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Tactical Decision Making in Team Sports — A Model of Cognitive Processes

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Abstract In dynamic situations such as sports, athletes use environmental information to compare the current situation with similar situations in the past. On the basis of this experience a recognized option will be generated and chosen [1]. We evaluated decision making in team handball by tracking the eye movements of participants during the decision-making process. We performed two studies using the same sample that differed in the format of visual presentation. In Study 1 we presented different offensive scenes on a virtual tactic board via a computer screen. In Study 2, the participants watched real decision-making situations in a large video projection on a wall. The same participants took part in both studies (i.e., experienced both formats). The studies were intended to extend previous research on the take-the-first heuristic (limited cue use and limited option generation). An option-generation paradigm was used to measure choice behavior in participants with high and low expertise levels. Results of Study 1 showed that all participants produced nearly the same gaze behavior but experts generated options with a higher probability of success. In Study 2 we conceptually validated the effect in more complex situations. Benefits of that information search and choice behavior are explained based on a simple heuristics approach, and practical recommendations are provided.

Keywords Decision making, Eye tracking, Handball

1. Introduction

In team sports, complex decision-making situations are characterized by a high number of possible actions in a very short time. Thus successful athletes not only must pay attention to physical and psychological factors but must train their tactical skills, as well [2-4]. Previous reviews have acknowledged and quantified decision making as a determining factor in complex team sports [5, 6]. One main result found in these reviews is that high-level players generated options with a higher probability of success [5, 7].

In recent years explanations of such advanced choices have been summarized in over 250 theories that can be applied to sports [for an overview: 8]; about a dozen of these theories have been applied to individual [4] and team sports [9]. The consensus seems to be that the dynamic choices in team sports require models that encompass choices in natural environments.

Several approaches have been summarized as natural decision making [NDM: 10, 11]. The NDM approach assumes that in real situations, people generate not the best decision alternative on the basis of a detailed comparison of options available [12] but rather multiple “satisficing” options that do not necessarily represent the optimal solution (for more on the notion of satisficing, see [13]). This approach takes into account key aspects of complex real-world settings: action/feedback loops, time pressure, multiple players, uncertain dynamic environments, ill-structured problems, ill-defined or competing goals, high stakes, and organizational goals and norms [14]. The methodological inclusion of these aspects in laboratory studies has allowed the transfer of the findings to real-world settings (experimental small world; see [15, 16]).

Another approach, called simple heuristics for decision making, was developed by Gigerenzer et al. [17]. This approach has been applied to sports by Johnson and Raab [18] and summarized by Bennis and Pachur [19]. Heuristics represent simple cognitive strategies for acting quickly and successfully in complex decision situations. The basic assumption proposed by both the NDM and the heuristic approach is that humans have cognitive limitations [19, 20]. Todd and Gigerenzer [21] argued that NDM can be understood from the perspective of bounded rationality, which describes why less information processing is beneficial if the cognitive system is limited or bounded. Combining the NDM and simple heuristics approaches to

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decision making in naturalistic settings under specific emphases in team sports can lead to new insights into human behavior and the mechanisms of decision making [22].

For team sports settings, let us illustrate with an example. The take-the-first (TTF) heuristic describes how options are generated and which option is chosen. Evidence for the TTF heuristic has been validated in different sports, including handball [18], basketball [23], and Australian rugby [24]. Results indicate further that expert players generate more successful options than players of lower expertise. In addition, these first, intuitive options are more successful than later generated ones. So the options generated first are going to drive motor action [25]. Moreover, less expert players generate more options with lower quality.

Klein [1, 26] formulated the decision-making process as a recognition process of matching a specific situation with experiences in which a mental simulation of a single alternative may be sufficient. The mental simulation describes the inspection and selection of the intended action. The generated option will be evaluated on whether it is feasible. The advantage of recognition-primed decision making (RPD) is it allows rapid response without comparing more or all possible options. There are four versions of RPD that apply to different situations. The first version describes the generated options as obvious reactions to a situation [27]. The second includes intuitive option generation with the comparison of expectancies. The third version does not compare expectancies, but the generated option will be analyzed in a process of mental simulation. The fourth RPD model includes both ways of generating options: intuitively and analytically [1, 28].

The RPD model emphasizes the roles of domain-specific knowledge and experience. On that basis, experienced decision makers differ in several aspects from beginners. For example, highly skilled people generate fewer alternatives in real-world decision settings [25, 26, 29, 30]. They also differ from beginners in the ability to assess a situation [26, 31, 32]. Calderwood et al. [33] showed that chess masters generated moves with approximately the same qualities in situations with and without time pressure, but less-skilled players generated more successful actions under the condition without time pressure [33, 34]. In a paradigm that compared a videotaped match and self-confronted interviews with volleyball players to these situations, Macquet [35] confirmed the four aspects of situation classification in RPD (as a part of recognition): expectations, relevant cues, plausible goals, and typical action [1]. These various findings point to the key characteristics of expert decision making: quick identification of relevant cues, differentiated situation classification, awareness of possible options, and generation of successful action [34].

NDM theories are particularly applicable to decision making in sports (for overview, see [34]). RPD theory explains the influence of (visual) information and stored experiences [1]. The findings of Simon [13] have been used to describe the execution of satisfactory alternatives without comparing different options (the notion of “satisficing”). For typical team sport situations, however, the RPD model is not always applicable. For instance, the process of situation classification is limited by the rules of the game. The actions, expectancies, and plausible goals are virtually predetermined.

From a simple heuristics perspective, TTF heuristic describes only deterministic choices in the decision-making process, but, probabilistic choices are more probable in team sports in which opponents can exploit deterministic behavior and counteract it. One crucial question to answer for TTF heuristic is if processes before option generation starts are described in the search rules of simple heuristics. Furthermore, TTF heuristic has not yet been tested in realistic conditions [but see, 24]. For instance, the decision maker in the experiment of Johnson and Raab [18] had to watch several videos scenes, which were stopped at a special attack constellation. This last frame was shown for 5 s. At this time, the participant was asked to call the intuitive and deliberate options. In a realistic sports setting, 5 s is a long time for decision making. Nevertheless, results of applications of TTF heuristic describe the option-generation process of high-level players in team sports. For future studies of decision making, RPD and TTF heuristic should be combined to illuminate the search processes early in choices.

We developed a model called DEMATS (decision making in team sports) using RPD theory adjusted to special team sports situations. Decision making in team sports is a good test bed for testing the assumptions of RPD under realistic conditions [14, 34]. In this current study we enabled realistic conditions via action experience (participants of different performance classes), time stress (real game performance), presentation of multiple players (teammates and opponents), uncertain dynamic environments (dynamic decision situations), ill-structured problems (scenes cannot be exactly anticipated), shifting, ill-defined, or competing goals (individual goals are not given), high stakes (missing goals are possible), and organizational goals and terms (typical decision situations in handball).

The DEMATS model includes the central processes of (visual) information recording, situation classification, and mental simulation of the main components of RPD principles (Figure 1). The motor performance initiation represents the transition to motor execution. The acquisition of visual information is - as in RPD - described as a separate process in DEMATS. The situation classification is based on this and therefore it precedes the cognitive decision-making process.

Situation classification can be simplified because of the specific nature of team sports. The set of rules in a team sport defines the range of plausible goals, expectancies, and possible actions. Situation classification includes the option generation that follows. Combining classification, choice, and option generation extends RPD, as in sports not only does the choice itself need to be appropriate but the temporal-spatial details of the option are important for successful performance. The inspection and selection of the intended action take place in the mental simulation (same to RPD). With a positive comparison, the motor action will be initiated. If a mental simulation is not successful, the action will be modified or the situation reclassified (negative mental simulation). At this point, the findings for TTF heuristic will be considered. The selection of the final action is based identically on the process by TTF heuristic [18]. This heuristic assumes that the intuitive option is also the decision maker's most promising alternative. As a result, action modification and the generation of other options can be combined without compromising the realistic nature of the decision model. The mental simulation can indicate difficulties in the implementation and the possible outcome. Domain-specific expertise leads to early, differentiated mental simulation [34, 36].

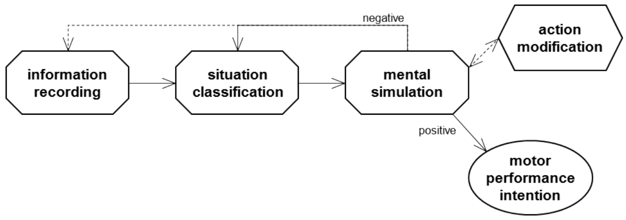

Figure 1. Model of decision making in team sports (DEMATS)

Action initiation corresponds to the results of the mental simulation [28]. The DEMATS model aims at connecting the presented visual cues and the final action [1]. The evaluation of this action thus corresponds to the evaluation of the cognitive process of mental simulation. In this regard, the DEMATS model describes three interdependent processes: recording visual information, situation classification, and mental simulation. The difference between DEMATS and RPD is in the separate process of information recording and the specific aspect of action execution. Klein [1] described both aspects as a part of situation classification. The difference between DEMATS and TTF heuristic is in the different ways options are generated. From here the specific issues and hypotheses can be derived. We first show that players with different performance levels have different gaze behaviors (hypothesis 1). This serves to confirm the TTF heuristic in this setting [25]. Subsequently we check for differences in the processes of situation classification and mental simulation (hypothesizes 2 and 3). Another step for assessing DEMATS is to test the influence of the visual behavior and the situation classification on the decision-making process. In particular, the DEMATS model evaluates the relation of situation classification with final action and the relation of information recording with final action.

2. Method

The assessment of decision makers' cognitive processes requires domain-specific situations. We used handball-typical offensive situations that we presented by video. The videos showed different offensive scenes, similar to those used for basketball [23, 37], handball [18], or soccer [38, 39]. Such dynamic and realistic videos allow information presentation that corresponds to the experimental small-world approach [15]. This approach combines the necessary abstraction and high complexity of real decision situations and uses the criteria of decision-making behavior for typical team sports. Different from previous paradigms, the videos are not paused at a particular scene; participants have to stop the video by pressing a manual switch.

2.1. Participants

A total of 26 young handball players took part in two studies. Handball players of the elite youth team of Saxony-Anhalt (Germany) represented the highest performance class (n = 9; M = 15.89 years; SD = 0.33; hereafter high-level group). The overall domain-specific experience of the high-level group was M = 9.22 years (SD = 1.41; on the highest level for youth players: M = 1.28 years; SD = 0.75). The lowest performance class was represented by nine players in the district league (M = 15.11 years; SD = 0.78; domain-specific experience: M = 5.89 years; SD = 2.11; hereafter low-level group). The novice group (Study 2 only) consisted of eight students who had no experience in club handball (M = 15.63 years; SD = 0.52). Goalkeepers and players with glasses or contact lenses were excluded. All groups were familiar with the basic rules of handball via physical education at school but they differed in their deliberative practice in clubs, controlling for age.

This selection as the independent variable follows the suggestion of Abernethy et al. [40], that the control groups in expertise research should not consist exclusively of inexperienced people. The number of participants matched samples in previous investigations that found a unique effect for a different quality of the generated option in decision-making situations in team sports [30, 41] and individual sports [chess: 29, 33].

The high-level and the low-level group took part in Studies 1 and 2. Thus we were able to explore if any differences found between groups in simplified situations (Study 1) are also found in complex settings (Study 2). To confirm the differences, we introduced the novice group in Study 2 [40].

2.2. Instruments

In Study 1, visual stimuli were presented dynamically on a virtual tactic board, where players in the videos are represented by symbols (simplified representation). In Study 2, the decision situations were presented as videos of actual scenes (complex representation). The presentation was orientated with regard to tasks of visual information recording and decision making in a specific team sport.

The main difference from earlier studies [e.g., 18, 38, 42] is in the task participants had to perform. Participants had to mentally envision themselves as a selected player in a rear position, and solving the task meant scoring or preparing a goal (exclusively offensive scenes). They had to control the start and end of each video. Participants started the scene by pushing and holding a manual USB switch button. By releasing the button would cause the video to stop directly (information search stopped). Participants then needed to verbalize as fast and as accurately as possible their final action for the selected player. The participants were not required to make a choice [16]. Furthermore, no options were predetermined. The participants had to generate only one option under nearly realistic conditions [14]. This methodological approach is based on the TTF heuristic [25]. For tasks in team sports, it is advisable to specify the use of this heuristic, because the best option is intuitively the one generated first [24].

The trigger action of each individual scene began after the team had passed several times. There were different constellations presented for a final action. The generated action should be understood as the conclusion of the attacking team (e.g., throw on goal, final pass). If no action was generated, the scene would end with a throw on goal by a teammate (after 20–30 s). Thus, a realistic situation in handball was simulated as closely as possible [43]. After the participants stopped the video and chose the following action, they were asked to outline the last perceived constellation on paper. We evaluated the reproduced scene to assess the cognitive process underlying situation classification [44, 45]. The influence of visual behavior in decision making was measured in terms of the success of final actions.

2.3. Dependent Variables

Three groups of dependent variables were recorded for gaze behavior, perception of situation, and quality of the generated action. The parameters reflect the processes as described in the DEMATS model (information recording, situation classification, and mental simulation).

Gaze behavior parameters included the percentage of fixation, number of fixations, and duration of fixation (fixation is a stationary view of at least 120 ms; [38]). The percentage of fixation describes the period of global uptake of visual information and is expressed as a percentage because the video scenes were of different lengths. The fixation duration provides information on the individual recording speed of visual information [46, 47]. Participants' eye movements were recorded with an eye-tracking system (iView X HED, SMI, Berlin, Germany) and are referring to the DEMATS model. The data were analyzed frame-by-frame (25 frames per second; software fairplay lite, CCC, Leipzig, Germany).

We examined *situation perception* to assess the conscious process of recording visual information (recognition test: based on [45]). Two independent raters evaluated the outlines participants created of the last perceived scene [44, 48]. Each participant received one point for correctly identifying a player at the correct position. For a correct player but at the wrong position on the court a half point was awarded. The individual values are summed and specified in relation to the maximum achievable score. The maximum score indicates the correct processing of all visual information.

The *quality of the generated action* refers to whether a behavior is situation appropriate and will be operationalized by the TTF strategy [18] and describes the process of mental simulation. Quality was determined by an expert rating assessment (double-blind method; A-license coach of the German Handball Federation). Three experts also assessed the quality, level of difficulty, and practical nature of the videos. Furthermore, the coaches call for improvement, which are retrofitted. The experts also assessed the different final actions with a dialogue. The probability of success is the result of a community estimating. The quality of the generated action is specified in relation to the maximum achievable score of probability.

2.4. Data Analysis

The three hypotheses regarding differences between the three groups were analyzed with a Kruskal-Wallis test and regarding differences between two groups with a Mann-Whitney test (parameters: gaze behavior, situation perception, quality of action). The independent variable in each of the three hypotheses was the performance level of the participants. The dependent variables were different parameters of gaze behavior (recording visual information: percentage, number, and duration of fixations; hypothesis 1), situation perception (for gauging situation classification; hypothesis 2), and the probability of success (for gauging mental simulation; hypothesis 3). In this way, spurious correlations were avoided (successful vs. unsuccessful vs. no generated action). The level of significance was reduced due to the dependence of the samples and the different distributions (adjusting the level of significance: $p = .05 / 6$ scenes = .008). The calculation of relations was done with univariate analysis of variance (ANOVA).

3. Study 1

Scenes from handball were dynamically presented on a virtual tactic board on a 22-inch computer screen with triangles representing forwards and circles representing defenders. We assessed only the high- and low-level players because the specific handball presentation would be unfamiliar and too complex for students. In team training this was a typical presentation. The presentation was limited to showing the positions and paths of field players. So this should be understood as simplified information representation.

3.1. Procedure

The participants were tested individual. He sat in front of the screen and held the manual USB switch in their dominant hand (Figure 2). The stimulus-generating computer, the eye-tracking computer, and the investigator were located behind the participant. The technical implementation was carried out with the software Handball Tactics (Otto von Guericke University, Magdeburg, Germany). The software allows the production and dynamic sequencing of exactly defined offensive scenes. We used six offensive situations for Study 1, which were randomly presented (time duration: *M* = 17.83 s; *SD* = 1.72). Offensive situations are more appealing to youth participants and allow more opportunities for action than defensive scenes. The quality of the output coming eye-tracking data was prefixed to the quantity of video scenes [49]. The flow of the game was presented from a bird's-eye perspective and based on a typical handball attack.

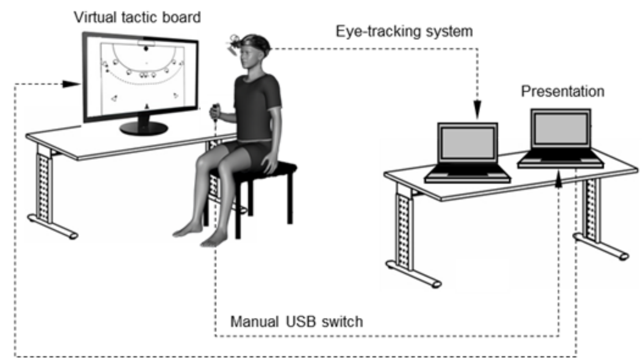

Figure 2. Study design of the simplified representation of a decision-making situation

3.2. Results

We first examined the information recording of the handball players in the two performance classes by analyzing their gaze behavior. Previous studies have shown difference between highly skilled and low-skill team players (see Table 1; [38, 42, 50]).

We used the eye-tracking parameters to interpret the cognitive processes during decision making (recording and processing of visual information) in the DEMATS model. There were no statistically significant differences between the groups in gaze behavior (hypothesis 1; variables averaged over time; see General Discussion). Furthermore, it is assumed that there are differences between the two test groups with regard to the classification of situation (hypothesis 2). Therefore here we discuss the parameter perception of situation. The high-level players achieved a significantly better percentage than the low-level players (Table 1). With regard to the output of the DEMATS model (hypothesis 3), it is assumed that the high-level players generate actions with a higher degree of success than the low-level players [18, 23, 24]. The results show that the high-level players reached a higher probability of success than the low-level players. Statistically, the two groups are significantly different.

Regarding the correlation of situation classification and option generation, results show no connection for the high-level players (*r* = .167, *p* = .668) but a significant correlation for the low-level players (*r* = -.636, *p* = .066). Both correlations are not statistically significant for the sample groups. The results of the correlation of gaze behavior and option quality are given in Table 2. A univariate ANOVA showed no significant differences for the gaze behavior parameters and the quality of the final option between the two groups in the offensive situations in the simplified representation condition.

Table 1. Results for Gaze Behavior in Study 1

Parameter	Group				Mann-Whitney test			
	High level		Low level		*U*	*z*	*p*	Φ
	M	*SD*	*M*	*SD*				
Percentage fixation	90.79 %	2.12 %	91.95 %	2.44	29.0	-1.015	.34	.24
Fixation number (per second)	1.75	0.45	1.82	0.49	38.0	-.221	.432	.05
Fixation duration (no. frames per fixation)	14.58	4.0	13.81	3.4	34.0	-.574	.605	.14
Perception of situation (percentage of maximum score)	82.29 %	3.17 %	58.10 %	16.65 %	0.5	-3.534	.001	.83
Quality of generated option (probability of success)	61.45 %	6.18 %	49.16 %	12.48 %	14.0	-2.341	.01	.55

Table 2. Univariate Analysis of Variance between Gaze Behavior and Quality of Generated Action in Study 1

Group	Gaze behavior	Quality of action		
		F	*p*	η^2
High level	Percentage fixation	0.276 (2, 47)	.760	.012
	Fixation number	0.257 (2, 47)	.775	.011
	Fixation duration	.597 (2, 47)	.555	.025
Low level	Percentage fixation	2.284 (2, 46)	.113	.090
	Fixation number	2.164 (2, 46)	.126	.086
	Fixation duration	1.324 (2, 46)	.276	.054

3.3. Discussion of Study 1

The hypothesized difference in gaze behavior between high- and low-level players was not supported. The youth team players of both sample groups recorded the visual information in the same way. These results contrast with those of Helsen and Pauwels [50], Williams, et al. [42], and Williams and Davids [38]. Research on expert performance [51] has shown that gaze behavior can differentiate expertise groups (necessary condition: long-term training scope; 45]). Gaze behavior appears to develop in different ways as a result of different training stimuli and qualifies as a key feature of adult high-performance sports players. However in early years, gaze behavior is not yet a factor for performance. According to Gegenfurtner et al. [47] and in context to Just and Carpenter [46] and Gaardner [54] we understand the results as a reference for the advantage of expert players, that they are able to process rapid visual information in shorter fixation durations than low level players. Or in other words, if the fixation duration is nearly the same between two groups, the high level players process the same information on a fortuitous level.

The degree of domain-specific experience seems to play an important role in the cognitive processes of situation classification and mental simulation. Our two groups differed significantly in their level of specific handball experience. Consequently, it can be assumed that the high-level players had had to solve more of the presented situations than the low-level players. Klein et al. [52] found that experience affects the order of generated options. People with more experience can successfully generate domain-specific actions earlier than those who are less experienced. Klein [36] and Johnson and Raab [18] confirmed this assumption. Further results on this study are replicating previous findings and extend them by combining early, late information processing with final actions (quality of generated option, [2, 18, 53]). In this regard, we conclude that the high-level players had more tactical skills and better physical conditioning.

In the following, the results are considered in terms of the DEMATS model. The process of recording information did not differ between high-and low-level players, who captured the same visual information. Thus the first DEMATS phase was identical in the two performance classes. Furthermore, the recorded information was cognitively processed and sorted to generate a single action. Gaardner [54] assumed that visual information is cognitively processed in phases between two fixations. In this process, the high-level players had an advantage over the low-level players. The information they processed was more detailed and accurate. The final cognitive process of DEMATS involves the generation and examination of actions (mental simulation). The high-level players generated final actions that had a higher probability of success than those generated by the low-level players. The available time for information processing was used more effectively by the high-level players.

However, there was no direct connection between recognition and mental simulation. The high-level players accomplished both cognitive processes with high quality. For the low-level players, there was even a negative correlation between the processes of recognition and mental simulation.

We interpret the minimal effects as being random and owing to the small sample size and the lack of significance. These results are similar to the above discussed findings for visual behavior. We found no influence of visual behavior on the decision-making process of youth athletes from different performance classes. The cognitive processes of visual information acquisition and information processing were identical in the two groups in a simplified representation condition of sport-specific offensive scenes.

The results of the first study (under simplified conditions) were checked under more practical and realistic conditions. This experimental step was necessary to judge if the findings are applicable to team sports. For this purpose we recruited a third group. Student of the same age but who were not members of a sports club solved the same tasks. In Study 2 we explored the differences between experienced (high- and low-level players) and inexperienced (students) participants. The hypotheses were identical to those of Study 1 with the extension of a third group (same-aged students).

Table 3. Results for Gaze Behavior in Study 2

Parameter	Group						Kruskal-Wallis test		
	High level		Low level		Novice		χ^2	p	Ω
	M	*SD*	*M*	*SD*	*M*	*SD*			
Percentage fixation	92.55 %	1.13 %	96.02 %	0.58 %	97.26 %	0.60 %	21.395	.001	.91
Fixation number	1.77	0.19	1.63	0.32	1.79	0.21	2.066	.356	.28
Fixation duration	13.86	1.7	15.83	2.8	14.78	1.84	2.873	.238	.33
Perception of situation	80.34 %	6.63 %	57.21 %	23.12 %	37.02 %	8.83 %	13.478	.001	.72
Quality of generated option	59.11 %	2.90 %	46.47 %	6.44 %	35.74 %	7.77 %	19.74	.001	.87

4. Study 2

In Study 2, participants watched realistic attack scenes that were projected on a wall. The visual information included many game-related aspects (e.g., field players in different jerseys, goalkeepers, body and partial body movements). To increase the fidelity of the game scenes, we included typical handball sounds (e.g., sounds of players and spectators, sounds of running on the floor).

4.1. Procedure

Three groups - high-level players, low-level players, and novices - participated in this experiment. The participants stood in front of a wall on which video scenarios were projected (180 × 300 cm; Figure 3). Experienced handball coaches picked 18 offensive video scenes that were presented in random order (time duration: M = 14.5 s; SD = 3.24). The view perspective corresponded to that of a field player; participants were asked to image themselves as that player. The main differences between this study and Study 1 are the amount of presented information and the view perspective. This study was also based on the key aspects of the experimental small-world approach [15, 16].

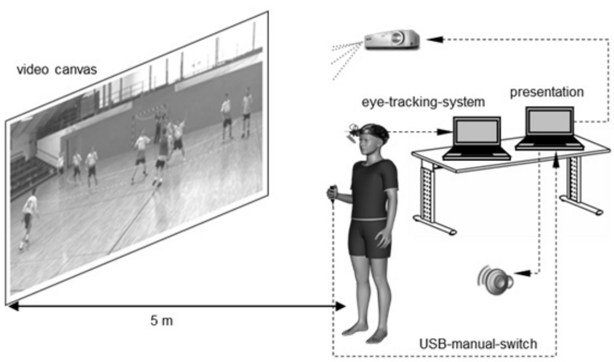

Figure 3. Study design of a complex representation of a decision-making situation

4.2. Results

With regard to the percentage fixation, it is hypothesized that the high- and low-level players and the novices would record the visually presented information in the complex representation condition to the same extent (see Table 3). The numbers of fixations did not differ significantly between the three groups. The fixation duration led to no significant differences between the three groups.

Furthermore, there were significant differences in the perception of situation between the three groups. The high-level players achieved the highest percentage and the novices the lowest. There were also significant differences in the quality of the generated options. The novices' quality of options was lowest among the three groups.

The results of the correlation of gaze behavior and the option quality are provided in Table 4. The impact on the quality of final action is significant only for the low-level players and is regarded as high (high-level players: r = .209; p = .589; low-level players: r = .714; p = .031; novices: r = -.5; p = .207). The results show no significant differences between the probabilities for success of the final actions. Depending on the longer fixation duration, the generated final action will be less successful.

Table 4. Univariate Analysis of Variance btween Gaze Behavior and Quality of Generated Action in Study 2

Group	Gaze behavior	Quality of action		
		F	p	η^2
High level	Percentage fixation	.829 (2, 142)	.439	.012
	Fixation number	.130 (2, 142)	.878	.002
	Fixation duration	.017 (2, 142)	.983	<.001
Low level	Percentage fixation	1.263 (2, 104)	.287	.024
	Fixation number	1.404 (2, 104)	.250	.026
	Fixation duration	.790 (2, 104)	.457	.015
Novice	Percentage fixation	1.547 (2, 117)	.217	.026
	Fixation number	2.647 (2, 117)	.075	.043
	Fixation duration	3.792 (2, 117)	.025	.061

4.3. Discussion of Study 2

The DEMATS phase of recording information is described by the gaze behavior (percentage fixation, number of fixations, fixation duration). The recording of information will be terminated earlier by the high-level players than by the low-level players and novices. The parameters number of fixations and fixation duration are not suitable for performance-class-based description. Participants in the three performance classes acquired the visual information with identical speed. The results for percentage fixation corresponded with similar results found by Rayner [55], suggesting that this parameter can be used as a measure of cognitive load and the difficulty of the task. The presented videos showed typical handball decision situations and were a highly challenging task for the novices. The parameter percentage fixation illustrates this conclusion, which is confirmed by the quality of the final action. The findings for the numbers and duration of fixations contradict the results of Williams et al. [42], Williams and Davids [38], and Mann et al. [5]. We conclude that this parameter is not indicative of cognitive recording processes.

We interpret the processing of the recorded information on the basis of perception of situation. The high-level players captured and reported back the complex represented situations in more detail than the other groups. The parameter points to a clear advantage being held by the high-level players. These handball players can process visual information more effectively.

Furthermore, the high-level players generated final actions with virtually identical success probabilities. In contrast, the low-level players' and the novices' probability of success was more varied. Note that the standard deviation of these groups increased in the same order as the quality of the final action decreased.

However, there was no correlation between the gaze behavior and the quality of generated actions. On one hand, the fixation parameter can be used as a distinguishing factor in terms of performance levels. On the other hand, no behavior can be identified in the study of complex decision-making conditions, which requires exactly the generation of successful final actions. The percentage fixation and the number and duration of fixations are not suitable for differentiated description of the gaze behavior in terms of the probability of success of the generated final action.

According to the arguments of Gaardner [54], the recorded information should be processed more effectively in the further available time period by the high-level players than by the other participants. This interpretation is clear from the context of the situation perception and action generation.

5. General Discussion

The aim of this study was to analyze the cognitive processes of decision making as they apply to decision making in team sports. We derived a model from RPD [1] to describe the decision-making process specifically in team sports (the DEMATS model). DEMATS includes the visual information search, the subsequent situation classification, and the mental simulation of action. The intended motor performance depicts the transition of the generated action to motor performance. Youth handball players of the highest and lowest performance class had to solve several offensive situations in this team sport in two representation conditions: simplified (Study 1) and complex (Study 2). In Study 2, we also examined novices matched in age who had no competitive handball experience. Several characteristics of real-world-situations were considered in both experiments [14].

Visual information recording

The oculomotor findings confirmed that the high-level players captured the information required for action faster than the low-level players. This finding is in keeping with those of Chi et al. [31], Klein and Woods [32], and Johnson and Raab [18]. Less important information is perceived peripherally. As a result of rapid information recording, high-level players can use the extra available time for cognitive processing. This process is associated with a period of saccades [54]. Accordingly, a lower percentage fixation corresponds to a lower gain of information and to a more detailed use of information. With regard to the percentage fixation, expertise has an influence on the level and cognitive processing of perceived information from a young age.

The shorter time period for the processing of information was more effectively used by the high-level than the low-level players. The reduced acquisition of information suggests a less-is-more effect. On one hand, the high-level players received a reduced range of information. On the other hand, they were able to concentrate on the most important aspects and ignore extraneous detail. The advantage held by the high-level players is their ability to capture the specific information of the decision-making situation faster and process it more accurately than the low-level players and the novices.

The two other variables of visual behavior collected in addition to the percentage fixation (fixation number, fixation duration) were not suitable for describing the decision-making process. The three groups did not differ from one another in the number of executed fixations and in the fixation duration. In addition, we can reach no conclusions concerning the generation of successful and unsuccessful final actions.

However, it must be noted that the variables were computed from pure medium values (averaged over time). In recent publications, decision makers were reported not to have adjusted the recorded information equally [2, 56]. Instead, previously acquired information is given greater importance in the decision-making process. Here, we focused on the quantitative evaluation of gaze behavior. An analysis of the adjusting sets would require at the same time the qualitative evaluation of gaze behavior, and so we cannot comment on this issue at this point.

Situation classification

In the DEMATS model, the cognitive process of situation classification includes the phase of information processing. In this regard, we found that the high-level youth players were able to more accurately describe the decision-making situations than the low-level players and the novices. The joint consideration of both cognitive processes (information recording and situation classification) leads to the conclusion that the quality of information processing is influenced by the available time (percentage saccade). It seem that what is important is less what is fixated on and more the quality of the cognitive processing.

Mental simulation

The high-level players often correctly classified the offensive decision-making situations instantaneously and generated a final action with a higher probability of success than the low-level players [18, 24, 29, 36, 50]. The low-level players and the novices referred to the incorrect and critical situation classification [34]. The high-level players processed selected information in terms of the cognitive classification of the decision situation. Subsequently they generated final actions with a higher probability of goal scoring than the low-level players. This corresponds to the findings of Raab and Johnson [25].

Conclusion

A relationship between detailed recorded information and the resulting action cannot be confirmed for a single decision-making situation in the present studies. Cognitive processes in addition to visual information processing appear to be involved in the process of action generation. Klein [1] described possible factors as plausible goals, possible actions, expectancies and relevant cues. In our study, plausible goals and possible actions were shared by the groups, because they are unique to the sport of handball. The generation of the final action appears to have depended largely on the situation-specific expectancies and the relevant cues. It can be assumed that for practical reasons, the high-level players often found themselves in such situations and, accordingly, the decision options and their success probabilities were stored differentiated in memory of the players. This corresponds to the observations of Klein [36] and confirms the findings of Klein et al. [52], Johnson and Raab [18], Hepler and Feltz [23], and Buszard et al. [24].

With regard to the study design, it was suitable for an empirical evaluation of decision making of young handball players. The research method allowed for class-specific performance analysis of adolescent handball players and novices without handball experience. The significant differences found indicated differentiated training for tactical situations. Accordingly, the findings of Johnson and Raab [18], Memmert et al. [53], and Raab and Laborde [2] were confirmed in terms of decision quality of generated sequence actions.

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