The effect of time constraint on anticipation, decision-making, and option-generation in complex and dynamic environments

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The results presented in this manuscript contain extended analyses and reports of data presented at the 11th international conference on Naturalistic Decision Making in Marseille, France (see Belling, Suss, & Ward, 2013).

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Abstract

Researchers interested in performance in complex and dynamic situations have focused on how individuals predict their opponent(s) potential courses of action (i.e., during assessment) and generate potential options about how to respond (i.e., during intervention). When generating predictive options, previous research supports the use of cognitive mechanisms that are consistent with Long Term Working Memory (LTWM) theory (Ericsson & Kintsch, 1995; Ward, Ericsson, & Williams, 2013). However, when generating options about how to respond, the extant research supports the use of the Take-The-First (TTF) heuristic (Johnson & Raab, 2003). While these models provide possible explanations about how options are generated in-situ, often under time pressure, few researchers have tested the claims of these models experimentally by explicitly manipulating time pressure. The current research investigates the effect of time constraint on option-generation behavior during the assessment and intervention phases of decision making by employing a modified version of an established option-generation task in soccer. The results provide additional support for the use of LTWM mechanisms during assessment across both time conditions. During the intervention phase, option-generation behavior appeared consistent with TTF, but only in the non-time-constrained condition. Counter to our expectations, the implementation of time constraint resulted in a shift toward the use of LTWM-type mechanisms during the intervention phase. Modifications to the cognitive-process level descriptions of decision making during intervention are proposed, and implications for training during both phases of decision making are discussed.

Keywords: Anticipation; Decision Making; Option-Generation; Expert Performance; Long Term Working Memory theory; Take-The-First heuristic

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1.0 Introduction

Traditionally, decision making research has focused on the strategies and heuristics employed by participants while choosing between a set of fixed options, as in a multiple choice format. Many researchers have explained such option selection behavior, for example, as a process of calculating the expected utility of each option (von Neumann & Morgenstern, 1947). However, others have focused on the human tendency to deviate from these seemingly rational and economic principles in favor of simpler—and potentially error-prone—heuristics (Tversky & Kahneman, 1975). While these classic approaches have much value in a number of domains, they ignore the process by which decision makers generate courses of action (i.e., options) in-situ while operating in naturalistic settings (cf. Johnson & Raab, 2003; cf. Zsambok & Klein, 1997). This 'option-generation' process is a critical component of decision making in a number of real-world domains (Klein, 1993).

The current research will investigate option-generation behavior during both assessment and intervention phases of decision making by modifying an established situational option-generation task (see Ward, Ericsson & Williams, 2013). During the assessment phase, decision makers will be asked to generate situational options—those heeded in the mind's eye—and anticipate one of them as the likely outcome of the situation. In the intervention phase decision makers will be asked to generate heeded response options, and select one as their likely course of action. Our aim is to test the claims of two models of skilled decision making that make specific predictions regarding option-generation behavior complex and dynamic domains, and examine how they extend to time pressured situations.

1.1 Option-Generation during Intervention

In an attempt to understand how skilled individuals make decisions in their domains of expertise, Klein (1993) conducted Critical Decision Method (CDM) interviews (see Klein, Calderwood, & Macgregor, 1989) with urban fireground commanders. Analysis of the interviews revealed that the fireground commanders did not weigh alternatives or assess probabilities as might be expected by more traditional, analytical models of decision making (e.g., Subjective Expected Utility, Multi-Attribute Utility Analysis). Instead, they were reacting to situations based on their relevant experience and training. Klein and colleagues presented the Recognition-Primed Decision (RPD) model of rapid decision making to account for these findings. Three variants of RPD were proposed, dependent on the complexity of and familiarity with the situation. In the simple case, decision makers recognize the situation as familiar or typical, which activates the associated response in memory, and the response is implemented. In less simple instances, skilled decision makers first check the effectiveness of the typical response by mentally simulating the response option. If deemed appropriate, the action is carried out. If not, another response option is generated and re-simulated to check for plausibility, and the cycle repeated (if necessary) resulting in a serial option generation. In complex instances, skilled decision makers may have to re-assess the situation and acquire more information until the situation is recognized and the typical response activated. In all three types of instances, a single response option in generated first (as opposed to multiple options from which to choose). Since the first option is a quickly-generated, typical, and workable solution, it is often selected and carried out. For this reason, proponents of RPD have claimed that skilled decision makers generate relatively few (i.e., 1 or 2) options (cf. Klein, 1995).

In addition to employing retrospective (e.g., CDM) interviews, previous research has investigated option-generation experimentally using an option-generation task. In one such study Klein (1995) examined option-generation in chess. Participants were presented with configurations of chess pieces and asked to verbalize each move they were considering selecting as their next. Of the 124 legal moves available for selection from the 64 configurations presented, 20 were rated as acceptable moves by Grand Master chess players. Given the base rate, one might expect the first option generated to be an unacceptable (as opposed acceptable) move if participants were randomly generating response options. However, 41 of the moves generated by participants as their *first* option were actually one of the 20 options that were rated as acceptable. Consistent with RPD, Klein (1995) demonstrated that the first option generated was higher quality than all other subsequent options generated, on average. Rather than being randomly selected, the first, immediately-generated option was more likely to be a workable solution.

Option-generation methods have also been employed to examine decision making in more dynamic domains/situations. For example, Johnson and Raab (2003) used video clips of typical handball game-play that were edited to freeze immediately prior to the player with the ball pursuing a course of action (e.g., pass to another player, shoot at goal). Eighty-five medium-skill-level handball players watched the simulations. In each trial, participants imagined themselves as the player with the ball; at the freeze point they were asked to generate the first option that came to mind, and then all other options. They were also asked to indicate the final option that they would select if actually playing handball. The number of options generated was recorded and an expert panel determined the final decision quality (i.e., the quality of the option selected as their intended course of action) for each trial. Johnson and

Raab (2003) present the Take-The-First (TTF) heuristic to describe the cognition of the handball players. Similar to RPD, participants generated relatively few (e.g., 2 or 3) options, with the first option typically being of higher quality than subsequently generated options. Furthermore, the total number of response options generated was negatively related to final decision quality. These results were extended by Raab and Johnson (2007) when comparing the performance of 69 expert, near-expert, and non-expert handball players. Using the same option-generation procedure, higher-skilled handball players generated fewer options and selected final options that were of higher quality than did the less-skilled players.

In general, RPD and TTF suggest that a less-is-more phenomenon may best describe skilled option-generation when deciding on a course of action for oneself (or during the intervention phase of decision making; henceforth intervention phase) in complex and dynamic environments. An initial, and often best, or at least workable, solution is generated first based on association with the environmental structure. Based on these findings, it seems logical that training in situations of this type should encourage adoption of a very limited option generation strategy and selection of an immediate and satisfactory intuitive option during the intervention phase of decision making.

1.2 Option-Generation during Assessment

In addition to generating and deciding on a course of action for oneself, an important component of performance in complex and dynamic domains involves generating and anticipating the courses of action to be taken by others, which we term the assessment phase of decision making (henceforth assessment phase). Klein and Peio (1989) suggested that the claims of RPD may also describe option-generation during the assessment phase. These authors investigated high- and low-skilled chess players' ability to predict their opponent's next move. When asked to anticipate the move their opponent would select in a game of chess, highly skilled players anticipated their opponent's move (i.e., the correct response), generated the correct option as their *first*—more often than less skilled players—and made fewer guesses in total about the opponent's move. These results suggest a similar mechanism to those proposed by RPD or TTF may support skilled option-generation during assessment, as well as intervention.

However, when anticipation has been investigated using option-generation methods in other complex and dynamic situations, the evidence has been somewhat inconsistent with the use of TTF-type mechanisms. According to Long Term Working Memory (LTWM) theory (see Ericsson & Kintsch, 1995), skilled decision makers do not always rely on simple, relatively intuitive processes to generate options in-situ. Instead, LTWM theory proposes that skilled decision makers develop an elaborate mental representation of their domain. Information is indexed within this representation such that direct access is maintained, not only to the likely situational outcome, but also to other relevant alternatives the opponent might pursue. The result is an updated situational model that incorporates previous relevant experiences with the current environmental structure. For example in soccer, this would mean a skilled defender may be aware of alternative, relevant and likely threats (e.g., a shot on goal, dribbling past a defender) in addition to the situational outcome (e.g., a threatening pass toward goal), which may afford greater flexibility and adaptivity (see Hoffman, et al., 2014).

Since, theoretically, performance should be associated with the ability to encode and maintain access to task-relevant information, Ward, Ericsson, and Williams (2013) investigated the relationship between anticipatory performance and the number of task-relevant/task-irrelevant options—as opposed to the total number of options generated (cf. Johnson & Raab, 2003). Based on LTWM theory, Ward et al. (2013) proposed that performance should be positively and negatively related to the number of task-relevant and task-irrelevant options generated, respectively. To test this claim, they employed an option-generation task similar to those used by Johnson and Raab (2003). In three experiments, participants viewed videos of typical patterns of soccer play from the perspective of a defender. They were asked to generate heeded options (i.e., those they thought) their opponent might pursue (e.g., pass to another player, shoot at goal) and indicate which of their generated options was the actual outcome. Performance was assessed by frequency with which the participants' anticipated outcome matched the actual situational outcome (i.e., what actually occurred next). For each trial, an expert panel of players and coaches determined *a priori* the task-relevant options. Consistent with their predictions derived from LTWM, performance (i.e., anticipation accuracy) was positively related to the number of task-relevant options generated (and to the ability to prioritize generated options effectively) and negatively related to the number of task-irrelevant options generated. Furthermore, highly skilled participants generated significantly more task-relevant and significantly fewer task-irrelevant options than less skilled participants. In two of their experiments, Ward and colleagues restricted access to perceptual information by employing an occlusion condition (where all information was removed from the screen except for the field lines and ball location)—and contrasted performance with that in a cued or freeze-frame condition (cf. Johnson & Raab, 2003). This manipulation forced participants to make their assessment based on their mental representation of the dynamic pattern of play, as opposed to a static image of the last view of this pattern—which would not be available when making decisions in actual gameplay. The result was a larger skill effect in anticipation accuracy during the occlusion condition than in the freeze-frame condition. In general, these findings suggest that, in similar sport situations, accurate anticipation during the assessment phase would benefit from training that increases the generation of task-relevant, and reduces the number of task-irrelevant options generated (as opposed to reduction in total number of options; cf. Johnson & Raab, 2003).

1.3 The Effect of Time Constraint

While proponents of TTF and LTWM have each made hypotheses regarding the cognitive mechanisms that facilitate skilled option-generation and decision making and support superior performance in complex and dynamic environments, these claims have not been subjected to an explicit time constraint manipulation. Although Raab and Johnson, and Ward and colleagues, each varied the amount of time perceptual information was available, neither explicitly manipulated time constraint and, in each study, time to respond was relatively unlimited. Time pressure is an integral component of complex and dynamic domains such as soccer and so understanding its effect in each phase of decision making and how well the TTF and LTWM-related claims predict performance under these conditions is an important next step in defining the bounds of the associated decision strategies.

The speed-accuracy trade off is well documented in physical tasks (see Fitts, 1954). Likewise, the effects of deciding between multiple (albeit simple) stimuli on choice reaction time, where the time taken to decide is influenced by its information-theoretic entropy, have long been understood (Hick, 1952; Shannon, 1948). Rather surprisingly, however, few researchers have experimentally manipulated time constraint and measured situation assessment and/or decision making performance in a complex and dynamic domain. A handful of studies have examined the effect of time constraint on decision making performance in a more traditional domain—chess. For instance, Chabris and Hearst (2003) recorded the number of blunders (i.e., bad moves) by grandmaster chess players when playing in rapid games (i.e., ~1 minute per move) and standard games (i.e., ~3 minutes per move). The authors found that the grandmasters made far more blunders under rapid games than standard games (cf. Gobet & Simon, 1996). Similarly, Moxley, Ericsson, Charness, and Krampe (2012) rated the quality of chess moves of both experts and tournament-level chess players and recorded the time of deliberation. They found a significant effect of time on quality of move, such that those moves deliberated for longer were better than those generated first (cf. Johnson & Raab, 2007). Furthermore, both skill groups benefitted from taking extra time to deliberate over a move (cf. Gobet & Simon, 1996). Likewise, Lassiter (2000) demonstrated that human chess experts become less likely to defeat skill-matched computer counterparts as time-to-move is reduced. Skill-matched computers had a significant advantage over their human counterparts when game time was limited to 25 minutes (~30 seconds per move). This advantage doubled when game-time was reduced to 5 minutes (~6 seconds per move). These findings are consistent with a speed-accuracy tradeoff (see Osman, et al., 2000), less and more time appear to result in worse and better decisions, respectively—at least in the domains in which this has been investigated (e.g., chess, choice reaction tasks). We speculate that performance on a representative task in a more dynamic domain (e.g., soccer) may also improve as time constraints are removed.

1.4 Hypotheses of the Current Research

Johnson and Raab (2003) propose that, in the types of dynamic sport situations they tested (i.e., handball), the number of options generated is negatively related to performance. In contrast, Ward et al. (2013) proposed that, in similar situations (i.e., soccer) the numbers of task-relevant and task-irrelevant options generated are positively and negatively related to performance, respectively. One of our aims in this paper is to understand whether the phase of decision making (i.e., assessment, intervention) and/or time constraint may account for these seemingly contradictory findings. For example, a simple resolution may be that different perceptual-cognitive strategies are useful in each phase of decision making. Likewise, it seems logical that time constraint may affect the ability to employ different strategies effectively. This is especially relevant given the need to generate an immediate workable solution under time pressure. Since TTF provides a potential mechanism that might explain RPD-type behavior, our hypotheses are primarily oriented towards TTF and LTWM.

1.4.1 The Effect of Time Constraint on Performance during Assessment and Intervention

In line with previous research (e.g., Osman et al., 2000; Chabris & Hearst, 2003; Lassiter, 2000; Moxley et al., 2012) we hypothesize that (during both assessment and intervention) participants will perform worse (i.e., decreased anticipation accuracy, selection of poorer options) on time constrained than non-time constrained trials.

1.4.2 The Effect of Time Constraint on Option-Generation during Assessment

Since both TTF and LTWM predict that better options would be generated first (see Ward et al., 2013), we speculated that a selective reduction would occur in response to time constraint. In other words, when time was limited, we expected that participants would reduce the number of task-irrelevant options generated, but not the number of task-relevant options generated. Accordingly, we expected to observe a two-way interaction of information type (within participants: task-relevant/task-irrelevant) by time constraint (within participants: present/absent) during assessment trials.

In accordance with Ward et al. (2013) and LTWM, we expected that the number of task-relevant and task-irrelevant options would be positively and negatively related to performance, respectively, during assessment trials. Our predictions about how time pressure would affect this relationship during assessment were more tentative. Given the anticipated selective reduction of task-irrelevant options under time constraint, we speculated that the negative relationship between the number of task-irrelevant options and decision quality generated would be stronger for time constrained trials than for non-time constrained trials. To explore the claims of TTF during assessment, we also examined the relationship between performance and the total number of options generated but had no reason to expect a relationship during this phase of decision making.

1.4.3 The Effect of Time Constraint on Option-Generation during Intervention

Similar to our hypothesis during assessment, we expected to observe a selective reduction in option-generation in response to time constraint. Participants were expected to generate fewer task-irrelevant options, but not fewer task-relevant options, during time constrained trials than during non-time constrained trials. Accordingly, we expected to observe a two-way interaction of information type (within participants: task-relevant/task-irrelevant) by time constraint (within participants: present/absent) during intervention trials.

Following Johnson and Raab (2003), we expected that the *total* number of intervention options generated would be negatively related to performance during intervention trials. Again, our predictions about the effects of time pressure during intervention were more tentative. Given the heuristic's focus on an immediately generated solution in response to time pressure, we speculated that this relationship would be stronger—in the negative direction—during time constrained trials than non-time constrained trials. In order to explore the claims of LTWM (see Ward et al., 2013) during intervention, we also examined the relationships between performance and the number of task-relevant and task-irrelevant options generated and performance.

2.0 Methods

2.1 Participants

Twenty-one (17 male) recreational-level soccer players with an average age of 19.8 years (SD = 1.94) participated in this study. The participants averaged 10.19 (SD = 6.04) years of experience playing under the supervision of a coach, including any recreational level or pre-collegiate level play. Participants received course credit for their participation in the research.

2.2 Materials

Stimuli were created from 30 video clips containing footage of a live soccer match between two Development Academy teams in the United States. The footage was filmed from an elevated perspective, above and behind the goal, providing a pseudo first-person perspective. This viewing perspective allowed participants to view the entire pitch and full team play (i.e., 11-player vs. 11-player). Previous research has demonstrated the effectiveness of this viewpoint at differentiating between skill groups in similar tasks (e.g., Ward & Williams, 2003). Each clip contained approximately 5-10 seconds of build-up play to provide context to the impending task, and was edited to stop at a critical decision point (i.e., was replaced by an occlusion image, described forthwith)—immediately prior to the player with the ball pursuing a course of action (e.g., shooting at goal, passing to a teammate, dribbling/running with the ball) (see Figure 1). Of the 30 trials created, 15 were used for assessment-phase trials and 15 for intervention-phase trials. In each set of 15 trials, 3 were used as training trials to familiarize participants with the specific tasks and condition. A high-definition projector was used to present the video stimuli to participants; the projected image was 249 cm wide by 158 cm high.

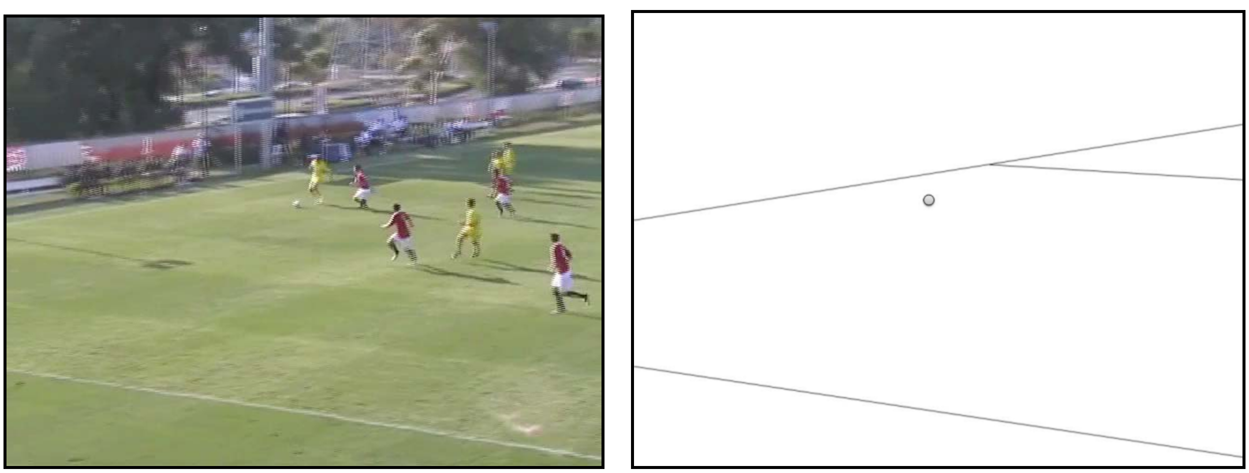

Image A Image B

Figure 1: The final frame of a video simulation (A) and the matching occlusion image (B).

A white screen with black lines (i.e., the occlusion image) replicating the orientation of the field lines and position of the ball appeared at the point of occlusion—all other perceptual information was removed (see Ward, et al., 2013) (see Figure 1). Response sheets for each trial were printed on white, letter-size (8.5 x 11 inches) paper, and matched the occlusion image (see Figure 1B). Two separate custom “stamps” were created, one for assessment trials and one for intervention trials, and were used to record participant ratings during each trial type. For assessment trials, the stamp displayed “LIKELIHOOD:_____” and “CONCERN:_____” in red ink on the response sheet (see Figure 2). For intervention trials, the stamp displayed “LIKELIHOOD:_____” and “QUALITY:_____” in blue ink on the response sheet (see *Procedure* below). Lastly, a stopwatch was used to implement time constraint on half of all scored trials and a soccer experience questionnaire used to assess the experience of each participant.

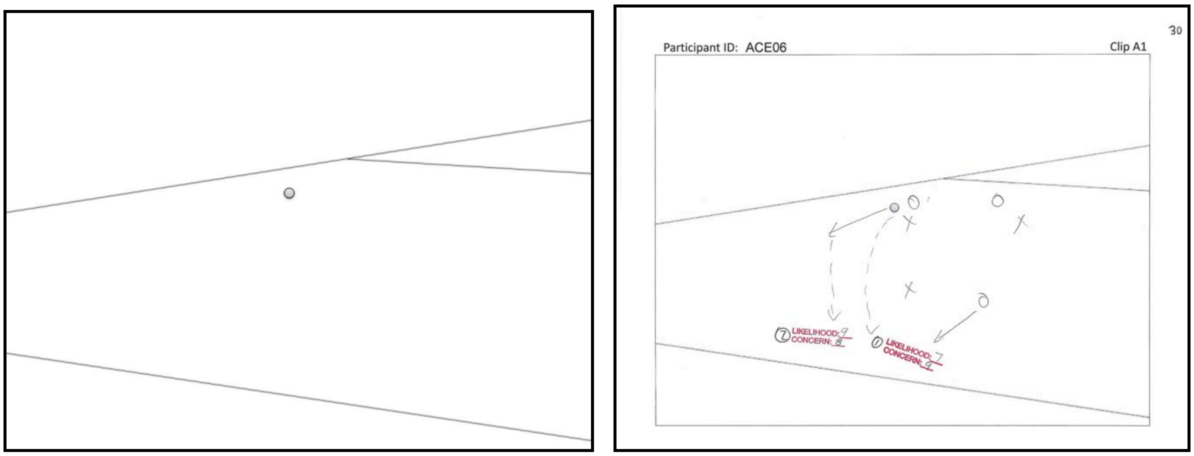

Figure 2: An occlusion-image on-screen (left) and a matching response sheet (right) with written and stamped options and ratings of likelihood and concern during assessment.

2.3 Procedure

For assessment trials, participants were instructed to watch the video simulations and envision themselves as members of the defensive team. They were told the opposing team would be attacking the goal at the bottom of the screen, which was their job to defend. Next, they were told each video simulation would end when a player on the opposing team with the ball was about to make a decision about what to do next. Participants were instructed to write down all of the heeded options that they, as a defender, were concerned about the opposing player with the ball doing next. An option was defined as any combination of players, their movements and actions, and the surrounding space used in a given play, the length of which was determined by the participant. Options invariably involved no more than the action by the player with the ball and their movement (where applicable) in a given location on the pitch, the movement of the ball (in the case of a shot at goal or clearance), and the movement/action of a receiving player in a given location on the pitch (in the case of a pass) (e.g.. player X runs down the wing, crosses the ball to another player who intercepts in an open space on the pitch) (see Ward et al., 2013). Participants were specifically instructed not to write down all of the options available to the player that existed in the environment, which could be an extremely exhaustive list. Instead, they were informed only to write down those options that they were actually thinking about when the video clip was occluded. Options were denoted on the response sheet using a simple notation scheme (see Figure 2). On assessment trials, a letter ‘X’ marked on paper represented a defensive player—and a teammate. A letter ‘O’ represented an offensive player—and member of the opposing team. Solid arrows were used to indicate player movement with or without the ball (e.g., the player with the ball dribbling in a direction, a player off-the-ball running into a space to receive it). Dashed arrows were used to represent the movement of the ball only (e.g., after a pass or shot). Once participants had generated their options, they were instructed to mark each with the custom stamp (for assessment trials). Participants then rated the likelihood that each option would be chosen by the opposing player with the ball and the level of concern (i.e., threat) they felt about each option as a member of the defensive team. The likelihood of, and concern for each option was rated using Likert-type scales that ranged from 0 (not at all likely; not at all concerned) to 10 (very likely; very concerned).

For intervention trials, participants were instructed to watch the video simulations and envision themselves on the attacking team, and more specifically, as the player with the ball at the moment of occlusion. They were informed each clip would end with their team attacking the goal at the far end of the pitch, which was at the top of the screen. They were instructed to generate those options that they considered pursuing at the point of occlusion. Using the same notation described above—with the exception that the letter ‘X’ represented the opposing players (i.e., defenders) and the letter ‘O’ represented teammates (i.e., attackers) during intervention trials—participants wrote their options down on the response sheet. After all options were generated, each option was stamped and rated using the custom stamp for intervention trials. Participants then rated the likelihood with which they would pursue that option, and the quality of that option (i.e., how good they felt that option was for them, given the current situation). Likelihood of pursuing and quality of each option were rated using Likert-type scales from 0 (not at all likely; not at all good) to 10 (very likely; very good).

Participants completed the option-generation task in small groups (up to a maximum of three) under the supervision of the experimenter to avoid collusion. Participants sat at a desk approximately 6 feet from the projected image. After consent was obtained, participants received the notation and task instructions and completed two training trials for both assessment and intervention under the guidance of an experimenter. During these trials, the experimenter read options back to the participant in order to ensure that the options conceived at the time of occlusion matched what was drawn on paper. A third training trial was completed under time constraint to familiarize participants with the time pressure to be implemented during time constrained test trials. In the time constrained condition, during half of the 24 test trials (i.e., 6 assessment and 6 intervention trials), participants were given 10 seconds (post immediate occlusion) to generate and mark options down on paper. They were permitted to 'clean-up' options that were illegible on the response sheet after the time limit but were not permitted to add (i.e., generate additional) options or change the functional meaning of any of the options that they had marked down. In the remaining half of all trials, participants generated options without time constraint.

2.4 Coding

Two subject-matter experts (SMEs) coded options generated by participants and also determined the task-relevant options for each trial. One SME had 18 years of playing experience, including a year as captain of a NCAA Division III collegiate level; the other had 17 years of playing competitive soccer, including multiple years as a collegiate club-level captain. Both SMEs had the advantage of watching video clips multiple times and were not limited to only the occluded version. SMEs also had the advantage of watching a non-occluded version of the stimuli and the subsequent sequence of play following the critical decision point.

Participants' responses were categorized in to options based on the action, direction, and location of players and ball movement. In order to do this, the response sheets were divided into spatial zones and players on the field were numbered. For instance, if the arrows on a response sheet indicated that the player with the ball (P1) was passing to a player (P2) in a given zone (zone A), the option was deemed '*P1-P2, zone A*'. All response sheets with the same configuration were grouped as this option. The function was also taken into consideration during coding. For instance, a pass between two defenders (P1, P2) both deemed to be a through-pass (TPass)—even if raters did not agree completely on their location (e.g., rated as adjacent zones A & B, respectively by each rater)—were rated as functionally equivalent (i.e., *'P1-P2, TPass'*). SME1 coded all of the options generated by participants using both methods. A portion of the data (approx. 17%) was coded independently by SME2. During assessment trials, inter-observer agreement in terms of functional coding was 85 percent (Cohen's Kappa = 0.82). During intervention trials, inter-observer agreement was 82 percent (Cohen's Kappa = 0.66). The SMEs discussed options where there was disagreement until agreement was reached.

In order to further categorize generated options into 'task-relevant' and 'task-irrelevant' (see Ward et al., 2013), both SMEs generated what they thought to be the task-relevant options for each assessment and intervention trial *a priori* to subsequent data collection. Agreement between SMEs in terms of task-relevance was 97 percent

(Cohen's Kappa = 0.96) across all trials. Those on which they disagreed were discussed until agreement was reached. Whenever a participant generated an option that matched the task-relevant options generated by the SMEs, it was deemed to be task-relevant. Any other options generated were deemed to be task-irrelevant.

2.5 Measures

Anticipation accuracy was used to measure performance during assessment. The assessment option rated highest in terms of likelihood was deemed the anticipated outcome. Anticipation accuracy was calculated using the frequency with which a participant's anticipated outcome matched the actual situational outcome. Decision quality was used as a measure of performance during intervention. Decision quality was measured as the frequency with which a participant selected the criterion best option—defined as the option deemed by the SMEs to be the highest quality course of action that could be taken at that point in the game. To measure option-generation during assessment and intervention, the number of total options, number of task-relevant options, and number of task-irrelevant options generated for each trial were recorded.

2.6 Analysis

Paired *t*-tests were used to test for effects of time constraint on performance (see section *1.4.1* above). The 2-way interaction (Information Type x Time Constraint) on the number of options generated was assessed using a factorial ANOVA, (see sections *1.4.2* and *1.4.3* above). Information type (task-relevant/task-irrelevant) and time constraint (present/absent) were within-participant variables. The number of options generated was the dependent variable. Partial eta squared (n^2_p) is used to describe effect size of main and interaction effects. Within-participant effect sizes were also calculated to measure the effect of time constraint on number of options generated, using the pooled standard deviation.

The relationships between option-generation behavior (i.e., the total number of options, number of task-relevant options, and number of task-irrelevant options) and measures of performance (anticipation accuracy and decision quality) (see sections *1.4.2* and *1.4.3*) were recorded using Pearson's *r*.

3.0 Results

3.1 The Effect of Time Constraint on Performance (see *1.4.1* above)

During assessment, counter to the stated hypothesis, participants did not demonstrate significantly lower anticipation accuracy during time constrained trials than during non-time constrained trials, $t(1, 20) = -0.22$, $p = 0.83$ ($ES = -0.08$) (see Table 1). Similarly, no effect of time constraint on decision quality was observed during intervention. Participants selected the criterion best option equally as often during time constrained and non-time constrained trials, $t(1, 20) = 1.34$, $p = 0.20$ ($ES = 0.38$). The data are presented in Table 1.

	Anticipation accuracy of actual outcome (i.e., assessment phase performance)	Selection of criterion best option (i.e., intervention phase performance)
Time constraint	1.33 (1.28)	1.33 (1.15)
No time constraint	1.43 (1.12)	0.90 (1.14)

Table 1. Mean (SD) frequency (i.e., proportion) scores for anticipation accuracy during assessment and decision quality during intervention.

3.2 The Effect of Time Constraint on Option-Generation during Assessment (see *1.4.2* above)

Counter to the hypothesis regarding a selective reduction in information, the Information Type x Time Constraint interaction effect was not observed during assessment, $F(1, 20) = 0.81$, $p = 0.38$, $n^2_p = 0.04$. However, there was a significant main effect of information type, $F(1, 20) = 4.23$, $p = 0.05$, $n^2_p = 0.17$. Participants generated more task-irrelevant than task-relevant options across both time conditions (see Table 2). Also, a main effect of time constraint on total number of options was observed, $F(1, 20) = 5.10$, $p = 0.04$, $n^2_p = 0.20$ (for a full review, see Table 2). Although there was no interaction effect observed, the effect size data suggest a trend towards task-irrelevant ($ES = -0.31$) but not task-relevant ($ES = -0.07$) information reduction under time constraint

	Condition of time constraint	Task-relevant options	Task-irrelevant options
Number of options generated	Time constraint	0.76 (0.33)	0.94 (0.44)
	No time constraint	0.79 (0.44)	1.13 (0.61)

Table 2. Mean (SD) number and type of options generated during assessment trials.

Next, we hypothesized that the number of task-relevant options would be positively related to anticipation accuracy during assessment trials, and the number of task-irrelevant options negatively related. We speculated that this latter relationship would be exacerbated under time constraint. The relationship between the number of task-relevant options and anticipation accuracy was not significant during non-time constrained ($r = 0.28$, $p = 0.21$) or time constrained trials ($r = 0.32$, $p = 0.16$). However, both were in the hypothesized direction.

The number of task-irrelevant options was not significantly negatively related to anticipation accuracy during non-time constrained (r = -0.30, p = 0.19) or time constrained trials (r = 0.14, p = 0.54). Under time constraint, the trend in this relationship was as predicted by Ward et al. (2013) but counter to our expectations the strength of this negative relationship did not increase under time constraint.

To explore these relationships further, we performed similar analyses on the relationship between task-relevant/irrelevant options and a complementary variable: the frequency with which participants anticipated the criterion *most threatening* option—defined as the option rated of most concern to the defense by the SMEs (rather than the actual outcome). During both non-time constrained and time constrained trials the observed relationships followed a similar pattern with the anticipation accuracy data, albeit more consistently with Ward et al. (2013) under time constraint. The number of task-relevant options generated was significantly and positively related to anticipation of the criterion most threatening option during non-time constrained trials (r = 0.45, p = 0.04) but not during time constrained trials (r = 0.18, p = 0.43). Likewise, the number of task-irrelevant options generated was negatively and significantly correlated with anticipation of the criterion most threatening option during non-time constrained trials (r = -0.43, p = 0.05) but not in time constrained trials (r = -0.17, p = 0.46).

To explore the claims of TTF, the relationship between the total number of options and anticipation accuracy was examined. No significant correlations were observed during time constrained (r = 0.35, p = 0.13) or during non-time constrained (r = 0.27, p = 0.23). In fact, these relationships trended in the opposite direction from the claims of TTF.

3.3 The Effect of Time Constraint on Option-Generation during Intervention (see *1.4.3* above)

The hypothesized selective reduction in task-irrelevant information in response to time constraint was observed in the form of an Information Type x Time Constraint interaction, $F(1, 20) = 5.10$, $p = 0.04$, $n^2_p = 0.20$ During intervention trials, participants reduced the generation of task-irrelevant information (ES = -0.70) significantly more than task-relevant information (ES = 0.17) when time constraint was implemented. A main effect of time constraint on total number of options generated was also observed, $F(1, 20) = 5.70$, $p = 0.03$ ($n^2_p = 0.22$). The data are presented in Table 3.

	Condition of time constraint	Task-relevant options	Task-irrelevant options
Number of options generated	Time constraint	0.80 (0.41)	0.89 (0.41)

Table 3. Mean (SD) number and type of options generated during intervention trials.

Following Johnson and Raab (2003), we hypothesized that the total number of options generated would be negatively related to performance on intervention trials. We speculated that this effect would be magnified under time pressure. While in the predicted negative direction, we did not observe a significant correlation between the total number of options generated and the selection of the criterion best option during non-time constrained trials ($r = -0.20$, $p = 0.38$). However, counter to expectations, the total number of options generated was not negatively related to the selection of the criterion best option during time constrained trials ($r = 0.28$, $p = 0.21$).

We also explored the claims of Ward et al. (2013) during intervention trials. Counter to expectations, the number of task-relevant options generated was not related to the selection of the criterion best option during non-time constrained trials ($r < 0.01$, $p = 0.99$). However, during time constrained trials the data were as would be expected by proponents of LTWM: the number of task-relevant options generated was significantly and positively related to skill at selecting the criterion best option ($r = 0.63$, $p < 0.01$).

The relationship between the number of task-irrelevant options generated and skill at selecting the criterion best option was not observed—although this was in the hypothesized direction ($r = -0.33$, $p = 0.15$). Likewise, during time constraint, the number of task-irrelevant options generated was not negatively related to selecting the criterion best option ($r = 0.27$, $p = 0.23$). To explore these relationships further, we also examined whether participants *generated* the criterion best option (irrespective of whether that option was rated as the best or selected as the course most likely to be pursued) and/or *accurately rated* that option as best (irrespective of whether they selected it as their next course of action). The number of task-relevant options generated was not significantly related to generating ($r = 0.36$, $p = 0.11$) or accurately rating ($r = -0.17$, $p = 0.46$) the criterion best option when no time constraint was imposed. However, during time constrained trials, the number of task-relevant options was positively related to skill at generating ($r = 0.72$, $p < 0.01$) and accurately rating ($r = 0.50$, $p = 0.02$) the criterion best option. The number of task-irrelevant options generated was not significantly negatively related to generating ($r = -0.09$, $p = 0.69$; $r = 0.23$, $p = 0.32$) or accurately rating ($r = -0.39$, $p = 0.08$; $r = -0.37$, $p = 0.10$) the criterion best option during time constrained or non-time constrained trials, respectively. However, the relationship between task-irrelevant option generation and accruately rating the criterion best option were in the direction that would be predicted by Ward et al. (2013).

4.0 Discussion

Counter to our hypothesis regarding time pressure, performance during assessment and intervention trials was not significantly affected by time constraint (cf. Osman et al., 2000; Chabris & Hearst, 2003; Lassiter, 2000; Moxley et al., 2012). We speculate that the effects of time pressure may vary across domains. The implementation of intense time pressure may have a stronger effect on performance in domains where this is uncommon (e.g., chess) than domains where it is a normal feature (e.g., soccer). Alternatively, the time constraint manipulation employed in this study may not have been stringent enough to affect performance (cf. option generation data). More research is needed to further examine the effect of time pressure on performance.

However, our results indicated that time constraint did have an effect on the option-generation process, and the effect varied between assessment and intervention trials. In line with models of activation by association (e.g., RPD, TTF, LTWM), we expected that better options would be generated earlier in the option-generation sequence. Accordingly, we expected to observe a selective reduction in information in response to time constraint during both assessment and intervention trials—that is, a reduction in task-irrelevant options. However, this selective reduction was only observed during intervention trials. As would be expected by proponents of TTF (Johnson & Raab, 2003), time pressure reduced the likelihood that additional task-irrelevant options would be generated when making decisions about which personal courses of action to pursue. Interestingly, this was not the case for assessment trials. This suggests that models that focus on the generation of an immediate and satisficing option provide a better description of the processes supporting performance during the intervention phase but not the assessment phase of decision making (cf. Klein & Peio, 1989; Ward et al., 2013).

The correlational data also provide some insight into the processes occurring during the assessment and intervention phases. In the assessment trials, although we did not observe the expected significant positive relationship between the number of task-relevant options generated and anticiaption accuracy, consistent with the LTWM-based claims of Ward et al. (2013), the findings in both time conditions were in the hypothesized direction. Moreover, exploration of an associated variable—anticipation of the criterion most threatening option—indicated that there was a stronger and positive relationship between this and the number of task-relevant options generated, but only when operating without time pressure. These data suggest that the ability to perceive the task-relevant structure of the environment facilitated the ability to prioritize the available threats but the addition of time pressure somehow disrupted this process. Since Ward et al. (2013) demonstrated stronger relationships than we observed when testing more skilled populations (both between between the number of task-relevant options generated and anticiaption accuracy, and between the ability to prioritize task-relevant options and anticiaption accuracy), we speculate that we would observe similar results in a higher skilled group. However, the current findings suggest that time pressure could eradicate this relationship. More research is needed to examine the effect of time pressure on decision making in more skilled populations.

Unexpectedly, the number of task-irrelevant options generated was not negatively related to anticipation accuracy during assessment trials although, again, it was in the hypothesized direction by Ward et al. (2013). Moreover, contrary to our hypothesis, this relationship did not become stonger in a negative direction under time constraint. Contrary to what might be predicted by TTF, the total number of options generated was not negatively related to anticipation accuracy. However, the exploration of the relationship between the number of task-irrelevant options generated and anticipation of the criterion most threating option followed a similar pattern to that observed in the analysis of the task-relevant option data. The predicted effects from Ward et al. (2013)—a significant negative correlation—were observed when participants performed the task without time constraint. Under time pressure, again, this effect largely dissappered. We speculate that non-time constrained trials permitted an extended search of the mental representation of the stimuli. The ability to focus on relevant—and not on irrelevant information—despite the opportunity for extended search, was related to higher performance. Based on these results, and consistent with claims derived from LTWM (see Ward et al., 2013) we suggest that perceptual skill training during the assessment phase of decision making in soccer should focus on the generation of task-relevant information and methods to reduce the generation of task-irrelevant information, especially under time pressure.

In intervention trials, the correlational data revealed an unexpected finding. Recall that we expected to observe a negative relationshop bewteen the *total* number of options generated and decision quality and for this relationship to become stronger under time pressure—an effect that might be expected if using the TTF heuristic. A significant negative relationship was not observed when participants were not subjected to time constraint, although this was in the direction predicted by TTF. Morevoer, rather than an increased reliance on a TTF-type strategy under pressure as we expected, the shift in the data toward a positive (albeit non-significant) correlation with the total number of options suggest that participants were less likely to use this simple heuristic when generating courses of action under time constraint.

The absence of a relationship between the number of *task-relevant* options generated and decision quality during non-time constrained, intervention trials also suggest that participants did not use a LTWM strategy when not under time pressure. However, during time-constrained, intervention trials the data partially supported Ward et al.'s claims derived from LTWM: the number of task-relevant options generated was significantly and positively related to skill at selecting the criterion best course of action. These data are corroborated, to some extent, by our exploration of the related variables: skill at generating and accurately rating (as opposed to selecting) the criterion best option. During non-time constrained trials no significant relationship was observed, but when under time pressure, the number of task-relevant options was positively and strongly related to skill at generating and accurately rating the criterion best option.

The task-irrelevant data were less clear. Although the relationship bewteen the number of task-irrelevant options generated and anticipation accuracy in the non-time constrained condition were in the direction predicted by Ward et al. (2013), albeit non-significant, under time constraint this relationship did not increase in size, in the predicted direction, or increase in significance; the opposite was observed. In contrast, the relationship between the number of task-irrelevant options highlighted and skill at accurately rating (as opposed to selecting) the criterion best option was strongly correlated in the predicted (i.e., negative) direction in both time constraint conditions. However, the expected increase in size of this relationship was not observed under time pressure. Based on these findings (i.e., change in direction of the relationship under time pressure vs. no change in the relationship, respectively), one can speculate that time pressure may be more detrimental to the processes supporting the selection of the best course of action, as opposed to those that support skill at rating the apparent quality of an option. We supsect that these data may also have been a function of skill: skill at executing the best decision under time pressure is likely to lag behind one's skill at appreciating the relative quality of possible courses of action.

In sum, the present data provide the first examination of the effect of time constraint on option-generation during both the assessment and intervention phases of decision making. Without time pressure—the condition that most closely resembles those used by Johnson and Raab (2003)—data were partially consistent with LTWM: task-relevant options were (or trended towards being) positively related, and task-irrelevant options were (or trended towards being) negatively related to several measures of performance in both assessment and intervention trials. The primary exceptions were the absence of a positive relationship between task-relevant options and anticipation accuracy (but there was a correlation with anticipation of criterion most threatening option) during assessment. We interpret the current data as providing tentative support for the use of LTWM-type mechanisms, at least during the soccer tasks employed in this study.We also interpet this data as being consistent, at least, with the sentiment rather than the specifc claims of TTF: generating additional options, when they are irrelevant to the task goal, may hinder performance.

Under time pressure, contrary to Ward et al (2013) and rather suprisingly, skill at generating task-relevant options during assessment trials was not related to any measure of performance. Consistent with both TTF and LTWM, participants reduced the number of task irrelevant options generated but only during intervention trials under time pressure. However, the relationships bewteen total/task-irrelevant options and performance suggest that this (irrelevant) information reduction strategy was not reliably related to performance success. Instead, skill at generating task-relevant options during intervention trials was related to performance. These data tentatively suggest a greater tendency to use a LTWM-type strategy as opposed to the TTF heuristic when making decisions for oneself under time pressure, at least in the representative soccer tasks explored in this research. More research is necessary to validate these claims across a number of other complex and dynamic situations and domains in addition to soccer. While TTF (Johnson & Raab, 2003) may offer a useful *prescription* for training intervention-phase decision making, our results suggest that LTWM theory offers a potentially better *explanation* of decision making during both assessment- and intervention-phases of decision making.

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6.0 Appendices

6.1 Appendix 1 – Mean (SD) frequency scores of all performance measures during six time constrained and six non-time constrained assessment trials and main effects of time constraint

	Anticipation accuracy of actual Outcome	Generation of criterion most threatening option	Accurate rating of criterion most threatening option	Anticipation of criterion most threatening option
Time constraint	1.33 (1.28)	2.05 (1.72)	1.62 (1.36)	1.57 (1.29)
No time constraint	1.43 (1.12)	1.95 (1.63)	1.86 (1.62)	1.62 (1.47)
Effect of time constraint	$t(1, 20) = 0.22$ $p = 0.83$, $d = 0.08$	$t(1, 20) = 0.22$ $p = 0.83$, $d = 0.06$	$t(1, 20) = -0.57$ $p = 0.58$, $d = -0.16$	$t(1, 20) = -0.12$ $p = 0.91$, $d = -0.03$

6.2 Appendix 2 – Mean (SD) frequency scores of all performance measures during six time constrained and six non-time constrained intervention trials and main effects of time constraint

	Generation of criterion best option	Accurate rating of criterion best option	Selection of criterion best option
Time Constraint	1.76 (1.18)	1.14 (1.15)	1.33 (1.15)
No Time Constraint	1.48 (1.03)	0.81 (0.87)	0.90 (1.14)

Effect of Time Constraint	$t(1, 20) = 0.74$ $p = 0.47$, $d = 0.25$	$t(1, 20) = 1.10$ $p = 0.29$, $d = 0.32$	$t(1, 20) = 1.34$ $p = 0.20$, $d = 0.38$