©Journal of Sports Science and Medicine (2012) **11**, 542-550
http://www.jssm.org

Research article

Field of vision influences sensory-motor control of skilled and less-skilled dart players

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Abstract
One characteristic of perceptual expertise in sport and other domains is known as 'the quiet eye', which assumes that fixated information is processed during gaze stability and insufficient spatial information leads to a decrease in performance. The aims of this study were a) replicating inter- and intra-group variability and b) investigating the extent to which quiet eye supports information pick-up of varying fields of vision (i.e., central versus peripheral) using a specific eye-tracking paradigm to compare different skill levels in a dart throwing task. Differences between skill levels were replicated at baseline, but no significant differences in throwing performance were revealed among the visual occlusion conditions. Findings are generally in line with the association between quiet eye duration and aiming performance, but raise questions regarding the relevance of central vision information pick-up for the quiet eye.

Key words: Perception, expertise, information-processing, eye-tracking.

Introduction

Over the last four decades, considerable evidence has amassed regarding the importance of perceptual expertise in elite sports (Abernethy et al., 2007; Hodges et al., 2006; Mann et al., 2007). Among the characteristics of skill performers is the duration of the 'quiet eye' period, which is assumed to reflect the time needed to cognitively process the information being fixated (Vickers, 2009). This visual-motor phenomenon is associated with better performance in many sports (for an overview, see Vickers 2007). In this study, we investigated the extent to which different components of the visual field, differentiated by central and peripheral vision, affect this visual-motor control. We used a contingent-change display paradigm (McConkie and Rayner, 1975), as proposed by Abernethy (1988), to differentiate between central (foveal and parafoveal) and peripheral contributions to skilled perception in sport.

The quiet eye is operationally defined as the final fixation or tracking gaze located on a specific location or object in the visual-motor workspace within 3° of visual angle for a minimum of 100 ms. Moreover, the onset of the quiet eye occurs prior to the final movement in the task and the offset occurs when the gaze deviates from the object or location by more than 3° of visual angle for a minimum of 100 ms (Vickers, 2007).

This phenomenon is associated with superior performance in a variety of different sports, especially aiming tasks (for an overview, see Vickers, 2007), and effects have been considered from both an inter- and intra-group variability perspectives (Mann et al., 2011). From an inter-group perspective, more skilled athletes seem to have longer quiet eye duration and an earlier onset of the final fixation during the initiation of the motor response (e.g., Causer et al., 2010; Harle and Vickers, 2001; Janelle et al., 2000; Panchuk and Vickers, 2006; Vickers, 1996; Vickers and Williams, 2007; Williams et al., 2002), while from an intra-group perspective, the association between quiet eye duration and throwing performance shows longer and better timed durations for hits compared to misses (e.g., Harle and Vickers, 2001; Janelle et al., 2000; Vickers, 1996; Vickers and Adolphe, 1997).

Nevertheless, there are some contradictory findings within the literature regarding the quiet eye phenomenon. For example, de Oliveira et al. (2006; 2008), based on the findings of Oudejans et al. (2002), disproved the unrestricted importance of an early onset and length of the final fixation. They used temporal occlusion techniques with a basketball free throw shooting task and their results suggested performance accuracy was equally high when target visibility was only given during the final 350-450 ms of the shooting action, generally contradicting the theoretical underpinnings of the quiet eye phenomenon. Glöckner et al. (2012) criticized the supposed sole importance of the quiet eye period. In an experimental setting predicting handball playmakers' choices and success, they demonstrated that shifts of attention over time need to be acknowledged and not only isolated fixations. The quiet eye is denoted as the "last piece of visual information", and only analyzing this period was insufficient.

While studies critical of the quiet eye are helpful for extending our understanding of the phenomenon, the robustness of the value of quiet eye is impressive. A recent meta-analysis of 30 years of research Mann and colleagues (2007) noted quiet eye duration as one of three predictors of perceptual-motor expertise (along with specific fixation location and low frequency of fixations), reinforcing that quiet eye is associated with optimal perceptual motor coordination (see also Vickers, 2007; Williams et al., 2002).

Despite the noticeable body of literature concerning the phenomenon, the underlying mechanisms responsible for the consistent expertise and performance differences in this perceptual skill are unclear. For instance, it is assumed that the quiet eye reflects a period of processing of force and direction components relevant for the specific task (Vickers, 2007). The timing of the quiet eye

Received: 18 April 2012 / Accepted: 27 June 2012 / Published (online): 01 September 2012

period is important (Vickers et al., 2000) and an optimal quiet eye period should help direct attention to the target and protect from distractions (e.g., Wilson and Pearcy, 2009). Thus, quantity and quality of information pick-up during the quiet eye period is seen as critical for programming movement parameters and environmental cues and synchronizing motor strategies (i.e. 'response programming'); for example, Williams and colleagues (2002) used billiard tasks with different levels of complexity to show that more complex motor responses required longer pre-programming time. Besides its optimal length, an additional characteristic of the quiet eye period is its location on the target (Harle and Vickers, 2001; Vickers, 1996). Here, directing the gaze to a single target location is important, as demonstrated for basketball free throw shooting (Harle and Vickers, 2001), although it does not seem to matter which target location is fixated (most shooters fixate the front of the hoop, followed by back center or middle of the hoop, as demonstrated by Harle and Vickers (2001)) as long as there is only one target location in gaze and attention (Vickers, 2007). Elite players fixate a narrower target area while less-skilled players let their gaze wander to several locations (Vickers, 2007). Thus, it seems that not only is the information picked-up critical (i.e. for response programming), but a stable quiet eye may help to increase postural stability which may be important for aiming tasks (i.e., a general quiescence of the psychomotor system, as proposed as mechanism by Vine et al. (2011)).

In accordance with these assumptions, Vickers (2009) postulated that the quiet eye period represents the time needed to cognitively process the information being fixated or tracked, as an indicator of optimal focus and attention. Moreover, experts control their gaze to acquire the optimal spatial information, thus allowing the neural structures to organize the underlying action optimally. When this spatial information is insufficient or incomplete, action is only partially organized and performance suffers (Vickers, 2011). The sole quiet eye study investigating this issue was conducted by Panchuk and Vickers (2009) using an *in situ* spatial occlusion paradigm for the interceptive task of ice hockey goaltending, occluding different shooter's body parts, stick-puck interface or all but the puck flight (Panchuk and Vickers, 2009). The aim of their study was to examine whether the underlying control strategy was predictive or prospective. A predictive control strategy assumes response selection is based on advanced information and movement is executed without modification, while a prospective control strategy supposes that the movement response is continuously specified until the point of interception. Results revealed significant performance decreases by masking critical areas (e.g., stick-puck interface). Furthermore, the highest percentage of fixations was located on the stick and puck as the shot was executed. Generally, the period of quiet eye was affected by spatial occlusion conditions and the authors assumed a predictive rather than a prospective control strategy in such rapid interceptive tasks.

A related issue in this context is the role of varying sources of visual information to the quiet eye. Panchuk and Vickers (2009) suggested that determining the extent to which participants picked-up peripheral target information was not possible because the eye-tracking technology is limited to measuring foveal vision. The general superiority of expert's peripheral perception is well assumed (for an overview, see Williams at al., 1999), but to our knowledge nothing is known about the role of peripheral information pick-up during the quiet eye period. If only fixated information is critical, as explicitly postulated by Vickers (2009), there is no rationale why information obtained from peripheral vision should be helpful during the period of quiet eye. Further, ecological paradigms are required for a deeper understanding of the influence of central and peripheral picked-up information in combination with eye-tracking (Williams and Ericsson, 2005; Williams and Ward, 2007). One methodological approach to study this is the contingent-change display paradigm (Abernethy, 1988; McConkie and Rayner, 1975), which was originally used in reading research (for a review, see Rayner, 1998). It involves changing the visual display in accordance to the participants' eye-movements so that there is a limited field of vision (i.e., only where the participants are fixating) with the rest of the display occluded. Thus, the field of vision moves according to the fixations of the participants and enables experimental control of given information; for instance, it allows control of central vision while limiting coincident peripheral information pick-up. By inverting the clear visual field, the converse effect applies. Consequently, the inner circle of the central field of vision is occluded by a black circle and the rest of the visual display is clear, allowing the possibility of investigating the role of peripheral vision without information from the central (foveal and parafoveal) area. An important modification from other spatial occlusion paradigms is that goggles occluding the whole vision are not used, but occlusion of the target information still occurs. Thus, it enables the researcher to investigate the role of central and peripheral vision for the quiet eye period. To our knowledge this is a relatively new methodological approach within sport sciences with few investigations to date.

In summary, the quiet eye phenomenon is based on two assumptions. First, centrally processed information is important for the quiet eye period (Vickers, 2009) and second, incomplete spatial information leads to a decrease in performance (Vickers, 2011). We investigated the quiet eye in this study by differentiating between central and peripheral vision conditions using the contingent display change paradigm in an *in situ* experiment. Our first aim was to replicate the association between quiet eye duration and location with better throwing performance under full vision in a baseline condition. This should be represented by longer quiet eye durations for skilled dart throwers (Harle and Vickers, 2001; Janelle et al., 2000; Panchuk and Vickers, 2006; Vickers, 1992; Williams et al., 2002) and narrower quiet eye locations (e.g., Harle and Vickers, 2001; Vickers, 1996) compared to less-skilled throwers. The throwing accuracy of skilled players should also be superior to the less skilled athletes (Duffy et al., 2004).

Our second aim was to probe the proposed components of the visual field, differentiated by the extent to which the period of quiet eye supports information pick-up in the central or peripheral visual field. Based on the assumption that centrally fixated information is important for quiet eye (Vickers, 2009), we expected a larger deterioration in throwing performance in centrally occluded vision conditions (peripheral vision condition) compared to peripherally-occluded vision conditions (central vision condition) in skilled performers compared to their less-skilled counterparts, although group differences in performance may still exist.

Methods

Participants

Thirteen skilled and sixteen less-skilled right-handed male dart players were recruited as participants for this experiment. The mean ages of the skilled and less-skilled groups were 36.6 (*SD* = 10.5) and 25.5 (*SD* = 1.3) years respectively. The skilled participants were advanced players. They were members of the local dart leagues (second and third division) with an average of 11.7 (*SD* = 6.5) years of playing experience. The less-skilled players (dart novices) were physical education students with only occasional experience with dart throwing (less than once a month). All participants provided informed consent and the study was conducted in accordance with the ethical principles described in the declaration of Helsinki (World-Medical-Association, 2008).

Apparatus and procedure

Prior to commencement, participants were given general verbal information on the experiment (brief introduction into eye tracker and setup) and were asked to complete a questionnaire detailing their dart experience. The experiment was conducted in a laboratory setting. Participants stood in front of a wooden board, where a raster with a square target in the middle was presented via a digital projector (600 x 800 pixels). The height of the target center was 1.73 m and participants stood 2.37 m away from the board, which are standard measures according to the World Darts Federation (WDF) in 2009 (Figure 1). The squared field included a yellow bull, 4.5 x 4.5 cm, and a bull's eye, highlighted in red, 1.5 x 1.5 cm. Horizontal and vertical lines separated by a distance of 1.5 cm were drawn around the bull creating squares. The total board showed a field of 10 squares in every direction on the x- and y-axis, for a total of 20 x 20 1.5 cm squares. A squared field with a squared central bull's eye was used for detailed capturing of x-and y-axis deviation (see also Schorer et al., 2012). All participants reported that this altered dart board did not affect their natural performance.

In order to measure throwing performance, the deviation in horizontal and vertical direction from the bull's eye was captured after every single throw. Competition steel darts (24 gram) were provided to all participants with the option to use their personal darts. This option was given because skilled participants believed their performance would be affected when they did not use their own darts. All personal darts were also regular competition steel darts with a weight of 24 grams.

For eye movement analyses, a head-mounted eye-tracking system was used (Eyelink II, SR Research). With this system it is possible to capture gaze behavior (binocular or monocular) at 500 Hz, < 0.5° of average spatial accuracy, and 0.01° RMS resolution. To prevent effects to the participant's normal throwing action, which can include adjusting the dart in front of the throwing arms' side of the faces, we decided to capture monocular vision (500 Hz) from the eye opposite to the throwing arm. Because all participants were right-handers, we captured gaze behavior of the left eye. The camera capturing the eye movement was adjusted at an angle of 45° and a distance of four centimeters, placed at the height of the participant's left cheek bone. The frame of reference for the eye-tracking system was the wooden board to which the squared raster was projected. Using four infrared based markers at the corners of the board, the frame of reference was established and within it, the eye-tracking system was

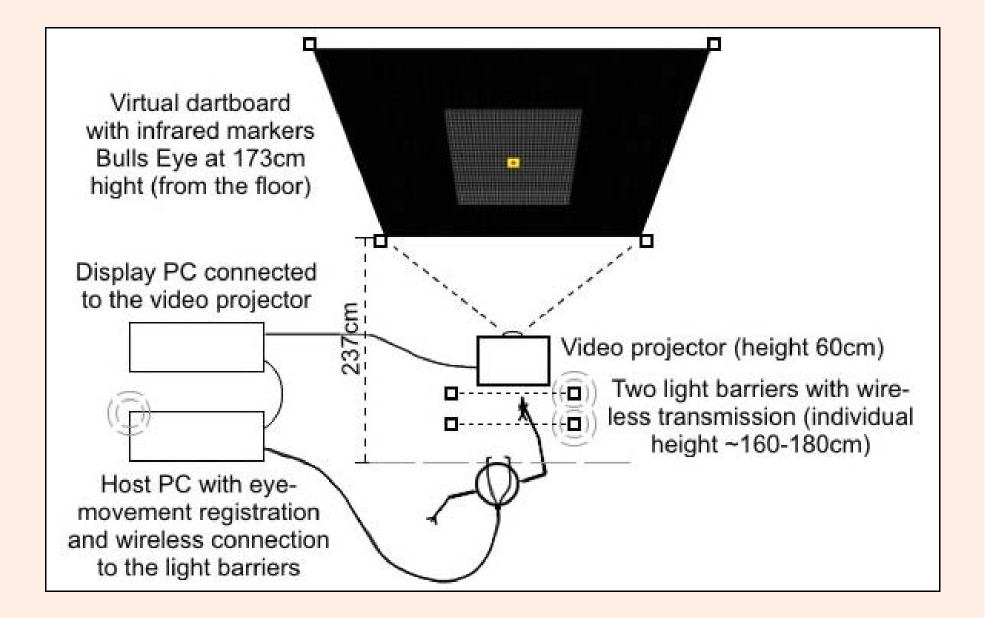

Figure 1. Aerial perspective of the experimental setup.

calibrated and validated (Figure 1). Furthermore, two light barriers (two Nintendo Wii controllers in combination with two infrared LEDs) were used to capture the movement of the participant's throwing arm. For the specific task of dart throwing, the quiet eye was defined as final fixation prior to the extension of the throwing arm (Vickers et al., 2000), which was determined by triggering two light barriers. These barriers were adjusted in height (i.e., between 160 and 180 cm) for each participant at the level of the wrist of each participant's throwing arm. The first light barrier was positioned closer to the participant's wrist, the second 20 cm further away. The distance between the two parts of each light barrier (Nintendo Wii controller and LED), positioned left and right from the participant's throwing arm, was 30 cm. The light barriers were placed in front of the participant in a way that both light barriers triggered the extension phase of the arm at 100 Hz. Thus, the first was positioned at the beginning of the extension phase and the other captured information later in the extension phase (Figure 1). Even though one light barrier would have been sufficient for capturing the relevant components for quiet eye analysis, using two light barriers guaranteed a reliable capturing of the whole shooting phase. These settings did not disturb natural throwing action and participants confirmed that they did not feel impaired and the setup did not affect their throwing movement or performance in general.

The contingent change display paradigm is a methodological approach to connecting gaze behavior and the field of vision. Until now, experiments in sport sciences have dealt with athletes' gaze behavior by using eye-tracking systems or temporal and spatial occlusion paradigms (e.g. video based systems or usage of special goggles). With the contingent change display paradigm, it is possible to combine both components. Thus, the field of vision can be influenced and as a result, it is possible to experimentally determine what information is extracted. The paradigm works using special programming within the eye-tracking software (i.e., *Experiment Builder* in Eyelink II). For the peripheral vision condition, a black mask in the form of a circle of 5° (central vision, represented by foveal and parafoveal vision) of visual angle was adapted to the point of gaze. This means, wherever the participants fixated or tracked on the visual display (the projected raster) was occluded by a size of 5° and only information from further than 5° was extracted (peripheral vision). For the central vision condition, the converse effect was implemented; a black mask occluded everything further than 5° of visual angle thereby allowing information up to 5° of visual angle to be picked-up with the rest of the visual field (periphery) occluded.

In summary, the visual display (the projected raster) was manipulated using occluding masks in accordance to the participants' eye movement. Parts of the raster were occluded, depending on where the participant was looking and what condition was presented (central or peripheral).Prior to data collection, participants took practice throws at the wooden board (without the projected raster) to enable individual adjustment of the eye-tracking system and light barriers. Dependent on how fast the adjustment of the system took place, participants took between six and nine practice throws (two or three blocks of three throws). After the adjustment of the eye-tracker and light barriers, a nine-point calibration, followed by a validation of this calibration, took place. Additionally, at the beginning of each trial, before the squared raster was presented, a drift correction was performed. The drift correction works by computing a corrective offset to the raw eye-position data and provides an additional check to ensure the captured gaze behavior was as accurate as possible.

The experiment was subdivided into three blocks of 15 dart throwing trials, for a total of 45 shots per participant. The instruction given to the participants prior to each block was to hit the bull's eye (the red center of the raster) and participants were told that throwing performance would be captured after every throw (generally dart players throw three darts in a row what is not possible within the current study design. Nonetheless participants reported not to feel effected by taking single throws). Thus, within each block, throwing accuracy was measured after each throw using projected images of vertical and horizontal lines. More specifically, after each participant threw the dart towards the target (movement execution of throwing action was completed), the projected raster was replaced by two consecutive pictures. First only the vertical lines of the raster with horizontal distances from the bull's eye were displayed (for capturing x direction of the throw), followed by the same procedure with vertical deviations displayed (for capturing y direction of the throw). As described earlier, a distance of 1.5 cm separated the lines. After registering both of these values (i.e., x and y direction of each throw), the experimenter removed the dart from the target and the next trial began after the drift correction.

Baseline data were collected for each participant using the first block of 15 dart throws with a full-vision condition. For the two additional blocks of trials with central and peripheral conditions, the contingent-change display paradigm was used (as described above) and the block order of central and peripheral conditions was counterbalanced across participants.

Statistical analyses and dependent variables

One-tailed independent sample t-tests were used to examine skill level differences in baseline performance. For the interaction of skill level and manipulated field of vision, repeated measures analysis of variance (ANOVA) was applied. To measure the association between throwing results with the quiet eye behavior, previous studies have administered ANOVAs or t-tests to differentiate between hits and misses (e.g., Harle & Vickers, 2001; Vickers, 1996). In the current investigation, we wanted to go a step further with the analysis of this intra-individual variability. The measurement of performance error from -10 to +10 on both, y- and x-axes enables us to use a more detailed ratio scale of performance measurement; instead of only comparing the dichotomic hits and misses; moreover, because of our ratio scaled data, two-tailed Pearson correlation coefficients were calculated instead of the mostly used t-tests and ANOVAs for hits and misses. This enabled us to also report the explained variance by the squared correlation.

Often, statistical data are interpreted on the basis of p-value. This statistic was used in the current investigation; however, additional statistical values were given to convey the most complete meaning of results and deeper discussion as advocated by APA (2010). For this purpose, effect sizes (d for t-tests, and f for analyses of variance) and test powers (1-ß) were calculated (Cohen, 1988).

The dependent variables were accuracy and consistency of the throwing performance as well as quiet eye duration and quiet eye location. Mean radial error was used as the measure of throwing accuracy, and bivariate variable error used for throwing consistency (Hancock et al., 1995). The mean radial error captures the error's magnitude in 2-D using the x and y coordinates of each shot. Because the performance across multiple trials is only partially described by the measurement of accuracy (mean radial error), the bivariate variable error for consistency was also measured to provide a more complete representation of throwing performance. The bivariate error is the measurement of standard deviation of intra-subject variability across 2-D, given by the square root of the shots' mean squared distance from their centroid (for concrete mathematical formula of mean radial error and bivariate error, see Hancock et al., 1995).

The quiet eye period in dart throwing was defined as the final fixation prior to the extension of the throwing arm (Vickers et al., 2000). The fixation had a length of at least 100 ms, based on previous fixation definitions (Young and Sheena, 1975). To determine the quiet eye period within the throwing movement of the participants, the light barriers were used to trigger the beginning of the extension phase of the participant's arm during trials and thereby determine the quiet eye period (in accordance to Vickers et al., 2000). In detail, triggering of the light barriers was inputed online into the *Data Viewer* analysis program (Eyelink II) via bluetooth-connections. This leads to online synchronization of data pertaining to gaze behavior with information about the throwing action (i.e., triggering the extension phase of participant's throwing arm). Consequently, the last fixation prior to the registration of the light barriers with a length of a minimum of 100ms within a visual angle of 3° (88 pixels) defined the quiet eye period in milliseconds. Quiet eye onset was the initiation of the fixation prior to triggering and quiet eye offset occurred when the eye deviated from the location by more than 3° (in accordance to earlier quiet eye definitions, for an overview see Vickers, 2007). For the analysis of quiet eye location, the x- and y-coordinates of the quiet eye on the target provided the mean radial error. The quiet eye period and its location were analyzed individually for every trial. All data were analyzed using PASW 18.0 and G*Power 3.10 (Faul et al., 2007).

Results

The results section is divided into two parts. First, the baseline results concerning the replication of throwing performance (accuracy and consistency), and gaze behavior (quiet eye duration and location) are presented. Second, results concerning the manipulated vision (central vs. peripheral vision conditions) are presented followed by correlations between throwing performance and quiet eye period.

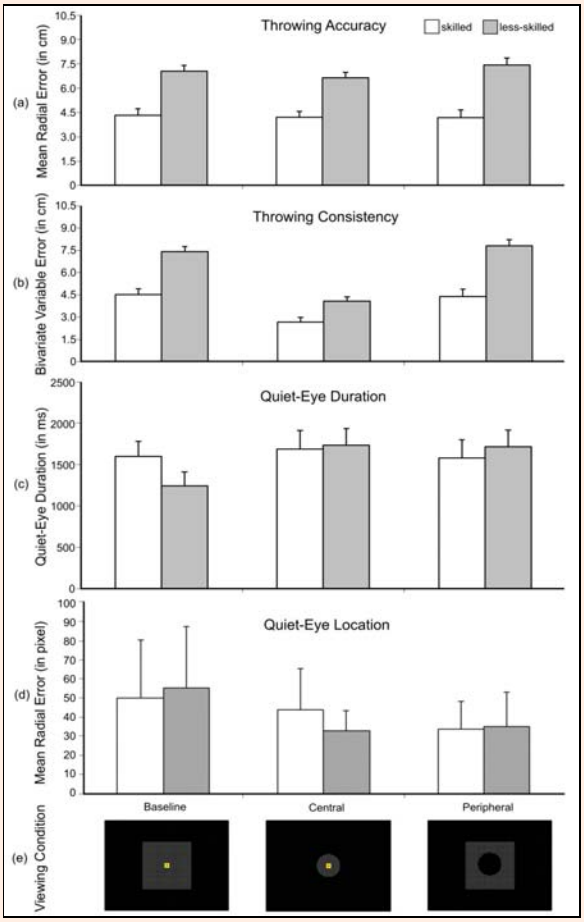

Figure 2. Throwing performance, presented as (a) throwing accuracy (in cm) and (b) throwing consistency (in cm), and eye-movement behavior, presented as (c) quiet eye duration (in ms) and (d) quiet eye location (in pixel) for skilled (n = 13) and less-skilled (n = 16) dart players for different viewing conditions illustrated in (e) (baseline, central, and peripheral vision). Error bars indicate standard deviations.

Baseline condition

As hypothesized, one-tailed t-tests for independent samples revealed significant differences between skill groups in throwing accuracy, t(27) = 5.29, p < 0.01, d = 2.00, and throwing consistency, t(27) = 5.50, p < 0.01, d = 2.01. The skilled group had superior performance with higher accuracy and greater consistency (Figure 2a and 2b). For quiet eye duration during baseline performance, differences between skilled and less-skilled groups were revealed, t(27) = 1.42, p = .08, d = 0.52 (Figure 2c) although without reaching the statistical level of significance on the basis of p-values; however, there was a not significant difference in quiet eye location between skilled and less-skilled groups, t(27) = 0.43, p = 0.67, d = .16, 1-β = 0.07 (Figure 2d). Significant correlations were found between quiet eye duration and both throwing accuracy and throwing consistency in full vision for the less skilled players (Table 1, column 3 - 4). No other

Table 1. **Correlations (r) between throwing performance (accuracy = ACC; consistency = CON) and perceptual behavior (quiet eye duration = QED; quiet eye location = QEL) among study participants (all participants, less-skilled and skilled) for full, central and peripheral vision conditions.**

		Full		Central		Peripheral	
		ACC	CON	ACC	CON	ACC	CON
all	**QED**	-.02	-.10	.23	.23	.14	.12/.54
	QEL	-.02	.07	-.15	-.15	.45 **	.46 **
less-skilled	**QED**	.76 **	.63 **	.53 *	.40	.12	.05
	QEL	-.31	-.05	-.46	-.28	.54 *	.54 *
skilled	**QED**	-.28	-.32	-.05	-.35	.10	.15
	QEL	.23	.11	.50	.50	.71 **	.73 **

* $p < 0.05$, ** $p < 0.01$.

correlations between quiet eye duration and throwing performance at baseline reached significance.

Central and peripheral vision conditions

For throwing performance, we predicted a decrease in throwing results when only peripheral vision was available (Vickers, 2009). A between-subject (groups) repeated measurement (central vs. peripheral) ANOVA showed, in contrast to our predictions, significant difference in throwing accuracy only between groups, F(1,27) = 26.87, $p < 0.01$, f = 1.00. Neither vision condition, F(1,27) = 2.14, p = 0.15, f = 0.27, 1-β > 0.89, nor their interaction, Fs(1,27) = 1.71, p = 0.20, f = 0.25, 1-β > 0.83, were significant factors affecting throwing accuracy. For throwing consistency, all factors and their interaction reached significance. The skilled group demonstrated better throwing consistency, F(1,27) = 20.24, $p < 0.01$, f = 0.87. In the central vision condition, both groups performed better than in the peripheral vision condition, F(1,27) = 132.68, $p < 0.01$, f = 2.21, but the less-skilled group showed a larger decrease in throwing consistency from central to peripheral vision conditions, Fs(1,27) = 15.76, $p < 0.01$, f = .77.

For gaze behavior, the repeated measures ANOVA revealed neither significant group differences in quiet eye duration, F(1,27) = 0.09, p = 0.75, f = 0.10, 1-β = 0.09, differences between visual conditions, F(1,27) = 0.58, p = 0.45, f = 0.14, 1-β = 0.36, nor their interaction, Fs(1,27) = 0.32, p = 0.57, f = 0.10, 1-β = 0.19. The same pattern of results was noted for quiet eye location. There were no significant differences for group, F(1,27) = 0.99, p = 0.33, f = .20, 1-ß = 0.25, visual condition F(1,27) = 1.13, p = 0.30, f = 0.20, 1 - ß = 0.65, or their interaction, Fs(1,27) = 2.69, p = 0.11, f = 0.31, 1-ß > 0.96.

Quiet eye duration and throwing accuracy in central vision conditions were significantly positively correlated for less skilled players (see Table 1, column 5 - 6). Also, positive correlations were revealed between quiet eye location and throwing accuracy, as well as between quiet eye location and throwing consistency for skilled players, less skilled players, as well as for both skill groups combined, but only in the peripheral vision condition. No other correlation was significant (see Table 1, column 7 - 8).

Discussion

Within this study, we investigated two assumptions concerning the quiet eye phenomena. On the one hand, centrally processed information seems to be important (Vickers, 2009) while on the other hand, incomplete spatial information accompanies a decrease in performance (Vickers, 2011). Our first aim was to replicate the association between quiet eye duration and location with better throwing performance in a baseline condition (full vision). Our second aim was to investigate the extent to which quiet eye is affected by central and peripheral components of the visual field. Based on the hypothesis that centrally fixated information is critical for the quiet eye (Vickers, 2009), varying fields of vision were associated with differences in the quiet eye and throwing performance of skilled dart players.

Concerning our first aim, our results replicate prior findings of Duffy and colleagues (2004) showing significant differences between skilled and less-skilled participants in baseline throwing performance. Further, skilled dart throwers were not only more accurate, but more consistent in their throwing performance (c.f., Schorer et al., 2012). For the perceptual measures, differences between skilled and less-skilled players in quiet eye duration were not statistically significant (p = 0.08). Surprisingly, we were unable to replicate the robust finding of expertise differences in quiet eye duration on the basis of p-values. Traditionally, this is the basis on which data are interpreted. However, we also calculated effect size and test power, and the effect size of the difference between groups was 0.52. In accordance to Cohen (1988), this represents a medium-sized effect, which emphasizes the weight of these differences in quiet eye duration. Furthermore, these effect sizes are in line with previously reported research results on throwing tasks (for a meta-analysis, see Mann et al., 2007). These findings do not replace significant differences on the basis of p-value, but clarify that our results are in the direction of previous investigations observing quiet eye differences for skill groups. Besides that, increasing sample size post-hoc might have reduced p to < 0.05; however, the practical significance expressed by medium effect sizes (arguably a more important statistic) would likely have remained constant for $p < 0.05$ (Rosnow and Rosenthal, 1989). Additionally, we found a strong positive correlation for less skilled players between quiet eye duration and throwing performance, which is in line with previous studies examining differences in quiet eye duration for hits versus misses (Harle and Vickers, 2001; Janelle et al., 2000; Vickers, 1996; Vickers and Adolphe, 1997).

These results highlight one point of concern for future investigations. On the basis of the effect sizes in this experiment, the sample size for a subsequent investigation using this setup should be pre-defined. This will help to create sample sizes for skill groups that are large enough to find significant differences in the dependent variables if they occur.

Concerning our second aim, we investigated whether the content of the fixated target during the quiet eye phase was important for superior performance by varying either central or peripheral vision using the contingent-change display paradigm. Throwing performance was analysed via throwing accuracy and throwing consistency. For throwing accuracy, between skill group differences remained, but none of the occlusion conditions seemed to influence these results. The observed test power for the differences between visual conditions and their interaction with skill supports the null-hypothesis (i.e., that there are no influences on throwing accuracy, Kline, 2005). A different picture arises for throwing consistency, where both factors and their interaction reached significance. While the higher consistency for skilled players is not surprising (Duffy et al., 2004), the interaction is of interest. For skilled players, varying the fields of vision seemed to have no effect; however, the less-skilled participants had superior performance in the central vision condition.

For the perceptual measures, quiet eye duration also seemed affected by the change in the visual condition. First, for less-skilled players, the quiet eye duration increased compared to baseline performance, but almost no change was observable for the skilled players. Within this context, subsequent studies may wish to add another throwing condition with full vision within the counterbalanced order of manipulated throwing conditions. Second, within the manipulated viewing conditions no significant differences for quiet eye duration were revealed, with no interaction between throwing condition and skill. Interestingly, quiet eye duration of skilled and less-skilled players seemed unaffected by spatial occlusion manipulation (central or peripheral). Moreover, it is notable that despite no significant changes in quiet eye duration between central and peripheral vision, there was a significant effect for throwing consistency with the less skilled participants in the central to peripheral vision conditions, although these results were not as strong as hypothesized. By only allowing peripheral vision, we expected not only a significant difference for consistency but a decrease in throwing accuracy, and a differentiation in quiet eye duration.

One possible explanation is that the black circle might have been used as a larger target in the central-occlusion condition, instead of the bull's eye, so the consistency was affected, but not throwing accuracy or quiet eye duration. The optimal size of the focus of attention has been discussed in sport (cf. Abernethy, 2001) with a smaller focus of attention leading to more efficient information handling per unit of area (cf. Castiello and Umiltà, 1990). Within the peripheral condition of the contingent change display paradigm, the overlaid area of the point of gaze had a size of 5° of visual angle. Because the 5° are wider than the target area (bull and bull's eye in the center of the squared raster), aiming at the center of the occluded mask is not equivalent to aiming at the target center. The target is clearly occluded in this condition, but the black mask is not precisely in the center of the raster; thus, aiming at the black circle's center would not necessarily involve aiming at the target center. With this in mind, we can hypothesize that for novice participants the peripheral vision condition prevented central information pick-up of the bull's eye but the larger black circle in the grid provided a bigger suitable target only by holding the gaze stable to the target's center; however, for investigating differences in throwing accuracy and quiet eye duration in a further experiment in this context, an additional no frame condition should be used where participants get neither central nor peripheral target information. Additionally, another effect of peripheral vision should be investigated. It is possible that in a targeting task like dart throwing, peripheral vision is used to control limb movements, such as the throwing arm. Abahnini et al., (1997) showed that vision of one's hand in the visual peripheral field is critical and the directional control of aiming movements is optimal only if peripheral visual information is available. Within the contingent change display paradigm, we only occluded parts of the visual display, thus the throwing arm is visible in the periphery in all conditions. Such an effect on the period of quiet eye should be investigated in a further study.

Taking these findings together two interesting topics arise. First, quiet eye duration does not seem to be associated with throwing performance in skilled dart players. In fact our results suggest their performance is negatively correlated (while not significantly, see Table 1). It is possible that in skills with little variability in their performance, the association between quiet eye duration and throwing performance shown in other studies (Harle and Vickers, 2001; Janelle et al., 2000; Vickers, 1996; Vickers and Adolphe, 1997) might not be detectible because the effect is small. This would explain why quiet eye explained almost 50 percent of the variance in throwing performance for unskilled players but not for skilled players. Second, occluding central information in skilled and unskilled players nicely highlights the importance of quiet eye location in dart throwing. When the bull's eye is not visible to the players, a good estimate of where it is (i.e., the black circle representing the occluded information) helped players to perform better in throwing accuracy and consistency. This was even stronger in skilled players with almost 50 percent explained variance compared to only 25 percent in unskilled players supporting the notion that, in addition to the type of information extracted, the stable quiet eye likely increases postural stability during aiming (Vine et al., 2011).

Conclusion

These findings add depth to our understanding of the quiet eye phenomenon in sport skills and add several new directions for future research. While findings are generally in line with the association between quiet eye duration and throwing performance, they raise several questions. Based on the non-statistically significant quiet eye differences for level of expertise future studies should consider whether additional factors or variables, beyond the period of quiet eye, are important for optimal throwing performance. Without a clear understanding of the specific mechanism behind the quiet eye effect, it is possible that quiet eye duration is a proxy for some other perceptual cognitive variable. Moreover, the role of centrally fixated (i.e., foveal) vision for the quiet eye period should be further investigated. Understanding the role of the different sources of vision to the quiet eye will lead to more comprehensive models of expert perception in sport. Our results show, the quality of the information obtained within the period of quiet eye seems less important than previously assumed for targeting tasks like dart throwing. Further experiments should investigate the underlying mechanism(s) of the quiet eye phenomena. It is currently still unclear why this effect occurs. For instance, is it really the quiet eye that is important, or does the final fixation benefit additional processes (i.e., the quiescence of the psychomotor system; Vine, Moore & Wilson, 2011). Thus, in future experiments postural stability occurring during movement execution should be investigated along with the quiet eye period to determine the relative importance of these mechanisms to understanding this intriguing phenomenon.

References

A.P.A. (2010) *Publication manual of the American Psychological Association.* 6 edition. Washington DC: American Psychological Association.

Abahnini, K., Proteau, L. and Temprado, J.J. (1997) Evidence supporting the importance of peripheral visual information for the directional control of aiming movement. *Journal of Motor Behavior* **29,** 230-242.

Abernethy, B. (1988) Dual-task methodology and motor skills research: Some applications and methodological constraints. *Journal of Human Movement Studies* **14,** 101-132.

Abernethy, B. (2001). Attention. In: *Handbook of sport psychology*. Eds: Singer, R.N., Hausenblas, H.A. and Janelle, C.M. New York: Wiley. 53-85.

Abernethy, B., Maxwell, J.P., Jackson, R.C. and Masters, R.S.W. (2007) Skill in sport. In: *Handbook of applied cognition.* Eds: Durso, F., Nickerson, R., Dumais, S., Lewandowsky, S. and Perfect, T. 2nd edition. New York: Wiley. 333-359.

Behan, M. and Wilson, M. (2008) State anxiety and visual attention: The role of the quiet eye period in aiming to a far target. *Journal of Sports Sciences* **26,** 207-215.

Castiello, U. and Umiltà, C. (1990) Size of the attentional focus and efficiency of processing. *Acta Psychologica* **73,** 195-209.

Causer, J., Bennett, S.J., Holmes, P.S., Janelle, C.M. and Williams, A.M. (2010) Quiet eye duration and gun motion in elite shotgun shooting. *Medicine and Science in Sports and Exercise* **42,** 1599-1608.

Cohen, J. (1988) *Statistical power analysis for the behavioural sciences.* 2nd edition. Hillsdale, NJ: Lawrence Erlbaum Associates.

de Oliveira, R.F., Oudejans, R. and Beek, P. (2006) Late information pick-up is preferred in basketball jump shooting. *Journal of Sports Sciences* **24,** 933-940.

de Oliveira, R.F., Oudejans, R.R.D. and Beek, P.J. (2008) Gaze behavior in basketball shooting: Further evidence for online visual control. *Research Quarterly for Exercise and Sport* **79,** 399-404.

Duffy, L.J., Baluch, B. and Ericsson, K.A. (2004) Dart performance as a function of facets of practice amongst professional and amateur men and women players. *International Journal of Sport Psychology* **35,** 232-245.

Faul, F., Erdfelder, E., Lang, A.-G. and Buchner, A. (2007) G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods* **39,** 175-191.

Glöckner, A., Heinen, T., Johnson, J.G. and Raab, M. (2012) Network approaches for expert decisions in sports. *Human Movement Science* **31,** 318-333.

Hancock, G.R., Butler, M.S. and Fischman, M.G. (1995) On the problem of two-dimensional error scores: Measures and analyses of accuracy, bias, and consistency. *Journal of Motor Behavior* **27,** 241-250.

Harle, S.K. and Vickers, J.N. (2001) Training quiet eye improves accuracy in the basketball free throw. *Sport Psychologist* **15,** 289-305.

Hodges, N., Starkes, J. and MacMahon, C. (2006) Expert performance in sport: A cognitive perspective. In: *The Cambridge handbook of expertise and expert performance.* Eds: Ericsson, K.A., Charness, N., Feltovich, P.J. and Hoffman, R.R. New York: Cambridge University Press. 471-488.

Janelle, C.M., Hillman, C.H., Apparies, R.J., Murray, N.P., Meili, L., Fallon, E.A. and Hatfield, B.D. (2000) Expertise differences in cortical activation and gaze behavior during rifle shooting. *Journal of Sport and Exercise Psychology* **22,** 167-182.

Kline, R.B. (2005) *Beyond significance testing.* 2nd edition. Washington, D.C.: American Psychological Association.

Mann, D.T.Y., Coombes, S.A., Mousseau, M.B. and Janelle, C.M. (2011) Quiet eye and the Bereitschaftspotential: Visuomotor mechanisms of experts motor performance. *Cognitive Processing* **12,** 223-234.

Mann, D.T.Y., Williams, A.M., Ward, P. and Janelle, C.M. (2007) Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology* **29,** 457-478.

McConkie, G.W. and Rayner, K. (1975) The span of the effective stimulus during a fixation in reading. *Perception and Psychophysics* **17,** 578-586.

Oudejans, R.R.D., van de Langenberg, R. and Hutter, R.I. (2002) Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting. *Human Movement Science* **21,** 457-480.

Panchuk, D. and Vickers, J.N. (2006) Gaze behaviors of goaltenders under spatial-temporal constraints. *Human Movement Science* **25,** 733-752.

Panchuk, D. and Vickers, J.N. (2009) Using spatial occlusion to explore the control strategies used in rapid interceptive actions: Predictive or prospective control? *Journal of Sports Sciences* **27,** 1249-1260.

Rayner, K. (1998) Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin* **124,** 372-422.

Rosnow, R.L. and Rosenthal, R. (1989) Statistical procedures and the justification of knowledge in psychological science. *American Psychologist* **44,** 1276-1284.

Schorer, J., Jaitner, T., Wollny, R., Fath, F. and Baker, J. (2012) Influence of varying focus of attention conditions on dart throwing performance in experts and novices. *Experimental Brain Research* **217,** 287-297.

Vickers, J.N. (1992). Gaze control in putting. *Perception* **21,** 117-132.

Vickers, J.N. (1996) Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception and Performance* **22,** 342-354.

Vickers, J.N. (2007) *Perception, cognition and decision training: The quiet eye in action.* Champaign, IL: Human Kinetics.

Vickers, J.N. (2009) Advances in coupling perception and action: The quiet eye as a bidirectional link between gaze, attention, and action. *Progress in Brain Research* **174,** 279-288.

Vickers, J.N. (2011) Mind over muscle: the role of gaze control, spatial cognition, and the quiet eye in motor expertise. *Cognitive Processing* **12,** 219-222.

Vickers, J.N. and Adolphe, R. (1997) Gaze behaviour while tracking an object and aiming at a far target. *International Journal of Sports Vision* **4,** 18-27.

Vickers, J.N., Rodrigues, S.T. and Edworthy, G. (2000) Quiet eye and accuracy in the dart throw. *International Journal of Sports Vision* **6,** 30-36.

Vickers, J.N. and Williams, A.M. (2007) Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior* **39,** 381-394.

Vine, S.J., Moore, L. and Wilson, M.R. (2011) Quiet eye training facilitates competitive putting performance in elite golfers. *Frontiers in Psychology* **2,** 1-9.

Williams, A.M., Davids, K. and Williams, J.G. (1999) *Visual perception and action in sport*. London: Routledge.

Williams, A.M. and Ericsson, K.A. (2005) Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science* **24,** 283-307.

Williams, A.M., Singer, R.N. and Frehlich, S.G. (2002) Quiet eye duration, expertise, and task complexity in near and far aiming tasks. *Journal of Motor Behavior* **34,** 197-207.

Williams, A.M., Vickers, J.N. and Rodrigues, S. (2002) The effects of anxiety on visual search, movement kinematics, and performance in table tennis: A test of Eysenck and Calvo's processing efficiency theory. *Journal of Sport and Exercise Psychology* **24,** 438-455.

Williams, A.M. and Ward, J.D. (2007) Anticipation and decision making: Exploring new horizons. In: *Handbook of sport psychology*. 3rd edition. Eds: Tenenbaum, G. and Eklund, R. New York: Wiley. 203-223.

Wilson, M.R. and Pearcy, R.C. (2009) Visuomotor control of straight and breaking golf putts. *Perceptual and Motor Skills* **109,** 555-562.

World-Medical-Association. (2008) Declaration of Helsinki - Ethical principles for medical research involving human subjects. Available from URL: http://www.wma.net/en/30publications/10policies/b3/index.html

Young, L.R. and Sheena, D. (1975) Survey of eye movement recording methods. *Behavior Research Methods and Instrumentation* **7,** 397-429.

Key points

- Investigation of throwing performance and quiet eye duration in dart throwing under several vision conditions
- First investigation using a dynamic occlusion paradigm, manipulating field of vision *in situ*
- Replication of previous findings concerning throwing performance and quiet eye duration
- New insights about the role of central (and peripheral) vision concerning the quiet eye phenomena

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