Considerations for the study of individual differences in gaze control during expert visual anticipation: An exploratory study

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Citation:

RAMSEY, H., BUTTON, C., DAVIDS, Keith, HACQUES, G., SEIFERT, L. and DICKS, M. (2020). Considerations for the study of individual differences in gaze control during expert visual anticipation: An exploratory study. Movement and Sports Sciences - Science et Motricite, 2020-J (110), 39-47. [Article]

Running Head: Variation in Gaze Control

Considerations for the study of individual differences in gaze control during expert visual anticipation: An exploratory study

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Accepted for publication in Movement & Sport Sciences - Science & Motricité on 22nd April 2020

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Abstract

Recent perspectives for the study of perceptual-motor expertise have highlighted the importance for considering variability in gaze behaviour. The present paper explores the prevalence of variability in gaze behaviour in an anticipation task through examining goalkeepers gaze behaviours when saving soccer penalty kicks, with a primary focus on offering new considerations for the study of variability in gaze behaviour. A subset of data from five goalkeepers in the previously published article of Dicks et al. (2010) were reanalysed, with a focus on ten successful penalty saves for each goalkeeper. As the aim was to conduct exploratory analyses of individual differences in goalkeeping performance, data were not averaged across participants and instead intra- and inter-individual differences are described using descriptive statistics. The main observation was that variation in the goalkeepers' gaze behaviours existed and were evident both between and within individuals, specifically with regards to quiet eye duration but also for percentage viewing time and visual search patterns. However, QE location appeared to represent the only invariant gaze measure with the location being on the ball for the majority of trials. The current exploratory analysis suggested that experienced goalkeepers did not converge on the same gaze patterns during successful anticipation performance. The implications of these findings are discussed in relation to extant gaze behaviour literature before considering implications for future research.

Considérations pour l'étude des différences individuelles dans le contrôle du regard lors de l'anticipation visuelle: une étude exploratoire

Résumé

De récentes perspectives ont souligné l'importance de tenir compte de la variabilité du comportement visuel dans l'étude de l'expertise perceptivo-motrice. Cet article explore la prévalence de la variabilité du comportement visuel dans une tâche d'anticipation en se focalisant sur la proposition de nouvelles méthodes pour étudier la variabilité du comportement visuel. Pour ce faire, nous avons examiné le comportement visuel de gardiens de but lors d'arrêts de pénaltys. Des données provenant de 5 gardiens de but d'un précédent article de Dicks et al. (2010) ont été réanalysées en se focalisant sur 10 arrêts réussis pour chacun des gardiens de but. L'objectif de cette étude est de réaliser une analyse exploratoire des différences interindividuelles. Les caractéristiques du comportement visuel de chaque gardien de but ont été décrites à l'aide de statistiques descriptives plutôt que de moyenner les données pour l'ensemble des participants. La principale observation a été que la variabilité du comportement visuel des gardiens était présente à la fois entre les individus, mais aussi pour un même individu entre ses essais. Plus précisément, ces variabilités apparaissaient pour la durée du « quiet eye » (QE, dernière fixation visuelle avant l'amorce du mouvement) mais aussi dans la répartition du temps de regard et du pattern de recherche visuel. Cependant, la localisation du QE a été la seule mesure invariante, le regard étant dirigé vers le ballon sur la plupart des essais. Cette analyse exploratoire suggère que les gardiens de but expérimentés ne convergent pas vers un comportement visuel similaire pour réussir des tâches d'anticipation. Ces résultats sont discutés au regard de la littérature existante avant de proposer des pistes de recherches futures.

Introduction

In the domain of expertise research in sport, an extensive body of literature now exists on the perceptual-motor processes that underpin elite performance (van der Kamp, Rivas, van Doorn & Savelsbergh, 2008; Williams & Ericsson, 2005). One facet of this research has been dedicated to the examination of gaze behaviours that are associated with the control of highly-skilled perceptual-motor behaviours. Gaze behaviours have typically been studied in three broadly conceptualised sporting contexts: aiming tasks (e.g., a basketball free throw), anticipation tasks (e.g., a goalkeeper anticipating the direction of a penalty kick prior to the penalty taker's foot-ball contact), and decision-making tasks (e.g., deciding which teammate to pass the ball to) (Vickers, 2007). Typically, authors have used experimental designs that compare between a group of expert and non-expert performers to attain differences in gaze behaviour (Williams & Ericsson, 2005). Several measures have been studied to enhance understanding of differences in gaze behaviours, usually focussing on variations around the location, duration, and number of fixations (McGuckian, Cole, & Pepping, 2018; Dicks, Button, & Davids, 2010).

Research has demonstrated an experimental advantage for experts in perceptual-motor skill and such differences tend to be reflected by differences in gaze patterns. For example, in anticipation tasks, a common finding is that experts tend to use fewer fixations of a longer duration than novices (Dicks, Davids, & Button, 2009). Moreover, in aiming tasks such as the basketball free-throw, experts tend to utilise a longer final fixation compared with non-experts prior to final movement onset (Vickers, 1996). The tendency of researchers to analyse gaze measures at the group-level by averaging data across participants and trials (e.g., Dicks et al., 2010) has recently been questioned as this approach implies that the same gaze pattern, when utilized by all participants in the same task or experiment, will lead to equivalent levels of success (Dicks, Button, Davids, Chow, & van der Kamp, 2017). Implicit within this view is the implication that a consistent and repeatable gaze pattern may be replicated from trial to trial with little deviation between or within individual participants. However, evidence indicates that individual differences in gaze behaviour appear to exist between performers of the same skill level when successfully completing the same task (e.g., Croft, Button, & Dicks, 2010; Mann, Coombes, Mousseau, & Janelle, 2011). For instance, in a ten-pin bowling study, when participant data were considered at the group level, Chia et al. (2017) observed that experts utilised a longer QE duration than novices. However, the authors identified large inter- and intra-individual variation in QE duration without consequence for performance in the expert group. Thus, the implication is that research which does not consider variations in perceptual capacities within a skill-group or during learning, may not adequately reveal the gaze patterns used during perceptual-motor control (Dicks et al., 2017).

With the above concerns in mind, findings derived from comparative studies of gaze behaviours have often been used as the basis for learning studies, within which novices are trained to replicate the gaze patterns of experts. This approach has provided evidence of performance improvements after gaze training in aiming tasks (e.g., Vine, Moore, & Wilson, 2011) although such findings have not been replicated across all studies, including anticipation training interventions (Klostermann, Vater, Kredel, & Hossner, 2015). The finding that training individuals to replicate the gaze patterns of more skilled performers does not always lead to increased performance in anticipation tasks raises possible doubt over whether purported *optimal* or universal gaze patterns exist (Dicks et al., 2017).

Representative of the approach to train novices to anticipate using the average of expert gaze patterns, Savelsbergh and colleagues (2010) used evidence from prior research to create a visual search pattern for recreational goalkeepers to learn to use when attempting to anticipate the direction of penalty kicks (see Savelsbergh, Williams, van der Kamp, & Ward, 2002; Savelsbergh, van der Kamp, Williams, & Ward, 2005). From run-up initiation to ball contact, the visual search pattern aimed to guide the keeper to first look at the head of the penalty taker, then hip region, and then to the lower leg regions, specifically the orientation of the non-kicking leg. The authors found support for training on the basis of this pattern because recreational goalkeepers that used this gaze behaviour, improved their performance of predicting the direction of penalty kicks (see Figure 1). However, the authors found that another visual search pattern correlated positively with anticipation performance, suggesting that more than one gaze pattern could be used to be successful within a given task.

The finding that more than one gaze pattern can be used to successfully anticipate the direction of penalty kicks (Savelsbergh et al., 2010), is supported by results from Navia and colleagues (Navia, Dicks, van der Kamp, & Ruiz, 2017) who analysed expert futsal goalkeepers gaze behaviours when saving penalty kicks under differing spatiotemporal constraints (from 6 m and 10 m distances). The authors found that gaze behaviours in the first phase of the run up differed markedly between participants in the location and timing of fixations, whereas the gaze variation decreased in the second phase, which was interpreted as the pick-up of more reliable visual information as the kickers' actions unfolded (specifically within 250 ms of ball contact) (Navia et al., 2017; Diaz, Fajen, & Phillips, 2012). These findings therefore indicated that skilled anticipation may not be reliant on a consistent and repeatable search pattern (e.g. Abernethy, Schorer, Jackson, & Hagemann, 2012; Savelsbergh et al. 2005, 2010). Further, it was reported that gaze variables, such as the percentage viewing time spent looking at different locations, were highly variable between participants, suggesting that this measure does not necessarily capture expert gaze behaviour. Instead, it was proposed that looking in the right time(s) at the right place(s) may, in fact, be particularly critical for successful performance in penalty kick interceptive actions (e.g., Mann, Spratford & Abernethy, 2013), and that the search pattern used to arrive at a particular gaze location may not be a necessary prerequisite for successful performance.

The findings of Navia and colleagues (2017) may be indicative of a quiet eye (QE) gaze pattern. QE, which is the final fixation prior to final movement onset (Vickers, 1996; Vickers, 2007), has been proposed to reflect the parameterization of the necessary movement without the pick-up of further visual information during the control of action (Panchuk & Vickers, 2009). For example, Panchuk and Vickers (2006) reported that skilled ice hockey goaltenders utilised significantly longer QE durations for saved shots in comparison with trials in which goals were conceded. However, in contrast to this finding, Piras and Vickers (2011) reported an equivocal result with regard to the importance of QE and response accuracy amongst skilled goalkeepers when facing instep penalty kicks. Specifically, it was reported that QE duration associated with a fixation on the ball led to less successful performance whereas a QE duration associated with a visual anchor location (Williams & Davids, 1998) between the ball and penalty taker led to more successful performance. Thus, evidence concerning the suitability of QE as a facet of expertise in anticipation appears to warrant further investigation to understand whether the duration or location of this fixation differentiates successful performance (see also, McPherson & Vickers, 2004; Rodrigues, Vickers, & Williams, 2002).

With a primary focus on anticipation in penalty kicks, the aim of this paper is to offer new considerations for the study of variability in gaze patterns. A subset of data from the previously published article of Dicks et al. (2010) will be reanalysed in order to help achieve this aim. In this original study, eight skilled goalkeepers had their gaze patterns and anticipation performance measured across five experimental conditions. In one condition, participants were required to attempt to save non-deception penalty kicks in real-time as is required during competition. Five out of the eight goalkeepers tested in the original study of Dicks et al. (2010) saved more than ten penalty kicks and subsequently, these goalkeepers had their gaze data reanalysed to permit a focus on ten successful trials for each participant (e.g., Land & McLeod, 2000; Mann et al., 2013). Different gaze behaviour measures that are commonplace in extant research will be examined in order to ascertain how the respective measures might vary both between and within participants, despite the fact that they achieved equivalent levels of success in the task. Specifically, QE (Vickers, 1996), visual search patterns (Savelsbergh et al., 2010) and percentage viewing time on fixation locations (Dicks et al., 2010) will be analysed.

Method

Participants

Five experienced association football goalkeepers participated in the experiment (M age = 24.2 years, SD = 4.7). These five goalkeepers were selected as they saved at least 10 penalty kicks in the study of Dicks et al. (2010). Specifically, in the original study, goalkeeping performance was analysed for 15 trials, with kicks directed towards each side of the goal (eight to the right and seven to the left). Participants faced five additional trials distributed to varying goal locations with the aim of masking awareness of the task procedure. Goalkeepers had the following percentage success rates on the basis of the 15 kicks faced in the original study: P1 = 86.7%; P2 = 86.7%; P3 = 80.0%; P4 = 93.3%; and P5 = 93.3%. As recognised by Dicks et al. (2010), these response accuracies are substantially higher than those in competition and reflective of the decision to include only non-deception trials with the aim of regulating variability in the penalty taker's kicking action (see Schorer Baker, Fath, & Jaitner, 2017). Following previous literature (Piras & Vickers, 2011), gaze data were calculated on the basis of the first 10 saves. All had played to at least the level of the New Zealand Southern Premier League, with an average of 12 years (SD = 5.4) competitive experience. One penalty taker aged 24 years, who was matched to the goalkeepers by performance standard and length of experience (cf. Panchuk & Vickers, 2006), was recruited to execute all kicks. Prior to testing and contacting participants, ethical clearance was obtained from the local University ethics committee. All players provided written consent prior to participation in the study.

Procedure and Apparatus

The procedure and apparatus are as reported in the original study of Dicks et al. (2010) from which the current data set is derived. Specifically, the penalty kick data are from the *in situ* interception condition. In this condition, the penalty taker followed a script which included information about which part of the goal to aim each kick. The player was instructed to use a non-deception strategy in order to minimize any variability in his kicking action and initiated the run-up at an approach angle of between 10 and 30°, 4.0m from ball contact for each trial. Penalty kicks were executed using a regulation size 5 football in an indoor Astroturf facility at a full-size goal (7.32 x 2.44m) represented by a white screen marked with six target areas (0.81 x 1.50m). Movements were recorded using a high-speed 100 Hz digital video camera (JVC GRDVL9800), placed 1.5m horizontal to the penalty spot facing the goal. To enable assessment of QE, goalkeeper movements were subjected to frame-by-frame analysis relative to illumination of the LED array triggered during the penalty taker's approach.

Measurement of Gaze Behaviours

A mobile eye-tracking system (MobileEye™, ASL Ltd, Massachusetts, USA) was used to record gaze behaviours. Gaze behaviour data were collected at a rate of 25 frames per second and subjected to a frame-by-frame analysis following testing using Focus X2 (Elite Sports Analysis, Fife, United Kingdom). The scene video was recorded and captured for offline analysis.

Data Analysis

The analysis started at 2000 ms prior to foot-ball contact which included the run-up and a portion of the penalty taker's preparation time to provide sufficient duration before penalty kick initiation (Panchuk & Vickers, 2006). As the aim of the study was to conduct exploratory analysis of individual differences in goalkeeping performance across each dependent measure, data were not averaged across participants and therefore differences between participants are described using descriptive statistics (see Chia, Chow, Kawabata, Dicks, & Lee, 2017).

Percentage viewing time. Ten fixation locations were used to categorize position of gaze: the penalty taker's head, upper body (including arms), upper kicking leg and hip, upper non-kicking leg and hip, kicking leg (including foot), non-kicking leg (including foot), turf between the player and ball, the ball, the turf in front of the ball, and "other". The "other" category was used when gaze could not be coded due to extraneous jarring movements by the participant, or when gaze was directed outside of the fixation location categories.

Visual search patterns. Gaze behaviours were analysed following the procedures of Savelsbergh, et al. (2010) in order to identify the visual search patterns utilised by each participant for each trial in each condition. The gaze patterns in each individual trial were qualitatively matched to one of seven different global categories (Figure 1), which were the same as those developed by Savelsbergh et al. (2010). Code–recode reliability ranged between r = .87 for an independent coder and r =.98 for the same experimenter.

INSERT FIGURE 1 NEAR HERE

1) Fixation on the head/upper body, followed by a fixation on the hip region, then a fixation on the lower leg region and finally a fixation on the ball.

2) Fixation on the hip region followed by a fixation near the ball area.
3) Fixation on the lower leg region followed by a fixation near the ball area.
4) Fixation on the head/upper body followed by a fixation on the hip/leg region.
5) Fixation on the head/upper body followed by a fixation near the ball area.
6) Fixation on the head/upper body followed by a fixation near the lower-leg/ball area then a return fixation on the head/upper body followed by a fixation near the ball area
7) Fixation on the ball location with no alternative fixation location.

Quiet eye. Fixation/tracking was defined when the point of gaze remained within 3 degrees of visual angle of a location or moving object for a minimum duration of 3 frames or 120 ms (Dicks et al., 2010). QE was then categorised as the final fixation with an onset prior to the initiation of the final movement response by the goalkeeper and offset when gaze deviated off the location for a minimum of 120 ms (Panchuk & Vickers, 2006; Vickers, 2007). Moreover, following past work (Chia et al., 2017; Rodrigues et al., 2002), if a trial was missing a QE, a value of 0 ms was recorded.

Results

Percentage Viewing Time

The percentage viewing time results revealed that the most fixated location consistent across all participants, with the exception of P2, was the ball (Figure 2). However, despite this being the most fixated location, there were variations between goalkeepers P1, P3, P4, and P5; P3 and P5 tended to fixate primarily on the head and ball above all other locations, whereas P1 and P4 fixated the lower kicking leg after the ball as well as some fixations on the head and other body locations. The distribution of fixations across different body locations was more reflective of P2 who oriented gaze towards all body locations as well as the ball. Moreover, there was also the observation of relatively large standard deviations in P2's data suggesting that there was intra-individual variability between trials, something that was also a general trend across the other participants. Finally, although a relatively small duration, goalkeepers P1 and P5 spent a proportion of time looking at the visual anchor location between the player and ball (Piras & Vickers, 2011), whilst P2, P3, and P4 spent comparatively more time fixating the turf (in front of the ball), suggesting a pattern whereby the fovea "lay in wait" for ball-flight (cf. Land & McLeod, 2000).

INSERT FIGURE 2 NEAR HERE

Visual search patterns

Figure 3 demonstrates that visual search patterns 5 and 6 were the most commonly used gaze patterns across all participants. In these patterns, fixations began at the head/upper body followed by a fixation near the ball area (visual search pattern 5) or fixations were distributed at the head/upper body followed by a fixation near the lower-leg/ball area then a return fixation on the head/upper body before a fixation near the ball (visual search pattern 6). Although fewer by comparison, visual search pattern 7, which comprised fixations exclusively toward the ball, were used on some trials by P4 and P5 whilst P1 and P2 used visual search pattern 3 for some trials, which comprised fixation on the lower leg region followed by a fixation near the ball area. Thus, taken together, this categorical reflection of gaze patterns appeared to globally capture the variation between and within participants, with the general indication being that participants tended to utilise variations on visual search patterns 5 and 6.

INSERT FIGURE 3 NEAR HERE

Quiet Eye Duration and Location

Figure 4 shows the QE durations for each participant. Mean QE duration for participants P1, P3 and P4 were within a relatively small range of approximately 700ms –

900ms, however this was not the case for P2 (400ms) and P5 (1200ms). Moreover, the overall characteristic of the QE duration data is a representation of both inter- and intra-individual variation with all participants exploiting an array of different QE durations during successful trials, suggesting that this measure did not adequately capture any invariant characteristic of gaze patterns.

QE location, on the other hand, was consistent for all of the participants with the location for the majority of trials being at the ball (see Figure 4). There was minimal variation both within and between participants as QE for P3 was located on the ball for all trials, P2 had two trials were QE was located on the head and one on the kicking leg, P4 had one trial were QE was located on the turf in front of the ball, and P5 had one trial were QE was located on the non-kicking leg. Also, P1 had one trial with no QE and P2 had three.

INSERT FIGURE 4 NEAR HERE

Discussion

The aim of the current analysis was to examine individual differences in gaze behaviour of five experienced goalkeepers each of whom saved at least ten penalty kicks during a previously published experiment (Dicks et al., 2010). The individual-level analyses showed that, rather than participants converging on the same gaze behaviours, there were some discrepancies between and within participants in the dependent variables measured, most notably QE duration but also percentage viewing time and visual search patterns. This analysis builds on findings from past work, which have also indicated variability between equally-skilled participants and from to trial for the same participant during skilled interceptive actions (Croft et al., 2010; Navia et al., 2017). In the following discussion, the implications of these findings are discussed in relation to extant gaze behaviour literature before considering implications for future research.

The current analysis revealed that, perhaps above the other measures considered, the visual search categories of Savelsbergh et al. (2010) best captured some of the invariant features of gaze patterns between participants. In particular, there was a general indication that participants tended to utilise variations on visual search patterns 5 and 6 (Figure 1), during which, fixations began at the head/upper body followed by a fixation near the ball area (pattern 5) or fixations were distributed at the head/upper body followed by a fixation near the lower-leg/ball area then a return fixation on the head/upper body before a fixation near the ball (pattern 6). Further to the current findings, this mode of analysis has permitted evaluation of the efficacy of perceptual training methods in previous research (Savelsbergh et al., 2010). However, the classification procedure remains subjective and arguably lacks the finite precision that could accurately differentiate between critical timings of information pick-up (Navia et al., 2017). For instance, the visual search categories do not presently differentiate gaze patterns such as a visual anchor location between the player and ball (Piras & Vickers, 2011) or a fixation ahead of the ball (Land & McLeod, 2000; Mann et al., 2013), both of which have been suggested critical to the performance of interceptive actions.

Unlike the search pattern measure, the percentage viewing time data (Figure 2) enabled the identification of critical gaze locations, however, as used in the current analysis, this measure did not provide understanding on the timing of gaze patterns. Thus, although this measure revealed that the ball was the most fixated location consistent across all participants with the exception of P2, this method of analysis does not detail on when this location was fixated. Beyond the observation that the ball was the most fixated location, there was variation between and within goalkeepers for percentage viewing time in line with the results of Navia et al. (2017) who revealed that there was variability between participants for this dependent measure. That is, across the duration of the trials, participants attended to different gaze locations when successfully saving penalty kicks. Furthermore, assuming that the penalty taker is not attempting to deceive during the run-up as was the case in this study, it is recognised that the kinematics of the kicker may provide information on time to contact (when the kicker will make contact with the ball) rather than on kick direction (Diaz et al., 2012; Lopes et al., 2014). Thus, it is possible that variation in fixation locations could be present because multiple variables may provide useful information on time to contact (van der Kamp, Savelsbergh, & Smeets, 1997). Overall, the results of this measure imply the duration of fixations at certain locations may not be what differentiates between successful and unsuccessful performance, rather, it might be that looking at the right time at the right place is most critical for successful performance.

In addition to the observed between-participant variations, results were also characterised by intra-individual differences. That is, goalkeepers varied in the amount of time spent fixating different locations when successfully saving penalty kicks (see also, Croft et al., 2010). The observation of intra-individual differences was particularly evident in QE duration (see Figure 4). Previous research (e.g., Panchuk & Vickers, 2006; 2009; Piras & Vickers, 2011) has suggested that longer QE durations are associated with more successful performance during anticipation tasks. However, the current results revealed that each participant utilised a range of QE durations during successful performance. For example, the QE of Participant 4 during one successful trial was 1960 ms while a QE duration of 160 ms was recorded on a separate successful trial for the same participant. Similarly, Participant 2 revealed QE durations ranging between 0 ms and 1520 ms. Thus, comparable to previous research in aiming tasks including basketball (de Oliveira, Oudejans, & Beek, 2008) and ten-pin bowling (Chia et al., 2017), the present findings indicate that variation in QE durations can occur without negative performance consequences.

Previous results of Piras and Vickers (2011) reported that the location of QE was more important than the duration. Specifically, these authors reported that QE duration associated with a fixation on the ball led to less successful performance whereas a QE duration associated with a visual anchor location (Williams & Davids, 1998) between the ball and penalty taker led to more successful performance. In the current study, the location of QE appeared to be more important than the duration but in contrast to Piras and Vickers (2011), the majority of successful saves were characterised by a QE location on the ball and none were characterised by use of the visual anchor. This finding is likely due to differences in the kickers angle of approach with a narrower approach angle in the present study compared to that of Piras and Vickers (2011). With a wider runup, there is space for a visual anchor fixation between the kicker and ball right up until foot-ball contact. However, with a straighter run up (< 30°), the horizontal distance between the kicker and ball is greatly reduced early during the run up meaning there is no observable visual anchor location between the ball and kicker. This explains why the QE location was almost exclusively located on the ball during the present study. Future work might consider how differences in angle of approach, and also run up duration, might affect the gaze patterns employed when attempting to save penalty kicks. Such findings would provide insight into how goalkeepers adapt gaze behaviour to different task constraints experienced when facing penalty kicks.

Interestingly, participant 2 tended to utilise the same two visual search strategies as the other participants (patterns 5 and 6) but differed markedly on percentage viewing time. This finding suggests that even within this same visual search pattern there, exists considerable variation in fixation duration at each location and likely therefore, in the timing of saccades from one location to the next. Furthermore, P2 appeared to explore different gaze behaviours to a greater extent than the other participants as they utilized more QE locations on successful trials than all other participants. This exploration did not negatively affect performance suggesting this participant utilized a number of gaze behaviours to pick up the required information to successfully anticipate and intercept penalty kicks therefore indicating the omission of a universal optimal gaze strategy (Dicks et al., 2017).

Future directions

The current exploratory analysis suggested that experienced goalkeepers do not converge on the same gaze patterns during successful anticipation performance (Navia et al., 2017). The data therefore indicated that multiple information-movement couplings can be used by different performers when achieving successful performance outcomes during visual anticipation (Dicks et al., 2017), although it is important to note further rigorous studies are required to support this claim. Indeed, work is still required to establish why such differences appear to have emerged. Specifically, whether the expressed variability characterises a better ability to adapt to different situations or whether it is noise that limits performance (Dicks et al., 2017). On the one hand, the observed results are comparable to observations in the coordination literature, which demonstrate that there are different coordination solutions that can be utilised by performers in order to achieve success within the same performance context (e.g., Chow, Davids, Button, & Koh, 2008; Hong & Newell, 2006). Thus, variation in gaze patterns may provide performers with the flexibility to utilise different information-movement couplings in order to adapt to the variable coordination patterns utilised by skilled opponents during fast-ball sports (see Schorer et al., 2007). Furthermore, it is possible that the differences in gaze behaviours may be a reflection of changes in movement patterns between goalkeepers. To our knowledge, there have thus far been limited attempts to integrate movement and gaze measures to fully understand how gaze and movement patterns are coordinated together, and therefore, this remains a research priority in future work.

Whilst an in-depth study of the relationship between gaze behaviour and movement variability will further current empirical understanding, such empirical endeavour would also require the development of novel measures. Adopting a more individualized analysis approach, rather than conventional group based averaging methods, has the promise to further understanding of expert gaze control, and comparable to perspectives in the coordination literature over two decades ago (e.g., Bates, 1996), single-subject methodology can provide important evidence for the development of theoretical and applied perspectives. Thus, a fruitful avenue for future research would be to apply methods of analysis including cluster approaches (Chow, Davids, Button, & Rein, 2008; Seifert, Leblanc, Herault, Komar, Button, & Chollet, 2011) and neural networks (Memmert & Perl, 2009) in order to gain a greater understanding of the high dimensionality of the gaze behaviour datasets. Future research could also consider employing multiple regression analysis to identify which gaze variable(s) best predict anticipation success (e.g. Le Runigo, Benguigui, & Bardy, 2010; Mallek, Benguigui, Dicks, & Thouvarecq, 2017). As an example, using the penalty kick, a regression model could be run with QE duration, QE location, the different search patterns used, and percentage viewing time to identify a model for the gaze variables that best predicts goalkeeper save success. However, researchers must be mindful of the guidelines on sample size in order to run this analysis (Darlington & Hayes, 2016). The importance of developing knowledge in this area will have implications for developing expertise in sport and developmental contexts.

Conclusion

This article has revealed evidence of variation in gaze behaviour both between and within goalkeepers for the successful anticipation and interception of penalty kicks. This finding is comparable to the variation in motor control observed in the coordination literature. Yet, there are still significant grounds to be made in understanding to what extent variability is a characteristic of successful expert performance and why such variation is evident.

Notably, a fruitful endeavour for future work is to examine how vision is used during the control of movement. That is, combining motion capture and eye tracking offers the ability to measure participants gaze and movement coordination simultaneously in representative tasks in order to determine a comprehensive understanding of experts successful anticipation. Such advancements promise to bring implications for the understanding and development of sporting expertise.

Funding

Harry Ramsey is a postgraduate research student at the University of Portsmouth, funded by the ESRC South Coast Doctoral Training Partnership (SCDTP) (Grant Number ES/P000673).

Data Availability

For more information on the data that support the findings of this study please contact the corresponding author, H. Ramsey. Participants of this study did not agree for their data to be shared publicly. Therefore, the supporting data is not publicly available.

Acknowledgements

The authors thank the anonymous reviewers for their feedback that undoubtedly improved the quality of the manuscript.

Author Contribution Statement

Harry Ramsey and Matt Dicks contributed to writing all sections of the manuscript, Chris Button and Keith Davids contributed to writing the introduction, method, and discussion, and Guillaume Hacques and Ludovic Seifert contributed to writing the introduction and discussion. The experiment was conducted by Matt Dicks, Chris Button, and Keith Davids. The data were analysed by Harry Ramsey and Matt Dicks.

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Figure Captions

Figure 1: A Figure representing the seven categories of the visual search patterns utilised by goalkeepers during the penalty taker's run-up and kicking action. The circles represent fixations and the straight lines represent the saccades between the fixation locations.

Figure 2: Mean percentage time spent viewing each location during the total duration of the penalty kick (Note. Torso = upper body (including arms); UKL = upper kicking leg and hip; UNKL = upper non-kicking leg and hip; LKL = kicking leg (including foot); LNKL = non-kicking leg (including foot); F-B = turf between the player and ball; TURF = the turf in front of the ball). The vertical bars indicate the standard deviation.

Figure 3: The frequency with which each participant utilised each respective visual search pattern during successful penalty kick trials.

Figure 4: Quiet eye duration and location for each trial utilised by the participants. Each circle data point represents an individual trial, the horizontal bars represent the mean duration, and the grey bars represent the standard deviation from the mean.

Figure 1

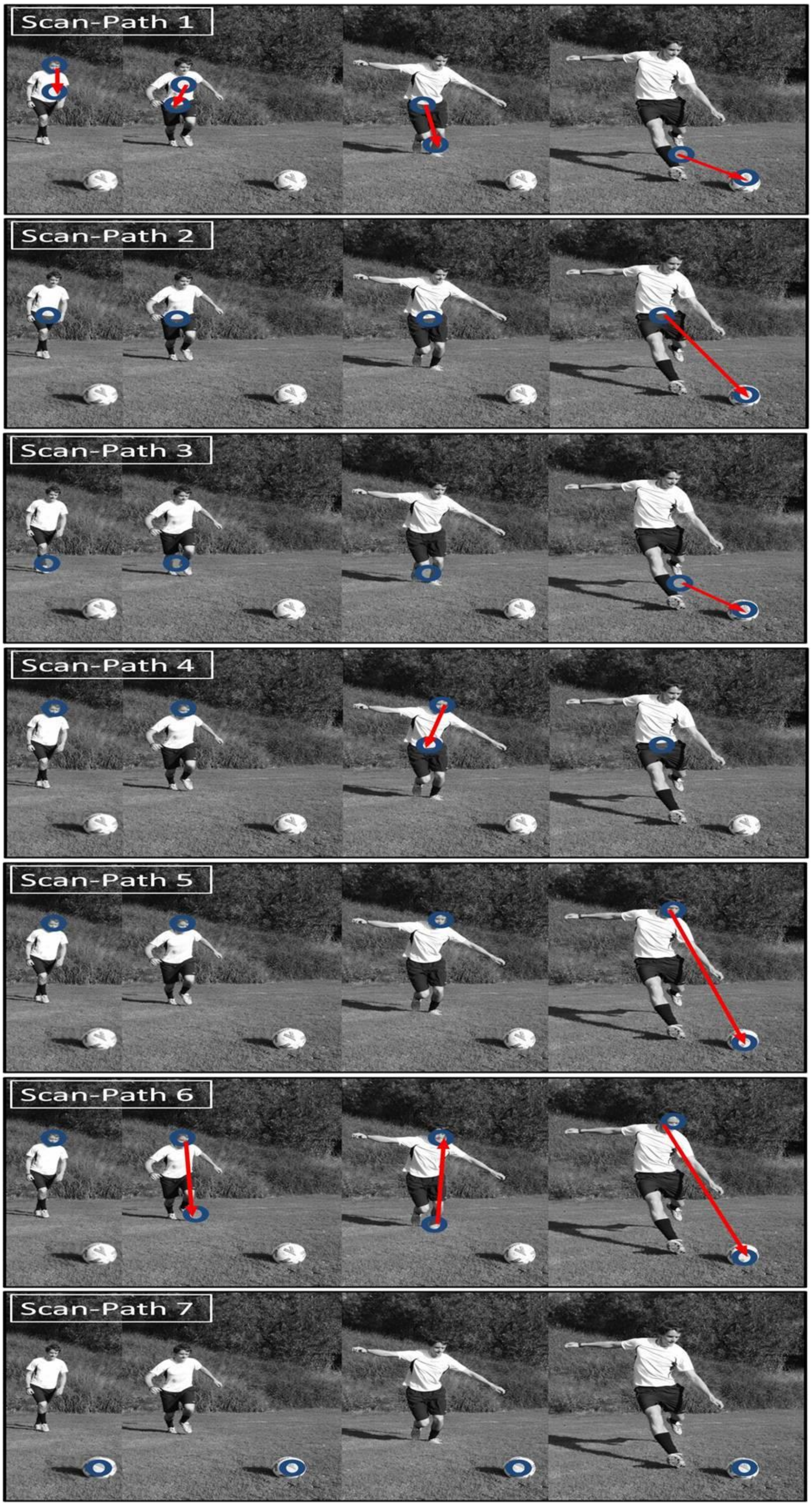

Scan-Path 1
Scan-Path 2
Scan-Path 3
Scan-Path 4
Scan-Path 5
Scan-Path 6
Scan-Path 7

Figure 2

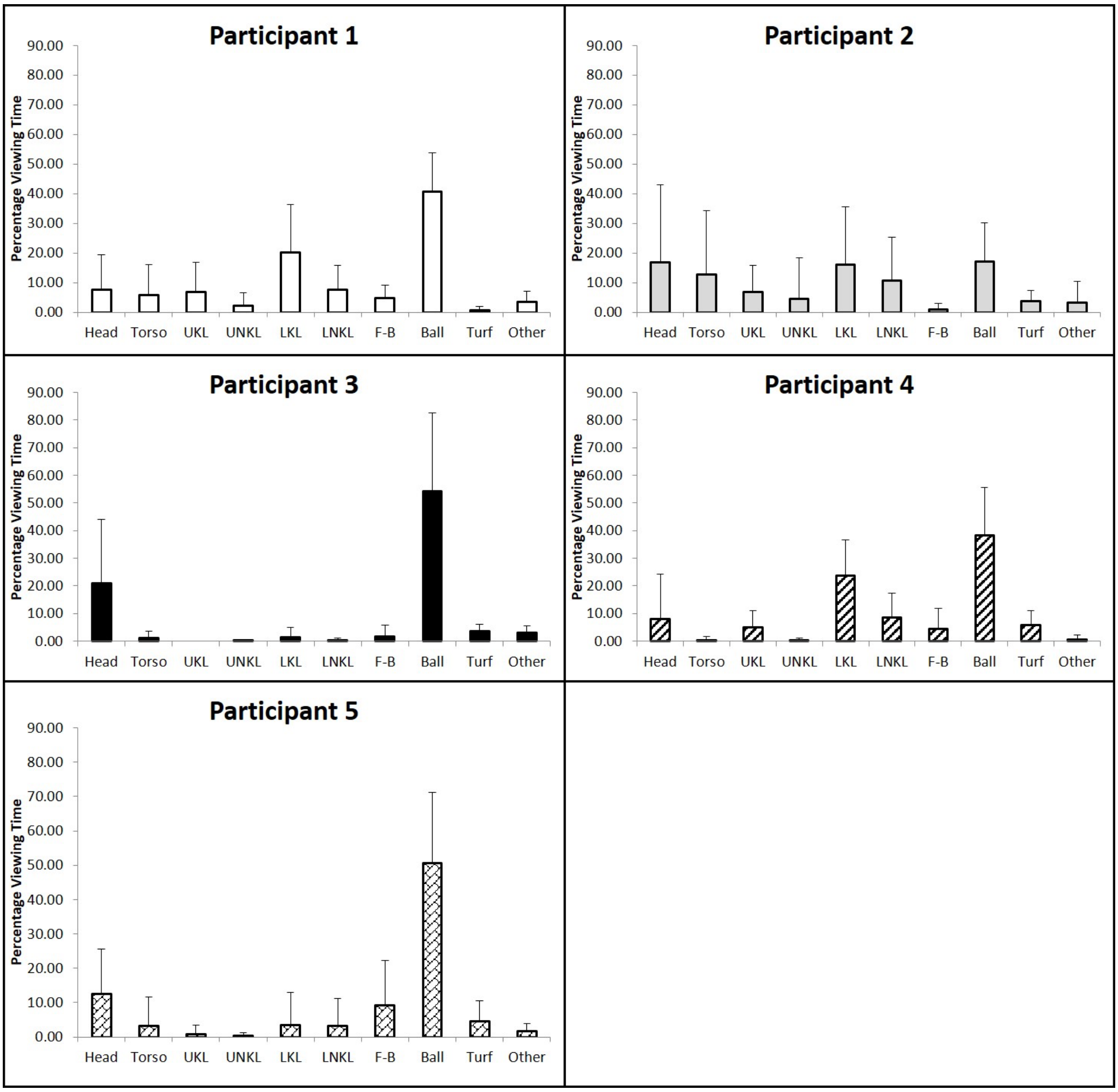
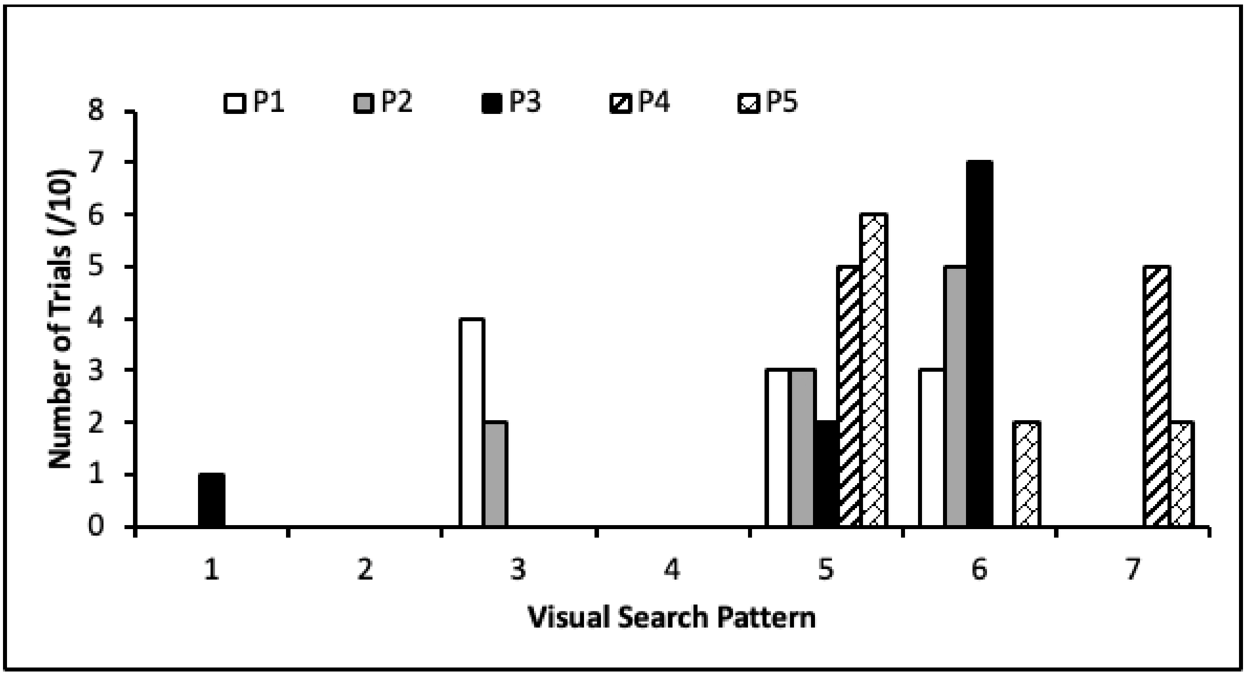
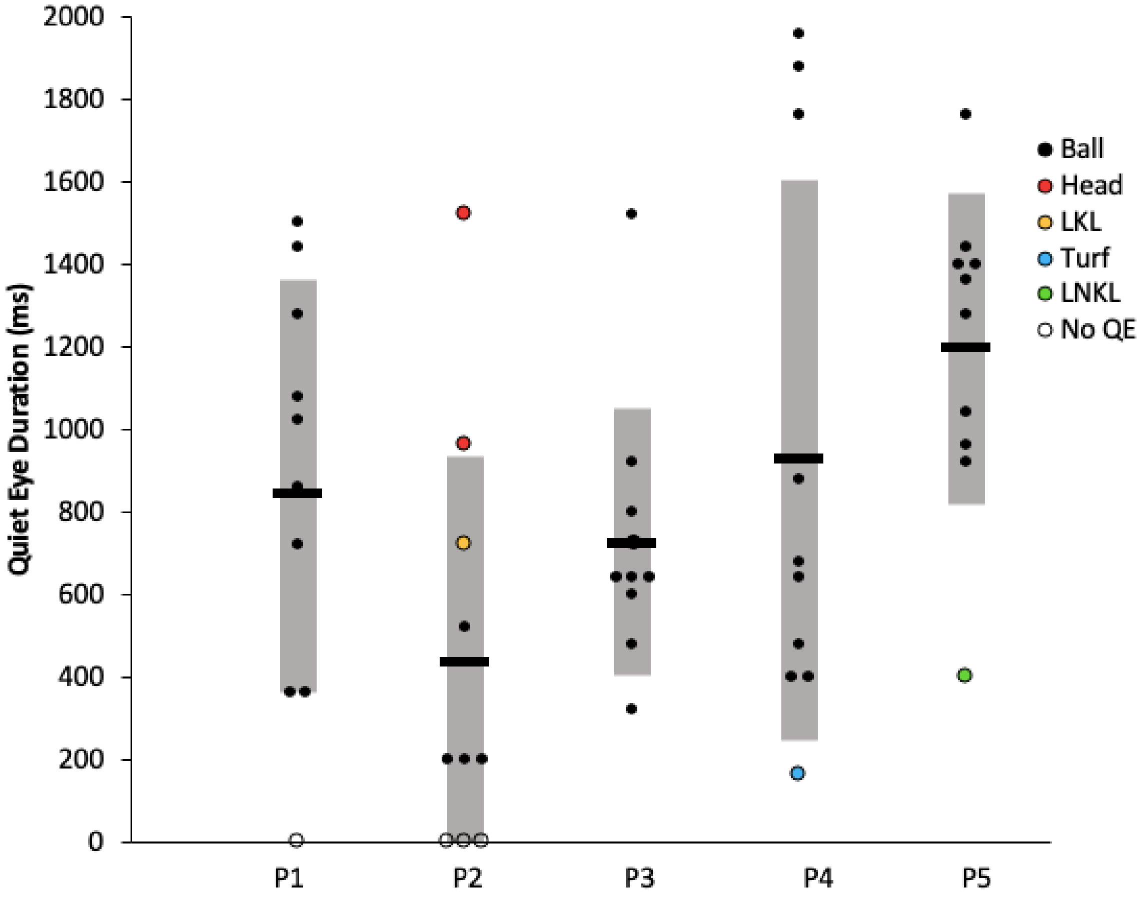

Participant 1
Participant 2
Participant 3
Participant 4
Participant 5
Percentage Viewing Time
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
Head
Torso
UKL
UNKL
LKL
LNKL
F-B
Ball
Turf
Other

Figure 3


P1
P2
P3
P4
P5
Number of Trials (/10)
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
Visual Search Pattern

1 Figure 4


Quiet Eye Duration (ms)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
P1
P2
P3
P4
P5
Ball
Head
LKL
Turf
LNKL
No QE

2