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ORIGINAL ARTICLE

Inter-distance differences in aiming error and visual perception influence shooting performance in basketball

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ABSTRACT

This study is the first to use inter-distance differences in shooting direction error to investigate the influence of visual perception on basketball shooting performance. Thirty-two experienced basketball athletes (NCAA Division I-III: n = 15, Canadian U Sports Association: n = 13, National Basketball Association: n = 4) attempted blocks of 25 jump shots from a near (free throw) and far distance (three-point attempt). Differences in the root-mean-square deviation of lateral direction error as distance increased, Δ_{LDE}, were used to measure an individual's change in lateral accuracy as the target changed within their visual field. The mean Δ_{LDE} was -0.18 degrees (*p* < .001, 95% CI: -0.25 – -0.11) indicating that an individual's lateral direction accuracy worsened as shooting distance decreased and external visual cues transitioned away from their central vision. Shooting performance had a strong positive correlation with Δ_{LDE} (*r* = 0.57, *p* = .001) indicating that better shooters have a higher ability to adapt to the changes in visual perception with distance and experienced smaller reductions in lateral accuracy as shooting distance decreased. These findings show that visual perception has a significant role in basketball shooting performance and that Δ_{LDE} is a valuable measure for assessing how an athlete's proficiency in visual perception contributes to their performance.
Keywords: Performance analysis of sport, Physical conditioning, Free throw, Jump shot, Far aiming, Visuo-motor control.

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INTRODUCTION

Sports research on far target aiming such as shooting in basketball has found that visual perception and gaze are strongly linked to performance (Klostermann et al., 2018; Poltavski and Biberdorf, 2015). Specific vision training has been shown capable of enhancing performance in basketball and soccer (Harle and Vickers, 2001; Vickers et al., 2017; Savelsbergh et al., 2010). While some visual functions are associated with improved performance, it has also been shown that basketball shooting can be resilient to high levels of visual degradation such as retinal defocus and occlusion (Bulson et al., 2015; de Oliveira et al., 2006; Vickers, 2007). Although it is evident that vision plays an important role in basketball shooting performance, uncertainty remains regarding many of the details within the combined visuo-motor task such as timing, region of attention, and response to pressure situations.

The two most prominent areas of vision research concerning shooting in basketball are gaze fixation which emphasizes eye-tracking and studies investigating visual timing which often utilize segments of occluded vision. In gaze behavior, the phenomenon referred to as quiet eye (QE) refers to the duration of a target fixation preceding a final motor response (Vickers, 2007; Vickers, 2009). Researchers have reported that early visual fixations and longer QE periods are strong predictors of motor performance (Lebeau et al., 2016; Rienhoff et al., 2016; Vine and Wilson, 2011). This has led some to theorize that aiming movements are preprogrammed before execution (Vickers, 2016; Vickers, 1996; Klostermann, 2019). The other ecological studies using intermittent vision or timed occlusions have found that long fixations are not required for good performance (Oudejans et al., 2002; de Oliveira et al., 2007). Even when vision is occluded for significant early portions of a shot attempt, good performance still occurs (de Oliveira et al., 2006), suggesting that late vision was most important (de Oliveira et al., 2007). These findings have led to theories prioritizing the role of online control (de Oliveira et al., 2006; Oudejans et al., 2002; de Oliveira et al., 2007; de Oliveira et al., 2009).

The competing viewpoints emphasizing the importance of gaze duration as compared to the timing of acquisition of visual information, however, usually complement and/or qualify each other rather than contradict. Their mutual dependence is supported by the findings of Schütz et al. (2013) who hypothesized that gaze-dependent and gaze-independent information may be shared during visual processing rather than being dissociable. Both viewpoints acknowledge that neither is sufficient to fully explain how visual information is used in far aiming tasks with Vickers et al. (2019) and de Oliveira et. al. (2008) providing insight into how the theories compare, contrast, and interact.

There remains much unknown about how visual information is processed in far aiming tasks such as basketball shooting. This is partially due to distinct limitations of the methodologies used to investigate gaze behavior and timing which restrict the scope of their conclusions. The use of eye-tracking provides gaze location and duration, but it doesn't reveal the level of attention or use of the visual periphery. In contrast, occluded vision may inform the timing of relevant visual information but cannot specify which details provide essential cues. Three visual functions relevant for successful performance in sports are not captured by either eye-tracking or occlusion methodologies. The first is the integration of peripheral and central vision with Ryu et al. (2013) suggesting that gaze may only reflect a central vision anchor point from which peripheral information is extracted. Second, the presence of landmarks near a target has been found to reduce aiming error and may combine with other allocentric information even when targets are temporarily occluded (Schütz et al., 2013). Third, neither methodology captures the ability of egocentric position, direction, and allocentric perceptions to respond differently to visual variations (Schütz et al., 2013; Nakashima et al., 2015) and thus an important performance factor may be their ability to interact as a single shared visual perception.

This study aims to investigate how these visual functions contribute to performance in the far aiming task of basketball shooting. Lateral direction errors in the sagittal plane are compared for conventional jump shots taken from a near (free throw) and far distance (three-point attempt). The variation in distance provides several target differences within the visual field. First, closer attempts result in a visually larger target hoop within central vision as compared to attempts from farther distances. Next, landmarks such as the shooting square on a regulation backboard, which is intended to provide a visual guide, and the backboard will transition from peripheral to central vision as shooting distance increases. Another variation is that the ball and/or hand will either fully or partially occlude vision of the target at some time during the attempt as the ball move in front of the face. At closer distances, the portion of the target and duration occluded will be less than when shooting from a farther distance.

As shooting distance is increased, three possible responses in lateral direction error exist. If lateral control is unaffected by changes in visual perception with distance, no significant effect would be found in lateral direction error since others have already shown that increases in motor noise are largely absent when transitioning from free throws to three-point attempts (Slegers et al, 2021). However, if lateral direction errors increase with distance, it would indicate that changes in visual perception with distance increase the task complexity. The third possibility is that lateral direction errors decrease with distance, suggesting that changes in visual perception with distance decrease complexity. It's hypothesized that the movement of landmarks toward central vision and the visually smaller target with increasing distance will provide more benefits to lateral accuracy in basketball shooting than any hindrances from increased target occlusion. Therefore, the first hypothesis is that aiming error will decrease as distance increases from free throws to three-point attempts. It's also hypothesized that better shooters will demonstrate a higher ability to adapt to changes in visual perception with distance and will have smaller changes in lateral aiming error as distance changes.

MATERIALS AND METHODS

Participants

Thirty-two basketball athletes (n = 32) were recruited for this study (males: n = 24, age = 21.8 ± 3.3 yrs, height = 190 ± 10 cm; females: n = 8, age = 20.7 ± 1.5 yrs, height = 172 ± 6 cm). Participants were actively involved in institutionally sponsored competitive basketball teams (NCAA Division I-III: n = 15, Canadian U Sports Association: n = 13, National Basketball Association: n = 4) with 3.8 ± 3.1 years of post-secondary playing experience. Each participant gave their voluntary consent for inclusion in the study, which was approved by the local ethics committee.

Measures

Lateral error (LE) for an attempt is defined as the deviation of the ball center from the sagittal plane when the lowest portion of the ball falls to the height of the target hoop (3.05 m). Positive and negative distances indicate misses to the right and left, respectively. The ball center is identified by using three points on the edge of the ball to estimate its geometric center where the width of the shooting square (0.61 m) on the backboard is used as a calibration distance.

Lateral shot deviation in basketball varies linearly with distance, i.e. the ball doesn't swerve, meaning that for a fixed error in throwing direction the final lateral error at the target increases as the shot attempt distance increases. To compare lateral control and isolate visuo-motor effects at different distances the performance indicator used in this study is lateral direction error rather than lateral distance error. Lateral direction error (LDE) is defined as the ratio of LE to shot attempt distance and has two interpretations as illustrated in Figure

1. First, LDE can be interpreted as the target aiming error since *tan*(LDE) ≈ LDE for small angles. Alternatively, LDE can also be viewed as a distance normalized lateral error (slope). Both perspectives are presented simultaneously in this study with a lateral error of 0.07 m from the free throw line (4.57 m) reported as an LDE of 0.88 deg (1.53 cm/m) to represent both the aiming and normalized lateral error. The root-mean-square deviation (RMSD) of LDE for each participant is used as a measure of their lateral aiming accuracy and addresses both aiming variance and bias. The total shooting percentage is determined by calculating the make percentage including both free throw and three-point attempts and is used as an additional performance indicator to quantify overall participant accuracy and skill level.

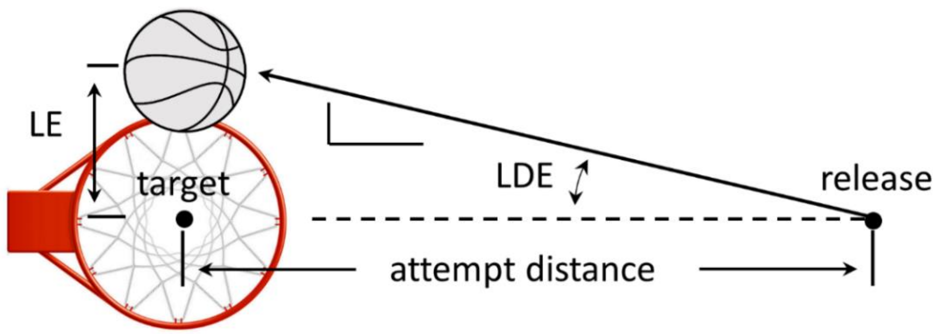

Figure 1. Top view of target illustrating the interpretations of LDE as both an aiming error and normalized lateral error (slope).

Procedures

Participants attempted blocks of 25 jump shots on a regulation height hoop (3.05 m) from both the free throw line (4.57 m) and regulation three-point line (female: 6.75 m, male: 7.13 m). The order of blocks was counterbalanced across participants to reduce sequence effects. To ensure a typical jump shot at each distance, attempts began with the participant throwing the ball up, catching the ball off one bounce, then directly proceeding into a shooting motion. All attempts were taken directly facing the backboard. Each shot was recorded using a tripod-mounted 1080p HD digital video camera, at 120 fps, and with a shutter speed of 1/720 seconds. The camera was placed 1.5 m behind the shooter, within the sagittal plane, 2.5m above the floor, and directly facing the target hoop. Processing of digital video for each attempt was done using Tracker 6.0.7 software (Open Source Physics Java framework).

Analysis

Statistical analysis was performed in Matlab v9.2.0 R2017a (Mathworks Inc., Natick MA, USA). Descriptive statistics are presented for participant root-mean-square deviation (RMSD) of LDE for both free throws and three-point attempts. The intra-individual change in LDE RMSD between three-point attempts and free throws is presented as Δ_{LDE} where positive values indicate the RMSD is higher for three-point attempts than free throws. Individual total shooting percentage is presented as a mean ± SD. A paired t-test was used to determine if Δ_{LDE} is significantly different than the null hypothesis and Cohen's d was used to estimate effect sizes (ES), in which d = 0.2, 0.5, and 0.8 were interpreted as small, medium, and large, respectively. For each t-test, an Anderson-Darling test was used to verify the data didn't significantly vary from normality. A test-retest reliability analysis was performed on one participant for lateral error to assess the reliability of the digitization of the ball center. The reliability coefficients and SD of test-retest differences were 0.997 and 0.6 cm for free throws and 0.998 and 0.5 cm for three-point attempts. All correlations are presented using the

Pearson product-moment coefficient, r, and interpreted as almost perfect (> 0.9), very strong (> 0.7), strong (> 0.5), moderate (> 0.3), weak (> 0.1), or trivial (< 0.1). In all cases, statistical significance was set at .05.

RESULTS

Descriptive statistics, presented as means, SD, and ranges, are provided in Table 1 for inter-individual free throw LDE (LDE_{FT}) RMSD, three-point LDE (LDE_{3PT}) RMSD, the intra-individual difference between three-point and free throw LDE RMSD (Δ_{LDE}), and participants' combined shooting percentage composed of both free throw and three-point jump shots. Intra-individual changes in LDE RMSD with distance, Δ_{LDE}, are provided as a box plot in Figure 2 where a t-test results in a mean Δ_{LDE} of -0.18 degrees (p < .001, 95% CI: -0.25 – -0.11, Cohen's d = 0.95) or -0.31 cm/m (p < .001, 95% CI: -0.43 – -0.19, Cohen's d = 0.95). In general, LDE RMSD among individuals is lower for their three-point attempts than their free throws (Δ_{LDE} < 0) with only five participants having a marginally positive Δ_{LDE}. This suggests that as the jump shot distance increased, participants typically decreased their LDE RMSD, or as distance increased, participants were more accurate with their lateral direction when compared to closer attempts.

Table 1. Descriptive statistics of lateral direction error and shooting percentage (n = 32).

Variable	Mean	SD	Range
LDE_{FT} RMSD, deg (cm/m)	0.93 (1.63)	0.24 (0.42)	1.37 – 0.53 (2.38 – 0.92)
LDE_{3PT} RMSD, deg (cm/m)	0.74 (1.23)	0.15 (0.26)	1.05 – 0.41 (1.84 – 0.71)
Δ_{LDE}, deg (cm/m)	-0.18 (-0.31)	0.19 (0.33)	0.18 – -0.68 (0.31 – -1.12)
Combined percentage (%)	70	12	91 – 48

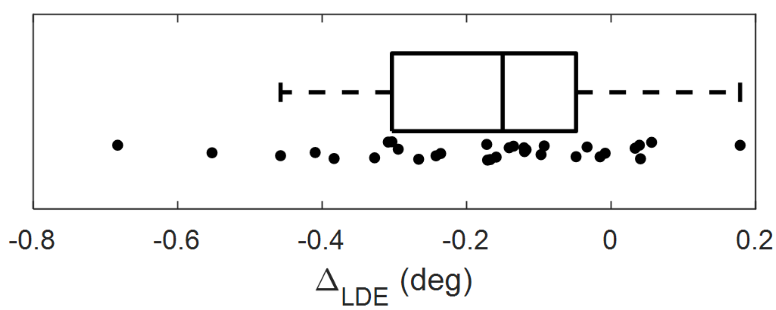

Figure 2. Box plot of Δ_{LDE}, the difference between three-point and free throw LDE RMSD.

Figure 3a illustrates the relationship between LDE RMSD and combined shooting percentage for both free throws and three-point attempts with both exhibiting very strong negative correlations (FT: r = -0.88, p < .001 3PT: r = -0.67, p < .001). This indicates that better shooters in this study, as determined by combined shooting percentage, have lower LDE RMSD and are more laterally accurate at both distances. Slopes (β_1) of each linear regression in Figure 3a are negative (FT: β_1 = -1.8 deg/%, 95% CI: -2.1 – -1.4, 3PT: β_1 = -0.87 deg/%, 95% CI: -1.2 – -0.52), where the larger negative slope for free throws results in the LDE RMSD difference between three-point and free throw attempts being more pronounced for poor shooters and decreasing as the combined shooting performance increases. This trend is illustrated in Figure 3b with Δ_{LDE} and combined shooting percentage having a strong positive correlation (r = 0.57, p = .001). Combined, the results from Figure 2 and 3b show that while the participants demonstrated more lateral precision (smaller LDE RMSD) as shooting distance increased, better shooters had smaller differences between the distances than the less accurate shooters.

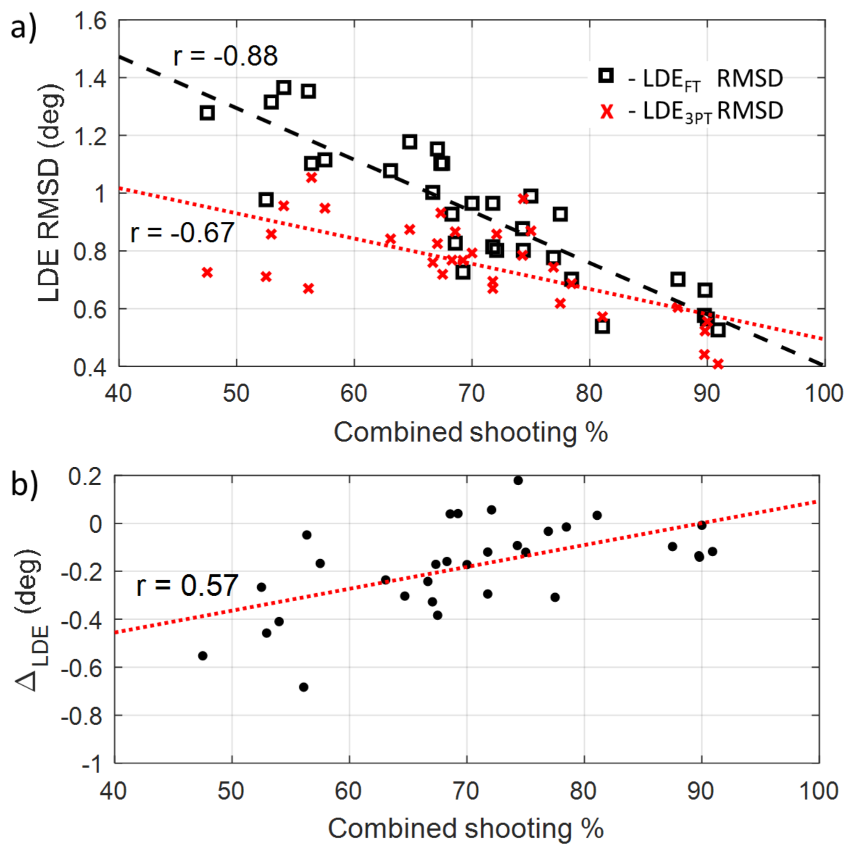

Figure 3. Lateral direction error vs. combined shooting percentage a) Comparison of free throw and three-point LDE RMSD b) Difference between three-point and free throw LDE RMSD, Δ_{LDE}.

DISCUSSION

Changes in lateral direction error with distance

A primary finding of this study is that LDE RMSD decreases as distance increases ($\Delta_{LDE} < 0$ in Figure 2). Therefore, the first hypothesis that aiming error decreases as distance increases from free throws to three-point attempts is accepted. The reduction in LDE RMSD with increased distance suggests that the visuo-motor complexity of aiming within the sagittal plane decreases with distance. The decrease in complexity can be attributed primarily to changes in perception within the visual field since any velocity-dependent motor noise effect would have led to an increase in Δ_{LDE} with increased distance, in contrast to the current findings. The absence of any significant contribution from velocity-dependent motor noise on lateral direction error is consistent with the results from Slegers et al. (2021). They showed that as distance is increased from free throws to three-point attempts, variation in longitudinal error remains unchanged since the required increases in force with distance are well within participants' ability and don't approach a maximal force task. Similarly, it has been observed that for three-point attempts, release strategies are not significantly influenced by velocity-dependent motor noise effects since shooters use strategies that maximize their success rather than using a minimum velocity (Slegers, 2022).

From among the changes to the visual field, the decrease in LDE RMSD with distance suggests that neither the increased spatial or temporal occlusion of the target by the hand and/or ball during the shooting motion as distance increases pose a significant challenge to regulating LDE. This agrees with earlier results that conclude basketball shooting performance is robust to even significant occlusion of vision throughout the shooting motion (Oudejans et al., 2002; de Oliveira et al., 2007, de Oliveira et al., 2008). Therefore, one or both of the remaining changes to the visual field as distance increases, a visually smaller target hoop within the central vision, and the transition of external landmarks (shooting square and backboard) from peripheral to central vision must contribute to increased lateral accuracy with increasing distance. A theoretical basis for central vision's role in LDE is provided by van Maarseveen et al. (2018), who contrasted peripheral vision's role in decision making and the reliance on central vision for execution. The latter is more closely related to the visuo-motor task of shooting. A limitation of this study is that the contribution from a visually smaller target and landmarks moving toward central vision cannot be isolated. All that can be said is that either one or both are beneficial for reducing LDE.

This study provides further evidence that in the far aiming task of shooting in basketball, the processing of visual cues is a significant contributor to performance. Within the context of earlier studies that investigate gaze behavior using QE and timing, the changes in the visual field from an increased distance observed here demonstrate that multiple visual cues may be essential and used simultaneously. Similar to the findings of Schütz et al. (2013) and Nakashima et al. (2015), overall visual processing that leads to the mean $\Delta_{LDE} < 0$ likely shares multiple features which are not dissociable.

Performance and inter-distance lateral direction error variation

While LDE RMSD decreased with distance ($\Delta_{LDE} < 0$) for most participants regardless of performance, Figure 3b illustrates that the effect decreases as the total shooting percentage increases. Using Figure 3a it's observed that for the best shooters, with shooting percentages greater than 90%, LDE RMSD converges at approximately 0.5 degrees for both distances representing $\Delta_{LDE} = 0$. Elite shooters, therefore, can maintain similar levels of LDE RMSD at different distances while less accurate shooters appear to increase LDE RMSD (decrease direction accuracy) as target visual cues move away from central vision as distance decreases. Therefore, the hypothesis that better shooters demonstrate a higher ability to adapt to changes in visual perception with distance and will have smaller changes in lateral aiming error as distance changes is accepted.

The coefficient of determination, $r^2 = .33$ in Figure 3b, shows that 33% of the variance in Δ_{LDE} is accounted for by the linear relationship with the total shooting percentage. This level is consistent with another study in which r^2 was .27 and related shooting percentage and lateral error induced by spin axis variation (Slegers and Love, 2022). A coefficient of determination near one-third is expected since longitudinal distance errors are the dominant cause of missed attempts and are approximately twice as common as lateral misses (Slegers et al., 2021; Slegers and Love, 2022).

These findings highlight that visual perception and processing is an important factor in basketball shooting performance. Results suggest that one way better shooters distinguish themselves is in their more developed visuo-motor ability that is less sensitive to the location of the target or other visual cues within central vision. Although this study did not assess gaze duration, and QE studies don't reveal the level of attention or use of the visual periphery (Vickers, 2009; Vine and Wilson, 2011; Vickers, 1996; Vickers, 2016), it's speculated that longer QE periods may be one way better shooters can quickly focus on the target and maintain lateral accuracy as distance is decreased even as important visual cues transition away from their central vision.

Implications for improving basketball shooting performance

Coaches and athletes may find that Δ_{LDE} provides a simple means of assessing an athlete's proficiency in visual perception related to basketball shooting or other sports with similar far aiming tasks. An advantage of using Δ_{LDE} as a metric is that it requires no special equipment unlike gaze fixation, QE, and visual occlusion, yet captures many of the dissociable features relevant to visual perception. Based on the results of this study it's suggested that a $\Delta LDE < -0.2$ deg (-0.35 cm/m) may indicate a visual perception deficiency in competitive basketball players. The use of Δ_{LDE} in addition to typical shooting performance measures such as shooting percentage may be valuable when assessing players who have mismatches in expected shooting percentages of free throws, undefended attempts, and in-game attempts. Mismatches in the expected performance among these categories may suggest that certain athletes find certain types of shots more challenging. In such cases, a below-average Δ_{LDE} may indicate a visual perception deficiency rather than a problem with shooting technique.

Since a below-average Δ_{LDE} indicates an athlete increases lateral aiming error as visual cues transition away from their central vision, practice designed to exercise such a condition may be beneficial for improving aiming performance. Regarding basketball shooting performance, the findings in this study may also guide coaches in developing training to improve visual function by implementing drills that mimic the process of quickly identifying the target and shooting in conditions in which visual cues are less prominent within the central vision, both stressing the visuo-motor system. Coaches can further develop customized practice methodologies by including defenders and making changes based on specific players' positions to further develop an ability to quickly identify and focus on the target within the central vision.

CONCLUSIONS

It was observed that visual functions such as peripheral vision, central vision, landmarks, and allocentric information play an important role in aiming accuracy and basketball shooting performance. Basketball players were found to reduce their lateral direction error as shooting distance increased ($\Delta_{LDE} < 0$) and visual cues of the target and external landmarks transitioned from their peripheral to central vision. The change in visual perception of a target as distance increased appeared to simplify the far aiming task and improve lateral accuracy. A significant finding of this study was that better shooters were more capable of maintaining low levels of lateral direction error even as the benefit of visual cues was reduced with decreasing distance. The difference in lateral direction error with distance, Δ_{LDE}, decreased as the total shooting percentage increased and approached zero for the best shooters. The use of Δ_{LDE}, or simply qualitative changes in lateral accuracy with distance, may provide coaches and athletes a means to identify potential deficiencies in visual perception acumen concerning far aiming tasks. Regarding basketball shooting performance, the findings in this study may also guide coaches in developing training to improve visual function by implementing drills that mimic the process of quickly identifying the target and shooting in conditions in which visual cues are less prominent within the central vision.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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