$_{(2.00-60.00)} = 0.251$; $p = 0.779$; $\eta_p^2 = 0.008$
Tension	3.95 (±2.46)	1.62 (±1.72)	1.67 (±2.27)	$F_{(2.00-60.00)} = 7.93$; $p < .001$; $\eta_p^2 = 0.209$
Vigour	10.3 (±2.73)	10.1 (±2.64)	9.10 (±3.63)	$F_{(2.00-60.00)} = 0.985$; $p = 0.380$; $\eta_p^2 = 0.032$
TMD	0.429 (±7.72)	-3.48 (±7.90)	-3.19 (±8.93)	$F_{(2.00-60.00)} = 1.48$; $p = 0.236$; $\eta_p^2 = 0.047$

TQR: Total Quality Recovery; TMD: Total mood disorder; GLM: General linear model; [a] Significant difference Vs. 1st day.

Perceptual-cognitive performance

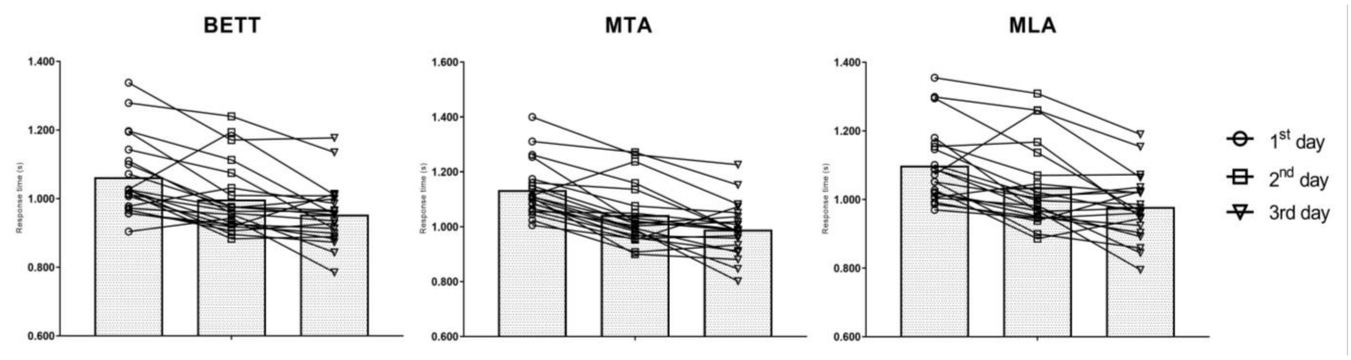
Figure 4 shows the individual response times for each of the performance indicators. The BATT indicator showed a significant time effect across days [$F(2.00 - 60.00) = 6.01$; $p = 0.004$; $\eta_p^2 = 0.167$]. A significant difference was observed between the 1st day [1.06 (±0.113)] Vs. 3rd day [0.954 (±0.089); $p = 0.003$; $d = 1.042$], but not between the 1st day Vs. 2nd day [0.998 (±0.103); $p = 0.135$; $d = 0.573$], or between the 2nd day Vs. 3rd day ($p = 0.500$; $d = 0.457$).

The MTA performance indicator also showed a significant time effect [$F(2.00 - 60.00) = 10.60$; $p < 0.001$; $\eta p^2 = 0.262$]. Therefore, a significant difference was observed between the 1st day [1.13 (±0.099)] Vs. the 2nd day [1.04 (±0.110); $p = 0.016$; $d = 0.860$], as well as between the 1st day Vs. 3rd day [0.990 (±0.097); $p < 0.001$); $d = -1.428$], but not between the 2nd day Vs. 3rd day ($p = 0.304$; $d = 0.482$).

Similarly, the MLA performance indicator showed a significant time effect [$F(2.00 - 60.00) = 6.34$; $p = 0.003$; $\eta_p^2 = 0.174$]. Thus, a significant difference was observed between the 1st day [1.10 (±0.110)] Vs. the 3rd day [0.978 (±0.096); $p = 0.002$; $d = 1.182$], but not between 1st day Vs. 2nd day [1.04 (±0.122); $p = 0.195$; $d = 0.517$], and between 2nd day Vs. 3rd day ($p = 0.295$; $d = 0.565$).

Figure 4

Individual and mean of BETT, MTA, and MLA perceptual-cognitive performance indicators across three testing days.



BATT = Best Attempt; MTA = Mean of Three Attempts; MLA = Mean of Last Two Attempts.

Test-retest reproducibility

Table 3 presents the ICC, SEM, and $MDC_{95\%}$ values between days for each of the performance indicators. The MLA performance demonstrated good reliability across all scenarios ("1^{st} day Vs. 2^{nd} day" and 2^{nd} day Vs. 3^{rd} day) and obtained the highest ICC mean (ICC = 0.776). Additionally, the mean SEM for this performance indicator was 0.046, and the mean $MDC_{95\%}$ was 0.141 s.

Table 3

Test-retest reproducibility by intraclass correlation index (ICC) of the perceptual-cognitive performance indicators

	Days	**BETT**	**MTA**	**MLA**
ICC	**1^{st} day Vs. 2^{nd} day**	0.763[g] (0.219 – 0.915)	0.714[m] (-0.173 – 0.912)	0.789[g] (0.305 – 0.924)
	2^{nd} day Vs. **3^{rd} day**	0.785[g] (0.412 – 0.917)	0.781[g] (0.357 – 0.917)	0.763[g] (0.333 – 0.909)
	ICC_{mean}	0.774[g]	0.748[m]	0.776[g]
SEM	**1^{st} day Vs. 2^{nd} day**	0.050	0.058	0.056
	2^{nd} day Vs. **3^{rd} day**	0.041	0.045	0.046
	SEM_{mean}	0.045	0.051	0.051
$MDC_{95\%}$	**1^{st} day Vs. 2^{nd} day**	0.139	0.161	0.155
	2^{nd} day Vs. **3^{rd} day**	0.114	0.125	0.127
	MDC_{mean}	0.126	0.143	0.141

BATT: Best Attempt; MTA: Mean of Three Attempts; MLA: Mean of Last Two Attempts; [m] moderate reliability; [g] good reliability.

Table 4 shows the coefficients of variation and standardized coefficients of variation. Overall, the MTA coefficient of variation was 5.22 (±3.14), with significant differences observed between 1^{st} day Vs. 2^{nd} day, and 3^{rd} day (p = 0.006; p = 0.003; respectively). Furthermore, the standardized coefficient of variation for MTA was 3.19 (±3.22), with significant differences between 1st day Vs. 2nd day, and 3rd day ($p < 0.001$; $p = 0.002$; respectively). In relation to MLA, the coefficient of variation was 3.96 (±2.89), and the standardized coefficient of variation was 2.51 (2.90), with no significant differences between days (see Table 4 for further details).

Table 4

Comparison of the coefficient of variation (CV%) and the standardized coefficient of variation (CV%^{standardized}) of the perceptual-cognitive performance indicators

	CV%	
Days	**MTA**	**MLA**
1st day	7.18 (±4.06)	4.80 (±3.54)
2nd day	4.32 (±1.91)[a]	3.79 (±2.20)
3rd day	4.17(±2.17)[a]	3.18 (±2.70)
GLM	$F_{(2.00\ 60.00)}$= 7.42; $p = 0.001$; $\eta_p^2 = 0.198$	$F_{(2.00\ 60.00)}$= 1.72; $p = 0.188$; $\eta_p^2 = 0.054$
	CV%^{standardized}	
Days	**MTA**	**MLA**
1st day	5.41 (±5.41)	3.45 (±3.54)
2nd day	1.93 (±1.93)[a]	2.07 (±2.20)
3rd day	2.24 (±2.24)[a]	2.00 (±2.70)
GLM	$F_{(2.00\ 60.00)}$= 9.55; $p < 0.001$; $\eta_p^2 = 0.241$	$F_{(2.00\ 60.00)}$= 0.170; $p = 0.191$; $\eta_p^2 = 0.054$

Mean (±standard deviation); GLM: General Linear Model; [a] Statistically significant difference Vs. 1st Day; MTA: Mean of Three Attempts; MLA: Mean of Last Two Attempts.

Pleasure or displeasure sensation (PDS)

Participants reported an overall pleasure score of 3.81 [±1.81 (good pleasure)], with no significant differences between days [1st day = 3.95 (±1.32); 2nd day = 3.33 (±2.44); 3rd day = 4.14 (±1.46); $F_{(2.00-60.00)} = 1.15$; $p = 0.323$; $\eta_p^2 = 0.037$].

DISCUSSION

This study aimed to develop and evaluate the test-retest reproducibility of an upper-extremity perceptual-cognitive test using the SwitchedOn® smartphone app. In addition, the sensation of performing the test (i.e., pleasure and displeasure) was assessed. The state of readiness was consistent across days, minimizing the likelihood of confounding effects due to residual fatigue in subsequent reproducibility analysis. Slight differences were observed in the confusion and tension dimensions on the first day compared to the other days. Overall, the BETT and MLA performance indicators appear to be the most effective for practical use, as they demonstrate consistent performance over time and exhibit minimal variation. Furthermore, the participants reported experiencing heightened pleasure while performing the test, which did not diminish over time. Therefore, the all hypothesis were confirmed.

Visuomotor response time is an important skill for sports performance (Hülsdünker et al., 2019; Laby et al., 2018; Zwierko et al., 2010). In addition, a fast motor response time has been associated with injury prevention (Wilkerson et al., 2017) and can be used in clinical proposals to assess cognitive changes after concussive injury (Lempke et al., 2020). The test presented in this study demonstrated adequate reproducibility based on the ICC results (Bédard et al., 2000; Koo & Li, 2016). For example, Brinkman et al. (2021) reported an ICC value of 0.80 in a test that evaluated upper-extremity visuomotor response time using the FitLight system. In contrast, our test showed ICC values ≥ 0.748 for all the perceptual-cognitive performance indicators assessed. Furthermore, although Pojskic et al. (2019) founded higher ICC values (ICC = 0.90; ICC = 0.87), the coefficient of variation in our test was smaller (MLA – CV95% = 3.18 - 4.80 Vs. 6.7 - 8.2).

In relation to familiarization attempts, in contrast to the approaches described by Brinkman et al., (2021) and Wilkerson et al. (2017) no familiarization attempts were employed in the present study. Instead, all three attempts were considered to identify the most suitable performance indicator in terms of reproducibility and measurement errors. Furthermore, the reproducibility of the process was evaluated over a period of fourteen days. In this context, the best indicators were identified as BETT and MLA, because they demonstrated superior consistency over time and a low standard error of measurement. [i.e., less chance of systematic bias - (Atkinson & Nevill, 1998)]. In this sense, a two-minute interval between attempts was essential to avoid fatigue and, consequently, systematic bias.

The minimal detectable change at the 95% confidence level (MDC95%) ranged between 0.12 and 0.14 seconds. This measure is important for determining whether a real change in an individual's performance has occurred (Weir, 2005). Previous research by Brinkman et al. (2021), reported a lower MDC95% (0.03 s). However, this difference does not necessarily indicate lower sensitivity of the present test, but rather reflects differences in task configuration and the components of performance being measured. In the present study, the task required participants to identify the target stimulus and execute a goal-directed movement involving two sequential touches (target and smartphone), thereby incorporating both perceptual-cognitive processing and motor execution components. In contrast, in the protocol used by Brinkman et al. (2021), the response was completed immediately upon touching the target, minimizing the motor component. Therefore, the higher MDC95% observed in the present study likely reflects the increased contribution of movement execution time, indicating that the test assesses a broader visuomotor response rather than a simple reaction time.

Referring to pleasure or displeasure sensations, the use of challenging stimuli appears positive among young athletes. For instance, although young basketball players reported increased subjective effort during a training session using the Fitlight system, their enjoyment of the session remained high (Silvestri et al., 2023). Similarly, the participants in this study reported good enjoyment, which was maintained throughout the research days. This suggests that there was no loss of interest when the test was repeated. Finally, although the test was designed to assess visuomotor response time, other cognitive processes are inherently involved in task performance. For instance, participants must maintain task rules and relevant stimulus-response mappings, which engages working memory, and suppress incorrect or premature responses to non-target stimuli, reflecting inhibitory control. Working memory has been associated with superior sports performance and plays a key role in attentional regulation (Vaughan & Laborde, 2021), while inhibitory control is often more developed in athletes compared to non-athletes (Albaladejo-García et al., 2023). Therefore, these findings support the importance of assessing cognitive processes in sport contexts and suggest that the present test may provide a more comprehensive evaluation of perceptual-cognitive functioning beyond simple visuomotor response time.

Additionally, some limitations of this study must be noted. Only one smartphone model was tested; therefore, potential differences in performance based on hardware remain unknown. To mitigate this, it is recommended to use the same device model for successive measurements. In addition, only young female volleyball players participated in this study. Future research should explore the reproducibility of the results in other populations and verify the discriminant validity of the scale for different types of sports (e.g., open vs. closed sports skills) and performance levels (i.e., national vs. international). Additionally, evaluating the impact of integrating this visual stimulus configuration with training regimens would be beneficial.

CONCLUSION

In conclusion, the perceptual-cognitive test to assess upper-extremity visuomotor response time using the SwitchedOn® app showed acceptable reproducibility in young volleyball players and was perceived as enjoyable. In practice, the BETT and MLA performance indicators are recommended for use.

PRACTICAL APPLICATIONS

In practical applications, this test can be used by coaches to monitor visuomotor response performance in volleyball players, a key component of sport performance (Zwierko et al., 2010). Given its low cost and ease of use, the test can be integrated into regular training routines, particularly during the warm-up phase or as part of neuromotor training sessions. Moreover, laboratory tests appear to be related to performance in specific sports tasks (Hülsdünker et al., 2019). For implementation, it is recommended that athletes complete one familiarization session on a separate day to minimize learning effects and reduce potential influences on mood states such as tension and confusion. During regular assessments, each athlete should perform three trials, with a two-minute rest interval between attempts. The first trial may serve as a familiarization or warm-up, while the best attempt (BETT) and mean of the last two attempts (MLA) are recommended for performance monitoring. To ensure consistency, testing should be conducted under standardized conditions (e.g., same time of day, controlled environment, and similar pre-test instructions). Coaches may use the MDC95% values (0.12–0.14 s) to determine whether observed changes in performance reflect meaningful improvements or declines. Additionally, the test can be applied periodically (e.g., weekly or biweekly) to track adaptations over time. Alternatively, the test could also be used in future experimental studies investigating visuomotor perception.

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