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Research article

Reliability, Validity and Usefulness of a New Response Time Test for Agility-Based Sports: A Simple vs. Complex Motor Task

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Abstract
The importance of response time (RT) in sports is well known, but there is an evident lack of reliable and valid sport-specific measurement tools applicable in the evaluation of RT in trained athletes. This study aimed to identify the validity, reliability, and usefulness of four newly developed RT testing protocols among athletes from agility-saturated (AG) and non-agility-saturated (NAG) sports. Thirty-seven AG and ten NAG athletes (age: 20.9 ± 2.9; eleven females) volunteered to undergo: three randomized simple response time (SRT-1, SRT-2, and SRT-3) protocols that included a single limb movement, and one complex response time (CRT) protocol that included multi joint movements and whole body transition over a short distance (1.5 and 1.8m). Each RT test involved 3 trials with 5 randomized attempts per trial. Two sensors were placed at the left- and right-hand side for SRT-1 and SRT-2. Three sensors were positioned (left, middle, right) in SRT-3 and CRT. The intra-class-correlation coefficient (ICC) was calculated as a measure of reliability. Independent sample t-test, effect size (d), and area-under-the-curve (AUC) were calculated to define discriminative validity of the tests. The results showed the newly developed tests were more reliable and useful in the AG than NAG athletes (i.e., ICC between 0.68 and 0.97 versus 0.31 - 0.90, respectively). The RT of AG athletes was faster than that of NAG athletes in the CRT test from the left ($p < 0.01$, $d = 2.40$, AUC: 0.98), centre ($p < 0.01$, $d = 1.57$, AUC: 0.89), and right sensor ($p < 0.01$, $d = 1.93$, AUC: 0.89) locations. In contrast, there were no differences between the groups in the SRT tests. The weak correlation (i.e., r= 0.00 - 0.33) between the SRT and CRT tests suggests that response time of the single limb and multijoint limb movements should not be considered as a single motor capacity. In conclusion, this study showed that AG athletes had faster response time than their NAG peers during complex motor tasks. Such enhanced ability to rapidly and accurately reprogram complex motor tasks can be considered one of the essential qualities required for advanced performance in agility-based sports.

Key words: reaction time, reactive agility, neuromotor memory, perception, reach and touch.

Introduction

Successful performance in different sports such as racket sports (i.e., tennis, badminton) and team sports (i.e., soccer, basketball, volleyball, handball) requires not only well-developed physical capacities but a high level of perceptual and decision-making skills as well (Fiorilli et al., 2017; Loturco et al., 2017; Uljevic et al., 2017). One of the perceptual and decision-making skills is reaction time, which has been defined as the time needed for a person to perceive, process and initiate a movement in response to a stimulus (Edwards, 2010).

Despite being recognized as one of the critical perceptual skills in sports where athletes constantly respond to different sport-specific stimuli, reaction time has frequently been tested with protocols that do not closely replicate sporting actions (Carling et al., 2009; Eckner et al., 2015; Quintana et al., 2007; Spiteri et al., 2013; Vänttinen et al., 2010; Wells et al., 2014). Specifically, the measurements used so far include both computer-based and -independent protocols, where a subject's fine motor control movement task has been used, such as to press a button or catch a dropped object in response to flashed light (e.g., "ruler drop test"), respectively (Carling et al., 2009; Eckner et al., 2015; Geiger et al., 2018; Spiteri et al., 2013). Testing in such way can be debatable because most reactive actions in sports are multi-joint movements that require athletes to recruit large muscle groups (Spierer et al., 2010; Spiteri et al., 2013). Moreover, it cannot be ignored that testing only a simple reaction time, such as the one used in previously explained tests, might lack important information typical for sport-specific movements (e.g., speed, accuracy, magnitude).

Consequently, the development of reliable and valid measurement protocols that would not only test reaction time but also the whole response time of various simple and complex sport-specific actions in response to a stimulus are warranted. Response time (RT) has been defined as the time needed for a person to perceive and respond to some external stimulus (Edwards, 2010; Schmidt et al., 2018). In other words, it is the time required for one to complete a certain motor action in response to an external stimulus (e.g., the time needed to spot and catch an incoming ball). It should be noted that, RT includes both the reaction time (i.e., the time prior to movement initiation) and movement time (i.e., the time from the onset to the end of the motor response) (Edwards, 2010; Schmidt et al., 2018).

Taking a closer look, it can be instantly noticed that the definition of RT is very similar to the definition of agility that has previously been described as "a rapid whole-body movement with change of speed or direction in response to a stimulus" (Sheppard and Young, 2006). This definition is based on a model that separates agility into

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two components: the change of direction speed (CODS) and perceptual and decision-making processes (Sheppard and Young, 2006). However, agility includes the CODS after an external stimulus, whereas RT test can but does not necessarily have to include CODS. In fact, RT can be as simple as the time needed to move only a single limb such as the time required for a volleyball defender to rapidly move the arm to save the ball (e.g., after an opponent´s spike). Alternatively, it can be the time needed to perform quick consecutive movements of the limbs such as to run from a stationary position over a short or long distance in response to some external stimulus (e.g., a 60m sprint) (Spierer et al., 2010; Zemková et al., 2013; Zouhal et al., 2018). In the first example, based on its simple joint movement, the motor task can be defined as a simple response time (SRT), and the second one can be defined as a complex response time (CRT) task due to its complex skilled multiple joint movements (Ohta, 2017).

Defined in such a way, we can say that both SRT and CRT are critical characteristics in athletic performance, especially in rapid-action sports where athletes need to react quickly and accurately in various sporting situations in response to game-specific cues (e.g., movement of the ball, opponent player, etc.) (Pojskic et al., 2018a; Schwab and Memmert, 2012; Sekulic et al., 2014a; Spiteri et al., 2013). Therefore, it appears reasonable to conclude that speed, acceleration and agility-based tests both preplanned and non-preplanned may not be the appropriate response time tests for all sporting situations in fast-action sports, especially for those sport-specific situations involving "reach and touch" motor tasks (e.g., a rapid arm movement to save the ball in tennis or volleyball). As a result of these sport-specific requirements, there is an evident trend for the development of sport-specific tests aimed to evaluate different types of reactions, movements and response times in agility-based sports such as tennis, football and basketball players (Knoop et al., 2013; Spierer et al., 2010; Spiteri et al., 2013; Zemková, 2017; Zemková et al., 2013; Zouhal et al., 2018). The tests aimed to investigate perceptual and sport-specific movement components such as short-distance sprinting, changing of direction, turning, jumping and diving in response to a visual and audio stimulus. In general, results of the studies showed that RT is age-, sex-, playing level-, skill- and sport-dependent. Moreover, RT showed to be depended on the side of the visual stimulus (i.e., footedness and eyedness) (Zouhal et al., 2018).

However, the studies (Knoop et al., 2013; Spierer et al., 2010; Spiteri et al., 2013; Zemková, 2017; Zemková et al., 2013; Zouhal et al., 2018) did not include lateral shuffle movement, although it is a characteristic aspect and the most frequently used movement for effective lateral acceleration during the defensive performance of team sports (Gamble, 2006; Sekulic et al., 2017; Spasic et al., 2015). The shuffle movement has been a standard part of CODS (e.g., T-agility test) and sport-specific reactive agility tests in soccer, handball and basketball (Pojskic et al., 2018b; Pojskic et al., 2015; Sekulic et al., 2017; Spasic et al., 2015). Nevertheless, the movement as a part of the tests was tested only after acceleration and deceleration phases, or in so called "stop and go" manoeuvres (Sekulic et al., 2014a; Sekulic et al., 2017), emphasizing the contribution of the eccentric muscular contraction (i.e., a stretch-shortening cycle). Therefore, the previously developed and investigated tests did not assess one's ability to rapidly accelerate laterally from a stationary position (e.g., "low and wide" position) when an athlete stands still and waits for a stimulus (e.g., a basketball player waits for attacker to make a drive). Thus, it appears reasonable to include the shuffle movement from the stationary position in test protocols when the legs´ push-off action at the beginning of the movement is only dependent on the concentric muscular contraction.

Therefore, on the basis of previously described studies and evident lack of testing protocols that include some important sport-specific movements typical for agility-based sports, the current study intended to design four different RT testing protocols that would include: a) a quick start from the stationary position (i.e., "low and wide"), b) a compatible and complex choice response stimulus with 2 vs. 3 alternatives (i.e., left and right vs. left, middle and right), c) the lateral movement pattern, d) simple and complex response time tasks (e.g., a rapid single arm and/or the whole body movement). The primary aims were i) to investigate the tests´ reliability, validity and usefulness, ii) to investigate the correlation between response time in simple (i.e., single-limb) and complex (i.e., multi-joint) motor tasks, and iii) to examine if the increased tests' complexity would affect performance of athletes involved in agility and non-agility sports in the same way. We hypothesized that athletes involved in agility-based sports would outperform non-agility athletes in both simple and complex response time tests (Sekulic et al., 2014a; Zhongfan et al., 2002).

Methods

Study design

In this study, both within-subject and between-subject experimental designs were used to determine the reliability, usefulness and validity of the newly constructed RT tests. The experimental approach consisted of five phases. In the first phase, we consulted seven experts (i.e., internationally recognized coaches with more than 15yrs of experience) from different agility-saturated sports (e.g., basketball, soccer, handball, volleyball and tennis) regarding the importance of response time and agility movement patterns that are relatively common and essential across the sports in both defensive and offensive actions. All coaches agreed on two important sport-specific actions: (a) a quick single-limb movement in response to a stimulus and (b) quick consecutive lateral and forward movements over a short distance between 2 and 4m in response to a stimulus. They provided several examples of when an athlete is required to quickly react by moving a single arm or leg: i) a volleyball player who quickly moves his arm in response to an opponent´s spike, ii) a rapid lateral step of a basketball defender who reacts to opponent´s dribbling etc.

Additionally, they highlighted the importance of quick consecutive lateral movements as a reaction to an external stimulus. For instance, a basketball defensive technique called "help-and-recover", where an off-ball defender rapidly reacts and usually diagonally shuffles approximately 2–3 m to help out on-ball defender by stopping penetration of the offensive player and afterwards quickly returning to the initial position. The coaches additionally agreed on the importance of multiple choice response time when athletes have to choose the movement direction, and speed depends on several potential stimuli. For instance, in the situation when the athletes do not know in advance how, when or where to initiate the movement (e.g., left, right, forward, backward, upward, etc.). Asked about the optimal starting position prior to movement initiation, the coaches agreed on a “low and wide” position similar to the tennis “split-step” position or basketball and volleyball defensive stance (see a detailed description in the “Response time measurements”).

The second phase included the development of the novel testing system (hardware) and protocols based on the consensus reached by the experts on the most appropriate RT movement scenarios. We constructed wireless-based digital equipment for the initiation, detection and recording of multiple time points throughout the tests (see more about the equipment in the “Response time equipment”). The system was shown to be convenient for testing RT of ballistic movements. Briefly, the infrared (IR)-based movement sensors allowed participants to complete an RT test (i.e., to stop a timer) by placing the hand in front of the sensor (i.e., breaking an IR beam) without being required to touch or strike it as is the case with a touch or pressure sensor. This prevented the occurrence of the movement deceleration phase prior to reaching maximum speed, which in return provided more valid data. In other words, a respondent was not afraid of striking a “target” and getting injured by rapidly executing a movement toward it, which otherwise could inherently increase RT.

To test quick single-limb and multijoint movements in response to a visual stimulus, four different RT testing protocols were developed. We decided to develop RT tests that would include: a) a quick start from the stationary position (i.e., “low and wide”), b) a compatible and complex choice response stimulus with 2 vs. 3 alternatives (i.e., left and right vs. left, middle and right), c) the lateral movement pattern, d) SRT and CRT tasks (e.g., a single arm and/or the whole body movement).The distance between the sensors and between the sensors and participants were adjusted and normalized to a subject’s arm span (AS) in the SRT tests, whereas the distance was the same for all participants in the CRT test (see the “Response time measurements” and Figure 1 for more information).

In the third phase, we made an a priori estimate of the sample size. To obtain the sample size estimate, we used data obtained in a pilot test of 14 athletes (7 involved in agility-saturated sports and 7 non-involved in agility-saturated sports). An analysis using the G*Power software (version 3.1.9.2; Heinrich Heine University Dusseldorf, Dusseldorf, Germany) for an independent t-test analysis (p-value of 0.05, power of 0.90, and effect size (ES) of 0.5) recommended 46 participants as an appropriate sample size. The fourth phase of the experiment included recruitment, testing, and reliability, validity and usefulness analyses for the newly constructed tests. The fifth phase involved data analyses.

Participants

Forty-seven athletes of both sexes voluntarily participated in the study. For the purposes of this study, the participants were additionally divided into two groups. The first group included thirty-seven athletes (age: 20.11 ± 2.85 yr; height: 1.83 ± 0.11 m; mass: 79.6 ± 13.0 kg) involved in agility-saturated sports ([AG]; basketball, volleyball and soccer; 11 women and 26 men). The second group involved ten athletes (age: 20.3 ± 0.72yr; height: 1.79 ± 0.07 m; mass: 79.72 ± 6.32 kg) involved in non-agility saturated sports ([NAG]; track and field (i.e., sprint and jumping events), and gymnastics; 3 women and 7 men) as previously suggested by Sekulic et al. (2014a).

Participants were recruited if they competed at the highest national level, had at least 5 years of experience in competing, trained more than three times per week in the previous 12 months, had currently a training frequency of at least 10 h per week, and did not have existing medical conditions. The provided health-related questionnaire included questions about current and previous visual impairments and skeletal and neuromuscular injuries. Participants were in the preparation period and underwent approximately 5 weeks of regular preseason training before testing was conducted. Both groups had a similar training volume with a training frequency of 6–10 sessions per week comprised of approximately 30-40% strength and power, 20-30% aerobic and anaerobic endurance, and 20-30% sport-specific technical training. Participants were asked to refrain from high intensity training and tobacco, alcohol and caffeine use and to avoid sleep deprivation for at least 2 days before the testing sessions. The ethical approval for the research experiment was provided by Institutional ethical board (Ethical Board Approval No: 2181-205-02-05-18-002). All participants were informed of the purpose, benefits, and risks of the investigation. Written informed consent for participation in the study was received from all participants older than 18 years of age. For participants under the age of 18, legal representatives signed an informed consent. Participants under the age of 18 also provided written informed consent.

Procedures

Athletes participated in three experimentation sessions separated by 48 hrs at the Exercise Science Laboratory. The first session was allotted for anthropometrics and familiarization. For the second and third sessions, athletes completed four randomized RT tests (i.e., two tests per day) with 5 minutes of rest between them. To avoid diurnal variation, the testing sessions were performed between 10 and 12 am. A standardized warm-up of approximately 12 min in duration was performed at the beginning of all testing days. This warm-up included a general warm-up, dynamic stretching and specific warm-up exercises. The general warm-up consisted of 6 min of stationary running with a self-paced increase in movement speed. Three minutes of dynamic stretching included front and lateral lunges, squats with dynamic exercise for the leg adductors, and exercises for the gluteus and gastrocnemius muscles. This was followed by 3 minutes of a specific warm-up using RT protocols. After the warm-up, there was an active rest of 3 min prior to the testing. Additionally, to reduce a systematic change, the RT tests were tested under similar conditions for all participants (temperature 20–25°C, polyvinyl floor, and self-preferred type of footwear that provided an optimal grip) in a single day. Moreover, the participants were instructed to use as much effort as possible during all tests, but they were not provided with any verbal encouragement.

Familiarization session

Prior to familiarization, the participants were asked to answer a questionnaire that was designed to assess the type of sport in which they were engaged, playing experience, activity level, and the health status. Thereafter, the participants' height, body mass, body fat percentage and arm span were determined. The participants subsequently underwent the test familiarization that consisted of several attempts at each test in the study. Research personnel demonstrated the proper form for the execution of all tests. The participants were required to perform 2-3 trials to demonstrate technique proficiency and procedure familiarity. This was of substantial importance because of the intention to develop new RT tests. Previous studies within the field have reported that familiarization is a crucial component as athletes typically find a preferable movement repertoire that enables them to achieve their best result (Sekulic et al., 2014b).

Anthropometrics measurements

Body height (BH) was measured to the nearest 0.01 m with a portable stadiometer (Astra 27310; Gima, Italy). Body mass (BM) and body fat percentage (BF%) were measured with a bioelectric body composition analyzer (TanitaTBF-300, increments 0.1%; Tanita, Tokyo, Japan). Based on BH and BM measures, we calculated the body mass index (BMI) for each player (BM (kg) / BH $(m)^{-2}$). Arm span (AS) was measured as a length between the end of the middle finger of one hand to the middle finger of the subject's other hand. The participants stood with their back to a wall and arms kept parallel to the ground against the wall. The measurements were taken using measurement tape.

Response time equipment

In this study, the researchers developed a novel hardware device system based on wireless technology. The system consisted of three infrared (IR) light sensors. Each of them consists of a microcontroller (Adafruit Feather MO RFM69 868 or 915 MHz, Adafruit, USA), infrared proximity sensor (GP2YOA21YKOF, SHARP, USA), RGB light-emitting-diode (LED) indicator (Adafruit, USA), and a bluetooth module (BLE MICRO, Adafruit USA). The IR sensors were connected to a "smart" mobile phone via a bluetooth module and a specially developed mobile application that worked on an android operating system. The application enabled a random activation of IR sensors and LED indicators, recording, storing and real time data view and analysis. Response time (RT) was measured from the time an LED indicator was randomly activated (i.e., turned on) until the subject places one hand ≤30 mm from the IR sensor, which causes the LED indicator to turn off.

Response time measurements

For the purposes of our study, four RT tests were developed to measure quick single-limb and multijoint movement RT. For all RT tests, participants stood in a comfortable "low and wide" position with their feet slightly wider than shoulder width, knees flexed between 130° and 140°, flat back, upper arms away from body at an angle of ~45°, and elbows flexed between 50° and 60°. Head position was kept neutral with eyes looking forward so they could see all of the IR sensors. They were asked to keep their body weight on the balls of their feet and to keep their heels off the ground.

For all tests, the participants had to stay still without any movement prior to the LED being turned on. When seeing a subject in the proper starting position, a test leader would say "ready!", which represented a warning signal. The time between the warning signal and activation of the LED indicators was set randomized between one and three seconds, which prevented the participants from anticipating the time prior to the LED turning on (Zemková, 2017). In each RT test, three trials were executed with each trial consisting of five attempts with each IR sensor. This number was based on the results of the previous study (Zemková, 2017). The rest interval in between trials was 2 minutes with 5 seconds between attempts plus the warning time. The RT was measured in intervals of 0.001 second (i.e., 1 millisecond). The best and worst attempts were taken out, and the rest were averaged for the analysis. Any improper attempt execution (e.g., starting before the LED indicator turned on, missing the IR sensor, etc.) caused an additional attempt to be utilized.

For SRT-1, one IR light sensor along with an LED indicator was placed at the left (L) and at the right (R) side of a wooden post at a fixed height of 1.2m. L and R sensors were separated at a distance of the subject's arm span (AS). The line that connects them is assigned as line (A) (Figure 1a). The subject stood at the starting position at the centre of the marked line (B) (i.e., the starting line), which is parallel to line A and lies 1/4 of the AS length away. After the sign "ready", participants waited for one of the LED indicators to turn on and as quickly as possible moved a hand (i.e., making an elbow flexion)toward the IR sensor to turn the LED indicator off (i.e., to stop the time).

The same procedures were employed in SRT-2 with the difference that the distance between lines (A) and (B) was increased to 1/2 of the subjects' AS. Thus, the participants had to make a rapid step and move their hand toward one of the sensors to break the IR beam and stop the time (Figure 1b).

In SRT-3, the test setup was the same as in SRT-1 with the difference that we added a 3rd sensor (M) in the middle of the line (C) that is parallel and 1/4 of the AS away from the line (A)(Figure 1c). The sensor was placed at a fixed height of 1.8m. In this way, the subject was provided with three visual stimulus sources (i.e., left, middle and right).

The CRT-4 protocol included three visual stimulus sources as in SRT-3 with the difference that the distance between the sensors was the same for all subjects (i.e., not normalized to subjects' AS). The distance between sensors L and R was 3m. The starting line (B) was placed 1m from the line (A), and 1.5 m from the line (C) (Figure 1d). In that way, the subject stood 1.5m away from the M sensor and 1.8m from the L and R sensors, respectively. Therefore, the subjects had three alternative movements to perform for one attempt. More specifically, they had to make rapid consecutive shuffle steps diagonally left, diagonally right or straight forward to break the beams of the respective sensors with their hand (i.e., to stop the timer).

Statistical analyses

Descriptive statistics (mean, standard deviation and range) were calculated for each outcome variable. Data sets were checked for normality using the Shapiro Wilk test and by visual observation of the normality QQ plots.

Absolute reliability (within-subject variation) was established using coefficient of variation (%CV) expressed in percentage (Hopkins, 2000). It was calculated as the percentage of the within-subject standard deviation. A CV of <10% was set to be acceptable reliability (Atkinson et al., 1999; Clark et al., 2006). Intraclass correlation coefficient (ICC, model 3.1) was used to determine the relative reliability (Bruton et al., 2000; Hopkins et al., 2009; Weir, 2005). A high test-retest reproducibility was considered to exist for ICC > 0.70 (DeVellis, 2016).

Usefulness was computed by comparing typical error (TE) and the smallest worthwhile change (SWC), both expressed in milliseconds for each RT test (Hopkins, 2000). TE was calculated by dividing the standard deviation of the trial to trial difference score by √2 (Hopkins, 2000). SWC was derived from between-subject standard deviation (SD) multiplied by either 0.2 ($SWC_{0.2}$) (Hopkins, 2004; Pyne et al., 2005), which is the typical small effect, or 0.5 ($SWC_{0.5}$), which is an alternate moderate effect (Cohen, 1988; Lockie et al., 2013). A TE below SWC indicates test usefulness as "good", and TE similar to SWC is rated "acceptable". If TE is higher than SWC, it is deemed to have "marginal" usefulness (Hopkins, 2004; Pyne et al., 2005).

Discriminative validity was evidenced by differentiating the AG and NAG groups using the Student's t-test for independent samples. Additionally, magnitude-based ES with 95 Confidence Intervals (CI) were calculated to establish differences between the groups using the following criteria: <0.02 = trivial, 0.2–0.6 = small, >0.6–1.2 = moderate, >1.2–2.0 = large, and >2.0 very large differences (Hopkins, 2000). Further, the receiver operator characteristic (ROC) curve analysis was done, with an area under the ROC curve (AUC) of >0.70 indicating proper (good) discriminative validity of the applied tests (Deyo and Centor 1986, Helm et al. 2018).

Within and between test correlations were calculated using Pearson product moment correlation coefficient (r). The strength of the correlations was interpreted using the following qualitative descriptors: <0.20 = very weak, 0.20 – 0.40 = weak, 0.50–0.70= moderate, 0.80–0.90 = strong and >0.90 = very strong correlation (Salkind, 2007).

The statistical significance for all tests was set at $p \leq 0.05$. Statistical analyses were performed using freely available MS Excel charts (Hopkins, 2001) and SPSS®24.0 (IBM SPSS Statistics, New York, USA) for Windows.

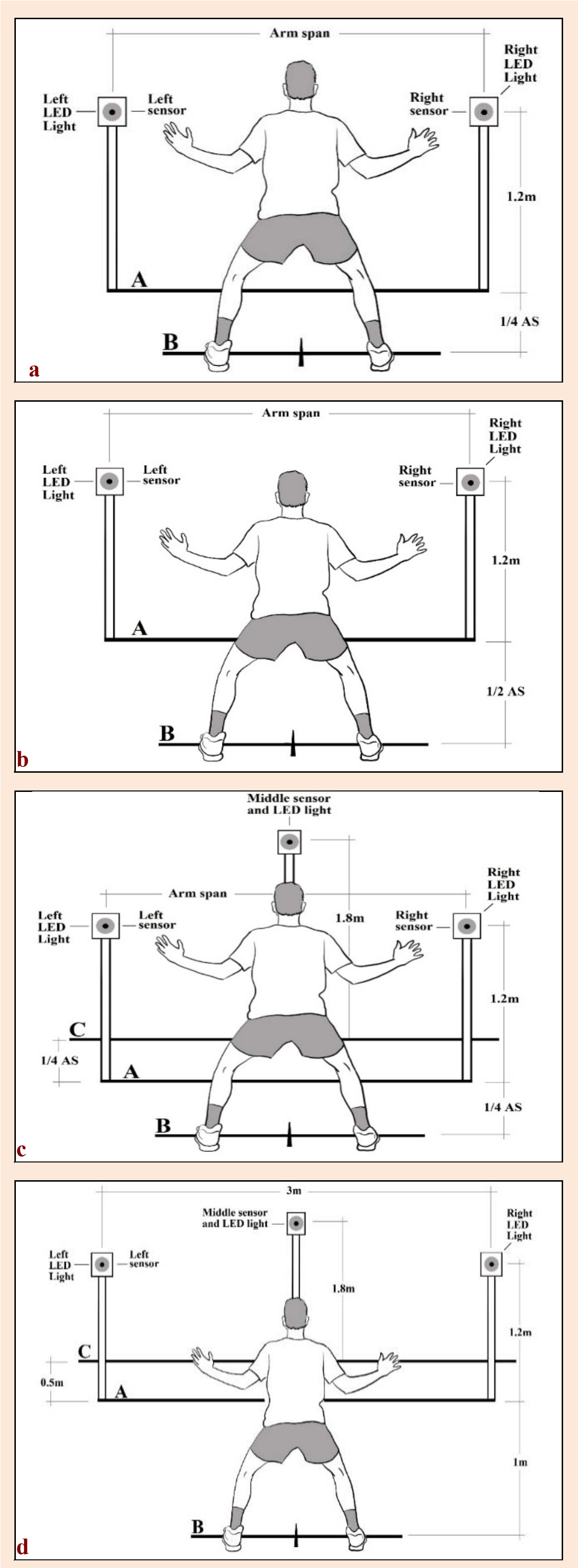

Figure 1. **Schematic representation of the newly developed Simple Response Time test (SRT), and Complex Response Time test (CRT) protocols: (a) SRT-1; (b) SRT-2; (c) SRT-3; (d) CRT. Legend: AS = arm span; A = the line that connects left and right sensor; B = the starting line; C = the line where the middle sensor is positioned.**

Table 1. Comparison between athletes involved in AG and NAG sports.

Variables	AG (n = 37) Mean ± SD	NAG (n = 10) Mean ± SD	t-test t (p)	Effect Size d (95%CI)	AUC
Age (years)	20.11 ± 2.85	20.03 ± 0.72	0.52 (0.59)	0.12 (-0.55 - 0.82)	0.38
Playing experience (years)	10.76 ± 3.86	10.40 ±2.98	0.27 (0.78)	0.09 (-0.60 - 0.79)	0.46
Body Height (m)	1.83 ± 0.11	1.79 ± 0.07	2.28 (0.04)	0.61 (-0.06 - 1.31)	0.28
Body Mass (kg)	79.61 ± 13.02	79.72 ± 6.32	0.84 (0.39)	0.2 (-0.45 - .91)	0.41
BMI (kg/m^2)	23.57 ± 2.06	24.75 ± 1.83	1.63 (0.11)	0.57 (-0.14 - 1.27)	0.60
Body fat (%)	15.11 ± 7.83	15.40 ± 9.81	0.11 (0.91)	0.04 (-0.65 - 0.74)	0.47
Arm span (cm)	190.62 ± 13.72	177.30 ± 7.27	2.94 (0.01)	1.05 (0.31 - 1.77)	0.22
SRT-1-L (ms)	279 ± 68	294 ± 54	0.61 (0.54)	0.21 (-0.48 -0.91)	0.59
SRT-1-R (ms)	287 ± 57	310 ± 78	1.05 (0.29)	0.37 (-0.33 - 1.07)	0.63
SRT-2-L (ms)	474 ± 76	476 ± 62	0.05 (0.95)	0.02 (-0.67 - 0.71)	0.49
SRT-2-R (ms)	453 ± 67	484 ± 58	1.3 (0.19)	0.46 (-0.24 - 1.16)	0.67
SRT-3-L (ms)	278 ± 104	305 ± 37	0.78 (0.43)	0.28 (-0.42 - 0.98)	0.75
SRT-3-M (ms)	355 ± 82	360 ± 64	0.17 (0.85)	0.06 (-0.63 - 0.76)	0.53
SRT-3-R (ms)	298 ± 99	310 ± 64	0.37 (0.7)	0.13 (-0.56 -0.83)	0.60
CRT-L (ms)	679 ± 79	867 ± 75	6.76 (0.01)	2.4 (1.54 - 3.25)	0.98
CRT-M (ms)	649 ± 112	819 ± 83	4.4 (0.01)	1.57 (0.79 - 2.33)	0.89
CRT-R (ms)	700 ± 79	863 ± 101	5.43 (0.01)	1.93 (1.12 - 2.73)	0.89
Norm-CRT-L (ms/cm)	3.67 ± 0.78	4.88 ± 0.30	4.75 (0.01)	1.69 (0.90 - 2.46)	0.81
Norm-CRT-M (ms/cm)	3.54 ± 0.97	4.61 ± 0.45	3.35 (0.01)	1.19 (0.44 - 1.92)	0.86
Norm-CRT-R (ms/cm)	3.80 ± 0.83	4.86 ± 0.56	3.81 (0.01)	1.35 (0.59 - 2.10)	0.71

SRT = simple response time test; CRT = complex response time test; L = left side; R = right side; M = middle; ms = milliseconds; Norm. = values normalized to arm span; SD = standard deviation; 95%CI = 95% confidence interval, BMI = body mass index; AG = agility-saturated sports; NAG = not involved in agility-saturated sports; t = values of the Student's t-test for independent samples; p = statistical significance (p value): d = effect size; AUC = area under the curve.

Results

The results of the Shapiro Wilk test showed that the data for all measures were normally distributed. Descriptive statistics were calculated for all tested variables including age, playing experience and anthropometric characteristics. RT increased with the increased distance between the sensors and the starting line and tests' complexity in both groups (Table 1).

Reliability and usefulness

The reliability and usefulness values of the RT tests are presented separately for the AG and NAG groups in Table 2. The absolute reliability for the SRT-2 and CRT tests was shown to be better than those of SRT-1 and SRT-3 tests in both AG and NAG groups with %CV ranging from 11.1 to 19.1% and from 5.7 to 9.8%, respectively. The relative variability for all RT tests in the AG athletes was shown to be better than in NAG athletes (ICC: 0.68 to 0.97 and 0.31 to 0.58, respectively). In the NAG group, the TE exceeded both $SWC_{(0.2)}$ and $SWC_{(0.5)}$ for all RT tests. In contrast, for each test in the AG group, the TE was only shown to be larger than $SWC_{(0.2)}$ whereas it was below the $SWC_{(0.5)}$.

Discriminative validity

Table 1 presents the descriptive statistics of the outcome variables and comparison values between the AG and NAG athletes. Independent t test revealed the RT of the AG was faster than that of the NAG group in the CRT from the left (p = 0.00, *d* = 2.40 [188ms differences]), middle (p = 0.00, *d* = 1.57 [169ms differences], and right sensor (p = 0.00, *d* = 1.93 [162ms differences]) locations. Normalized values for the same test also showed significant differences in RT at the left (p = 0.00, *d* = 1.69 [1.2ms/cm differences]), centre (p = 0.00, *d* = 1.19 [1.1ms/cm differences]), and right (p = 0.00, *d* = 1.35 [1.0ms/cm differences]) locations between the groups. There were non-significant differences between the groups in the SRT tests. Additionally, the groups differed in the AG athletes shown to be taller (p = 0.03, *d* = 0.64 [6.8cm differences]) and having a longer arm span (p = 0.00, *d* = 1.05 [13.4cm differences]) than the NAG athletes.The area under the curve (AUC) derived from the ROC curve analysis indicated good discriminative validity for the SRT-3 from the left sensor location (AUC: 0.75), the CRT from the left, middle and right sensor locations (AUC: 0.98, 0.89, and 0.89, respectively), and for the normalized CRT values from the left, middle and right sensor locations (AUC: 0.81, 0.86 and 0.71, respectively). Differences between the athletes involved in agility and those involved in agility nonsaturated sports in response time tests were presented in Figure 2.

Within and between test correlation

The within test correlation showed that within test performance (e.g., the RT values from the L, M and R sensors) shared between 49 and 81% variance (r = 0.80 and 0.79 for correlation between L and R performance in SRT-1 and SRT-2, respectively, r = 0.89, 0.85, and 0.78 for correlation between L and R, L and M, and R and M performances in SRT-3 and r = 0.77, 0.82, and 0.70 for correlation between L and R, L and M, and R and M performances in CRT, respectively (Table 3). The shared variance of the different SRT ranged from 10 to 35% (r = 0.33-0.59). In the meantime, the SRT tests and the CRT shared less than 10% variance (r = 0.00-0.33) (Table 3).

Discussion

Several important findings were obtained in this study. First, the newly developed tests aimed at the evaluation of sport-specific response time were shown in the AG athletes to be more reliable and functional than in the NAG athletes.

Table 2. Descriptive statistics, reliability and usefulness parameters for the response time protocols in AG and NAG athletes.

Response time Protocols	AG (n = 37)						NAG (n = 10)					
	Mean ± SD	CV%	TE	SWC0.2	SWC0.5	ICC	Mean ± SD	CV%	TE	SWC0.2	SWC0.5	ICC
SRT-1-L (ms)	279 ± 68	14.4	32.9	13.6	34	.87	294 ± 54	11.1	26.0	11.0	27.5	.83
SRT-1-L trial1 (ms)	299 ± 83						308 ± 77					
SRT-1-L trial2 (ms)	267 ± 71						290 ± 45					
SRT-1-L trial3 (ms)	273 ± 75						282 ± 61					
SRT-1-R (ms)	287 ± 57	12.5	27.5	11.6	29	.85	310 ± 78	11.5	32.3	15.8	39.5	.90
SRT-1-R trial1 (ms)	304 ± 65						317 ± 75					
SRT-1-R trial2 (ms)	281 ± 60						314 ± 99					
SRT-1-R trial3 (ms)	275 ± 72						298 ± 81					
SRT-2-L (ms)	474 ± 76	7.7	29.6	15.2	38	.91	476 ± 62	8.1	29.9	12.6	31.5	.90
SRT-2-L trial1 (ms)	490 ± 80						504 ± 64					
SRT-2-L trial2 (ms)	470 ± 87						456 ± 57					
SRT-2-L trial3 (ms)	463 ± 79						466 ± 80					
SRT-2-R (ms)	453 ± 67	7.2	26.8	13.4	33.5	.90	484 ± 58	10.2	41.4	11.8	29.5	.70
SRT-2-R trial1 (s)	460 ± 73						481 ± 72					
SRT-2-R trial2 (ms)	452 ± 69						500 ± 81					
SRT-2-R trial3 (ms)	447 ± 77						469 ± 69					
SRT-3-L (ms)	278 ± 104	12.2	24.4	21	52.5	.95	305 ± 37	15.4	41.8	7.4	18.5	.48
SRT-3-L trial1 (ms)	292 ± 111						345 ± 70					
SRT-3-L trial2 (ms)	271 ± 111						273 ± 46					
SRT-3-L trial3 (ms)	273 ± 105						296 ± 37					
SRT-3-M (ms)	355 ± 82	8.9	27.6	16.6	41.5	.92	360 ± 64	9.9	41.8	7.4	18.5	.89
SRT-3-M trial1 (ms)	361 ± 84						388 ± 88					
SRT-3-M trial2 (ms)	357 ± 97						358 ± 69					
SRT-3-M trial3 (ms)	347 ± 84						334 ± 48					
SRT-3-R (ms)	298 ± 99	9.8	25.6	19.8	49.5	.97	310 ± 64	19.1	54.4	13.0	32.5	.31
SRT-3-R trial1 (ms)	303 ± 101						324 ± 78					
SRT-3-R trial2 (ms)	304 ± 112						306 ± 125					
SRT-3-R trial3 (ms)	285 ± 93						299 ± 89					
CRT-L (ms)	679 ± 79	8.1	39.1	15.8	39.5	.68	867 ± 75	9.6	63.1	15.0	37.5	.58
CRT-L trial1 (ms)	679 ± 126						926 ± 116					
CRT-L trial2 (ms)	686 ± 86						829 ± 99					
CRT-L trial3 (ms)	670 ± 85						846 ± 88					
CRT-M (ms)	649 ± 112	8.2	37.2	22.6	56.5	.90	819 ± 83	6.7	38.7	16.8	42	.87
CRT-M trial1 (ms)	673 ± 123						868 ± 95					
CRT-M trial2 (ms)	650 ± 128						797 ± 85					
CRT-M trial3 (ms)	624 ± 119						789 ± 98					
CRT-R (ms)	700 ± 79	5.7	32.5	15.8	39.5	.85	863 ± 101	9.4	65.6	20.4	51	.77
CRT-R trial1 (ms)	713 ± 102						901 ± 115					
CRT-R trial2 (ms)	695 ± 84						868 ± 134					
CRT-R trial3 (ms)	691 ± 79						818 ± 117					

SRT = simple response time test; CRT = complex response time test; L = left side; R = right side; M = middle; ms = milliseconds; SD = standard deviation; CV%, coefficient of the variation; TE = typical error of the measurement; $SWC_{0.2}$ = smallest worthwhile change (0.2 x SD);$SWC_{0.5}$ = smallest worthwhile change (0.5 x SD); ICC = Intra-class correlation coefficient.

Second, only the CRT test aimed to measure response time of complex multijoint movements shown to be sensitive to discriminate the AG and NAG athletes. Third, the weak correlation between the SRT tests and CRT test suggests that response time of the single-limb movement and the complex multijoint movements should be observed as independent capacities.

Reliability and usefulness

Previous studies have frequently reported the relative reliability of different types of reaction, movement and response time measurements with ICCs ranging between 0.61 and 0.97 (Born et al., 2016; Eckner et al., 2015; Knoop et al., 2013; Langley and Chetlin, 2017; Spierer et al., 2010; Spiteri et al., 2013; Wells et al., 2014; Zouhal et al., 2018). This range is in line with the present results obtained in the AG athletes showing "good" to "excellent" relative reliability (ICC = 0.68-0.97) for all RT tests with somewhat lower values in the CRT test (i.e., L direction). This means that systemic and random errors are highest when the stimulus is presented at the left sensor position in the CRT test (Weir, 2005). Logically, the execution of the tests on the left side, and its relatively lower reliability, is almost certainly related to the fact that 71% of tested participants were right-handed, which directly resulted in "nondominancy" of the left side and, consequently, relative nonfamiliarity with the movement template performed on the left side (Zouhal et al., 2018). This has been directly confirmed in recent studies where authors compared reliability of the agility tests performed on dominant and nondominant sides (Sekulic et al., 2017). Moreover, Zouhal et al. (2018) reported that soccer players had significantly faster reaction time when the stimulus appeared on their dominant-eyed side.

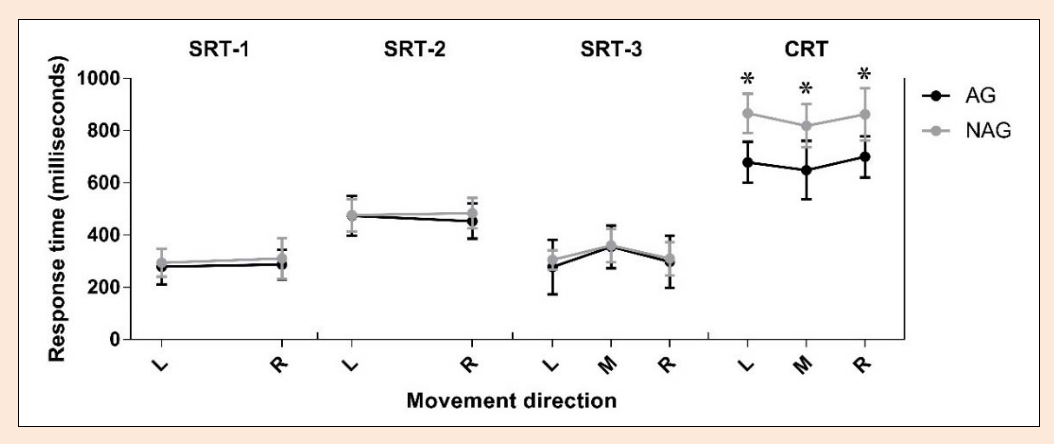

Figure 2. Differences between the athletes involved in agility and those involved in agility nonsaturated sports in response time tests. SRT = simple response time test; CRT = complex response time test; L = left side; R = right side; M = middle; AG = agility-saturated sports; NAG = not involved in agility-saturated sports; *= indicates values significantly different from those obtained in the NAG athletes at $p < 0.05$.

Table 3. Pearson's product-moment correlation coefficients (r) with 95% confidence interval (95% CI) between and within the reaction time tests (n = 47).

	SRT-1-R r (95% CI)	SRT-2-L r (95% CI)	SRT-2-R r (95% CI)	SRT-3-L r (95% CI)	SRT-3-M r (95% CI)	SRT-3-R r (95% CI)	CRT-L r (95% CI)	CRT-M r (95% CI)	CRT-R r (95% CI)
SRT-1-L	.80 (.67-.88)*	.59 (.36-.75)*	.61 (.39-.76)*	.51 (.26-.70)*	.43 (.16-.64)*	.44 (.17-.65)*	.18 (-.11-.44)	.10 (-.19-.37)	.18 (-.11-.44)
SRT-1-R		.51 (.26-.70)*	.58 (.37-.74)*	.41 (.16-.62)*	.33 (.05-.56)*	.41 (.16-.62)*	.22 (-.07-.48)	.21 (-.08-.47)	.24 (-.03-.49)
SRT-2-L			.79 (.66-.87)*	.33 (.05-.56)*	.36 (.08-.59)*	.37 (.09-.60)*	.17 (-.14-.44)	.11 (-.18-.38)	.18 (-.11-.44)
SRT-2-R				.33 (.05-.56)*	.30 (.01-.54)*	.40 (.15-.61)*	.31 (.05-.55)*	.16 (-.13-.43)	.33 (.06-.56)*
SRT-3- L					.85 (.74-.91)*	.89 (.81-.94)*	.12 (-.17-.39)	.00 (-.29-.29)	.00 (-.29-.29)
SRT-3-M						.78 (.66-.87)*	.12 (-.17-.39)	.23 (-.06-.48)	.12 (-.17-.39)
CRT-L							.11 (-.18-.38)	-.02 (-.31-.27)	-.01 (-.30-.28)
CRT-M								.70 (.50-.82)*	.77 (.66-.86)*
CRT-R									.82 (.70-.90)*

SRT = simple response time test; CRT = complex response time test; L = left side; R = right side; M = middle; 95% CI = 95% confidence interval; *= Statistical significance of $p \leq 0.05$.

However, lower consistency in the CRT test is not surprising and can be attributed to its higher complexity comparing to those of the SRT tests. Namely, it is established that the complexity of a test directly alters the consistency in the achieved testing results, and this is confirmed for tests of different conditioning capacities and various sports (Idrizovic et al., 2015; Pehar et al., 2018; Pojskic et al., 2018a; Sekulic et al., 2017). Specifically, the CRT performance always includes complex multijoint movements and longer traveling distance, which do not occur in the assessment of the SRT tests. Moreover, the CRT includes 3 stimulus-response alternatives compared to only 2 in the SRT 1 and 2 tests. These additional "covariates of performance" are natural sources of mistakes, potential sources of measurement error, and consequently factors that may alter the reliability (Sekulic et al., 2017). Therefore, the lower reliability of the CRT than the SRT tests may be attributed to the higher complexity of the CRT test.

Similarly, to the AG group, "good" to "excellent" consistency was seen for SRT tests 1 and 2 in the NAG group as well (ICC =0.70-0.90). In contrast, "poor" reliability was evidenced for SRT-3 and CRT tests in the NAG athletes (e.g., ICC =0.31-0.58). Again, these differences in the reliability between the tests are probably related to the test complexity. In particular, SRT tests 1 and 2 were certainly simple (e.g., a single arm movement), even for the NAG athletes, to be consistently executed across the attempts and trials, whereas the SRT 3 and CRT tests required more sport-specific motor proficiency to be consistently performed. It is reasonable to conclude that the NAG athletes due to their non-agility sport background had lower motor capacity to execute the tests that required fast reaction and multi-joint movement response. It seems that the relative reliability was more affected by test complexity in the NAG group than in the AG group, which is in line with several studies comparing performance levels (Pojskic et al., 2018a; Spasic et al., 2015).

Furthermore, the absolute reliability established by CV% values was shown in the NAG group to be lower than that in the AG group. This higher within-subject variation in the NAG group can be attributed to either lack of the required test-dependent motor proficiency that is more common in fast-action sports or the relatively small sample size of the NAG group (Buchheit et al., 2011). However, it should be noted that, although being "acceptable" (i.e., ≤10%) for all except the SRT-1test, the established absolute reliability is in general lower than previously reported for similar response time tests (i.e.,1.4-7.6% in sport science students) (Langley and Chetlin, 2017; Spiteri et al., 2013; Zemková and Hamar, 2013). One of the reasons that might compromise reliability may be the starting position of the hands before each attempt. Namely, although being required to hold a described "low and wide" position, the subjects could, even with small fluctuation in the hand position, increase variation in distance between the hands and sensors with each attempt, which could inherently increase RT, especially in the SRT tests.

Although this study was the first one to examine the test presented herein, we may suppose that a possible solution to reduce error was to remove the best and worst attempts and average the other three attempts for the analysis, as suggested by Quintana et al. (2007).

The usefulness of the tests was identified by comparing the TE and both the $SWC_{(0.2)}$ and $SWC_{(0.5)}$. For all of the tests, $SWC_{(0.2)}$ was shown to be "marginal" (i.e., TE > SWC) in both the AG and NAG groups. Furthermore, TE was similar to $SWC_{(0.5)}$ in SRT-1 and higher than $SWC_{(0.5)}$ for the other tests indicating "OK" and "marginal" usefulness, respectively, of the tests for the NAG athletes (Hopkins, 2004). In contrast, in the AG group, $SWC_{(0.5)}$ exceeded TE in all tests, showing "good" usefulness. In other words, the tests can be utilized to detect moderate changes that exceed 0.5 times the tests standard deviation showing "good" measurement usefulness in the AG athletes (Hopkins, 2004; Lockie et al., 2013).

The discriminative validity

The discriminative validity of four RT protocols was established by identifying differences between the AG and NAG athletes as previously suggested by Sekulic et al. (2014a). It was found that only the CRT test was able to discriminate AG and NAG athletes independently of their arm span, and there were no significant differences between the groups in the SRT tests. The lack of differences in the SRT tests is not unexpected. Namely, the SRT tests required only a simple motor performance (e.g., a single-arm movement) in response to the simple and "clear" visual stimuli (i.e., illumination of the LED light). Therefore, it seems reasonable to conclude that the SRT tests lacked fieldsports-related complexity, which in turn could cause athletes from both groups to go through their information processing stages (i.e., the stimulus-identification, the response-selection and the response-programming) in the same way and, as a result, have very similar RT performances.

More specifically, the provided visual stimuli lacked the sport-specific cues (e.g., movement of a ball or opponent player) (Frýbort et al., 2016; Sheppard and Young, 2006; Young and Farrow, 2006), which made the stimulus-identification stage equally simple for both groups. In short, a high performance level of athletes involved in fast-action sports is largely dependent on their pattern recognition ability (e.g., to recognize a body movement, ball spin direction, etc.), which is improved both by training and competition (Sekulic et al., 2014a; Sheppard and Young, 2006; Young and Farrow, 2006). On the other hand, one's ability to recognize the pattern is not crucial in closed-skill sports where athletes perform under stable and predictable conditions (Schmidt et al., 2018). Taking this into account, we can conclude that the lack of real game stimuli in the SRT tests reduces the possibility of AG athletes outperforming the NAG group.

Moreover, the required motor response in the SRT tests (i.e., single-arm or/and -leg movement) was simple and usual task for both groups. Consequently, both groups went through the response-selection and response-programming stage equally (Schmidt et al., 2018). In other words, the equal RT performance of both groups was due to the equal pre-knowledge of how to select and initiate the appropriate movement response. A lack of the movement complexity in the SRT tests simplified the response-programming stage and made the response simple for both groups. In other words, athletes from both groups stored the required motor program that they could easily retrieve and use to initiate an appropriate motor response. Consequently, simplicity of the task together with lack of sport-specific stimuli resulted in equal performance of both groups in the SRT tests.

Meanwhile, the AG group outperformed the NAG group in the CRT test. From the lack of significant differences between the groups in the SRT tests, we can conclude that the obtained difference in the CRT test was not due to their ability to recognize and react to the simple stimuli (e.g., LED-light) but rather was due to the test's sport-specific nature and motor task complexity that in a different way affected their response-programming stage. It has been reported that complex motor action increased RT due to a bigger number of motor programs needed to be retrieved from the memory, programmed and synchronized as a whole functional movement (Klapp, 1996; Schmidt et al., 2018). Compared to the SRT tests, the CRT test is more complex because of the inclusion of additional movement components (e.g., lateral multijoint movement) and increased accuracy demands (e.g., increased distance to the target), which in turn increased RT in both groups (Christina, 1992; Fischman, 1984). However, the test complexity in the NAG athletes increased response time more than in AG athletes. This finding is supported by results that presented differences between AG and NAG athletes in RT of complex motor tasks (Sekulic et al., 2014a; Zhongfan et al., 2002). Namely, Sekulic et al. (2014a) showed that athletes who were involved in agility-saturated sports outperformed those who were not in motor tasks that included change of direction speed in response to visual stimulus (i.e., reactive agility tests). Moreover, Zhongfan et al. (2002) reported that both experts and novice female soccer players performed better than the closed-skill athletes on speed and accuracy of motor execution in response to visual stimuli.

In line with this discussion, we can suppose that the AG athletes from the current study had both better connection between the central nervous system and muscles and enhanced ability to program motor tasks prior to execution of movement than those of the NAG athletes (Zhongfan et al., 2002). This made it possible for the AG athletes to have better motor control of their lower limbs, i.e., to move them faster and more accurately. Furthermore, the significant difference observed by subjects' CRT but not SRT performance suggests that sport-specific actions that include multijoint movement are motor skills that are improved through training in fast-action sports (Born et al., 2016; Legros et al., 1992; Makhlouf et al., 2018; Pojskic et al., 2018a; Quintana et al., 2007; Sekulic et al., 2014a; Zhongfan et al., 2002; Zisi et al., 2003). In other words, the AG athletes were constantly exposed to complex movements from various stimuli in training and competition that resulted in the different motor programs being well-learned, stored, programmed and retrieved from memory when needed (Henry and Rogers, 1960; Schmidt et al., 2018; Zhongfan et al., 2002). The bigger repertoire of stored motor programs (i.e., neuromotor memory) provided the AG players with advanced neuromotor coordination, that is to say, ability to rapidly and accurately format motor response, which resulted in quicker and higher quality task execution (Henry and Rogers, 1960; Zhongfan et al., 2002).

Moreover, the very weak correlation obtained between the SRT tests and the CRT test (i.e., between 0 and 10% of shared variance) support the previous discussion and provides strong evidence that the simple and complex tests measure independent neuromotor qualities. This finding is in line with a study by Zemkova and Hamar (2013), who found that the reactive agility tests while moving distances of 0.8 m (i.e., a rapid step execution) and 5 m (i.e., a sprint) shared approximately 7% variance. Consequently, the ability to quickly identify the visual stimulus *per se* and to select appropriate motor response was not something that differentiated the athletes in the CRT, but their ability to perform the required motor task. In that light, the findings emphasize a concept highlighted by Zhongfan et al. (2002) that "only knowing what to do (decision-making) and being able to do it (execution) are not necessarily related in ball-game sports".

Limitations

This study is not without limitations. First, the tests included simple reaction stimuli (i.e., response to LED lights) that reduced the external validity of the measurement. In other words, the stimuli do not provide game-specific cues (e.g., movement of an opponent, teammate or ball) that could increase the influence of the pattern recognition in the stimulus-identification stage during the required motor tasks and potentially make a bigger distinction between tested groups (Frýbort et al., 2016; Sheppard and Young, 2006; Young and Farrow, 2006). Second, the distance between the sensors was normalized to the subjects' arm span in the SRT tests, but the height of the sensors was the same for all, fixed at a height 1.2m for L and R sensors and 1.8m for the M sensor in the SRT-3 and CRT tests. This could differently affect the RT due to the different arm spans. More specifically, although all subjects were asked to keep the clearly defined starting position that would provide them the quickest movement initiation, the fixed sensor height could affect the distance from the subjects' hands and the sensors in athletes with different arm spans and thus affect the RT. Third, although the participants from both groups were selected based on performance and training level, the established differences may not be explicitly attributed to the group's affiliation *per se*; they may be a result of other non-controlled factors (i.e., physical capacities, sex). Fourth, although the variances were equal in the both groups, the number of participants in the NAG group could be higher to interpret the within-group differences with greater certainty. To obtain more valid data, further research may be needed to investigate the differences in the tests between different expertise levels. Moreover, in real game settings, players often react to external stimuli while dribbling the ball. Therefore, to increase the internal validity of the tests the inclusion of a simple ball handling technique is warranted (e.g., the initiation of the first step and dribbling in basketball in response to external stimulus).

Conclusion

This study confirms that both reliability and usefulness of the newly developed simple and complex response time tests were better in the AG group. Even though the usefulness of the tests is questioned to detect small performance effects in the AG athletes, the tests can detect moderate effects in RT in simple and complex motor tasks. Therefore, the proposed tests may be used as reliable and useful testing protocols aiming to measure RT in simple (i.e., single-joint) and complex (i.e., multijoint) motor tasks in AG athletes.

The results from present study indicate that the CRT test is a valid assessment tool of complex stimuli-response motor tasks in the differentiation of athletes who are involved in agility-saturated sports from those who are not. On the other hand, the SRT tests may be used as reliable testing protocols to evaluate RT in simple motor tasks irrespective of the sport affiliation. Furthermore, simple (i.e., single-joint) and complex (i.e., multi joint) motor tasks should be observed as distinct motor qualities. Therefore, to objectively evaluate them, independent testing of these qualities is warranted. In doing so, special attention should focus on familiarization with different testing protocols. This approach will enable each player to individually determine the most appropriate way to execute the test(s), which inherently will increase measurement consistency.

Moreover, the present findings suggest that the AG athletes had better ability to deal with complex response tasks than did the NAG athletes. This enhanced ability to rapidly program and execute complex motor tasks can be considered as one of the essential qualities required for advanced performance in agility-based sports. Therefore, coaches and conditioning specialists who work with field-sports athletes should be aware that development of rapid response time in complex motor tasks is mostly dependent on the training of neuromotor coordination (i.e., specific motor proficiency). This means that, in designing training programs, special attention should be focused on proper learning of various sport-related motor programs (i.e., playing technique) that once learned can be rapidly retrieved from neuromotor memory and formatted as an efficient motor response.

Specifically, the exercise program aimed at developing an advanced response time in complex motor tasks should involve several important aspects that improve specific neuromuscular patterns. First, the learning should start with generic closed-skill drills and gradually progressed to sport-specific opened-skill drills where athletes will be progressively exposed to various perceptual challenges (e.g., single to multistimuli response, simple to complex motor response) (Born et al., 2016). At the end of the learning continuum should be exercises that include decision-making and sport-specific "read and react" drills with real opponent(s) (e.g., "mirror drills", "one on one basketball play", etc.)(Gamble, 2006). Second, special attention should focus on development of hip abduction strength that in return would improve lateral acceleration by developing the ability of lower limbs to generate muscular force in the medial–lateral direction (McLean et al., 2004). Third, the "low and wide" starting position should be emphasized and instructed early in any player's development because it enables rapid movement initiation in all directions (Gamble, 2006).

Furthermore, improvements in the infrared (IR)-based movement-sensors technology allow more convenient testing of RT of ballistic movements, which means that a respondent will not be afraid of striking a "target" by rapidly executed movement toward it. Briefly, the technology will allow a subject to complete an RT test (i.e., to stop a timer) by placing a hand in front of the sensor (i.e., breaking an IR beam) without being required to touch or strike it as it is a case with touch or pressure sensors. This would prevent occurrence of the movement deceleration phase prior to reaching its maximum speed, which in turn would provide more valid data. Additionally, the developed tests and measuring system including an android based real-time data acquisition can enable trainers to detect bilateral differences (i.e., motor dominance or preference) and to create different multi-choice stimuli-response drills under both compatible and noncompatible conditions.

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Key points

- The newly developed response time tests showed to be reliable, valid and useful testing tools for athletes involved in fast-action sports
- The very weak correlation obtained between the simple response tests and the complex response test indicated that the test measures independent neuromotor qualities
- The agility athletes had advanced ability to rapidly program and execute complex motor tasks which can be considered one of the essential qualities required for advanced performance in agility-based sports.
- Development of rapid response time in complex motor tasks is mostly dependent on the training of neuromotor coordination (i.e., specific motor proficiency).
- Training of athletes involved in agility-sports should be focused on proper learning of various sport-related motor programs that once learned can be rapidly retrieved from neuromotor memory and formatted as an efficient motor response.

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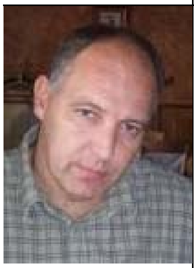

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