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Adaptive Regulation in a Stable Performance Environment: Trial-to-trial Consistency in Cue Sports Performance

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Abstract

This study aimed to investigate individual trial-to-trial performance in three tests to define adaptive regulation as a key feature of expertise in 9-ball. Thirty-one male players were assigned into the low-skilled (n = 11), intermediate (n = 10), or high-skilled groups (n = 10). The power control, cue alignment, and angle tests were selected to assess participants' ability to control the power applied in shots, strike the ball straight, and understand the ball paths, respectively. Error distance and correction of error distance were identified for each shot using 2D video analysis. Results of one-way ANOVA showed that the high-skilled group performed better in 2 out of the 3 tests than the other two groups ($p = 0.010$ for the cue alignment test, $p = 0.002$ for the angle test). However, the adaptation effect represented by the decreased error distances across trials was not observed. Pearson's correlation revealed only a few significant correlations between the error distance and its correction within each participant in all tests ($p < 0.05$) and hence, the hypothesis that 'low correction happened after small error and vice versa' is not supported.

Keywords: 9-ball, pool, billiards, error, correction

Introduction

In sports, the evaluation of performance can be helpful for training (D'Isanto et al., 2019) since sportspersons benefit from the feedbacks cornering error information about sports performance (Winstein & Schmidt, 1990). When evaluating sports performance and identifying errors, video-assisted analyses are widely employed. For instance, 2D video analysis was used to quantify the positions of the darts in dart-throwing tasks (Ong et al., 2015). In the dart-throwing study, a vertical error, which referred to the vertical distance between the dart at the release time and the bull's eye (center of the target), was measured to evaluate the performance. The smaller the vertical error, the better the performance. Similarly, in snooker (Chung et al., 2014) and 9-ball (Pan, Komar, & Kong, 2021), which also require precision, error distances were also obtained based on the video analyses as the distance between the end position of the ball and the preset target. Additionally, a study on pool measured the directional error (the angle between the correct line for pocketing the ball and the actual ball path towards the pocket) to present the shot performance in each shot (Haar et al., 2020). However, many of these studies solely considered the 'absolute' error which was the distance from the positions of the darts/balls to the preset targets (Chung et al., 2014; Ong et al., 2015) or the 'absolute' directional error (Haar et al., 2020). These 'absolute' errors could show the amplitude of error but lacking information regarding the 'direction' of the error (e.g., too high / too low, too short / too long, further right / further left). By giving the results 'positive' signs, in the study on darting throws (Ong et al., 2015), a 'positive' vertical error may indicate that the dart position is too high and above the bull's eye. A 'negative' error distance in the power control test in the study on snooker (Chung et al., 2014) would illustrate that 'too less' power was applied in the shot. Hence, reporting the number of errors along with 'positive' and 'negative' signs may enrich test results.

In the previous studies on sports, descriptive feedback such as error correction were reported to help enhance sports performance, which can be explained by the interactions of the task and individuals' ability to correct deviations and errors during expertise acquisition (Seifert et al., 2013). For example, feedback was reported to effectively improve players' skills in football (Smith & Ward, 2006; Stokes et al., 2010) and performance in badminton (Tzetzis et al., 2008). Concerning the acute effect of the error information, players/participants are also expected to perform better and better by learning from previous trials in a task involving repeated trials. In a face categorization task conducted by Reimers and Maylor (2006), participants were informed the results (right or wrong) immediately after each test. They found that participants improved their performance substantially towards the end of the tasks, as reflected by the reduced reaction time and error rates. In precision sports such as dart throw (Ong et al., 2015) and snooker (Chung et al., 2014), players can be self-informed about the errors by observing the end positions of the darts/balls with respect to the target. This error information could positively or negatively influence the subsequent attempts (Stokes et al., 2010). A previous study on pool (Haar et al., 2020) has reported a learning curve as the directional error decreased over the 200 repeated trials during the one-visit experiment session, with the greatest decay shown in the first 50 trials.

More than merely exhibiting a particular movement pattern, adaptability or flexibility has been demonstrated to be a key feature of expertise in sports (Seifert et al., 2013; Shadmehr et al., 2010). In that sense, expert performers may show specific strategies in correcting their trial-to-trial performance as they are more able to adapt their past movement to reach the task goal. Motor variability should be actively controlled and this process is called adaptive regulation (Dhawale et al., 2019). Given that sportspersons are expected to show an ‘adaptation effect’ in repeated bouts, it would be of interest to investigate the amplitude (i.e., how much the error is) and direction (i.e., the error is too high / too low, too short / too long, or further right / further left) of the error and how error correction is executed in subsequent trials.

In the present study, a series of 9-ball shots was proposed to investigate players’ error and the error correction. Nine-ball is included in the family of cue sports, played with a cue stick on a rectangular table. In a study comparing expert, intermediate, and novice snooker players, it was found that the expert group was superior in sport-specific perceptual recall and recognition tasks (Abernethy et al., 1994). In addition, similar finding was reported in swimming, where the authors concluded that the expert’s advantage is not a general but a specific one, arising from acquired processing strategies (Komar et al., 2015). In the existing literature on cue sports, specific tests have been developed to evaluate players’ skill levels, such as power control test, cue alignment test, and angle test (Chung et al., 2014; Pan, Komar, & Kong, 2021). These tests have been shown to successfully discriminate among cue sports players of different skill levels, where the error distances of 10 trials were averaged to present the performance of each test (Chung et al., 2014; Pan, Komar, & Kong, 2021). While it is not surprising that skilled players had smaller errors and higher consistency than less skilled counterparts in cue sports, traditional statistical analysis may mask the individual optimization and adaptation capacity in sports performance by averaging the trials (Davids et al., 2008; Davids & Araújo, 2010; Pan, Komar, & Kong, 2021). Thus, it is necessary to further explore how individual players improve their performance from trial to trial instead of simply taking the averaged results of all trials (Davids & Araújo, 2010).

This study, therefore, aimed to investigate the individual trial-to-trial performance of selected 9-ball shots in order to define adaptive regulation as a key feature of expertise. Firstly, it was hypothesized that the high-skilled players would perform better than low-skilled players and show an adaptive regulation with errors decreased across repetitions. Secondly, it was expected that skilled players would be able to make high correction when the performance error is large and low correction when the performance error is small. On the other hand, low-skilled players would neither be fully attuned to the relevant information to effectively correct their error nor have the required motor skill to do so. Thus, the second hypothesis was that the adaptation effect would be less pronounced in low-skilled players. Their error correction would be more stable across the trials and not adapted to the error level (i.e., unable to modify regardless of small or large errors).

Methods

Participants

This study was approved by the Nanyang Technological University Institutional Review Board (IRB number: IRB-2019-05-013). All participants provided written informed consent to participate. Thirty-one male 9-ball players were recruited from the national cue sports team of Singapore, university teams of Nanyang Technological University and Singapore Management University, and recreational population. All participants were active 9-ball players at the time of the current study, and they all had minimally one-year playing experience. Participants who had any history of surgery on the upper body, or experienced pain or discomfort during the experiment were excluded.

Before the commencement of the experiment, participants were required to warm up on the experiment pool tables for approximately 10 minutes. A new set of pool balls (diameter: 57.2 mm, Cyclop ZEUS Tournament TV set, Xinzhan Co., LTD, Shanghai, China) was used. Two pool tables at two different venues were used for the current experiment. Both pool tables were standard 9-ball tables with the same dimension (Figure 1a, 9 feet; height: 0.8 m; playing surface: 2.45 m × 1.27 m). Throughout the experiment at both venues, a digital camera (30 Hz, model EX-100, Casio Computer CO., LTD, Tokyo, Japan) was applied to record the ball movements on the pool tables. The digital camera was mounted on a tripod besides the pool table. Next, a 15-ball test was administrated in order to define groups in different skill levels, whereby the number of the potted balls was recorded for each participant. The 15-ball test is a common training drill during training process (Capelle, 2006; Eckert, 2015). The participants were required to try to pot the 15 object balls that were set in a straight line on the pool table center as many as possible. In each of three trials, the participants were given only one chance to pot the balls consecutively. The trial would end immediately if the participants failed to pot an object ball. According to the test results (the sum of the best two out of three trials, and hence maximum 30 balls) (Pan, Komar, & Kong, 2021), the participants were assigned into three groups: low-skilled [n = 11, potted 4.9 (1.9) balls, age 26.1 (2.3) years old, height 1.72 (0.05) m, body mass 66.3 (9.9) kg, playing experience 3.5 (3.9) years], intermediate [n = 10, potted 11.0 (2.2) balls, age 23.0 (3.2) years old, height 1.76 (0.05) m, body mass 73.8 (14.0) kg, playing experience 4.3 (3.3) years], or high-skilled groups [n = 10, potted 20.9 (4.7) balls, age 28.9 (10.2) years old, height 1.70 (0.07) m, body mass 69.1 (12.4) kg, playing experience 10.7 (8.5) years].

Procedures

Three tests consisted of power control, cue alignment, and angle tests were adopted from a previous 9-ball study on the development of testing protocols (Pan, Komar, & Kong, 2021). These three tests were selected since both low-skilled and high-skilled players are able to conduct these kinds of shots. Other shots requiring advanced skills and techniques (e.g., back spin) may not be possible for some low-skilled players and hence, they likely keep exhibiting the same errors.

Insert Figure 1 about here

Power control test. Only one ball was used and placed at the center of the head string (Figure 1 b). Participants were required to strike the ball towards the bottom cushion and make it stay at or close to the top cushion after bouncing off. This test not only assesses players' mastery of the power but also simulates the lagging and pushout shots in 9-ball games. An error distance was measured between the center of the ball and the top cushion (Figure 1 b) and considered negative if the ball did not touch the top cushion while positive if the ball bounced off the top cushion.

Cue alignment test. Only one ball was used and also set at the head string center. Same as the power control test, participants drove the ball to the bottom cushion (Figure 1 c). The cue stick kept the position when it hit the ball and waited for the ball to return. This test is commonly applied during training and quickly informs players whether they can strike the ball straight. The error distance was 0 if the ball hit the tip of the cue stick. A positive error distance was obtained when the ball was at the left side of the cue stick (Figure 1 c). Error distance was defined negative when the ball was at the right side of the cue stick.

Angle test. Only one ball was used in this test. Participants were asked to drive a ball to the opposite middle pocket without any side spins applied (Figure 1 d). The ball was placed at the head string and aligned with the first diamond of the top cushion. This test could simulate the game situations where the target ball is blocked by other ball(s) and the player cannot directly hit the ball. If the ball failed to go into the middle pocket, a negative error distance was measured when it ended close to the top cushion (Figure 1 d), and a positive error distance was gotten when it was near the bottom cushion.

The participants were informed on the protocol before the commencement of each skill test. Practice of each test was allowed until they felt comfortable with the shots. For example, participants were asked to position the ball at the top cushion in the power control test, have the ball touch the cue tip after bouncing off the bottom cushion in the cue alignment test, and make every ball fall into the middle pocket in the angle test. In each test, 10 trials (Chung et al., 2014) were used for analysis. Participants were encouraged to try their best in each shot and were allowed to rest *ad libitum.* The researchers were not allowed to communicate with the participants about their shots during the experiment to avoid making possible influence on their shot performance.

Data Processing

Performance. Videos were processed and analyzed using Kinovea (version 0.8.27, available for download at: http://www.kinovea.org) (Pan, Komar, & Kong, 2021; Pan, Komar, Sng, et al., 2021). The tool 'Perspective grid' was applied to calibrate the pool table in the software. Only half of the pool table was used because the balls all ended in this area, which was calibrated to a surface of 1.27 m × 1.27 m. Thereafter, a 'Line' tool was used to measure the distance between the preset target and the center of the ball. A positive or negative sign was given for each test according to the protocol of each test previously explained (Pan, Komar, & Kong, 2021). Intra-individual standard deviation (SD) across 10 trials for each test was obtained to examine the performance consistency for each participant (Pan, Komar, & Kong, 2021). The smaller the SD, the better the performance consistency.

Correction of Error Distance. The correction of error distance (CED) was calculated by subtracting the error distance of one trial from that of its previous trial (Equation 1). Small CED represented a small modification during the following trial. A negative CED in the power control test indicated a correction towards shorter error distance, and a positive CED indicated a correction towards longer error distance. In the cue alignment test, a negative CED indicated a correction towards further right error distance, and a positive CED indicated a correction towards further left error distance. In the angle test, a negative CED indicated a correction towards smaller angle, and a positive CED indicated a correction towards bigger angle.

$$CED_n = \text{error distance}_{(n)} - \text{error distance}_{(n-1)} \quad (1)$$

where n = 2 to 10. Hence, there would be 10 error distances coming from the 10 trials and 9 CEDs. To summarize, based on the video analysis, three variables were computed: 1) error distance of each trial, 2) SD of error distances within each participant, and 3) CED after each trial. Due to the co-existence of both negative and positive error distance and CED, the 10 absolute error distances were averaged for each participant for subsequent analysis. Absolute CED was used as well to reflect the magnitude of the error correction.

Statistical analyses

Statistical analyses were performed using SPSS (version 26.0, IBM Corp, Armonk, USA). Data normal distribution was confirmed using Shapiro-Wilk test. One-way analysis of variance (ANOVA) was conducted to evaluate the group differences among the low-skilled, intermediate, and high-skilled groups in the shot performance and intra-individual consistency (SD). The assumption of homogeneity of variances was confirmed using Levene’s test. Where necessary, a Bonferroni *post-hoc* test was performed accordingly. The association between the error distance and its correction was assessed using Pearson’s correlation across the 10 repetitive trials for each participant. Absolute correlation coefficient (|r|) close to zero indicates a week or no correlation and conversely indicates a strong correlation when it is close to 1 (Coughlin & Jones, 2007; Earthman, 2015). If a participant always performs shots with small error distances, he needs only to make low corrections in the subsequent shots and vice versa, and hence, a strong positive correlation would be observed. In contrary, a weak or no correlation would be found if one is unable to adjust the magnitudes of corrections based on the errors.

Results

Across the 10 trials, there was no consistent pattern of error reduction as the number of trials increased (Figure 2). Significant differences in the error distances (Table 1) were found in the cue alignment (p = 0.010) and angle tests (p = 0.002). According to the *post hoc* results, in the cue alignment test, significant difference in error distance was only identified between the low-skilled and high-skilled groups (p = 0.009). In the angle test, the low-skilled group had greater error distances than the intermediate (p = 0.015) and high-skilled groups (p = 0.003). The intra-individual consistency (Table 1) significantly differed among the three groups in the cue alignment (p = 0.005) and angle tests (p < 0.001). The results of *post-hoc* analyses indicated that, in the cue alignment test, the low-skilled group had lower performance consistency than the high-skilled group (p = 0.006); in the angle test, the low-skilled group had lower performance consistency than the intermediate (p = 0.007) and high-skilled groups (p < 0.001).

Insert Figure 2 about here

Insert Table 1 about here

Both high-skilled and intermediate groups (Figure 3) showed higher density of small CEDs (near 0) than the low-skilled group, except in the power control test where the numbers of small CEDs (between -50 and 50 cm) were similar among the three groups (59, 58, and 61, respectively). In the cue alignment test, the numbers of small CEDs ranged -5 to 5 cm were 38, 48, and 62, respectively in the low-skilled, intermediate, and high-skilled groups, and 38, 44, and 53 in the angle test (CEDs ranged -5 to 5 cm). Pearson's correlation on individual correlation showed that there were only a few significant correlations between error distances and following CEDs (Figure 4, each significant correlation is shown in a line). In the angle test, 5 participants [3 in the low-skilled group ($r = 0.798$, $r = 0.829$, $r = 0.918$), 2 in the high-skilled group ($r = 0.711$, $r = 0.698$)] had significant positive correlations between the error distances and CEDs (Figure 4). Five [3 in the intermediate group ($r = 0.841$, $r = 0.674$, $r = 0.829$) and 1 in each of the low-skilled and high-skilled groups ($r = 0.716$ and $r = 0.680$, respectively)] in the power control test. Three [2 in the low-skilled group ($r = 0.760$, $r = 0.918$), 1 in the high-skilled group ($r = 0.800$)] participants exhibiting significant correlations were identified in the cue alignment test.

Insert Figure 3 about here

Insert Figure 4 about here

Discussion

This study aimed to investigate the trial-to-trial performance of the selected three 9-ball shots. Intra-individual error distances and corrections (CEDs) were analyzed and compared among three groups of players in various skill levels. The results of the 15-ball test confirmed that the test was sensitive to differentiate participants of various overall skill levels since only 2 (both were youth players under 16 years old and had much less playing experience than the high-skilled group) out of 8 participants from the national team were assigned to the intermediate group and the remaining 6 were all in the high-skilled group. Similarly, only 1 recreational participant was assigned to the intermediate group and the rest of the recreational players were assigned to the low-skilled group.

The first hypothesis of the present study was that high-skilled players would perform better than low-skilled player and show a better adaptive regulation. As shown in Table 1 and Figure 2, in both cue alignment and angle tests, the high-skilled group had smaller error distances than the low-skilled group. Furthermore, two out of three skill tests indicated that high-skilled players conducted shots more consistently than their less skilled counterparts. As shown in Table 1, in the cue alignment and angle tests, the high-skilled group had higher intra-individual consistency than both the intermediate and low-skilled groups. This finding is in good agreement with the previous snooker study on expertise which found good shot consistency in expert players (by comparing interquartile range of the test data among groups) (Chung et al., 2014). It is unsurprising that high-skilled players had smaller error distances and higher consistency than low-skilled players since cue sports players need to perform consistently well during games. A recent study on an elite snooker player has reported similar cueing techniques across various types of tasks (Kong et al., 2021) which may also explain the good and consistent performance by the high-skilled group in the current study. However, the error distances and intra-individual consistency of the power control test were similar among the three groups. The reason could be that cue sports players are not used to this shot although control power is essential in every shot. Striking a ball down the pool table without hitting other balls is not common in 9-ball games. In contrast, players are often confronted with the scenarios similar to the cue alignment and angle tests and thus, participants in both intermediate and high-skilled groups exhibited higher consistency than the low-skilled group. However, it should be noted that the high-skilled group had a few senior players who were about 40 years old and would have an older mean age than the other 2 groups. As different ages could also contribute to different performance in sports (Abernethy, 1988), future studies are recommended to consider participants' ages in the study design.

This study, however, did not observe the trend that the error distances decreased towards the end in any one of the three skill tests (Figure 2). Different from the great decay over the 50 trials performed by beginners with very limited or zero experience in pool (Haar et al., 2020), this present study recruited players with at least one year of playing experience in cue sports. Thus, the criteria of the participants may explain the lack of learning curve (presented by the decrease in performance errors over trials) in the current study. In the power control, participants were self-informed about the error visually (i.e., whether they applied too much or too little power according to the ball's end position) immediately after each shot. While they understood how to correct the next shot according to the feedback (by applying smaller or greater amount of power in the subsequent shot), they may not be able to do so. This is likely due to the fact that skills and techniques are needed in combination with the understanding of power control and ball path in cue sports. Thus, making adjustments in cue sports performance is difficult. The same explanation may be applied to the other two skill tests in which the participants noticed the deviations immediately. Therefore, only being informed how to correct may not be helpful for the next shots.

The second hypothesis that cue sports players would perform a low error correction after a shot with small error and vice versa is rejected according to the correlation analysis. CED was defined as the difference between the error distances of two consecutive trials, and a small CED represented small modification after a shot. Since averaged values across participants may mask individual performance and lead to a 'false' result (Davids et al., 2008; Davids & Araújo, 2010), Pearson correlation was conducted for the repetitive 10 trials for each participant. The results showed that in each test, only 3 to 5 participants had significant positive correlation between the error distances and CEDs (Figure 4). Given the total participant number of 31, roughly 5 significant correlations were very few in each test. Furthermore, the numbers of significant correlations were similarly distributed in the low-skilled and high-skilled groups (2 or 3 in each group), while very few in the intermediate group. This cannot support the hypothesis that high-skilled players would be better to correct their errors when comparing with the low-skilled players.

An optimal adaptability, as a low correction after a small error and vice versa (Shadmehr et al., 2010), was not observed in these three 9-ball skill tests. The reason could be that low-skilled players were unable to adapt quickly and improve the performance within a short period of time. The lack of immediate improvement was also found for novices in a study on soccer kicking (Chow et al., 2007). In this earlier study, novice soccer players were found incapable of varying their kinematics in different tasks, while high-skilled and intermediate players successfully managed to adapt their kinematic parameters to achieve good performance. However, in the current study on 9-ball, even high-skilled and intermediate players failed to make those adaptations. Further studies should consider time-lagged effects, since the previous pool study found visible performance improvement over the first 50 trials (Haar et al., 2020). As this present study did not find an adaptation effect as expected, the errors of the intermediate and high-skilled groups were not 'corrected' to show enhanced performance later. This could be related to their mastery of the skills and understanding in 9-ball, and unable to quickly adapt movements based on the previous error information during repeated trials. As a closed skill sport, 9-ball performance may be related to players' execution consistency in a stable environment (unchanging environment which requires concentration and self-pacing) (Lerner et al., 1996), which could also explain the lack of players' adaptations. Further studies are needed to combine performance analysis with motion analysis, such that the transient adaptation and variability (Seifert, 2012) of high-skilled and intermediate players in repeated trials can be better understood.

There were a few limitations to the current study. Firstly, only a small sample size (roughly 10 participants in each group) was investigated. Future studies are warranted to include a larger sample size. Additionally, it is desirable to recruit a group of participants in similar ages as age could be a factor influencing sports performance (Abernethy, 1988). Secondly, in the selected three skill tests, hitting a single ball could be less common than the real-game situations where an object ball is propelled by a cue ball. Players, in particular for skilled players, may perform less well in these uncommon shots. Hence, modifications to the experiment protocols can be made to better assess players' performance using more realistic scenarios. Lastly, this study only examined 10 trials per shot. As novice players would show a visible learning curve within the first 50 trials (Haar et al., 2020), future studies should investigate more repetitive trials to explore if there is any time-lagged effect on shot consistency in cue sports.

Conclusion

This study found that the high-skilled group performed better in two out of the three 9-ball skill tests than less skilled players. However, an adaptation effect in 10 repeated bouts of shots was not identified. Both high-skilled and intermediate players had a higher intra-individual consistency compared with the low-skilled players. The hypothesis that 'low correction happened after small error and vice versa' is not supported by results of the current study. Cue sports players may not be able to quickly alter their movements to improve their performance. High-skilled players' constructed movement patterns could inhibit performance improvement while low-skilled players were unable to make adaptations based on the error information.

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Table and Figure captions

Table 1. Comparison of performance (indicated by error distance) and intra-individual consistency of the three skill tests among three groups.

Figure 1. (a) Scheme of a standardized 9-ball table, and three skills tests: (b) power control test, (c) cue alignment test, and (d) angle test.

Figure 2. Error distances of the 10 trials of all participants in the low-skilled, intermediate, and high-skilled groups (each line shows the error distances of each participant).

Figure 3. Histograms of the error corrections in the low-skilled, intermediate, and high-skilled groups. In power control test, a negative correction error distance (CED) indicates a correction towards shorter error distance, and a positive CED indicates a correction towards longer error distance. In cue alignment test, a negative CED indicates a correction towards further right error distance, and a positive CED indicates a correction towards further left error distance. In angle test, a negative CED indicates a correction towards smaller angle, and a positive CED indicates a correction towards bigger angle.

Figure 4. Scatter plots of the error distances and corrections for all participants in the three skill tests. Each line indicates a significant correlation ($p < 0.05$) between error distance and its correction (CED) within each participant in the three 9-ball skill tests (5, 3, and 5 participants exhibited significant correlations in the power control, cue alignment, and angle tests, respectively) according to Pearson's correlation.

Table 1

Comparison of performance (indicated by error distance) and intra-individual consistency of the three skill tests among three groups.

	Low-skilled (N) (n = 11)	Intermediate (I) (n = 10)	High-skilled (S) (n = 10)	*F(2,28)*	*p*	*post-hoc*	
Performance [cm]							
Power control	39.5 (16.9)	34.1 (5.9)	30.5 (9.8)	3.429	0.334		
Cue alignment	6.6 (4.1)	4.0 (2.6)	2.4 (1.5)	1.229	**0.010***	S<N	
Angle	7.2 (2.2)	4.0 (2.7)	3.3 (2.3)	0.533	**0.002***	I<N	S<N
Intra-individual consistency [cm]							
Power control	45.0 (20.5)	39.7 (9.6)	35.6 (12.2)	2.175	0.371		
Cue alignment	6.7 (2.6)	4.2 (2.2)	3.3 (1.9)	0.116	**0.005***	S<N	
Angle	10.1 (2.8)	6.2 (2.9)	4.8 (2.2)	0.379	**<0.001***	I<N	S<N

Significant difference ($p < 0.05$) is shown in bold text and indicated by an asterisk.