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COMPUTER STRATEGY OF

DECISION MAKING UNDER TIME PRESSURE *

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The study focuses on the cognitive processes underlying decision making in a dynamic context. The purpose is to formally define the predecisional structure and to describe the cognitive strategy a subject employs when solving a decision problem under time pressure. A model was elaborated defining the cognitive-decisional strategy of a defensive player (D) in squash when selecting a motor act in response to his opponent's eventual shot. (Sarrazin et al., 1983). Computer simulation based on protocol analysis was applied aiming at verifying the inner validity and logic of the proposed model. Results points to a viable predecisional information structure established on predefined methods used to reach a specific preparation state. These methods are sequences of goals and operators that are stored in property listed and are activated by transistory knowledge states in working memory. The computer program could also account for a substantial part of the variation in the length and accuracy of processing. Discrepancies observed between the program decisions and the ones reached by expert players led us to question the use of a normative decision rule in a dynamic context.

Previous research in the field of psychomotor learning and performance has dealt with either mechanisms governing movement or the perceptual factors involved in performing a motor task. It is interesting to note, however, that investigations into the processes underlying decision making in a context subject to time pressure, such as sport, has been virtually ignored (Whiting,

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1979). This dearth or empirical research is probably attributable to methodological difficulties identifying cognitive processes in a fast-paced environment. These shortcomings have led us to explore the relevance of conceptual frameworks and methodological tools related to cognitive psychology (Einhorn & Hogarth, 1981; Kleinmuntz & Kleinmuntz, 1981) in gaining insight into the cognitive processes involved in choosing a motor act.

The study reported hereafter is formulated in light of problem solving theory and methodology (Newell & Simon, 1972). The decision maker is placed in a problem solving situation. He should be viewed as a symbolic information processing system employing certain cognitive operations as adapting mechanisms in order to cope with a complex environment (Hogarth, 1981). In addition, verbal protocols can provide significant information about deliberately selected processes underlying decision making (Kellog, 1982; Payne, 1982). Finally, it is possible to establish some functional equivalence between performance patterns on a computer and a human being during a given task (Card, Moran & Newell, 1980; Bhaskar & Simon, 1977).

Through the use of verbal protocols and computer simulation, the present study investigated the cognitive processes involved in solving decision problems under time pressure. The aims were to verify the inner validity of a proposed model of decision making in squash (Sarrazin & al. 1983) and to evaluate the extent in which this model accounts for the variability in speed and accuracy of the motor reaction.

Task analysis and decision making model

The decision task facing a defensive player (D) in squash was considered. It consisted in choosing the best preparation state in order to react appropriately to an opponent's impending shot. A preparation state is regarded as a physical bias toward the chosen response. Previous results (Alain & al. 1983) revealed that expert squash players considered three different preparation state: 1) total preparation according to which D totally favors a unique response to be executed by his opponent without taking into consideration any other possible responses. 2) Partial preparation whereby D primes one response without excluding the possibility that an alternate reaction may be required. 3) Neutral preparation according to which D's bias is the same for each of the possible response.

An integral part of the simulation task was to provide a detailed description of the structural characteristics of the task environment. Data collection and verbal protocol analysis of D attending an opponent's shot in squash competition were completed. The methods and theoretical constructs underlying these stages are reported elsewhere by Alain & al. (1983) et Sarrazin et al. (1983). This led to the formulation of a model of D's decisional behavior.

In the course of reacting to repetitive decisions made in face of time pressure, an expert squash player will formally define a problem space. This problem space consists of a highly organised internal representation of the task environment. Operators and goals would then be applied to varying knowledge states in order to construct a search sequence within this space. A production system consisting of conditional statements spells out the logic guiding this search. It describes a set of methods (sequence of goals and operators) and a selection rule that D uses to choose the best possible state of preparation. This choice would be accomplished through the extention of the subjective expected utility principle (S.E.U.) (Coombs, Dawes &

Tversky, 1970). That is, D. would assign varying S.E.U. values to each preparation state and subsequently choose the one with the highest value. Assignment of these values is achieved by computing various sources of information related to the three following functions: 1) The subjective probability assigned to each possible shot of the offensive player. 2) The time pressure attributed to each shot, and finally 3) the utility value that D assigns to each preparation state he might choose. The various sources of information related to the task of choosing the best preparation state are, for instance, the respective positions of the players on the court, play habits of the offensive player, the opponent's ability to aim the ball to the chosen position, the estimated time required to reach the ball, the time available to reach the position the ball is expected to touch the court, and the significance or score of the game.

In sum, data collected thus far have led to the formulation of a conceptually viable model of decision making in squash. However in order to further corroborate the viability of this model, this study was designed to verify the inner logic. The goals, operators, methods and selection rule were integrated into a computer simulation program. In this regard the following sections outline how the information processing approach was applied to the study of decision making in sport.

Computer representation of a decision making problem

The basic structures of the simulation program were elaborated and operationalized on a PDP-10) computer using a recent version of UCI-LISP (Meehan, 1979). The resulting LISP program comprised a set of production rules governed by an adapted translation of Winston's (1977) production system interpreter. This interpreter is an internal aspect of processing which

TABLE 1

Production System

COMPUTER TRACE	PSYCHOLOGICAL STEPS
P_1 : Heuristic = First	P_1: FIND THE FIRST PREDICAT T OF AN ITERATION AND EVALUATE IT.
Itération 1 Prédicat = (EQ(Preparation-P)(Quote Note)) Action = Print solution Production = Stop	ITERATION 1 = IF D POSSESSES ALL THE NECESSARY INFORMATION TO CHOOSE A SPECIFIC STATE OF PREPARATION IN HIS PRODUCTION MEMORY THEN PRINT THE CHOICE OF A SPECIFIC STATE OF PREPARATION AND STOP THE PROCESSING.
Itération 2 Predicat = T Action = Nothing Production = P_2	ITERATION 2 = BY DEFAULT, THE PREDICAT IS T AND D SETS THE GOAL OF EVALUATING THE NEXT PRODUCTION
P_2 : Heuristic = First	P_2: FIND THE FIRST PREDICAT T OF AN ITERATION AND EVALUATE IT.
Itération 1 Predicat = (EQ(Preparation-P)(Quote Uncertain) Action = Nothing Production = P_3	ITERATION 1 = IF D IS UNCERTAIN OF THE PREPARATION STATE TO CHOOSE THEN D SETS THE GOAL OF FINDING THE BEST POSSIBLE PREPARATION
P_9 : Heuristic = All	P_9 : EVALUATE EVERY ITERATION THAT HAS A PREDICAT T
Itération 1 Predicat = (EQ(POS-P)(Quote Desire)) Action =(DPOS) Production = Stop Itération 2 Predicat = (EQ(ORI-P)(Quote Desire)) Action = (DORI) Production = Stop Itération 3 Predicat = (EQ(ID-P)(Quote Desire)) Action = (ID) Production = Stop Itération 4 Predicat = (EQ(Habd-P)(Quote Desire)) Action = (DHABITUD) Production = Stop Itération 5 Predicat = (EQ(HABL-P)(Quote Desire)) Action = (DHABILET) Production = Stop Itération 6 Predicat = (OR(EQ(POSP)(Quote Note)) (EQ(ORI-P)(Quote Note))(EQ(ID-P)(Quote Note)) (EQ(HABD-P)(Quote Note))(EQ(HABL-P) (Quote Note))) Action = (ASPS) Production = Stop	ITERATION 1, 2, 3, 4, 5, 6 = THE SAME PRINCIPLE IS GOVERNING ALL OF THESE ITERATIONS IF D IS UNCERTAIN OF THE STATE OF PREPARATION TO CHOOSE AND D WANTS TO CHANGE OR TO GIVE A VALUE TO THE EXPRESSION POSITION (OR ORIENTATION, SHOT, HABITS, ABILITY) ON SET OF EXPRESSIONS UNCLEAR, THEN D APPLIES THE HIGHER LEVEL OPERATOR DPOS (OR DORI, ID, DHABITUD, DHABILET) AND STOP THE EVALUATION OF THIS ITERATION.

also consists of a lisp program. Simple rules verify the presence of certain antecedent conditions then initiate specific actions. For illustrative purposes, table 1 presents 3 production rules from the total set of productions which are outlined in the process of choosing a specific preparation state.

The complete set of production rules encompasses 8 general production rules which are broken down into 22 iterations. A production rule is defined as one or more iterations, an iteration being composed of a predicat-action-production triad. Each triad constitutes a specific strategy and the whole series of 22 iterations comprises D's global cognitive strategy. This strategy determines D's predecisional information structure and also contributes to the actual choice of a specific preparation state. The predicat is a simple function that verify whether or not the goal conditions and the stored problem characteristics from the property list are met. As such it essentially determines which iteration is to be evaluated by the interpreter. As soon as a predicat is dubbed true, the action associated with it is initiated.

The actions of an iteration are either inexistant (nothing), as in simply establishing a goal (iteration 2 of P1, table 1), or constitutes applications of operators involved in D's decision process, namely lower and higher level operators. Their respective definitions characterizes the grain of the anlysis. The lower level operators consist of the few basic processes used by D to generate, manipulate, store, or retrieve symbolic expressions from property lists. These property lists are simple pair lists (name-value) associated with an identifier placed in D's production memory. The basic processes define the higher level operator used by D to solve the decision problem. Each higher level operator is applied to a knowledge state. This produces a new knowledge state which brings D closer to his choice of a specific preparation state.

Methods and task characteristics

A sequence of goals and higher level operators in the program represents a particular method of reaching a specific preparation state. The program's simplest method is the one associated with the goal of retrieving a preparation choice already located in production memory. However, if D does not have a pre-established preparation choice, then he must use a more elaborate sequence of goals and operators. The simulation trace in figure 1 illustrates the result of a complete assessment of iterations. In this case, after computing the differente sources of information for two specific shots, D selects according to the S.E.U. rule a total preparation for a pass shot.

Preference for one method over another depends on the specific information D possesses when he becomes a defensive player as well as other processing characteristics emerging from the context. For instance, figures 2 and 3 illustrate the influence of situation repetition on D's process duration. Figure 2 shows a relatively long processing time (production rules P1, P2..) attributable to D's engagement in the production system without a well defined internal representation of the task environment. Therefore, in order to make a choice the player must use more computational phases. Figure 3 illustrates a situation later on in the game. D's progressive involvement in the game has lead him to identify the offensive player's habits and abilities as well as other information pertaining to this situation. As a consequence, the values within certain property lists remains the same when facing repetitive decisions. Given this initial knowledge state, D

C. SIMULATION TRACE OF DECISION PROCESS

```
* (SETQ ACTIONFLG T)
* (SETQ %%TRACE-P T)
T
* (EXE-P P1)

Operator
  DPOS                 = (10 . 6)

Operator
  DORI                 = (6 . FACE)

Operator
  1D                   = (BOAST PASS-SHOT)

Operator
  DHABITUD             = ((BOAST 0.600)(PASS-SHOT 0.799))

Operator
  DABILIT              = ((BOAST WEAK)(PASS-SHOT STRONG)

Operator
  ASPS                 = ((BOAST 0.357)(PASS-SHOT 0.643))

Operator
  PR-TEMP              = ((BOAST LOW)(PASS-SHOT HIGH))

Operator
  ASPR                 = ((BOAST (1.0 0.799 1.0 0.899 1.0))(PASS-SHOT
                          (0.0 0.899 0.300 0.799 0.300)))

Operator
  DPOINT               = (2 2 1 1 1)

Operator
  DSTR                 = (2 2 2 2 2)

Operator
  DFAT                 = (1 1 1 1 1)

Operator
  ASVU                 = (5 5 4 4 4)

Operator
  SEU                  = (1.785 4.322 2.200 3.343 2.200)

Operator
  CHOICE               = SEU VALUE NO 2

TOTAL PREPARATION FOR BOAST          = 1.785
TOTAL PREPARATION FOR PASS-SHOT      = 4.322
PARTIAL PREPARATION FOR BOAST        = 2.200
PARTIAL PREPARATION FOR PASS-SHOT    = 3.343
EQUAL PREPARATION                    = 2.200

Selected motor reaction is
TOTAL PREPARATION FOR PASS-SHOT      = 4.322
```

Fig. 1. Simulation trace of D's decision process

A. INTERNAL REPRESENTATION OF TASK ENVIRONMENT

DEFENSIVE PLAYER:

POSITION	10
ORIENTATION	FACE
SCORE	8
TIREDNESS	EXHAUSTED
STRATEGY	FAKE
HABITS	((BOAST 0.600)(LOB 0.199)(DROP-SHOT 0.000) (PASS-SHOT 0.799))
ABILITY	((BOAST WEAK)(LOB WEAK)(DROP-SHOT WEAK) (PASS-SHOT STRONG))
TIME-PRESSURE	((BOAST LOW)(LOB LOW)(DROP-SHOT HIGH) (PASS-SHOT HIGH))
PS-EFFICACY	((TP AUGMENTED)(PP AUGMENTED)(EP DIMINISHED))
PS-ENERGY-COST	((TP NORMAL)(PP NORMAL)(EP EXHAUSTING))

ATTACKING PLAYER:

SCORE	2

B. COMPUTATIONAL PHASES

PRODUCTION RULES	ITERATIONS	PRODUCES
P1	2	(P2)
P2	1	(P3)
P3	2	(P4)
P4	1	(P5)
P5	1	(P9)
P9	1	(STOP)
P9	2	(STOP)
P9	3	(STOP)
P9	4	(STOP)
P9	5	(STOP)
P9	6	(STOP)
P5	2	(P15)
P15	1	(STOP)
P15	2	(STOP)
P5	3	(P17)
P17	1	(STOP)
P17	2	(STOP)
P17	3	(STOP)
P17	4	(STOP)
P5	4	(P3)
P3	1	(P1)
P1	1	(STOP)

Fig. 2

PRODUCTION RULES	ITERATIONS	PRODUCES
P1	2	(P2)
P2	1	(P3)
P3	2	(P4)
P4	1	(P5)
P9	1	(P9)
P9	2	(STOP)
P9	3	(STOP)
P9	4	(STOP)
P9	5	(STOP)
P9	6	(STOP)
P5	2	(P15)
P15	1	(STOP)
P15	2	(STOP)
P5	4	(P3)
P3	1	(P1)
P1	1	(STOP)

Fig. 3. Influence of situation repetition on D's decision process

needs to process less information and less computational phases. The length of the process also appears to increase according to uncertainty (Hick, 1952; Hyman, 1953). In the proposed strategy, increasing the quantity of information to process (for instance, more shots introduced in the problem space) will lead to computation of numerous productions, which in turn increase processing time.

Further analysis of program function have led us to question the use of the S.E.U. rule in the choice stage of the decision making process. According to the program, computation is characterized by a small sequence of dimensional processing in the assesment stage followed by a more complete holistic processing when selecting the best possible preparation stage (Walsten, 1980; Payne, 1982). In this regard, the normative S.E.U. rule used requires that D possesses all the available information on all alternatives and dimensions in order to compute S.E.U. values and subsequently choose a preparation state. This implies that D must be placed in an ideal situation where he feels no information overload and has the necessary time to process all related information. Under time pressure the vast majority of decision making will be made without a complete evaluation of the available information, therefore a normative rule is likely to be used in a dynamic context.

Furthermore, in examinating the structural organisation of the lower level operator involved in the choice rule used in this program, it also becomes apparent that the computational demands are considerable, time consumming, and presumably overloading short term memory. These claims that are suported by the results of Kleinmuntz & Kleinmuntz (1981) done while observing an extreme computational complexity of the bayesian strategy as opposed to generate and test or heuristics strategies. Therefore, the intricate nature of computing S.E.U. values suggests that the choice stage is made under simple rules, such as lexicographic ordering (Fishburn, 1974), or through elimination by aspects (Tversky, 1972).

The above results emphasize the need to consider computational effort, demands on memory, and speed of execution when assessing a choice strategy in a fast-paced environment.

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