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ORIGINAL ARTICLE

Characteristics and determinants of repeated change of direction ability at multiple angles

Seita Kuki ✉ **.** *Associate Professor. Faculty of Human Sciences. Osaka University of Economics. Osaka, Japan.*
Ryu Nagahara. *Professor. Faculty of Sports and Budo Coaching Studies. National Institute of Fitness and Sports in Kanoya. Kagoshima, Japan.*
Yoshimitsu Nishizato. *Strength Coach. Professional Trainers Team Inc. Hyogo, Japan.*
Koji Akashi. *Associate Professor. Faculty of Human Sciences. Osaka University of Economics. Osaka, Japan.*

ABSTRACT

This study examined repeated change of direction (RCOD) performance across three angles (45º, 90º, and 180º) and its relationship with physical fitness indicators. Seventeen male collegiate handball players performed RCOD tests involving 10 sprints, with mean time and percentage decrement score (Sdec) used as performance metrics. Physical fitness tests included one repetition maximum (1RM) squat, Yo-Yo IR1 test, countermovement jump (CMJ), drop jump (DJ), and 40 m sprint. Results showed that mean time was slower and Sdec was larger at 180º, indicating greater physiological and mechanical demands compared to smaller angles. A significant correlation was found between mean time and Sdec only at 180º, highlighting its sensitivity to fatigue development. Furthermore, mean time correlated with Yo-Yo IR1 performance at all angles, but no significant associations were observed between Sdec and other fitness indicators. These findings suggest that the 180º RCOD test could be used to impose higher physical demands on athletes, while the Yo-Yo IR1 test can be altered with RCOD tests to assess aerobic ability more in line with sport-specific movements. Coaches and athletes can use this information to tailor training programs based on sport-specific demands, optimizing RCOD angles to enhance performance and manage athlete fatigue effectively.

Keywords: Performance analysis, Sprint performance, Agility, Physical fitness, Team sports.

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✉ **Corresponding author.** *Faculty of Human Sciences, Osaka University of Economics, 2-2-8 Osumi, Higashi Yodogawa-ku, 533-8533, Osaka, Japan.*
E-mail: s.kuki@osaka-ue.ac.jp
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INTRODUCTION

Repeated sprint ability (RSA), the capacity to repeatedly exert maximal effort sprints interspersed with short recovery periods, is widely recognised as a crucial physical ability of athletes in intermittent sports. Generally, the fastest and mean times of repeated sprints, as well as the percentage decrement score (S_{dec}), have been used as indicators of RSA performance (Girard et al., 2011). Physiologically, phosphocreatine resynthesis (Bogdanis et al., 1996) and maximum oxygen uptake (McGawley and Bishop, 2008) influence indicators of RSA performance. Previous studies reported that these indicators are related to player performance levels in handball (Buchheit et al., 2010) and the total sprint (>7 m/s) distance in a soccer match (Rampinini et al., 2007). Therefore, RSA is one of the physical determinants of ball gameplayers' performance.

The RSA test protocol usually consists of sprints with a change of direction (COD) of 180º and a short recovery period between bouts. Stojanovic et al. (2012) reported an S_{dec} of 3.5% in elite basketball players using a protocol that consisted of 10 shuttle sprints of 30 m with 180º COD and 30 s passive recovery. Buchheit et al. (2010) demonstrated that repeated COD (RCOD) sprints at 180º have a greater impact on sprint time and physiological response than a protocol consisting of straight-line sprints without COD. Specifically, the mean time of RCOD at 180º was 1.2 s slower than the test consisting of repeated straight-line sprints without any COD, while the blood lactate concentration was 0.7 $mmol·L^{-1}$ higher than that in repeated straight-line sprints. In match situations, players are required to repeatedly perform COD sprints at various angles. Moreover, COD performance is angle-specific and requires different motor abilities at each angle (Young et al., 2001). Although RCOD tests at various angles, including 100º (Wong et al., 2012) and a combination of 180º and 90º (Daneshfar et al., 2018), have been implemented, studies comparing the indicators of RCOD performance at different angles are limited. To the best of our knowledge, only one study has examined the influence of small differences in COD angles on RCOD performance. Buchheit et al. (2012) compared the indicators of RCOD performance, such as the fastest time, mean time, and S_{dec}, among different angle conditions (straight-line, 45º, 90º and 135º) and showed small-to-large correlations in S_{dec} among different RCOD angles (r = 0.33–0.75), indicating that S_{dec} is likely a common factor among angles. They also found that S_{dec} was 2.2% higher in the RCOD at 135º than in the RCOD at 45º. Thus, larger COD angles impaired COD sprint performance and induced a greater physiological load during RCOD. Although Buchheit et al. (2012) provided general differences in RCOD performance among angles, they did not include the RCOD at 180º, which has been widely used (Stojanovic et al., 2012). Examining the differences in RCOD performance at 180º and other smaller angles would be helpful for our understanding of the angle-specific differences in RCOD for training and assessment purposes.

Investigating the relationship between RCOD performance and physical fitness indicators, such as strength and aerobic capacity, is useful because it may suggest strength and endurance training levels that can enhance players' RSA. Previous studies demonstrated that the total sprint time of the RSA test correlates with countermovement jump (CMJ) height (Stojanovic et al., 2012), straight-line sprint time (Pyne et al., 2008) and running distance in the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Daneshfar et al., 2018). However, the relationships between RCOD performance at multiple angles and physical fitness indicators remain unknown. Different COD angles may have varying associations with physical fitness indicators because the force production required during COD is angle-specific. For instance, COD at 45º does not require large braking and propulsive forces, whereas those at 90º and 180º require the use of a sideway leaning posture and sufficient lateral force to the ground to successfully change direction (Buchheit et al., 2012). Understanding the angle-specific association between RCOD performance and physical fitness is beneficial when considering a training programme based on a specific COD angle that is frequently performed in a match.

This study aimed to investigate the differences and relationships in performance indicators among three different angles (45º, 90º, and 180º), hypothesizing that S_{dec} was greater and more strongly correlated with mean time at RCOD with COD at 180º than at 45º and 90º. Additionally, this study explored the connection between RCOD performance and physical fitness measures, expecting that RCOD performance at 180º would be more strongly influenced by physical fitness. These findings would be helpful for coaches and athletes in selecting appropriate RCOD angles for training and testing.

MATERIAL AND METHODS

Participants

Seventeen male collegiate handball players with at least 3 years of specific training experience participated (age, 19.6 ± 0.8 years; stature, 178 ± 6 cm; body mass, 74.0 ± 7.9 kg). They were fully informed of the aims, risks of involvement, and experimental conditions of this study, and each provided written consent before participating. This study was approved by the Research Ethics Committee of Osaka University of Economics (Approval No. 2020-H03).

Measures and procedures

Six test sessions were performed at 48-h intervals (to avoid fatigue) between sessions. All participants performed a strength test (one repetition maximum [1RM] of squat) in the first session, a Yo-Yo IR1 test in the second session, and 40 m straight line sprint and jump tests including CMJ and drop jump (DJ) in the third session. For the fourth to sixth sessions, participants performed RCOD tests at one angle (45º, 90º, or 180º) per day with angles randomly assigned (Figure 1). The test sessions were conducted in the university's gymnasium (urethane surface) except for the first 1RM session (weight training room). The participants wore their own handball shoes for all tests.

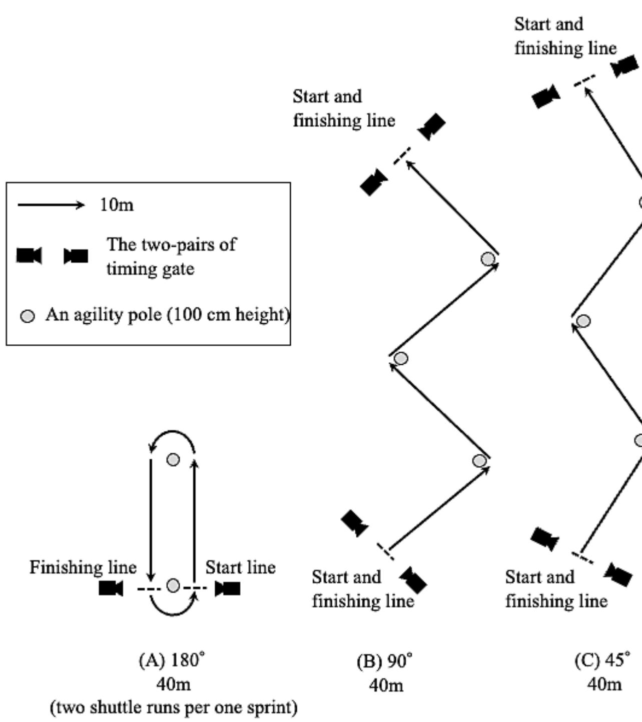

Figure 1. Description of the running courses, that were matched the distance and number of COD, for the RCOD with three different angles (A: 180º, B: 90º, C: 45º).

Repeated change of direction

The participants performed 10 COD sprints at each of the three different COD angle conditions (45º, 90º or 180º) with 30 s passive recovery (Figure 1). Agility poles (100 cm tall) were placed at the points where participants changed direction to standardise the COD movement and angle among the participants. Since agility poles were also placed in the RCOD test at 180º to match the other experimental conditions at 45º and 90º, RCOD sprints at 180º were not the same experimental setting as the usual shuttle type of COD testing, such as pro-agility and the 505 agility test. During RCOD test, participants walked back to the starting line after through the finish line and waited for the next sprint. The time for each sprint was measured using two timing gates (photocell placed 1.0 m from the ground) placed at the start and finish lines (Witty, Microgate, Italy). The participants started 0.3 m behind the start line to avoid early triggering. Verbal feedback, including sprint time and time countdown to the next start, was provided during the rest periods. The participants were instructed to complete all sprints as fast as possible without pacing themselves, and strong verbal encouragement was provided during each. The fastest time, mean time of 10 sprints, and S_{dec} were calculated to assess RCOD performance at each angle. S_{dec} was calculated as follows (Girard et al., 2011):

$$S_{dec}\ (\%) = (\text{total time} \times \text{ideal time}[\text{fastest time} \times 10]^{-1} - 1) \times 100$$

The ideal time was the fastest time at which the participants were able to complete the 10 sprints. The S_{dec} was selected as an indicator of intra-test fatigue development (Glaister et al., 2008).

Physical fitness tests

The participants performed a parallel back squat 1RM test to assess maximum strength. They were instructed to lower their bodies until their thighs were parallel to the floor. The participants performed three maximal 1RM trials with a 3-min rest period between them. They were instructed to perform three to five repetitions with approximately 80% of the estimated 1RM as a specific practice after a 10-min general warm-up. Because the participants were accustomed to the 1RM testing, they started from their estimated 1RM and increased by 2.5 kg if successful. The Yo-Yo IR1 was performed as described by Bangsbo (1994). The test was completed when the participant failed to reach the finishing line twice within a specific time at any stage and the total distance covered during the test was measured. Vertical jump tests, such as the CMJ and DJ, were also performed using a force plate at 1000 Hz (Ex-jumper, DKH, Japan).

The participants performed two trials for each jump modality in one trial. The participants were instructed to keep their hands on their hips throughout the jumps to eliminate the influence of arm swinging. Moreover, the participants were instructed to jump as high as possible for CMJ and jump as high as possible with a minimum contact time for DJ. For the DJ test, the participants dropped from a 30 cm high box to a force plate without jumping up before the drop and then immediately jumped up as high as possible after contacting the force plate. CMJ height was calculated as described by Chavda et al. (2018) using ground reaction forces. Since DJ can assess jump performance versus CMJ, assessing the DJ index would increase our understanding of the participants' physical characteristics. The DJ index, calculated as the jump height divided by the contact time, was used to assess DJ performance. The trials with the greatest CMJ height and the greatest DJ index were further analysed. Moreover, the 40-m sprint time was measured using two timing gates (Witty, Microgate, Italy). The timing gates were placed 0 and 40 m from the start line, and the photocell was positioned 1 m from the ground. The participants self-started from 0.3 m behind the start line to prevent early triggering. Each participant sprinted twice, and a passive rest exceeding 2 min was provided between trials. A faster 40-m time was used for the further statistical analysis.

Analyses

Descriptive data are presented as mean, standard deviation, and coefficient of variation (CV). A two-way analysis of variance (ANOVA) (angles × sprint repetitions) was performed to examine the differences in the indicators of RCOD performance (fastest time, mean time of 10 sprints, and S_{dec}) among the different angles (45º, 90º, and 180º) and among the sprints within each angle condition as well as the interaction between angles and sprints. Furthermore, the RCOD indicators were compared among angles using one-way ANOVA and post hoc Bonferroni's multiple-comparison test. Partial eta squared (η^2) was calculated as the effect size. Pearson's correlation coefficients were computed to test the relationships between the RCOD indicators and physical fitness measures. The threshold values for the interpretation of correlation coefficient as an effect size were 0.1 (small), 0.3 (moderate), 0.5 (large), 0.7 (very large), and 0.9 (extremely large) according to Hopkins et al. (2009). All statistical values were calculated using SPSS ver. 25 (IBM, Tokyo, Japan), and values of $p < .05$ were considered statistically significant.

RESULTS

Figure 2 shows the changes in sprint time during RCOD tests at each angle. The time differences between the first and tenth sprints during the RCOD test were 0.37 s at 45º, 0.68 s at 90º and 1.17 s at 180º. Two-way ANOVA (angles × sprints) revealed a significant interaction between angle and sprint ($F = 13.96$, $p < .001$, partial $\eta^2 = 0.47$). There were time differences between the first and second sprints from 180º onwards. In contrast, a decline from the first sprint time was observed in the third and fourth sprints at 90º and 45º, respectively.

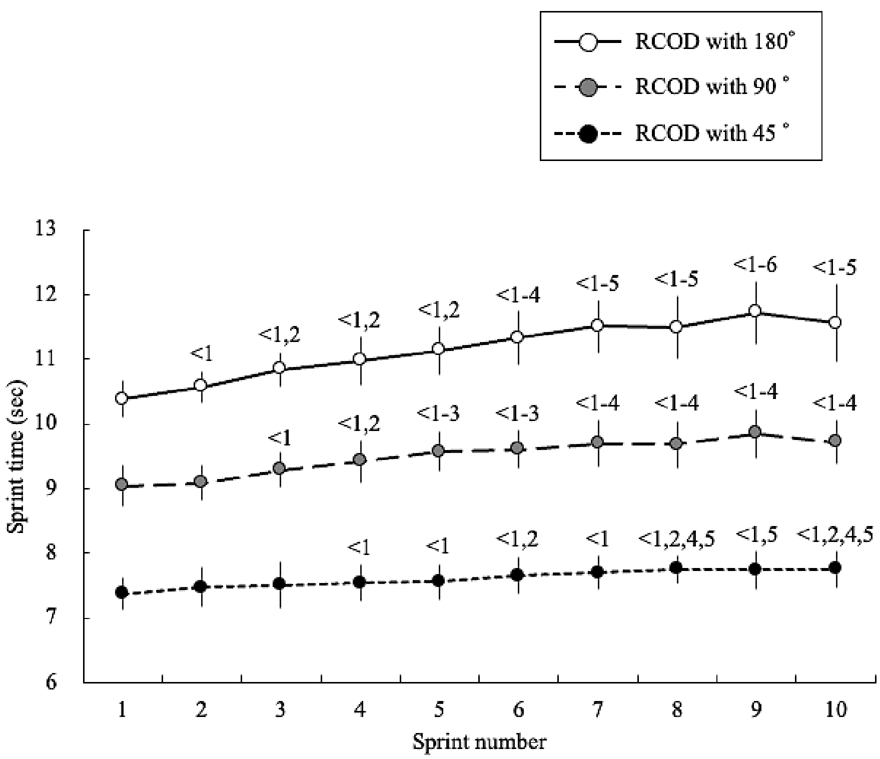

Figure 2. The impairment of sprint time induced by the fatigue in each angle. The black line and white circle is for RCOD with 180º, the dashed line and grey circle is for RCOD with 90º and the dotted line and black circle is for RCOD with 45º.

There were differences in the fastest time (F = 2344.89, $p < .001$, partial $\eta^2 = 0.99$), mean time of 10 sprints (F = 2808.72, $p < .001$, partial $\eta^2 = 0.99$), and S_{dec} (F = 24.35, $p < .001$, partial $\eta^2 = 0.60$) among angles (Figure 3). A post hoc multiple analysis revealed that the fastest time and the mean time of 10 sprints were significantly slower and S_{dec} was significantly larger in the RCOD at 180º than those at 90º and 45º.

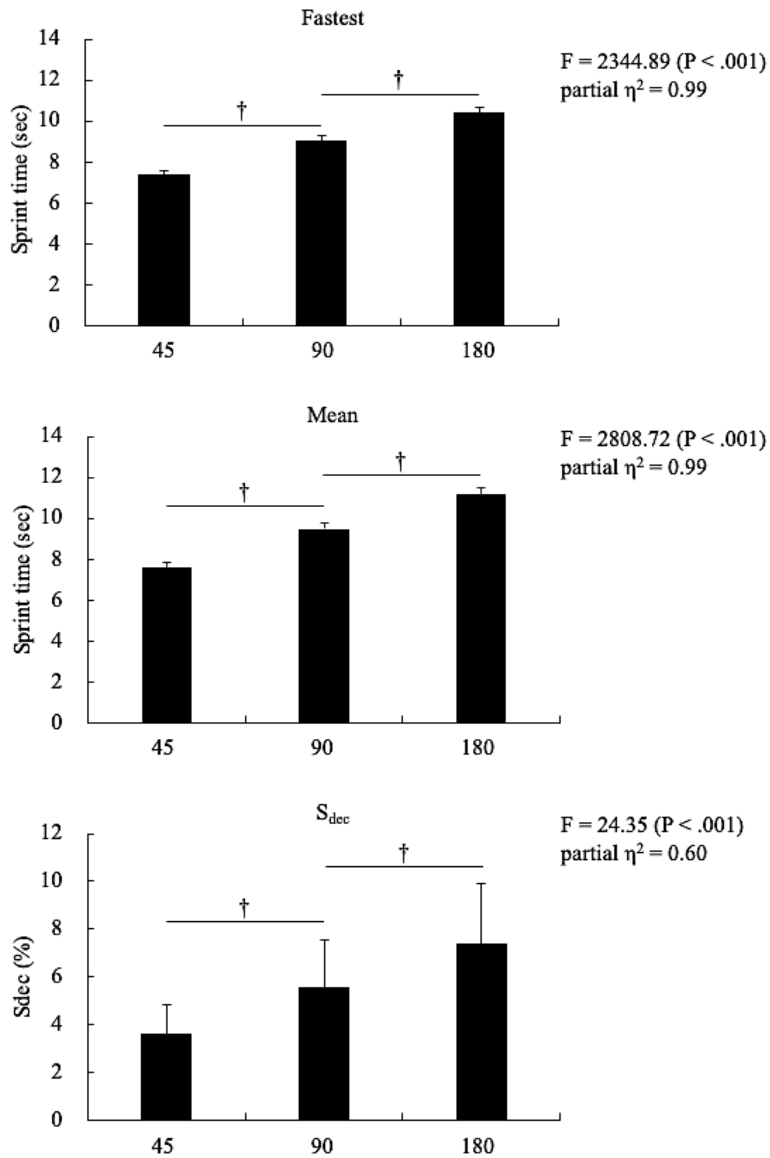

Figure 3. The comparison of indicators of RCOD between different angles. †: significant difference at $p < .05$.

The fastest time was positively correlated with the mean time of 10 sprints at each angle (r = 0.64–0.94) (large to extremely large effects) (Table 1). S_{dec} correlated with the mean time of 10 sprints at 180º (r = −0.50, large effect), but there was no correlation between S_{dec} and the mean times of 10 sprints at 45º and 90º. S_{dec} was not correlated with any of the physical fitness test variables (−.414 < r < .117). Mean times of all conditions were correlated with Yo-Yo IR1 performance (Table 2).

Table 1. Correlation coefficients between RCOD indicators in each angle.

	Mean	S_{dec}
45°		
Fastest	.937 (***p* < .001**)	−.285 (*p* = .268)
Mean	1	.065 (*p* = .804)
90°		
Fastest	.793 (***p* < .001**)	−.439 (*p* = .078)
Mean	1	.198 (*p* = .446)
180°		
Fastest	.700 (***p* = .002**)	−.064 (*p* = .808)
Mean	1	.502 (***p* = .040**)

Note. Bold font indicates statistically significant result. Fastest: the fastest time of 10 sprints, Mean: the mean time of 10 sprints, Sdec: the percentage decrement score from the1st sprint to the 10th sprint.

Table 2. Correlation coefficient between mean time and the physical performances in each angle.

	45°	90°	180°
1RM/BM	−.270 (*p* = .295)	−.144 (*p* = .580)	−.055 (*p* = .833)
CMJ	−.410 (*p* = .102)	−.394 (*p* = .118)	−.384 (*p* = .128)
DJ-index	−.400 (*p* = .112)	−.228 (*p* = .379)	−.351 (*p* = .167)
40 m sprint time	.521 (***p* = .032**)	.225 (*p* = .386)	.286 (*p* = .265)
Yo-Yo IR1	−.610 (***p* = .009**)	−.776 (***p* = .000**)	−.676 (***p* = .003**)

Note. Bold font indicates statistically significant result. 1RM/BM: 1 repetition maximum divided by the participant's body mass, CMJ: Counter movement jump, DJ-index: Drop jump index, Yo-YoIR1: Yo-Yo Intermittent Recovery Test Level 1.

DISCUSSION

This study compared RCOD performance at different angles and examined the association between RCOD performance and physical fitness test variables. The main findings were: 1) the fastest and mean time were slowest and S_{dec} was the largest at 180º RCOD; 2) mean time was correlated with the fastest time at all angles while S_{dec} was correlated with the meantime only at 180º RCOD; and 3) there were significant relationships between mean time at all angles and Yo-Yo IR1 performance.

For the RCOD performance at different angles, this study revealed that steeper COD angles could diminish both the fastest and the mean time of 10 sprints in RCOD tests. Moreover, the magnitude of impairment in sprint times in all 10 sprints was larger at 180º than at 45º and 90º according to the two-way ANOVA results. These results supported our hypothesis that S_{dec} was greater at the 180º RCOD than at the 45º and 90º RCOD, demonstrating the difference in the magnitude of fatigue development. It was also supported be a previous study that larger COD angles impose higher physiological and mechanical loads on the athletes than smaller COD angles (Buchheit et al., 2010). In terms of physiological load, previous studies revealed that RCOD at 180º elicited higher oxygen uptake during the RCOD test as well as higher blood lactate concentration after the test than repeated straight sprints without acute COD (Buchheit et al., 2010; Hader et al., 2014). While, in terms of mechanical load, the higher S_{dec} in RCOD at 180º compared to the 45º and 90º conditions in this study can be partly explained by the amount of muscle activation during the braking and accelerating phases in COD. For instance, COD at 180º requires higher eccentric and concentric muscle activation to produce larger braking and propulsive forces than COD at smaller angles (Buchheit et al., 2012). Accordingly, coaches and athletes should choose RCOD angle according to training purpose because a steeper COD angle imposes a greater impairment on sprint speed and higher physiological and mechanical loads.

Regarding the association between RCOD indicators, the mean time of 10 sprints was correlated with S_{dec} at 180º RCOD, although there were no significant associations between the mean time of 10 sprints and S_{dec} at 45º and 90º RCOD. The correlation analysis also supported our hypothesis that S_{dec} was more strongly correlated with the mean time at 180º RCOD than at 45º and 90º RCOD. The mean time of 10 sprints could be a useful and easy parameter for coaches and athletes to understand RCOD test results. Thus, the mean time of 10 sprints is usually adopted as the main indicator of RCOD performance. It could be advantageous to assess fatigue development using the mean time of 10 sprints in RCOD at 180º because of the large association between the mean time of 10 sprints and S_{dec} at 180º ($r = .502$). Daneshfar et al. (2018) also reported a positive correlation ($r = .599$) between total time, a similar parameter to the mean time of 10 sprints, and the fatigue index during RCOD at 180º, supporting our results. Meanwhile the mean time of 10 sprints of RCOD sprints at 45º and 90º did not correlate with S_{dec}. Therefore, it should be noticed that the mean time of 10 RCOD sprints did not directly reflect the amount of fatigue development at 45º and 90º RCOD.

There were no significant associations between S_{dec} under any angle condition, and mean time at all angles was correlated with Yo-Yo IR1 performance. It was not found any specific associations between RCOD performance and physical fitness measures in RCOD at 180º, not supporting our hypothesis. We expected that 1RM/BM and jump performances were associated with RCOD performance due to the greater braking and propulsive forces required at an RCOD of 180º (Buchheit et al., 2012). Although it is difficult to elucidate the reason for the non-significant associations at any angle condition between RCOD performance at 90º and 180º and physical fitness except Yo-Yo IR1 in this study, these results indicate that RCOD performance can be used to assess physical fitness ability other than strength and jump ability. While, based on the significant associations between mean time and Yo-Yo IR1 performance, coaches and athletes can consider altering the Yo-Yo IR1 test into an RCOD test to better reflect sport-specific movements.

CONCLUSIONS

This study demonstrated that the mean time of 10 sprints was slower and S_{dec} was greater in the 180º than the 45º and 90º conditions. Furthermore, mean time of 10 sprints at all angles was associated with Yo-Yo IR1 performance. Therefore, an RCOD of 180º is encouraged when coaches intend to apply higher physiological and mechanical loads on their athletes or assess the magnitude of fatigue development via the mean time of 10 sprints of RCOD.

AUTHOR CONTRIBUTIONS

Seita Kuki led the research, designed the study, collected and analysed data, and drafted the manuscript. Ryu Nagahara contributed to data analysis and manuscript writing. Yoshimitsu Nishizato contributed to data collection and analysis. Koji Akashi contributed to study design and manuscript writing. All authors reviewed and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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This study was conducted in compliance with the current laws and ethical guidelines of Japan, where the research was performed, and was approved by The Japan Society of Coaching Studies.

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