TransCoop: Prof. Raab and Dr. Johnson

Novel analyses of decision-making processes in real, complex environments.

Overview

Most broadly, the goal of this project is to gain a better understanding of individuals' decision-making processes under various task constraints. This project will focus on the use of a modeling methodology which is based on established theory but introduces novel techniques. This methodology will be applied to a specific task structure initially, to understand how various contextual (task, environment, situation, etc.) and individual (personality, goals, etc.) factors influence decision making processes under various circumstances. In particular, we use a computational model to capture the deliberation process in ill-defined situations (those with no objectively-correct solution) under stress and time pressure. By incorporating computational models from the judgment and decision making (JDM) literature with the task domains of sport science, there is mutual benefit to both fields. Models successful in "traditional" JDM tasks are applied to (sports) domains characterized by their complexity, formal structure, dynamic property, natural setting, and expert participants with intense involvement and self-motivation. For sport science, this approach provides a rigorous framework to formalize existing theories and develop/test new hypotheses. Furthermore, our research project will provide insights into decision-making that can also be extended to other situations. For example, the characteristics of sports tasks and the athletes who perform them (e.g., stress, emotional involvement, risk taking, varying expertise, time pressure) also describe other domains, such as military decisions or fighting fires.

Motivation and goals

The primary aim of the research project, as outlined here, is to develop a successful framework for describing and analyzing decision-making processes, stemming from previous work of the cooperation partners. First, we emphasize dynamic processes, realizing that cognition as well as the environments in which we are situated are indeed ever-changing. In order to better understand human behavior, we feel it is essential to understand the emergence of overt behavior (e.g., deliberation) rather than simply studying the latter (e.g., dependent variables such as choice probabilities). Concerning methodology, we stress the importance of an individual level of analysis and recognize the perils associated with aggregate modeling of individual phenomena. Second, we appreciate human variability, domain specificity, and individual differences. This involves the influences of personal experience in different domains on processes such as development of categorization structures, as well as memory influences including storage and retrieval efficiency, that affect the information framed for decision making. Also, individual differences can be studied in terms of strategy development, selection, and use that determine the choice process itself. We contend that these information and application characteristics can produce a closed set of individually-specific, domain- and context-dependent momentary equilibria. Together, these lines of research should converge in detailing the cognitive architecture of individuals and the information used in decision making, in addition to the constrained computational processes that connect the two.

The current work will integrate previous research into a comprehensive framework, guided by these research philosophies. Earlier attempts have been made in decision making and cognitive psychology to describe deliberation processes as symbolic operators or production rule systems (Anderson, 1990). Similar methods are employed in sport science for instructive purposes (i.e., a prescriptive approach), such as the use of "if-then" rules in coaching (Raab, 2003). However, such an approach may require a large collection of rules or mappings, and is often treated descriptively. A key motivation for the currently-proposed project is to replace these attempts with a more quantitative framework. Our computational approach produces precise predictions regarding choice probabilities, deliberation times, and process measures (information search, options considered, etc.).

Formalizing deliberation as a computational process, as we strive for in this research project, results in fruitful theoretical advances for the disciplines of sport science and cognitive psychology alike. Our research will thus provide answers to many questions that arise independently from within each discipline. For instance, are models in the judgment and decision making area in cognitive psychology applicable to real environments? More importantly, do they help researchers to describe and understand realistic decisions? Does applying decision models to sport decisions help to improve the underpinnings of mostly descriptive approaches in sports science to a priori predict choices and decision times? As a consequence of knowing the underlying mechanisms of choices, can training schedules or other instructional aspects be altered as one of the long-standing goals to improve performance?

Description

Several decades ago, the brain was an impenetrable black box, but with recent advances in neuroscience, we can start to look inside. It is informative to point out a conclusion arising from converging evidence obtained through neuroscience research on decision-making. A simple but important revelation from this work is that decisions in the brain are based on the dynamic accumulation of noisy activation for each action, and the action whose activation first exceeds a threshold is chosen (Ratcliff, Cherian, & Segraves, 2003). This process is illustrated in Figure 1, for three actions, with each trajectory representing the cumulative activation (i.e., preference state) for an action. The horizontal axis represents deliberation time and the vertical axis indicates the activation for each action at each moment in time. In this Figure, action A reaches the threshold first, and is chosen at time T = 69.

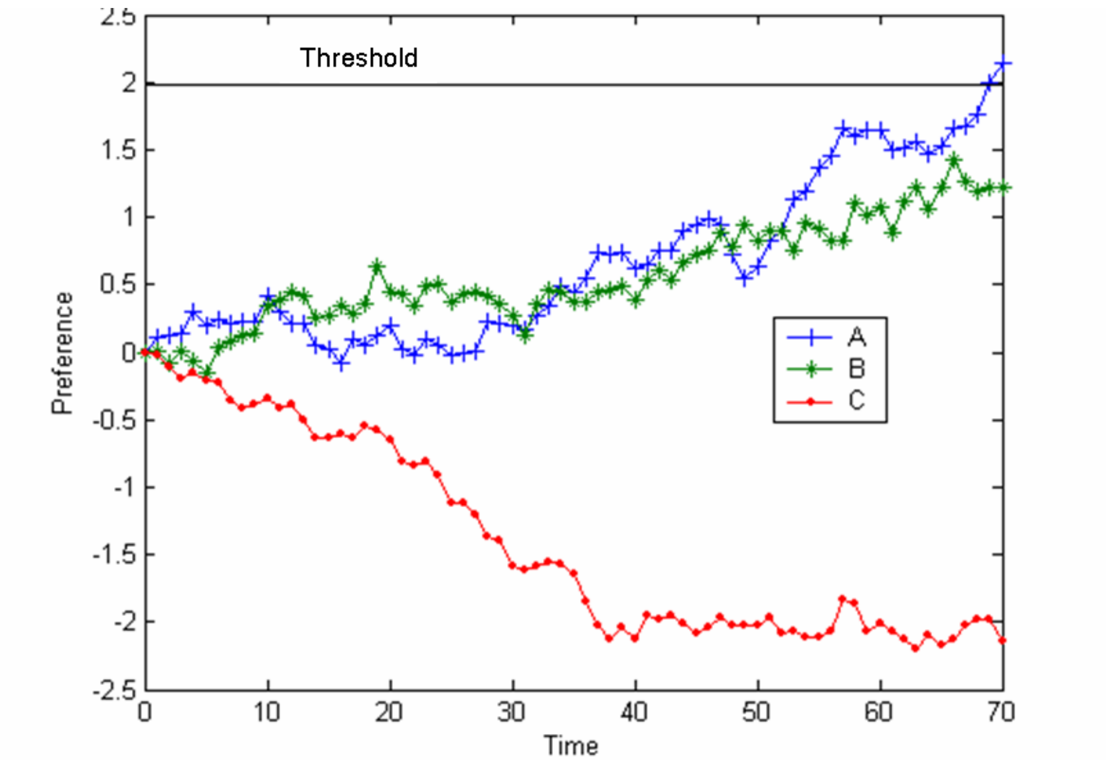

Figure 1: Simulated sequential sampling choice process

This dynamic decision process is known as a sequential sampling process (DeGroot, 1970). It forms the basis of decision models used in a wide variety of cognitive applications from sensory detection (Smith, 1995) and perceptual discrimination (Laming, 1968), to higher-order processes such as categorization (Nosofsky & Palmeri, 1997), probabilistic inference (Wallsten & Barton, 1982), and preferential choice (Aschenbrenner, Albert, & Schmalhofer, 1984). In this project, we formalize a particular model from this class (Decision field theory; Busemeyer & Townsend, 1993; Diederich, 1997; Roe, Busemeyer, & Townsend, 2001) to represent the decision making process. Furthermore, we introduce the often-overlooked aspect of option generation, modeled previously to some degree by the cooperation partners (Johnson & Raab, 2003). We now briefly describe each of these models, followed by a sketch of their planned integration for the current project.

Decision field theory (DFT). Decision field theory uses a sequential sampling process to make decisions, consistent with the other areas of cognition above. In this section, we briefly outline the core concepts of DFT as applied to the sports tasks of the proposed research project (Figure 2). We restrict ourselves here to a conceptual introduction, but note that one practical benefit of the model is its mathematical rigor.

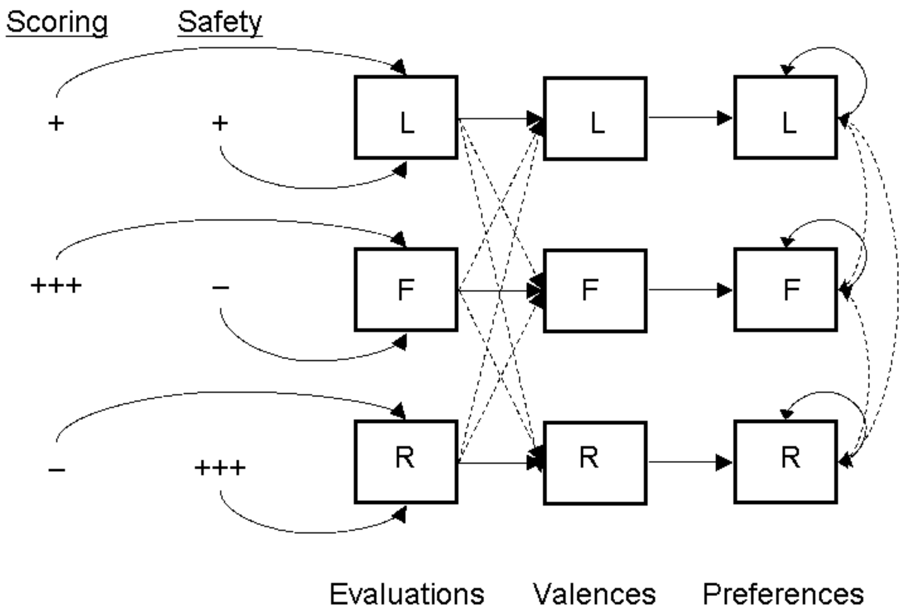

Figure 2: Schematic illustration of DFT model. Solid lines represent positive connections, dashed lines represent negative connections

Consider as an example a dynamic situation in soccer, where a midfielder has a number of options concerning whether to continue dribbling or to pass to other players; in the latter case, the midfielder must also decide how (e.g., dribble pass or lob) and where (e.g., to another midfielder or to a forward) to pass. According to DFT, the midfielder deliberates over various courses of action (e.g., lob pass to the left corner, dribble to the right, fake left and dribble to the right). Assume three options corresponding to a reduced set of actions for the midfielder (see Figure 2): a lob to the left corner (L), a quick pass to the forward (F), and dribbling to the right (R). Also, we simplify by assuming the midfielder thinks about the following possible dimensions: (1) the "scoring potential," associated with assisting on a game-winning goal; or (2) the "safety potential," incorporating concern for losing the ball to the opponent late in the game. So, each possible dimension produces some affective evaluations of each option of a decision, such as the highly positive evaluation of the consequence produced by passing to the forward for a game-winning goal, or the negative evaluation of the consequence produced by having that same pass stolen by a brave goaltender in the closing seconds.

Deliberation is driven by attention shifting from moment to moment over a period of time between the possible dimensions, thus dictating the momentary values under consideration. For example, at one moment the midfielder may remember something (e.g., the nature of her defenders) that makes her think a pass has a high risk of being stolen—focusing attention to "safety potential" momentarily. In this case, she realizes there is a good outcome if she dribbles, but not if she passes to the forward. But at another moment, she may see the streaking forward player, and remember the goalie's poor defense of a "one-timer," or quick pass and immediate shot—shifting attentional focus to "scoring potential." At this time, she may anticipate the glory of a game-winning goal associated with a center pass. The probability of attending to a particular dimension at each moment reflects the decision maker's underlying subjective concern about each dimension. We would quickly note that while the formulations here follow precedent in assuming attention shifts among dimensions, the current project also formulates the process with attention shifting among the options. This distinction is also a novel and important contribution of the proposed project.

We assume that, under each focus of attention, comparisons are performed among evaluations of the options, to produce what are called valences. A positive valence for one option indicates that the option has an advantage under the current focus of attention, whereas a negative valence signals a disadvantage. For example, if attention is currently focused on dimension 1 (scoring), then action L has an advantage over other options, and option R has a disadvantage under this state. But these valences reverse when attention is switched to dimension 2 (safety). The valence is computed for each option i within a set of n options by comparing the value for option i with the average of the other (n -1) options.

These momentary valences are accumulated over time to form a preference state. The preference state for an action represents the integration of all the preceding affective reactions (valences) produced by thinking about that action during deliberation. Conceptually, the new state of preference is a weighted combination of the previous state of preference and the new input valence. The relative influence of the previous preference state incorporates two factors (cf. Figure 2). First, we assume positive self-feedback, or memory, affecting the degree to which the previous preference within an option is carried into the next time step. Second, we assume negative feedback, such as “leaning towards” other options, that results in dependencies of the preference states between options (dashed lines among preference nodes in Figure 2). In particular, we assume that the strength of this inhibition is an increasing function of the similarity between a pair of alternatives. For example, options L and F are similar in that they are both passes downfield that could score. So, the lateral inhibition between L and F would be greater than that between either of these options and R. Finally, the initial preference state for an option, $P_i(0)$, is defined at the start of a decision problem to represent a preference recalled from past experience. This is used to explain carry over effects from previous decisions or past experience, such as previous games played by a midfielder, in a particular situation or against a particular team.

This deliberation process continues until the accumulated preference for one action reaches a threshold, which determines the choice and the deliberation time of the decision (refer back to Figure 1). The threshold bound for the decision process, symbolized $\underline{\theta}$, is a key parameter for controlling speed and accuracy tradeoffs. If $\underline{\theta}$ is set to a low threshold, then only a weak preference is required to make a choice. In this case, decisions are made very quickly, which may be reasonable for trivial decisions of small consequence. However, a low threshold would cause the decision to be based on little thought about the consequences, which is likely to lead to a choice with bad unforeseen outcomes. For more serious decisions, $\underline{\theta}$ is set to a very high threshold, so that a very strong preference is required to make a decision. In this case, deliberation takes longer, but the decision is based on a more thoughtful evaluation of all the consequences, producing a choice that is more likely to result in a positive outcome.

In summary, a decision is reached by the following deliberation process: as attention switches from one dimension to another over time, different affective values are probabilistically selected, these values are compared across actions to produce valences, and finally these valences are integrated into preference states for each action. This process continues until the preference for one action exceeds a threshold criterion, at which point in time the winner is chosen. Formally, this is a Markov process, and matrix formulas have been mathematically derived for computing the choice probabilities and distribution of choice response times (for details, see Busemeyer & Townsend, 1992; Busemeyer & Diederich, 2002). Alternatively, Monte Carlo computer simulation can be used to generate predictions from the model.

This theory has been applied to a variety of traditional decision making problems. It was introduced as a model of decision making under uncertainty (Busemeyer & Townsend, 1993), accounting for robust effects such as speed-accuracy tradeoffs, primacy and recency effects, etc. It was also extended to multi-attribute decision making (Diederich, 1997), and multi-alternative decision making (Roe et al., 2001), allowing it to account for context effects such as adding dominated or compromise options. Furthermore, it has been shown to account for the effects of time pressure (Diederich, 2003), and has been formulated for tasks requiring evaluation values such as prices and certainty equivalents (Johnson & Busemeyer, submitted). Finally, it has also been extended to account for decision rule or strategy learning, as well as routine behavior (Johnson & Busemeyer, in press). The most pertinent application of DFT for the current project was previously conducted by the cooperation partners, described next.

The cooperation partners explored the degree to which computational models (specifically, DFT) could help to better understand the underlying mechanisms for overt behavior (Raab & Johnson, 2004). Specifically, a personality trait (action orientation) was assessed using a standard survey tool, and behavioral decisions and response times in a dynamic basketball task were recorded. This work is novel in that it used independent data (a personality measure) to specify DFT model parameters a priori, rather than fitting parameters to the choice data. For example, those with a higher propensity towards action were modeled as having lower thresholds for the accumulation of preference necessary to initiate action. Yet, some concerns about parameter interactions (as well as task effects) remain unsettled, which will be addressed in the current project. Before describing these extensions, we must first quickly introduce the other component of the computational model: the option generation process.

Heuristic option generation. Experimental decision-making research often uses a task in which participants are presented with alternatives from which they must choose. This experimental format neglects an important aspect of many real-world decision-making environments—namely, the option-generation process. During their jobs at the Max Planck Institute of Human Development in Berlin, the cooperation partners helped fill this void by presenting a model that describes the link between the use of different strategies and the subsequent option-generation process, as well as the resulting choice characteristics (Johnson & Raab, 2003). Essentially, the model assumes that, in a given task, decision makers utilize environmental cues (e.g., defender position, game situation) and past experience in conjunction with a strategy (most generally, just a task-specific predisposition) to generate possible solutions to ill-defined problems. This generation process is closely linked to associative memory retrieval: the strategy and cues determine the first option considered, which results in "spreading activation" to other potential options based on a similarity measure derived from experience (e.g., past success of various options under given circumstances).

For example, the soccer midfielder may use a functional strategy to develop her options in the situation described earlier. Perhaps the game situation—late in the final period, facing a slow opposing goaltender, and seeing an open forward player—results in the "intuitive" or first inclination to pass to the forward. Her functional strategy (wanting to score) may cause her to focus on similar (scoring) options, and her past experience may implicitly tell her that if the forward is a good option, then often times a lob to the corner is a good option as well. This may result in her consideration of options L and F, but neglect of option R entirely. In this sense, it may not make experimental sense to ask the midfielder to choose between L, F, and R, when the situation would naturally only lead her to consider L and F.

Empirically, the cooperation partners examined the relationship between strategy use, number and order of generated options, choice quality, and dynamic inconsistency within this framework. An experiment involving a realistic (sports) situation was conducted on suitable participants (athletes) to test the predictions of the model. Initial results support the model's key predictions: strategies producing fewer generated options result in better and more consistent decisions. However, no explicit choice mechanism was included in this model; only relationships between option generation and final choice quality were considered. Thus, the current project will link this line of research with the DFT choice model outlined above.

Integrated computational framework. The proposed cooperation project will ultimately integrate and extend the two lines of research previously explored by the cooperation partners. The first project showed the ability to tailor models to individuals in predicting choice behavior (probabilities) and response times. Yet, DFT predictions can be derived only when the alternatives under consideration and the attributes that describe them are fully defined, and thus neglects option generation. The second model includes the important element of option generation, which is lacking in DFT and the majority of decision making studies. However, this model had some limitations, such as supposing deterministic behavior (neglecting choice variability). Furthermore, in neither of these projects was data collected about the information used by participants, and so both models had to make assumptions about, e.g., the attentional process. To overcome these limitations, we want to pursue an integrated research agenda, based off our previous collaborative efforts. This involves (a) complete specification of the DFT model including option generation, (b) designing sophisticated research to collect all the necessary independent variables and dependent measures, and (c) application of the model to the behavioral data, considering the other data collected. The latter involves, for example, using surveys and dispositional variables to specify model parameters and processes, which are then used to predict performance. In this manner, we can confirm parts of the previous models as well as extend them.

Application

It may be readily apparent that formalizing processes as complex as deliberation and decision making is no trivial task. On the contrary, it is very difficult to isolate the relevant factors or components of such a process. This is due primarily to two major concerns. First, one must consider the broad range of tasks that require “decision making,” as it is broadly defined, and try to enumerate the potentially interesting variables and cognitive operations. Second, there are a great deal of individual differences that may influence the processing style associated with decision making. Our line of inquiry must therefore necessarily be reduced to studying specific characteristics of the environment and/or decision maker; otherwise, the scope of a research project would be too large to be managed efficiently.

In light of these observations, our research project will impose a number of constraints for practical manageability. This does not, however, imply a limitation of our approach. In fact, relaxing the constraints we make initially will provide interesting avenues for future research. Specifically, we rely on distinct component processes, outlined above in the introduction of our modeling framework. Furthermore, we make specific assumptions about how individual characteristics (e.g. risk taking, impulsivity, self-monitoring, etc.) help to define the parameters of the model—these can loosely be considered as the relative impact of each component process. Finally, we focus on one particular domain: decision making of athletes in real, competitive situations.

Precisely, we want to model decisions of players in sports, such as the one facing the midfielder. Understanding the decision processes underlying the midfielder's choices has a number of theoretical challenges and practical implications we want to investigate in this project. Above all, we want to formalize these decisions so that they can be examined in our computational framework. This means that the decision-making process can be specified for implementation on an algorithmic level, such as a computer simulation, rather than being descriptively (and, as a result, often ambiguously) defined, such as with abstract flowcharts. Then, we can quantitatively determine the processes involved and examine influences upon them. We now summarize the objectives of the proposed research project, then detail the timeline for meeting these.

The first objective is the development of the computational framework, resulting from inclusion of the option generation process in the DFT choice model. This is primarily theoretical work already considered by the cooperation partners, although mathematical derivations and (computer) implementation must be completed. Second, we must obtain the necessary data through carefully-designed research. This involves more than just obtaining behavioral data to test the model. Equally importantly, it also involves assessing individual characteristics and task behavior (e.g. information search) in order to predefine some model processes and parameters. The empirical research will also include task manipulations to confirm hypotheses about task influences. Finally, model testing and comparison will highlight the utility of our approach, and contrast our approach with the more popular approach of model fitting.

Research plan

The research plan consists of three phases that represent the three years of grant duration. In the first year (Phase I) we want to collect data in Flensburg from two experiments on eye-tracking and option-generation of players of different performance level. In the second year (Phase II) we want to derive attention weight parameters from the eye-tracking data and constrain other parameters based on individual data (expertise, personality). This allows us to predict choices using the new combined model based on a direct estimation of the generation and search strategies, work to be completed in Ohio. In the third year (Phase III) we want to set up a conference (small group meeting) of experts in cognitive psychology as well as decision making in sports, to bring evidence together for discussing the theoretical and practical consequences of our findings (as well as others) in this area. The presentations and discussions are planned to be edited by the partners in a book volume to demonstrate the current state of the art in this area.

<u>Phase I Experiments</u>

Two experiments will be conducted: one with experienced players, and one with less experienced players. We will ask sport teams around Flensburg to take part in this study, and will use a handball task because our previous work (Johnson & Raab, 2003) used this task and because we have received preliminary agreement of cooperation from some quality handball teams in this area (e.g., the current German champions in both the first league and B-level of men's handball). In addition, some amateur teams train on the campus near one of the partners, enabling direct contact between research and the field.

The stimuli consist of a number of situations, taken from a videotape of a high-level handball team during practice (but performing as if it was in competition). Coaches will select the experimental stimuli (scenes) based on similarity to competition situations and multiplicity of possible solutions. To generate a variety of situations, the team depicted in the scenes varied its attack and defense systems. These situations can be labeled as ill-defined problems because there exists no objectively-defined correct solution or choice alternatives.

The task will be similar to that of Johnson and Raab (2003), with slight alteration to incorporate the new requirements for the eye-tracking data acquisition (see below). The selected scenes will play on a video projector for approximately ten seconds to preserve the flow of the situation, ending at the point where the ball is passed to the player whose role the participants are to assume. At this point, the scene is frozen and participants will speak aloud their first "intuitive" decision (e.g., pass to the left, bounce shot to the goal), followed by other possible actions. After enumerating possible actions, participants will state the best decision in a given situation. Appropriate controls, checks, practice, and elimination of confounds will be applied (cf. Johnson & Raab, 2003). Additionally, participants will complete a standard personality inventory for risk behavior (HAKEMP, Kuhl, 1986) and for the preference for intuition and deliberation (PID, Betsch, Betsch, & Haberstroh, in press). The independent variables will be the experience level of the player, the time pressure condition, and the personality scores. The dependent variables will be the generated options, the chosen "best" option, response times, and eye-tracking data.

We will collect eye-tracking data using a BioVision head-mounted Eye-Tracking System (Version 2.0). This system records horizontal and vertical position of one eye using 25 samples per second (40 Hz). The eye-position information will be calibrated to the video-based playing to determine spatial fixations when the freeze frame is active, and also provide the duration of each fixation. These fixations will be used to indicate attention to other players and to the goal. Pilot studies using eye-tracking in handball were conducted this year and can be applied to the task we will construct. The different allocations of attention inferred from the eye-tracking data will be referred to as "attention weights."

<u>Phase II: Simulations</u>

A variety of simulations will be conducted in connection with the proposed research project. Many of these will consist of mapping the parameter space for the computational model. That is, by parametrically manipulating attention weights, affective values, and parameters to create artificial athletes, we will derive two complete manifolds relating these variables to each of choice probabilities and response times.

To derive model predictions specific to the experimental task, we will use the following procedure. First, the model of option generation strategy will be defined. This entails enumerating all options defined by a single participant. These options will be classified on their spatial result (e.g. left, middle, right), as in Johnson and Raab (2003). The relative importance of these locations will be determined via eye-tracking (e.g. amount of time looking left) and compared to the relative number of generated options within the appropriate category (e.g., options resulting in leftward movement of the ball). In this manner, the option generation model is extended to derive probabilistic measures. Second, for the choice model, eye-tracking data will determine the relative attention weights to each spatial location. These weights will be used to generate model predictions for the "best" option named for the participant. Furthermore, in the choice model, appropriate parameters (e.g. thresholds) will be determined using the personality data, as in Raab and Johnson (2004). All other parameters will be held constant and a sensitivity measure is used to ensure that this constant default value does not influence the results (cf. Raab & Johnson, 2004).

Phase III: Exchange between Cognitive Psychology and Sport Science

We are confident that our research plan is practical and will provide for a new interdisciplinary research program. This assessment is based on the productive—in terms of publications as well as theoretical exchange—prior cooperation of the partners, during joint positions at the same institute of the Max Planck Society for one year in 2002. However, to establish a sustainable research program we will focus on two important endeavors during the proposed project. First, we will guide two PhD-students throughout the program in Germany and the U.S., starting after the first meeting of the principal investigators in 2005. They will conduct some of the pilots necessary to design the experiments, set up the simulation tools, and guide the student workers for all relevant data collection and data analysis. These activities will provide immediate experience in designing and conducting research, as well as in the methodological and theoretical advances of the proposed project. In Phase III they will also be part of the small group conference. For this they will learn to organize such a conference, present research professionally, and assist in editing the resulting book.

The conference will be hosted by one of the home institutions (potentially in Germany, see attached time table and budget plan) and will invite ten excellent fellows from the judgment and decision-making area in cognitive psychology, as well as ten excellent fellows from the sport science area conducting research on decision making. The conference will follow part of the Dahlem Conference strategy in which it aims to encourage interdisciplinary exchange of internationally-excellent scientists, through the planned workshop and the edited volume. The Dahlem conference strategy offers a special type of communication, that does not allow formal talks but groups scientists of different disciplines in thematic discussions prepared by the cooperation partners. These discussion groups will be provided with problems and gaps of knowledge, whereby the groups need to come up with new approaches or directions of research. We hope applying this strategy will result in the development of novel ideas and approaches, which individuals in the context of their own groups or traditional conference schemas are mostly unable to achieve. The book proposal will be sent to a well known international publisher and will contain disciplinary background papers and, most importantly, group reports with avenues to direct future research.

Summary and extensions

The proposed cooperation research project will produce a new framework for conceptualizing and analyzing individual decision making. This framework represents a significant contribution to both the cognitive psychology of decision making, and the study and assessment of decision processes in sport science. Previous collaboration of the cooperation partners has provided us with the ability to accurately assess our capabilities and potential. In response, we have set realistic, well-defined objectives and goals for this project, and have constructed a reasonable schedule for completing the work planned. More importantly, this project will establish a successful and enduring collaborative research program, with many avenues for extension beyond the specific examinations of the current project. For example, we would like to consider additional individual variables and trait characteristics that can be used for model specification. Also, we would like to explore other environments and context effects, to see how robust model specifications are to such changes. As mentioned, we have restricted our focus in the current proposal for efficiency, but the framework has limitless possibilities. The framework and methodology could also be applied to other domains of interest, such as military decisions and consumer behavior, or used for other applications, such as clinical assessment. Ultimately, the proposed research project will constitute an important first step towards a comprehensive understanding of decision-making behavior.

References

Anderson, J. R. (1990). *The adaptive character of thought*. Hillsdale, NJ: Lawrence Erlbaum.

Aschenbrenner, K. M., Albert, D., & Schmalhofer, F. (1984). Stochastic choice heuristics. *Acta Psychologica, 56*(1-3), 153-166.

Betsch, C., Betsch, T. & Haberstroh, S. (im Druck). Intuition: Wann sie ihren Bauch entscheiden lassen können [Intuition: When you can let your feelings decide]. *Wirtschaftspsychologie.*

Busemeyer, J. R. & Diederich, A. (2002). Survey of decision field theory. *Mathematical Social Sciences*, *43*, 345-370.

Busemeyer, J. R., & Townsend, J. T. (1992). Fundamental derivations from decision field theory. *Mathematical Social Sciences, 23,* 255-282.

Busemeyer, J. R., & Townsend, J. T. (1993). Decision field theory: A dynamic-cognitive approach to decision making in an uncertain environment. *Psychological Review, 100,* 432-459.

DeGroot, M.H. (1970). *Optimal statistical decisions*. New York: McGraw-Hill.

Diederich, A. (1997). Dynamic stochastic models for decision making under time constraints. *Journal of Mathematical Psychology, 41*(3), 260-274.

Diederich, A. (2003). MDFT account of decision making under time pressure. *Psychonomic Bulletin and Review, 10*(1), 157-166.

Johnson, J. G. & Busemeyer, J. R. (in press). Rule-based Decision Field Theory: A dynamic computational model of transitions among decision-making strategies. To appear in T. Betsch (Ed.). *The Routines of Decision Making*. Mahwah, NJ: Erlbaum.

Johnson, J., & Raab, M. (2003). Take The First: Option generation and resulting choices. *Organizational Behavior and Human Decision Processes, 91,* 215-229.

Kuhl, J. (1986). Human motivation: From decision making to action control. In B. Rehmer, B. Jungermann, P. Laures & G. Sevon (Eds.), *New directions in research on decision making* (pp. 5-28). Amsterdam: North-Holland.

Laming, D. R. (1968). *Information theory of choice-reaction times.* New York: Academic Press.

Nosofsky, R. M., & Palmeri, T. J. (1997). An exemplar based random walk model of speeded classification. *Psychological Review, 104,* 266-300.

Raab, M. (2003). Decision making in sports: Implicit and explicit learning is affected by complexity of situation. *International Journal of Sport and Exercise Psychology, 1,* 310-337.

Raab, M., & Johnson, J. (2004) Individual differences of action-orientation for risk-taking in sports. *Research Quarterly and Exercise Sport*, *75,* 326-336.

Ratcliff, R., Cherian, A., & Segraves, M. (2003). A comparison of macaque behavior and superior colliculus neuronal activity to predictions from models of two-choice decisions. *Journal of Neurophysiology, 90*, 1392-1407.

Roe, R., Busemeyer, J. R., & Townsend, J. T. (2001) Multi-alternative decision field theory: A dynamic connectionist model of decision-making. *Psychological Review, 108,* 370-392.

Smith, P. L. (1995). Psychophysically principled models of visual simple reaction time. *Psychological Review, 102*(3), 567-593.

Wallsten, T. S., & Barton, C. (1982). Processing probabilistic multidimensional information for decisions. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 361-384.