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THE UNIVERSITY OF ALBERTA

KNOWLEDGE, ANTICIPATION, AND THE SOLUTION OF MOVEMENT PROBLEMS BY MENTALLY RETARDED ADOLESCENTS

BY

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A THESIS

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Dédicace

A mon épouse, Francine, à mon fils, Jean-François, à qui je dois beaucoup de temps.

ABSTRACT

The ability of mildly and moderately mentally handicapped adolescents to solve movement problems was studied in a simulated racquet sport situation. Like many researchers, we reemphasize that movement skill development can frequently be viewed as problems to be solved. Due to the lack of empirical studies done on the problem solving behavior of mentally retarded persons in movement situations, we first generated a theoretical framework from which the problem solving behavior of the mentally handicapped could be studied.

Due to the documented inability of the mentally retarded to access and use knowledge to solve problems, we focussed, in the two studies reported, on the ability of mildly and moderately mentally handicapped to use information to solve movement problems. In Experiment 1, eight males and eight females without neuromuscular disorders, having IQs between 45 and 70 were randomly selected. The tasks used involved returning table-tennis balls with a bat. A ball projection machine, hidden from the player's view, was used to project the balls at four different targets on a table enlarged for the purpose of this study. During the experimental condition, the players were told, 3.5 s prior to the projection of each ball, a number representing the future landing target area of the ball on the table. No such information was available during

the control condition. The dependent variables used were the position of the players when they first saw the ball, the type of stroke used (forehand or backhand), and the number of balls hit. All but one subject used the information given during the experimental condition to select a position closer to the future path of the ball. Comparisons of the data across conditions indicated that most players changed the type of stroke used to return the ball. The solutions adopted were personal and appear to guided by metacognitive knowledge about the strokes. Only the high IQ group (60< IQ <70) hit more balls during the experimental condition. We suggest that it is only when movement consistency has developed that the players can benefit from the information given about the future landing location of the ball to hit more balls.

In Experiment 2, eight males and eight females were randomly selected according to the criteria discussed earlier. None of the subjects was involved in Experiment 1. The equipment used was the same as for Experiment 1 excepted that a "Barbie" doll figure, holding the posture of a table-tennis player, was rotating above the ball projection machine during the experimental condition. Barbie was fixed during the control situation. During both conditions, the players were asked to guess where the ball would land on the table. On the average, the players were better predictors during the experimental condition. Furthermore they selected, on the average, a location closer to the future landing area of the ball during the experimental condition, replicating, in a different movement situation, the results of Experiment 1. However, they did not hit more balls; the processing demands required for signal detection and guessing were too high, hence, impairing the tracking of the ball, the response selection and execution, as well as the processing of feedback. The players were also blocked according to the accuracy of their predictions during the experimental condition. A high association was found between accuracy of predictions and selection of a better location to return the ball. This underscores the importance of knowledge to the solution of movement problems. Finally, no strong evidence was found that the players changed the type of stroke used.

In conclusion, the results stress that mildly and moderately mentally handicapped adolescents can respond flexibly and adaptively to different movement situations. They are able to generate different solutions adapted to different movement problems. These solutions require a conscious assessment of the movement situation, the knowledge that different subroutines are available (metacognitive knowledge), as well as the ability to orchestrate the subroutines available (metacognitive skills).

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LIST OF ABBREVIATIONS

Abbreviation	Description
ANOVA	Analysis of variance.
BP	Bad Predictor.
C	Centre.
cm	centimeter.
del_p	The v_p measure proposed by Hildebrand, Lang, and Rosenthal (1976, 1977a, 1977b).
ESN	Educationally sub-normal.
F_{cons}	Conservative F test (the second step of the Greenhouse and Geisser [1959] procedure).
F_{eps}	An adjusted F test done by modifying the degrees of freedom by a value called epsilon (The third step of the Greenhouse and Geisser [1959] procedure).
F_{sat}	An adjusted F test done by modifying the degrees of freedom, as obtained from the Satterthwaite (1946) approach.

Abbreviation	Description
GP	Good predictors.
HSD	Honestly significant differences.
IQ	Intelligence quotient.
L	Left.
LC	Left-centre.
m	meter.
R	Right.
RC	Right-centre.
R^2	Squared multiple corelation coefficient.
s	Second.
S-R	Stimulus-response.
VBP	Very bad predictors.
VGP	Very good predictors.
WISC-R	Weschler Intelligence Scale for Children Revised edition.

CHAPTER 1

Introduction

Proficiency in motor skill is an important aspect of the development of all people. Some people are less proficient in motor skills than others; one such group is the mentally retarded. Mentally handicapped individuals demonstrate generally poorer gross-motor and fine-motor proficiency than their non-retarded peers (Bruininks, 1974; Linford, Jeanneraud, Karlsson, Witt, & Linford, 1971; Noble, 1975; Rarick, 1973; Wall, 1976; Watkinson & Wall, 1982).

Even though the inferior motor performance of the mentally retarded had been noticed for a number of years, attempts to explain their delayed motor development were made only relatively recently. As stressed by Hoover and Wade (1985), early movement skill development research on mental retardation was relatively atheoretical. The movement skill development area in general focussed more on products rather than process during the first half of this century (Hoover & Wade, 1985; Stelmach, 1976). This could partly be explained by the overwhelming influence of stimulus-response (S-R) associationism theory in experimental psychology (Stelmach, 1976). The S-R psychological view of motor learning was based on the chaining of responses, therefore rejecting unobservable mentalist constructs (or process) as a plausible explanation of movement skill acquisition. During the second half of this century, the monopoly of the behaviorist school has been weakened in psychology. This paradigm shift (Kuhn, 1970; Lachman, Lachman, & Butterfield, 1979) has had a considerable influence on movement skill development research in general. Nowadays, the emphasis has shifted to the process as well as the non-directly observable products of learning that underlies human movement skill development (for contemporary examples see Keogh & Sugden, 1985; Wall, McClements, Bouffard, Findlay, & Taylor, 1985).

Stemming from this paradigm shift, a renewed emphasis on control process rather than structural features (Atkinson & Shiffrin, 1968) to explain mental retardation has been observed (for reviews see Brooks, Sperber, & McCauley, 1984; Ellis, 1979; Sternberg, 1982, 1985). Recently the importance of problem solving difficulties that mentally handicapped people have in novel situations has been documented (e.g., see Borkowski & Büchel, 1983; Borkowski & Cavanaugh, 1979; Bray, 1979; Brown, 1974; Campione & Brown, 1977, 1978; Campione, Brown, & Ferrara, 1982; Sternberg, 1985). However, even though a number of theories about action have stressed the importance of problem solving in the acquisition of movement skills (e.g., see Adams, 1976;

Fitts & Posner, 1967; Gentile, 1972; Glencross, 1978; Keogh & Sugden, 1985; Newell & Barclay, 1982; Schmidt, 1975, 1976; Wall et al., 1985) to this writer's knowledge, no studies have been completed on this topic with the mentally retarded population.

Cognitive learning studies with mentally handicapped people show that they have great difficulty in using the knowledge they have acquired in problem solving situations. Mentally handicapped individuals often lack the ability to access their past knowledge in new contexts; that is they often "weld" their past knowledge to specific situations (Campione et al., 1982), which suggest that they have difficulty integrating existing knowledge in problem solving situations. Inasmuch as most theories of action stress the importance of problem solving in movement skill acquisition (Adams, 1976; Fitts & Posner, 1967; Gentile, 1972, Glencross, 1978; Keogh & Sugden, 1985; Newell & Barclay 1982; Schmidt, 1975, 1976; Wall et al., 1985) it seemed important to study the relationship between knowledge and knowledge use in a cognitive-motor learning context.

Recently a knowledge-based approach to movement skill development that specifically addresses the use of knowledge in planning and problem solving situations has been outlined by Wall et al. (1985). They differentiate between declarative, procedural, and affective knowledge and discuss how these categories of knowledge are related to skill acquisition. Briefly, declarative knowledge is the representation that people have about something, and includes the representation of facts as well as the knowledge that a person has about his own "cognitive resources and the compatibility between himself as a learner and the learning situation" (Brown & Campione, 1981, p. 521). Procedural knowledge refers to knowledge about how to do something. It includes skills, rules, algorithms, heuristics, and procedures. Regulatory cognitive activities like checking, monitoring, testing, planning, revising, and evaluating have been referred to as executive functions by Brown & Campione (1981) or metacognitive skills by Wall et al. (1985). Finally, affective knowledge is the third major type of knowledge about action that develop. Each time people perform, they attach subjective feelings to their actions within any of these situations. Wall et al. (1985) argue that the solution of movement problems depends largely upon the availability and accessibility of these three major categories of knowledge.

The lack of spontaneous use by mentally retarded people of information available to them has been attributed to a number of factors. Some researchers like Chi and Rees (1983) would argue that a deficient knowledge-base explains their inferior performance on cognitive talks, while other scientists like Brown and her colleagues (Brown, 1974; Brown & Campione, 1981; Campione & Brown, 1977, 1978; Campione et al., 1982), although they recognize the importance of the knowledge-base, stress the importance of strategies, metacognitive knowledge and skills to explain the differences. The importance of motivation (e.g., see Gibson, 1980; Griffin & Keogh, 1981, 1982; Haywood & Switzky, 1985; Hoffman & Weiner, 1978; Weisz, 1979; Zigler, 1969) and personality factors (e.g., see Zigler & Cascione, 1984) have been stressed to explain the frequent inferior performance of mentally retarded people in problem solving situations. Mentally handicapped people frequently develop the belief that, due to a lack of ability, failure is insurmontable (Gibson, 1980; Hoffman & Weiner, 1978; Weisz, 1979). Lacking trust in their own capabilities, mentally retarded people may consequently believe that their own efforts are useless. Hence, they may avoid becoming involved in new experiences that might alter their present beliefs. Without testing their beliefs, they would remain in a stable state of helplessness.

According to Griffin and Keogh (1981, 1982), the perception of a lack of ability affects movement confidence. In their view, movement confidence influences the decision of "whether to become involved or not ... how the individual will do, ... [and]

whether to continue involvement now and in the future" (Griffin & Keogh, 1982, p. 214). Confident persons are more likely to seek and choose participation than non-confident individuals. For non-confident persons it is "less likely that participation performance and behavior will be satisfying" (Griffin & Keogh, 1982, p. 214).

Perceived lack of ability, and low movement confidence, could be related to the lifestyle of mentally retarded people. It is well documented that their lifestyle is frequently different from that of their non-retarded peers (for a review, see Watkinson & Wall, 1982). They are frequently listless and inactive; most of their leisure activities are passive and solitary in nature (Cheseldine & Jeffree, 1981; Watkinson & Wall, 1982). Unfortunately this lifestyle is likely to lead to an impoverished coping repertoire.

Research on skill acquisition has underscored the key role of practice in developing a stable and consistent kinematic response (Marteniuk & Romanow, 1983). The work of Tyldesley (1980) and Tyldesley and Whiting (1975) demonstrates the importance of practice and how expert table-tennis performers are much more consistent in their responses than novices. One of the characteristics of mentally handicapped individuals is that they rarely develop such consistency of movement. Thus a fundamental question arises: given relatively unskilled motor responses, can mentally retarded subjects use cognitive knowledge relative to where a ball will land in a racquet sport situation to select a better position to return the ball. Furthermore, given that motor skill proficiency is usually found to be positively correlated with level of intelligence (Rarick, 1973; Rarick, Widdop, & Broadhead, 1970), do higher-functioning mentally retarded subjects make use of their cognitive knowledge better than their less intelligent counterparts? To investigate this question, subjects were included at two levels of intelligence; namely, 45 to 59 and 60 to 70. Futhermore, subjects with IQ's below 45 were not included in this study because they frequently have concomitant neuromuscular and/or behavior difficulties which would not allow them to meet the criteria for inclusion in this study. Due to problems associated with matching (Baumeister, 1967, 1984; Maguire & Haig, 1976), a non-retarded group was deemed unnecessary at this time. Finally, sex was included as a factor in the studies to be reported because it frequently accounts for a portion of the variance in motor performance observed (Haywood, 1986; Keogh & Sugden, 1985).

For a number of years, researchers in mental retardation and motor development have been concerned with the type of task and dependent variables to be used in research studies. There are certainly good reasons for using ecologically valid tasks (Baumeister, 1984; Brooks & Baumeister, 1977) including representational, motivational, and the age-appropriateness of the skill to be studied. However, the use of such tasks makes accurate measurement often more difficult and may be more time consuming than some laboratory tasks. However it was decided to use a relatively ecologically valid task in this study in an attempt to motivate the subjects and acquire information in a task which has relevance to these adolescents in recreational settings. Thus, the task that was selected was returning table-tennis balls shots in a relatively normal table-tennis setting. A table-tennis ball projection machine allowed for measureable control of the stimulus presented and videotape recordings facilitated accurate measurement of the player's behaviors for data-analysis purposes.

The above rationale resulted in the following questions:

1. Can mentally retarded subjects use cognitive information about where a ball will land to select a more appropriate response position to return the ball in a table-tennis setting?

2. If they can use such information, are different stroke strategies used to return the ball?

3. Does prior knowledge of where a ball will land

4. Can they use a visual model, representing a table-tennis player, to predict where a ball will land prior to its being projected at them?

5. Does level of intelligence and sex of the subject affect all of the above questions?

People are often confronted by novel situations or problems they must solve but for which they have not necessarily learned a specific solution. And yet they are often able to cope with these situations, sometimes with immediate success, other times after several trials. Some people are less successful in problem solving than others; one such group is the mentally retarded. They frequently are unable to use solutions which are part of their repertoire or they have difficulty in generating a solution that they have not as yet acquired (Campione et al., 1982). In fact, this difficulty in solving problems, or to learn in the absence of direct or complete instruction (Resnick & Glaser, 1976), is a key characteristic of mentally retarded people. Quite simply, they have difficulty making inferences; to go "beyond the information given" (Bruner, 1973a).

Movement situations often contain problems that must be solved. In many daily-life events involving a person and the surrounding environment, the person must produce movements to solve motor problems. The interplay of the performer and the environment creates a problem to be solved by a movement task (Keogh & Sugden, 1985).

Research on skill development has focussed mainly and the action level. Newell (1978) makes the following distinctions between movement and action:

> Movements generally refer to the motion of the body and limbs produced as a consequence of the spatial and temporal pattern of muscular contractions. Body movement can also occur, however, independently of the performer's efforts through the creation of an imbalance of forces acting externally on the body. Regardless of the cause of movement, the spatial and temporal pattern can be described rather precisely through kinematics. In contrast, space and time are not usually relevant criteria for actions. Rather, actions are identified by the goal to which are directed (e.g., open the door, lift the weight, etc.) or by specifying certain criteria to which the performer complies in what he does (e.g., walking, hopping, etc.). As a consequence, a variety of potential movements may be _generated_ to complete any one act (Bernstein, 1967), and, by the same token, a variety of movements may be _identified_ as a particular act. (p. 42)

Our major premise is that the execution of actions also can frequently be conceived as problem solving.

already available, sometimes not. In the last case, generation of an appropriate solution is required.

This review will be limited to the execution of action by mildly and moderately retarded individuals in action situations. As will become evident in this chapter, studies related to the execution of action by mentally retarded persons are relatively lacking. To this writer's knowledge none of them deal with ecologically valid tasks; tasks that are most likely to appear relevant to mentally handicapped people.

The following aspects of problem solving in action situations will be discussed. First, an attempt to define problem solving is outlined. Second, different theories that view movement skill development as the solution of movement problems will be reviewed. Third, factors responsible for the inferior performance of mentally retarded people on problem solving tasks will be discussed. When available, this review will include results of research completed with mildly and moderate mentally handicapped individuals. Finally, the last section of this chapter will outline the main objectives of this dissertation.

What is Problem Solving?

The learning of skills and actions have been conceived by many theorists of movement skill development as problem solving (e.g., see Adams, 1976, 1967; Gentile, 1972; Gentile & Nacson, 1977; Hughes & Stelmach, 1986; Singer, 1978; Singer & Gerson, 1979; Wall et al., 1985; Whiting & den Brinker, 1982). Problem solving can be partitioned into a number of inter-related steps. These steps include the definition or representation of the problem, the construction of an appropriate plan that would guide plan execution and finally, the evaluation of one's progress toward the goal (Pea, 1982).

Problem Representation

Representing a problem requires that the problem solver understand and define the goal state, define the initial state, note the difference between the initial state and the goal state, and know and understand the constraints on planning (Pea, 1982).

An accurate representation of the problem is essential to the planning process; without it, an appropriate solution cannot be found. For example, if a person playing table-tennis does not understand where he should return the ball (goal state), does not know his position in relation to the ball (initial state), does not note the difference between the initial conditions and the desired goal, does not know that he must return the ball, with the bat, according to the rules of table-tennis (constraints on planning), then the possibility of finding a solution to the movement

Plan Construction

This step is essential to "eliminate the differences between the problem and the goal state" (Pea 1982, p. 6). When an appropriate representation of the problem has been created, the planner can ask whether a method for solving the problem is known (Polya, 1945.) This may economize plan construction. If no plan appears to be available, then the person will have to construct an appropriate plan.

Pea (1982) argues that the notion of a strict hierarchical, top-down, process view of planning has met with disfavour during recent years. His view of plan construction is represented by the following points: (a) The formulation of an effective plan requires plan simulation in which alternative plans can be evaluated by the planner. (b) Simulating a plan is a complex process which requires knowledge about effects of a plan once it is executed. (c) During plan simulation or plan execution one may be required to redefine the initial goal state according to the feedback received. (d) Plan construction is an iterative process that includes a sequential cycling of initial proposal, simulations, evaluations and revisions until a suitable plan emerges that will reach the intended goal state. (e) Plan construction is an iterative multi-decision process that requires level.

Plan Execution

Plan execution may range from easy to difficult. Moving a chess piece from position A to B is usually an easy task. However, in many sport situations the time constraints (e.g., returning a smash in volleyball) or the complexity of the movement sequence (e.g., gymnastic sequence) is so great that plan execution is frequently a difficult matter. Moreover, although a plan can be correctly executed, the performer may fail to solve the movement problem because he has selected the wrong plan (Schmidt, 1982a, 1982b). Finally, plan execution may be difficult or impossible in certain cases of movement disorders (e.g., cerebral palsy, apraxia, etc.).

Evaluation of Progress

Progress evaluation can occur during all of the above stages, as well as after the plan has been executed. As Wessells (1982) notes, the problem solver must:

> Evaluate one's progress toward the goal. This requires making decisions about whether the problem has been solved, whether progress toward the goal has occurred, and whether the current strategy [plan] should be executed further or should be abandoned. These

type of strategy [plan] that has been chosen. (pp. 323-324)

Although all four steps are involved in problem solving, they are not necessarily executed in the strict linear order described above. The planning of a solution may lead to a better definition of the problem. A plan that is difficult or impossible to execute might be abandoned in favor of a more appropriate one; hence, the early steps of the problem solving process might be repeated a number of times (Wessells, 1982).

As noted by Das (1980), "foresight, planning, and the ability to reflect on one's own errors of achievements are, in the broadest term, manifestations of consciousness" (p.144). The capacity to evaluate progress is essential to movement skill development because we cannot control what we cannot in principle evaluate (MacKay, 1985).

In summary, problem solving can be partitioned into a number of inter-related steps. These steps include the definition or representation of the problem, the construction of an appropriate plan that would guide plan execution and, finally, the evaluation of one's progress toward the goal. Interaction occurs among all of these steps in the planning process.

Bruner's Theory

To understand Bruner's theorizing about the development of skilled actions it is useful to first discuss his view of intentionality. Skilled behavior is thought to be preceded by an intention that directs the execution of an action and provides a criterion for terminating an act. Bruner (1981) contends that an individual is intending when he or she chooses among alternative methods and/or routes to reach the intended goal state. Furthermore, intending is also characterized by the correction of the means available until the process reaches the desired goal. Intention is not only responsible for the initiation of an act but is also "signaled to related sensory and coordination systems" (Bruner, 1973b, p. 2) before the execution of an act. This broadcasting of information prior to action (feedforward) prepares the motor system in an adaptive way so that the task demands can be met; it is a crucial element of an act.

A second important point in Bruner's (1973b) theorizing is that, to solve a movement problem, the infant has at its disposal basic constituents that are instinctively given. With development, these constituents of the genetically-endowed motor pattern mature and become part of the action units available for solving voluntary action problems. Initially, an intention specifies a goal but contains few directions concerning means. The problem becomes which constituents or action units should be used, and in what order, to reach the goal. The appropriate use of these subroutines at the right time is what must be learned.

Initially, a clumsily organized sequence of constituents occurs following the arousal of an intention. Different sources of information, present in the learning situation, help to solve the movement problem. Exteroceptive, proprioceptive, and interoceptive feedback combined with knowledge of results, knowledge of performance, and reinforcement all contribute, if available, to the solution of a given movement problem. Through practice, these sources of information refine the sequence of constituents until an appropriate action is ultimately learned.

The organized pattern of action that emerges through exercise leads to the formation of modules: "the act gradually becomes less variable in latency and in execution time and more economical in expenditure of energy" (Bruner, 1973b, p. 4). As we will see later, these modules are similar to Norman and Shallice's (1986) "horizontal threads". Moduralized acts require less central processing capacity for their execution; hence, the available capacity can be used for other cognitive activities. The reduction in attention makes possible the attack of more complex problems; gradually more refined movement sequences emerge to solve more difficult movement problems.

Bruner (1972, 1973b) also underscores the importance of play in motor development. Although play is difficult to define, it has some typical features: the behavior is voluntary, the relation between the activity and the goal is not obvious to an external observer and, it is frequently characterized by repetition and/or repetition with variation (Millar, 1983). This intricate combination of intentionality and practice found in play contributes to the gradual refinement of the movement sequences involved in the play process.

Modeling is another ingredient that plays a crucial role in the acquisition of movement skills. Modeling helps to generate new intentions by demonstrating what is possible in play situations and, possibly, encourages children to consider other possibilities. Modeling in play situations does not only demonstrate specific action or skills but it also encourages children to go "beyond the information given" (Bruner, 1973a); that is, it facilitates creative behavior in the play environment (Bruner, 1972).

In summary, Bruner argues that the infant has received, through its genetic heritage, a set of subroutines that can be used to solve movement problems. The solution of movement problems consists in finding what subroutines should be used, and their order of execution, in order to reach the goal. Intention is responsible for the activation of subroutines that are, during the first few trials, clumsily organized to reach the desired goal. Feedback available during the movement learning situation shapes the movement pattern, reducing gradually the attentional capacity required. As new capacity becomes available, further task analysis is made possible and former movement sequences can be organized into higher order units. Play or practice is essential to reduce the attentional capacity required for the task, while modeling facilitates creative behavior in the play environment.

Schmidt's Schema Theory

In his schema theory, Schmidt (1975, 1976) conceptualized movement skill acquisition as problems to be solved. Schmidt's theory is reminiscent of Pea's (1982) views on planning and problem solving discussed earlier. In his theory, Schmidt (1975, 1976) underscores the importance of the initial conditions and the desired outcome. This could be viewed as the problem representation stage of the problem solving process. The performer, according to Schmidt (1975, 1976), must also determine the response specifications parameters that determine how the generalized motor program is to be carried out (Schmidt, 1976). This process is similar to the plan construction stage outlined by Pea (1982). Further, "when all the parameters have been selected for the response, they are applied to the motor program and the response is initiated and carried out" (Schmidt, 1982b, p. 229). This, of course, is the plan execution stage. Finally a movement has some sensory consequences (feedback) associated with it. This feedback, combined with other sources of information stored in memory can then be used to reflect upon past performance, evaluate progress, abstract rules (schemas), and make decisions about what should be done next. The final step is similar to the progress evaluation stage described by Pea (1982) and Wessells (1982).

In summary, Schmidt (1975, 1976) underscores that movement skill acquisition can be viewed as problems to be solved. In the next few pages, more details are provided about his theory.

The theory (Schmidt, 1975) postulates two separate states of memory: one for recall and one for recognition. Basically, the recall schema is responsible for determining the desired response, while the recognition schema is responsible for the evaluation of response-produced feedback.

Schmidt, (1975, 1976) also assumes that generalized motor programs are responsible for motor control within a given class of movements. For movements of short duration (less than 200 msec) the response is controlled entirely by the generalized motor program, hence, recognition memory has no role during the execution of this type of movement. For long duration movements (more than 200 msec), the movement can be controlled by both the recall and the recognition schemas.

The recall schema develops over time. It is the relationship among the initial conditions, the response specifications and the response outcome. By initial conditions, Schmidt refers to the information about the preresponse state of the subject's musculature and of the environment prior to the initiation of the action. The response specifications refer to the parameters selected to run the generalized motor program; whereas, the response outcome refers to the success of the response in relation to the outcome that was originally intended. Hence, the recall schema includes information gathered from all three aspects of action outlined above. In contrast, the recognition schema is abstracted from the relations between the initial conditions, the response outcome, and the sensory consequences of the movement.

When an action is executed, four kinds of information are stored for a brief period of time: the initial conditions, the response specifications, the

Schmidt (1982b) notes, this brief storage allows the formation of motor schemas:

> Over the course of experience in running a given program, after each response the subject briefly stores these four pieces of information and abstracts the relationships among them. The word "abstract" is important, and by it I mean that one generates (or updates) a rule that describes the relationship between these stored pieces of information. (p. 227)

After a brief period of storage the four pieces of information are "thrown away" but the generalized or updated rule is kept (Schmidt, 1982b). Schmidt contends that the elimination of this data tends to solve the storage problem (Schmidt, 1975, 1976, 1977, 1982b; Shapiro & Schmidt, 1982).

The recall and recognition schema rules play important roles in planning a response and predicting the consequences of that response. In an action situation, the recall schema allows a person to generate the response parameters that are required to run the generalized motor program (Schmidt, 1982b). The recognition schema is used to generate "the expected sensory consequences that will occur if he produces this outcome" (Schmidt, 1982b, p. 231). Hence, the experiences that a person stores and the active processing of that information.

Schemas have been viewed from different perspectives. In a recent discussion of the development of knowledge about action, Newell and Barclay (1982) note that:

> The major distinction between current interpretations of schema for action rests very much on the level of detail seen to exist in the structure. The cognitive science approach has focussed principally on the representation of the act itself (e.g., Rumelhart and Ortony, 1977), without recourse to the details of movement *per se*. In contrast, the motor skill learning orientation gives principal emphasis in schema representation to details of the response specifications (e.g., Schmidt, 1975), such as the kinematic and kinetic features of the movement. (pp. 180-181)

The authors stressed that the motor skill approach "is much narrower than it should be" (Newell & Barclay, 1982, p. 181) and that a link is needed between these two orientations.

Finally some control problems are not discussed by Schmidt. Presumably numerous schemas and generalized efficient execution of an action, relevant schemas should be activated and irrelevant ones should not interfere. The selection of appropriate schemas, their accessibility, and monitoring of performance should also be included in a more comprehensive theory of movement-skill development and, hence, the solution of movement problems. Norman and Shallice's (1980, 1986) theory of skilled actions represents a step in this direction.

Norman and Shallice's Theory of Action

Norman and Shallice's (1980, 1986) theory attempts to explain why certain actions can be executed automatically, without conscious control, and why they can also be modulated by a supervisory attentional mechanism when necessary. Although they use a terminology different from Bruner (1973b), their theory includes concepts that are similar to those he has used. Norman and Shallice (1980, 1986) propose that actions are controlled by sets of schemas that become progressively organized for a specific purpose over time. Well-learned actions usually do not require deliberate attentional control; they can be controlled by "horizontal threads". Horizontal threads are sets of processing units and knowledge schemas linked together in order to control action. When a horizontal thread is activated by appropriate stimuli, an action sequence is proper movements.

For well-learned, habitual tasks, a horizontal thread can control the sequence of movements in an action without deliberate attentional control. This is possible because a single rule governs schema selection: its activation level must exceed a specified threshold. Thus, if the appropriate activation exists, then a horizontal thread solely controls an action sequence; this represents an example of automatic control of action.

Once selected, a schema "continues to operate, unless actively switched off, until it has satisfied its goal or completed its operations, or until it is blocked when some resource or information is either lacking or is being utilized by some more highly activated schema" (Norman & Shallice, 1986, p. 4).

Norman and Shallice identify four major influences that activate schemas: those influences that satisfy trigger conditions, those from other selected schemas and "contention scheduling", and those from higher level "vertical thread" influences. An examination of each of these influences follows.

<u>Activation through trigger conditions</u>. Schemas are processors that recognize the degree of fit in a given situation. The trigger conditions within a schema specify when a schema should be used, "thus allowing for

existing conditions match the trigger specifications determines the amount of activation contributed by this factor" (Norman & Shallice, 1986).

Activation from selection of other schemas. The numerous schemas stored in human long-term memory have an hierarchical structure (Rumelhart, 1980; Rumelhart & Ortony, 1977). In well learned action situations, the source schema, that is, the highest level schema associated with a given situation, activates other component schemas related to it. Each component schema can then, in turn, act as a source schema for other component schemas.

Activation by contention scheduling. Some actions can be executed simultaneously, without conflict, while others cannot. Contention scheduling is proposed to resolve such conflict. Contention scheduling is a mechanism that resolves competition for selection through "lateral activation and inhibition among activated schemas" (Norman & Shallice, 1986, p. 5). Contention scheduling prevents:

> Competitive use of common or related structures, and negotiating cooperative, shared use of common structures or operations when that is possible. There are two basic principles of the contention scheduling mechanism: first, the sets of potential source

determination of their activation value; second, the selection takes place on the basis of activation value alone - a schema is selected whenever its activation exceeds the threshold that can be specific to the schema, and could become lower with the use of the schema. (Norman & Shallice, 1986, p. 5)

Activation through vertical threads. The most important activational influence upon schema, for the purpose of this dissertation, comes through "vertical threads". They operate through "the application of extra activation and inhibition to schemas in order to bias their selection by the contention scheduling mechanisms" (Norman & Shallice, 1986, p. 6).

Two major sources of activation come from the supervisory attentional system and motivational factors. Norman and Shallice (1986) propose that deliberate attentional resources are required when the task (a) involves planning, decision-making, or components of troubleshooting, (b) is ill-learned or contains novel sequences of actions, (c) is judged to be dangerous or technically difficult, or (d) requires overcoming a strong habitual response or existing temptation.

Motivational factors can also influence other schemas through vertical thread activation. In their view motivation is a relatively slow-acting system, working primarily to bias the operation of the horizontal thread structures toward the long term goals of the organism by activating source schemas" (Norman & Shallice, 1986, p. 7).

The exact nature of the supervisory attentional system and motivation is left rather unspecified by Norman and Shallice. In a recent paper Wall et al. (1985) suggest that Norman and Shallice's deliberate attentional control might better be termed the conscious control of action. For them, consciousness in the control of action depends upon access to declarative, procedural, and affective knowledge. It is to a discussion of these factors that we now turn.

Structural Features and Control Processes

Brown and her associates (Brown, 1974; Campione & Brown, 1977, 1978), following the work of Atkinson and Shiffrin (1968) made a distinction between "the structural features of an information processing system and its associated control processes as a way of classing intelligence-related differences" (Campione & Brown, 1978, p. 282). By structural features they refer to "basic, invariant, unmodifiable components of the system ... [that] are stable and untrainable" (Campione & Brown, 1978, p. 282). They are akin to the hardware of a computer. Control processes are seen as optional routines and strategies that an individual brings to bear on cognitive tasks. Any control process can be used, or not used, at the choice of the subject. They are trainable and modifiable (Campione & Brown, 1978).

An issue in the field of mental retardation during the last two decades has been whether information processing deficits were the result of inefficient use of control processes or a consequence of structural limitations (Campione & Brown, 1977). The distinction between control and structural failures is the same as that between production and mediation deficiencies (Flavell, 1970). If the deficiency responds to training, then control processes (production deficiency) can account for a portion of the variance in the memory performance. However, it is much more difficult to infer that structural features (mediation deficiency) explain inferior performance because "a failure of training may result from inappropriately designed training procedures" (Campione & Brown, 1977, p. 369). Strictly speaking, the inference of a mediation deficiency is only possible when all the training prodecures have been exhausted (Campione & Brown, 1977).

Although structural features and control processes can both explain partly the inferior memory performance of mentally retarded people, relatively recent studies done with experts and beginners (e.g., Chase & Simon, 1973; Chi, 1978) emphasized the possibility that the apparent processing deficit of mentally retarded people may be due to differences in non-processing limitations, such as the content of the long-term memory store. Evidence that support each of these positions will be presented in the next few pages.

Declarative, Procedural, and Affective Knowledge

It has been known for a long time that what a person knows determines, to a large extent, the problems that a person can solve. In this section, the role of different types of knowledge, their accessibility, and the importance of motivational factors is underscored. The importance of consciousness in the solution of movement problems is also stressed. Relevant literature coming from the field of mental retardation will be mentioned when available.

What is Knowledge?

To define knowledge is not an easy matter. However, for our purpose, knowledge is defined as the representations that people have in memory as a result of maturation or experience. Furthermore, it is useful to differentiate between declarative and procedural knowledge. Briefly, declarative knowledge is the representation that people have about something while procedural knowledge is the representation that people have about how to do something.

Declarative knowledge includes the representation of facts. An important type of declarative knowledge has been labelled metacognitive knowledge. This "cluster is roughly concerned with a person's knowledge about his own cognitive resources and the compatibility between himself as a learner and the learning situation" (Brown & Campione, 1981, p. 521).

Procedural knowledge includes skills, rules, algorithms, heuristics, procedures, and plans. These representations are frequently involved during the regulation of cognitive activities such as checking, monitoring, testing, planning, revising, and evaluating. These cognitive activities have been referred to as "executive functions" (Brown & Campione, 1981, p. 521) or "metacognitive skills" (Wall et al., 1985). They are concerned primarily with self-regulatory mechanisms during an ongoing attempt to learn or solve problem" (Brown & Campione, 1981, p. 521).

Another particular cluster of procedural knowledge includes strategies. A strategy is a set of decisions that determines what sequences of action to perform in order to insure certain forms of outcome and to insure against certain others (Bruner, Goodnow, & Austin, 1956; Chi, 1978). Some strategies like planning, checking, monitoring, testing, revising, and evaluating are metacognitive skills. Some others, like rehearsing, chunking, looking at certain features of the environment instead of others, are not part of the metacognitive cluster.

The Knowledge Base

The importance of knowledge as a determinant of human capability in problem solving has been recognized for a long time.

> It has been clear that what we know ... determines what and how we perceive, or speak, or imagine, or problem-solve, or predict; it is now becoming equally clear that all knowledge ... shape(s) what and how we learn and remember. (Flavell, 1971, p. 273)

In a benchmark study by Chase and Simon (1973), the importance of prior knowledge to memory problems was recognized. Three subjects were used: a master chess player, a level A player, and a novice. The subjects involved were given 5 s to view a chess board organized in actual game positions and then asked to recall these positions. On this task the master chess player was better than the A level player who, in turn, was better than the novice. On tests requiring recall of randomly placed pieces, all players performed equally well. Chi and Koeske (1983) note that "this ability has been related to the size of their knowledge base for chess patterns as well as the size of each pattern (Chase & Simon, 1973). That is, the expert has many more patterns or chunks that he or she recognizes, and the chunks also contain more pieces" (p. 29).

In a developmental study, Chi (1978) compared the recall performance of six children (mean age = 10.5 years) who played tournament chess and adults who knew little about chess on a digit span test, and a recall for chess position test. For recall of digits, the usual advantage of adults was found. However, children had a much better recall of chess position than adults replicating, in a sense, the Chase and Simon (1973) study. Chi (1978) suggested that "memory performance in developmental studies reflects, to a large extent, the influence of knowledge in a specific content area _rather than strategies per se_ [italics added]" (p. 82).

Similar results were obtained by Allard, Graham, and Paarsalu (1980) who investigated the recall ability of skilled and novice basketball players. They found that the skilled basketball players had better recall of structured offensive and defensive situations than novice players. However, in the unstructured setting, there was no difference in recall performance between the groups.

Jones and Miles (1978) examined the ability of tennis players (advanced versus beginners) to predict where the ball will land on the court after a serve. Film sequences, that were shown to both groups, were occluded either 1/24 s prior to ball-racquet impact and 1/8 or 1/3 s after impact. The design included repeated measures for all occlusion conditions. Both groups performed equally well when vision was occluded 1/3 s after impact; however, with occlusion prior to impact or 1/8 s after impact, advanced players were better at predicting ball landing position than were beginners.

Newell and Barclay (1982) report evidence on the possible role that existing knowledge plays in movement skill acquisition. They describe an early experiment done by Judd (1908) with fifth and sixth grade boys who threw darts at a target placed at different depths under water. One group was given a full theoretical explanation of the laws of refraction. The other group received no theoretical explanation of these laws. No difference between the groups was observed when the target was 12 inches (30 cm) under the water. However, when the target was 4 inches (10 cm) under the water, the group who received instruction about the refraction laws were superior to the control group. A more recent replication of this study (Hendrickson & Schroeder, 1941) found immediate performance benefits from a knowledge of the refraction laws. "This suggests an intricate relationship between knowing and doing" (Newell & Barclay, 1982, p. 198).

In a recent study Kirk (1981) investigated the acquisition of a perceptual-motor skill (copying of uppercase and lowercase letters) with kindergarten children between the ages of 4.8 and 5.9 years. Three ways of imparting rules were examined: demonstration, verbal description, and combined demonstration verbal description. Three rules governed the starting position: draw verticals from top-to-bottom, draw horizontals from left to right, and thread, that is draw with a continuous line. The usefulness of these methods was compared with that of copying without instructions. The analysis of post-test scores revealed that the performance of all instructed groups was better than that of the control group that simply copied. An analysis of gains from pre-test to post-test revealed that all groups made significant improvements on instructed letters. However, only instructed groups showed significant gains on non-instructed letters. The improvement in performance of instructed groups over the control group on non-instructed letters was due, according to the author, to the availability of a plan of action that had already been given to instructed groups. Therefore instructed children did not have to discover a plan of action and could then focus their attention on the coordination of movements required to execute the plan.

The availability of knowledge, its organization as well as the quality of the representation of the problem are essential to problem solving. Glaser (1984) contends that:

> The relation between the structure of the knowledge base and problem solving process is mediated through the quality of the

> representation of the problem. We define a problem representation as a cognitive structure corresponding to a problem that is constructed by a solver on the basis of domain-related knowledge and its organization. At the initial stage of problem analysis the problem solver attempts to "understand" the problem by constructing an initial problem representation. The quality completeness and coherence of this internal representation determine the efficiency and accuracy of further thinking. And these characteristics of the problem representation are determined by the knowledge available to the problem solver and the way the knowledge is organized. (p. 98)

Metacognitive Knowledge and Skills

The term metacognition is certainly a fuzzy concept that has been controversial over the years (Brown & Campione, 1981). However theorists like Becker (1975), Bobrow (1975), and Bobrow and Norman (1975), "have come to agree that an important requirement of any functioning system is that it include the _capacity for self-awareness, or accurate knowledge and understanding of its own weakness and properties [italics added]_" (Campione et al., 198[illegible] 433).

Concious metacognitive knowledge is believed to be central to an understanding of human flexibility.

> If the child is aware of what is needed to perform effectively then that child can take steps to meet demands of a learning situation more adequately. If, however, the child is not aware of his or her own limitations as a learner or of the complexity of the task at hand, then he or she can hardly be expected to take preventive actions in order to anticipate or recover from problems. (Campione et al., 1982, p. 433)

Brown (1977) suggested that in problem solving situations, efficient metacognitive control requires that learners: (a) recognize and predict their capacity limitations, (b) understand the heuristic problem solving routines that they have available and how they would be effective in a given situation or task, (c) identify the demands of the task at hand and characterize it in relation to the knowledge they have available, (d) select and schedule suitable problem solving strategies, (e) monitor and control the operation of the strategies that are used, and (f) evaluate the success or failure of the entire problem solving operation in relation to the demands of the task.

Research done during the last decade has shown that such self-regulatory behavior increases with age and experience (Brown, 1975, 1977, 1978; Flavell, 1976; Flavell & Wellman, 1977; Kopp, 1982; Wellman, 1977). A slower rate of development of these metacognitive skills has been found with mentally retarded persons (Belmont, 1978; Borkowski & Büchel, 1983; Borkowski & Cavanaugh, 1979, Campione & Brown, 1977, 1978; Campione et al., 1982; Glidden 1979).

The inaccuracy of metamemorial knowledge of two groups of educable mentally retarded children (mental age = 6 and 8 years) was documented by Brown and Barclay (1976). Their subjects were shown an array of 10 pictures and asked to predict how many they would be able to recall. Children whose predictions were within two items of their actual recall were termed realistic; the others were labelled unrealistic. Only 31% of the older children and 21% of the younger children were classified as realistic. This lack of awareness of task difficulty may explain, at least partially, the relative lack of strategic behavior by mentally retarded persons. "If an individual cannot determine when a problem is difficult, he would not be expected to produce deliberate memorization strategies" (Campione & Brown, 1977, p. 385). This lack of awareness may be related to their own "theory of mind" (Wellman, 1983, p. 36). More will be said about this possibility later.

Unfortunately, to our knowledge, no similar research has been completed in the cognitive-motor domain. Nevertheless, as suggested by Norman and Shallice's theory of action, the voluntary control an individual has over his or her own cognitive processes is certainly central to problem solving. This is not to say, however, that metacognitive skills are the only factors involved during the problem solving process. The knowledge base, the availability of strategies, the accessibility of domain-specific knowledge, and motivation are also key factors involved.

Strategies. The relative lack of the use of spontaneous strategies to appropriately solve memory problems has been frequently demonstrated within the mentally retarded population (for a review see Borkowski & Büchel, 1983; Borkowski & Cavanaugh, 1979; Bray, 1979; Campione et al., 1982; Glidden, 1979; Mulcahy, 1979; Taylor & Turnure, 1979). This failure in problem solving situations due to the lack of spontaneous strategy use, has been termed production deficiency by Flavell (1970).

The relevance of strategies to cognitive-motor skill learning has also received support from experimental studies. The purpose of an experiment done by Nacson, Jaeger, and Gentile (1972) was to demonstrate that accuracy in positioning could be facilitated by verbally providing the subject, prior to the task, a strategy for differentiating the test positions. The verbally instructed subjects produced less absolute error than the control subjects supporting the hypothesis that providing a verbal code or rule describing the relationship among the positions improves performance.

Using a manual lever task with university students Shea (1977) studied the effects of labeling on short-term motor memory. Subjects in the relevant labeling condition were told that while they held the lever against the peg defining the criterion position the experimenter would verbally present a label that would exactly describe the position of the lever. The labels were chosen so that they were representative of the hours on the face of a clock and specified positions analogous to 2:00, 1.00, 12.00, 11:00 and 10:00 o'clock. The provision of relevant labels at the presentation of a criterion position resulted in greater accuracy in recalling the position of the lever than either the provision of irrelevant labels or no labels.

In a recent experiment done by Singer, Hagenbeck, and Gerson (1981), male high school students were randomly assigned to five groups in order to learn a curvilinear repositioning task. Five conditions were compared: analogous imagery, relevant labeling, irrelevant labeling, kinesthetic, and control. Six positions, each different for each trial, had to be learned in sequence for 10 trials. The analysis indicated the general superiority of imagery and relevant labeling.

A free recall paradigm was used by Gallagher and Thomas (1984) to investigate the effects of three different strategies on the reproduction accuracy of a set of eight locations, with persons aged 5, 7, 11, and 19 years old. For the 5 and 7 year old children, a mature strategy facilitated performance over the child-like strategy. For the 11 an 19 year old groups, the use of the child-like strategy hindered the performance when compared to a self-determined or mature strategy.

The relative lack of spontaneous use of strategies by the mentally retarded has also been observed in short-term motor memory tasks. Sugden (1978) worked with 45 educationally sub-normal boys (ESN) in three mental age groups of 6, 9, and 12 years. They were examined for developmental trends and rehearsal strategies on visual motor short-term memory tasks. Comparisons were made with 45 normal boys aged 6, 9, and 12. Developmental trends and rehearsal strategies were almost totally absent in ESN boys. Normal boys were superior to ESN boys when central processing space was available during a condition of rest. No differences were evident when central processing was prevented during an interpolated activity condition. It was concluded that normal ESN differences could be attributed to a lack of mnemonic strategies in the ESN boys.

Similar results have also been obtained by Reid (1980a). His results suggest that mentally handicapped persons did not spontaneously engage in covert rehearsal of motor information while non-retarded persons did. The short-term motor memory of retarded and non-retarded groups was not different when covert rehearsal was not possible and during overt rehearsal.

The inference of a rehearsal deficit in the memory processes of retarded persons does not suggest a structural limitation but a failure to employ control processes. If so, training mentally retarded subjects to rehearse should improve their performance. Such results were obtained by Reid (1980b) who implemented a general strategy program to help mentally retarded people in a short-term motor memory task. Subjects in the strategy group were taught during the practice trials to remember the "feel" of the movement and where their hand stopped relative to their body (e.g., near your ear). The movement reproduction data supported the effectiveness of the memory strategy instruction package.

In summary, numerous memory studies have shown that young children and mentally retarded persons do not spontaneously use appropriate strategies to solve memory problems. When appropriate strategies are taught to these people, and they are required to use them, the memory performance is frequently better.

However, according to Belmont and Butterfield (1977) to determine the degree of success of any memory strategy training program it must be evaluated against three basic criteria of effectiveness: (a) performance must improve as the result of training, both in terms of accuracy and in terms of activities (strategies) used to effect this accuracy; (b) the effect of the training program must be durable; it is obviously desirable to show that what has been trained can be detected after a reasonable time period has elapsed; (c) training must result in generalization to a class of similar situations where the trained activity would be appropriate, for without evidence of breadth of transfer, the practical utility of any training program is doubtful.

Some evidence for maintenance exists in the literature. Recent studies have shown that extended training can result in durability of a trained behavior over a period of months and even years (for a review see Borkowski & Cavanaugh, 1979). But the tendency to maintain a trained behavior does appear to be related to developmental level as very young or retarded individuals are more likely to abandon the strategy than are more knowledgeable people.

The criterion of success that presents the most problems is generalization, or transfer to appropriate situations. Although there is some controversy over what constitutes a suitable transfer task, there is general agreement that flexible generalization to new situations has been lacking.

Evidence for far generalization was obtained by Brown, Campione, and Barclay (1979) in a study with educable mentally retarded children. One year following the original training with two memory strategies (anticipation and rehearsal) involving a self-checking component the younger children showed no effect of the training, whereas the older group both maintained the trained strategies and generalized it effectively to a novel situation involving recall of gist prose passages.

Bornstein and Quevillon (1976) also provided evidences for far generalization. Their subjects were 4 years olds who exhibited difficulty to control impulsive behavior. Bornstein and Quevillon taught their subjects (in a laboratory setting) to ask questions about solving intelligence test items, thereby inducing the children to set goals and helping them design strategies. They taught the children to instruct themselves in strategy implementation and monitoring as well as reinforce themselves for good performance. Transfer data were obtained by observing classroom performance, and impressive transfer was indeed obtained. This success is perhps due to the fact that Bornstein and Quevillon instructed more superordinate processes than other investigators up to this time.

To this writer's knowledge, the only research program concerned with the generalizability of strategies in the cognitive-motor domain appears to be the preliminary work completed by Singer and his associates (Singer & Cauraugh, 1984, 1985; Singer, Cauraugh, Luciarello, & Brown, 1985). The results obtained with pursuit rotor tasks (Singer & Cauraugh, 1984) and maze traversal tasks (Singer et al., 1985) support the notion that strategies are, to some extent, generalizable across related tasks. The author is not aware of any similar studies completed with mentally handicapped people.

In general, strategy maintenance and more specifically generalization has been obtained only when instructions are relatively complete. In our view these successful programs have three complementary dimensions. First, an appropriate strategy is taught. Second, subjects are trained to use relevant metacognitive skills like checking, planning, monitoring, testing, revising, evaluating, etc. Third, they give the immature learner more information about the working of their own mind which can lead to the development of a more comprehensive theory about the functioning of their own information processing system. The restructuring of such personal theories of the mind is possibly central to strategy generalization.

The importance of personal theories can be illustrated by research done on the metamemory-memory "connection" (Cavanaugh & Borkowski, 1979, 1980; Yussen, Mathews, Buss, & Kane, 1980). In general, these studies indicate only "a modest relationship between metamemory and encoding strategies across ability groups with different tasks and strategies" (Borkowski & Cavanaugh, 1981, p. 256). A serious problem in most of these studies is a general lack of reliability of measures used to assess metamemory (Borkowski & Cavanaugh, 1981; Cavanaugh & Perlmutter, 1982; Kurtz, Reid, & Borkowski, 1982; Rushton, Brainerd, & Pressley, 1983). A more pervasive problem is the relatively simplistic assumptions made by researchers. In the past, metamemory assessment usually tapped relatively isolated metamemory fact (or a list of such facts). As Wellman (1983) notes:

> This approach ignores the child's larger theory and integrated knowledge of memory of which it is one slice. For example, suppose the subject says, 'Yes, organization can make memory easier', but then does not employ organization in memory tasks. This, in fact, is the modal negative finding. Recall from the earlier discussion that children know that many factors influence memory but, within a larger conception of memory, may believe that

> the single most powerful factor is effort. A child with such a theory could both know that organization is better than nothing, in the metamemory assessment, and yet, when faced with the memory task itself, just decide that trying harder is the best strategy. In doing this, the child's memory behavior would indeed be influenced by his or her metamemory, if by that we mean the larger theory of memory. Yet, by correlating knowledge of organization with organization behavior alone, the opposite conclusion would seem warranted. (p. 42)

We contend with Wellman (1983; Fabricius & Wellman, 1984) that metamemory and its more general category, metacognitive knowledge, are particular types of knowledge and "like all knowledge, the child's metamemory [and metacognitive knowledge] is very likely to be a highly integrated set of notions, propositions, and concepts" (Wellman, 1983, p. 36). This is why metacognitive knowledge could be viewed as the person's "theory of mind" (Wellman, 1983, p. 36).

Personal theories about how to solve problems are most likely central to the problem solving behavior of human beings. Protocol analysis (Ericsson & Simon, 1984; Newell & Simon, 1972) has been used to gain information about these personal theories. To our knowledge only Sarrazin, Lacombe, Alain, and Joly (1983) have attempted to tap these personal theories in a competitive sport context.

<u>Accessibility</u>

Not all knowledge stored in long-term memory is accessible to solve movement problems. However, accessibility to knowledge and skills or subroutines is essential to problem representation, plan construction, as well as plan execution. In this section different notions of accessibility will be briefly discussed in relation to problem solving.

According to Brown and her colleagues (Brown, 1982; Brown & Campione, 1981; Campione et al., 1982), a key characteristic of intelligent behavior is "the ability to use flexibility and appropriately the information and skills available to the system" (Campione et al., 1982, p. 456). Based on the work of Pylyshyn (1978) they distinguish between two types of access: multiple and reflective. Multiple access refers to the ability to use information or knowledge flexibility under variable conditions, that is, "a particular behavior is not delimited to a constrained set of circumstances" (Campione et al., 1982. p. 456). Reflective access refers to "the ability to 'mention as well as use' the components of the system" (Campione et al., 1982, p. 456).

The relative lack of multiple access to the products of learning by the mentally retarded "is reported so often that 'welding' has been described as a characteristic feature of the learning of retarded children" (Brown & Campione, 1981, p. 522). The problem of multiple access appears to be central to strategy maintenance. In numerous memory studies it has been found that if appropriate strategies are taught to the mentally retarded their performance will improve (for review see Borkowski & Büchel, 1983). However, if they are not explicitely required by the experimenter to use the strategy taught, they frequently do not use it. Moreover, their spontaneous use of the instructed strategy (or some minor modification of it) to a new situation is frequently absent. This lack of transfer is more likely to occur if "explicit instruction in self-regulatory mechanisms is not provided. When training does include instruction in both the use and control of the desired skill(s), training attempts are successful" (Brown & Campione, 1981, p. 523).

Brown (1982) has suggested that multiple access has a developmental trend:

> The child expert could be seen as a learner who has considerable intellectual control in one domain, but can access this competence only in that domain... Similarily, the conscious control of problem solutions a child can use in one domain he cannot employ in another. Again the strategy a child can

on a novel transfer task unless given further training. Cognitive abilities are welded, or tightly wired, to specific domains of competence therefore not readily available to other domains. Thus, children are not only hampered by being universal novices, for even when they do gain expertise it tends to be strictly constrained by context. (p. 106)

The ability to consciously describe and discuss one's cognitive activites (reflective access) has been mainly studied through self-report techniques. Although some difficulties are associated with the use of these methods, a general conclusion is that immature learners are less than well informed about the working of their information processing system (Campione et al., 1982; Wellman, 1985). As noted earlier this lack of awareness is believed to be central to problem solving (for a discussion see the section on metacognitive knowledge and skills).

Motivation and Practice

It is well documented that the lifestyle of mentally retarded people is frequently different from that of their non-retarded peers (for a review see Watkinson & Wall, 1982). They are frequently listless and inactive: most of their leisure activities are passive and solitary in nature (Cheseldine & Jeffree, lifestyle is likely to lead to an impoverished coping repertoire.

Practice, either physical or mental, is essential to the solution of movement problems. Although practice alone does not make perfect, it is one of the most important movement-skill learning variables (Robb, 1972; Sage, 1984; Schmidt, 1982a). Lack of practice could be related to such motivational factors as learned helplessness, lack of movement confidence and minimal personal relevance of the task.

In a recent model of the development of movement competence and confidence, Griffin and Keogh (1981, 1982) stressed the importance of success experiences in movement situations for it is these experiences that lead to movement confidence. In their view, movement confidence is a product of a complex "cognitive evaluation of self in relation to task demands" (Griffin & Keogh, 1982, p. 214). Moreover, movement confidence influences the decision of "whether to become involved or not ... how the individual will do, ... [and] whether to continue involvement now and in the future" (Griffin & Keogh, 1982, p. 214). Confident persons are more likely to seek and choose participation than non-confident individuals. For non-confident persons it is "less likely that participation performance and behavior will be satisfying" (Griffin & Keogh, 1982, Although this writer is not aware of any empirical study having tested Griffin and Keogh's theory with mentally retarded persons, it seems highly plausible that these persons, in general, lack movement confidence. The proficiency of mildly and moderately mentally retarded people in prerequisite movement skills is considerably below that of their non-retarded peers (Watkinson & Wall, 1982). This lack of prerequisite skills should according to Griffin and Keogh directly affect movement confidence.

One line of evidence supporting the contention that the level of movement confidence of mentally retarded people is relatively reduced compared to the non-retarded comes from the studies based on attribution theory. Gibson (1980), using a pursuit rotor task found that mildly mentally handicapped adolescents attributed their success to luck and their failure to ability much more frequently than their non-retarded peers. This perception of lack of ability is most likely part of the complex cognitive evaluation leading to movement confidence and, hence participation choice, performance, and persistence in movement situation. "With an impoverished coping repertoire, he [the mentally retarded] is prone to experience failure (punishment) and, thus, is likely to develop little trust in his own resources. In turn, he looks to the external

Haywood and his associates (Haywood, 1968; Haywood, Meyers, & Switzky, 1982; Haywood & Wachs, 1966; Haywood & Weaver, 1968; Switzky & Haywood, 1974) differentiated between intrinsically and extrinsically motivated persons. Intrinsically motivated individuals are those who characteristically seek their principal satisfaction through task achievement, learning, responsibility, creativity, and aesthetic aspects of tasks, while 'extrinsically motivated' are persons who, instead of seeking satisfaction, concentrate on avoiding dissatisfaction through security, practicality, material gain, and avoidance of effort (Haywood et al., 1982).

A series of studies done by Haywood and his collaborators showed that intrinsically motivated mildly and moderately mentally retarded people achieve better performances than extrinsically motivated persons on a wide variety of tasks. Mildly mentally retarded children who are relatively intrinsically motivated had significantly higher school achievement scores in reading, spelling, and arithmetic than underachievers (matched on age, sex, and IQ) who tended to be motivated by extrinsic factors (Haywood, 1968). Haywood and Weaver (1968) used a hole punching task with institutionalized moderately mentally handicapped. Those who were relatively intrinsically motivated punched more holes under the task incentive condition incentive condition, while extrinsically motivated subjects punched more holes under the money incentive condition. Moreover, intrinsically motivated retarded adolescents learned a visual size-discrimination problem in fewer trials than did extrinsically motivated persons (Haywood & Wachs, 1966).

Briefly, motivation and the personal theories that the mentally retarded have about themselves are essential to an understanding of the problem solving behavior of the mentally handicapped person. Personal theories about self and lack of motivation may lead to a failure to retrieve or access relevant knowledge, use appropriate strategies, or use metacognitive skills available and, hence, impair all the steps necessary to solve a problem (Kurtz & Borkowski, 1984).

As mentioned earlier, this survey of the literature is relatively broad. The inclusion of this extensive review was judged necessary due to the lack of empirical studies done on the problem solving behavior of mildly and moderately mentally retarded persons in sport situations. The main objective was to create a framework within which the problem solving behavior of mentally retarded persons could be studied. This is not to say that the framework is complete. However, it represents an attempt to develop a coherent approach to this problem.

Significance of this Project

Most studies reviewed in this chapter have been concerned with memory problems. Although they have provided numerous insights into the problem solving behavior of the mentally retarded, the generalizability of these results across settings is relatively unknown. Moreover, most cognitive-motor tasks (e.g., move a cursor along a steel track while blindfolded) used with mentally retarded persons have a low degree of ecological validity. The generalizability of these results across tasks is also unknown.

Moreover, most studies reported in this review were done under relatively minimal time pressure. In many open skill situations, a person operates under severe time constraints, this implies that there is a minimal amount of time to consciously simulate different response alternatives.

As discussed earlier, solving movement problems is dependent upon information either available in the environment or stored in memory. This project focussed specifically on the relationship between knowledge and knowledge-use by mildly and moderately mentally handicapped adolescents within a simulated culturally-normative racquet sport environment.

The specific questions asked in this project are:

1. Can mentally retarded subjects use cognitive information about where a ball will land to select a

more appropriate response position to return the ball in a table-tennis setting?

2. If they can use such information, are different stroke strategies used to return the ball?

3. Does prior knowledge of where a ball will land improve their ability to appropriately hit the ball across the table?

4. Can they use a visual model, representing a table-tennis player, to predict where a ball will land prior to its being projected at them?

5. Does level of intelligence and sex of the subject affect all of the above questions?

Experiment 1

Method

Subjects

The players who participated in this study were eight males and eight females randomly selected from the subject pool available at L. Y. Cairns Vocational School in Edmonton, Alberta.

The subject pool was created according to the following criteria:

1. The chronological age range was from 13 to 15 years old.

2. The medical history of each potential subject was considered. Adolescents suffering from known medical problems were excluded from the study on the basis of the following criteria: (a) neurological or neuromuscular disorders, (b) cardiovascular problems, (c) visual acuity, with correction, inferior to 20/60 as estimated with the Snellen Chart, (d) moderate or severe auditory impairment with amplifier, (e) recent surgery prohibiting physical effort and, (f) the necessity for the adolescent to take drugs affecting the normal functioning of the central nervous system.

3. The estimated IQ had to be between 45 and 70 on the full scale of the Weschler Intelligence Scale for Children revised edition (WISC-R). Not more than 20 IQ points were tolerated between the performance scale and

were obtained from the school psychologist.

4. A letter of informed consent was sent through the regular mail system to the parents or guardians of the adolescents. A second letter, identical to the first one was sent again to the parents or guardian, with the help of the adolescent, if no reply was received within 15 days. Adolescents who received consent became part of the pool of available subjects.

Some of the characteristics of the subjects are presented in Table 1.[1] All but two players were right-handed. Subject 8 was the only left-handed person and subject 11 used her left-hand for approximately 10% of the trials.

Apparatus

A modified "Stiga-Robot" table-tennis ball projection machine with its appropriate power supply was used in this study. The robot was solidly fixed with clamps on a moveable turntable (see Figure 1).

As shown in Figure 2, a regular table-tennis table was used as a base for the playing surface. The size of the regular table was increased by placing a 243.8 cm x 121.9 cm piece of pressed wood on the side in which the player stood. The playing surface was painted dark green and four target areas (121.9 cm x 61 cm) were

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[1]All tables are presented after Chapter 7.

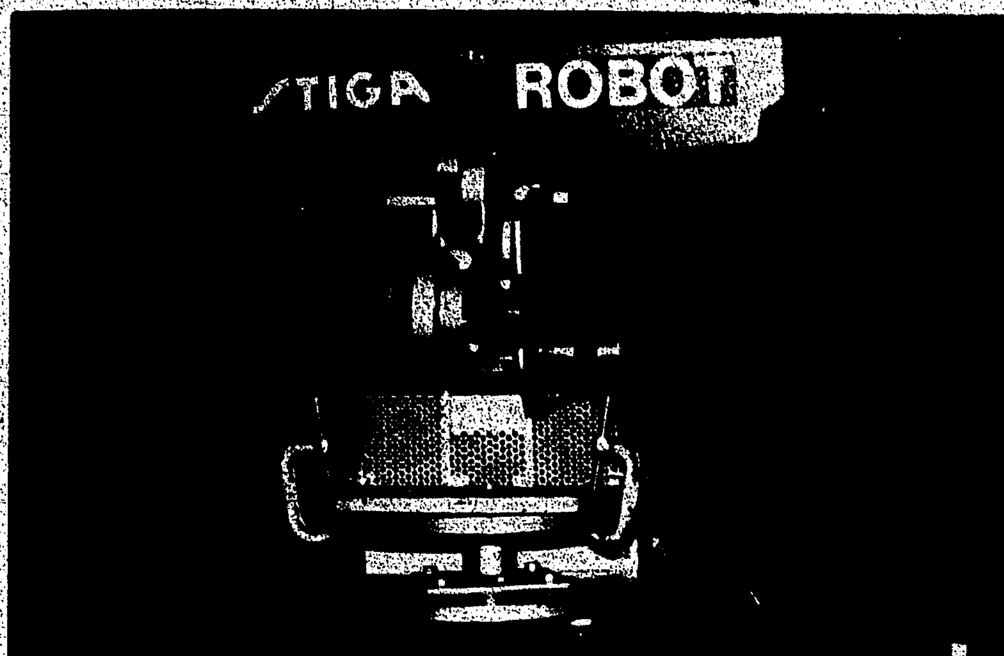

Figure 1. Front view of the "Stiga-Robot" table-tennis ball projection machine fixed with clamps to the upper part of the turntable.

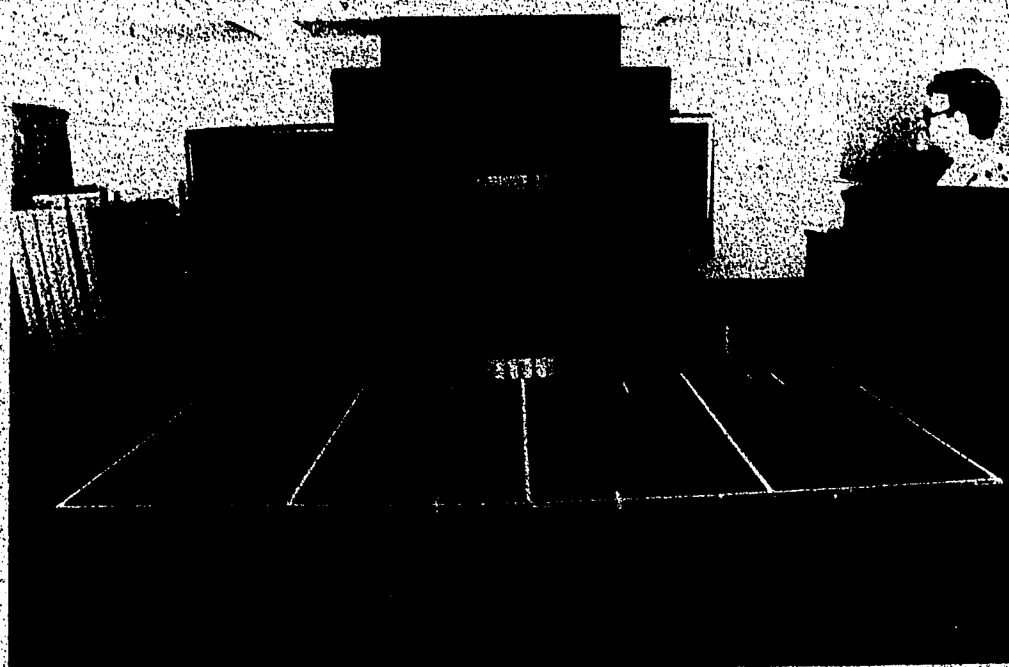

Figure 2. View of the display offered to the players during Experiment 1.

outlined in white on it. The numbers 1, 2, 3, and 4 were painted in white at the top centre of each of these target areas.

The letters A, B, C, and D were placed close to the net on the player's side of the table in order to minimize possible lapses of memory during the control condition. Two small white markers were also placed at the end of the table, close to the player, for coding purposes.

Markers were placed on the floor to ensure that the equipment remained in the same position throughout the experimental sessions. As shown in Figure 2, a set of black curtains served as a background and a dark-green screen prevented the subjects from seeing the Stiga-Robot. A green net was used to catch the balls and return them to the robot area for future use.

The position of the robot was controlled in the following manner. Four small holes were placed in a block of wood such that the robot could be fixed in four different positions depending on where the teflon pin was placed. As shown in Figure 3, the numbers one through four designated the robot positions which resulted in the balls landing in the four desired target areas. Specifically, the holes were placed at 10.4° steps to ensure that the correct direction was achieved. The robot was placed at the centre of the table at a distance of 95 cm from the end of the table.

Figure 3. View of the system allowing appropriate rotation of the "Stiga-Robot".

It was placed on a table so that it released the balls from a vertical height of 115 cm above the floor. Each ball was released at a speed of approximately 5.5 m/s at a delivery angle of 30° above the horizontal.

A half-inch video system was used to record the behaviors of the players, this system included a wide-angled lens which was hidden from the subject's view. A screen with vertical and horizontal stripes was placed behind the player to facilitate the coding of each response. Information on each subject and the experimental condition was placed on a board facing the camera beside the table.

Procedure

Each subject received preliminary instructions about the nature of the task. Subjects were told that they would have to return each ball with the bat, over the table-tennis net, such that the ball would land on the far side of the table. They were also taught the rules for a good return. Subjects were given a period of practice consisting of 16 balls landing on the left-centre target. Immediately after the practice period each subject's level of understanding of the rule for a good return was assessed. The player was required to look at four different diagrams, one at a time, representing good or bad returns. Each diagram was verbally described by the experimenter and the player was then required to say if it represented a good or a bad return and justify his or her response. Feedback was provided after each response and those adolescents who had difficulty understanding the rules for a good return received additional information. The next part of the experiment did not begin until a satisfactory understanding of the rules, as expressed verbally by the player, was achieved.

Players were then given further instructions. In preparation for the experimental condition, the players were told that they would have to repeat a number (1, 2, 3, or 4)[2], given verbally by the experimenter, which would indicate where the ball would land. They were also shown the meaning of the numbers. In doing so, the experimenter stayed in a fixed position behind the centre of the table and used a long pointer to touch the appropriate targets so as to avoid suggesting movements that would help them to solve the movement problem.

The experimenter assessed how well each player understood the meaning of numbers 1, 2, 3, and 4 by asking them the question "Show me where the ball will land if you hear 'a given number'?". In order to

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[2]To ensure that the same amount of time was available for the subjects to process verbal information before the landing of the next ball on the table, one experimenter was trained (a) to repeat covertly a four syllable word at normal speed, (b) use the sound produced by the landing of the ball on the table as a signal indicating when to initiate the above-mentioned process of time estimation and (c) to say verbally the appropriate letter or number when the time estimation period was finished.

respond to this question the subject had to stand behind the centre of the table and to show, with the pointer, the appropriate target. Feedback was provided after each response.

In preparation for the control condition, players were told that they would have to repeat a letter (A, B, C, or D), shown in front of them (see Figure 2), provided verbally by the experimenter. They were said that there was no link between the letters and the targets on which the ball will land.

Following the period of instruction subjects were reminded that they would have two things to do: (a) to repeat immediately the letter or the number and (b) to return the ball with the bat, over the table-tennis net, such that the ball would land on the far side of the table.

The balls were shot, with a light topspin, at a rate of one every 5 s. Two blocks of 16 balls were shot followed by three blocks of 32 balls shot under each condition (experimental and control). The subjects helped the experimenter to pick-up the balls between each block. The entire sequence was organized in such a way that the first order probability[3] was the same for each target. The first order and the second order

[3]The equality of the first order probability means that p(1) = p(2) = p(3) = p(4), where p(1) means the probability that the ball would land on target 1, etc.

sequential dependency were approximately[4] the same. The sequence of letters, used during the control condition, was constructed according to the same rules.

Design

The experimental design had two within subject factors. The landing area of the ball on the table was the first factor and had four levels: left (L), left-centre (LC), right-centre (RC), and right (R). The second within factor was the condition (control and experimental). Sex was the first between subject factor. Players having an IQ between 60 and 70 constituted the first level of the second between subject factor while those persons having an IQ between 45 and 59 were included in the second level of this factor. Finally, the third between subject factor was the order of each condition. Half of the subjects (4 males and 4 females) had to do the experimental

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[4]The first order sequential dependency concerns the probability of each pair p(11), p(12),..., p(44), where p(11) means the probability that a ball landing on target 1 would be followed by a ball landing on target 1, etc. A perfect equality of the first order sequential dependency would have required a sequence of 129 balls during each condition. However, the sequences were constructed in such a way that, all but one pair, had the same probability. The equality of the second order sequential dependency would have required a sequence of 130 balls. In the sequence used, all but two triplets had the same probability. These restrictions imply that if a player guessed where the next ball will land on the basis of (a) not considering the last ball (b) considering the last ball, and (c) taking into account the last two balls, the uncertainty about the future landing of the next ball was each time close to two bits (see Attneave, 1959).

condition first followed by the control condition, while the other half had the opposite order.

Data for both the experimental and the control conditions were collected on the same day. In order to reduce the fatigue of the subjects, a break period of 20 minutes was allowed between the two conditions. During this time a snack, paid for by the experimenter, was offered to each player. Discussion during this break period was centered on whatever seemed of interest to the player; however, comments about the experiment were avoided. Each experimental session including the break period lasted approximately 90 minutes.

Dependent Variables and Coding

The dependent variables used in this study reflected the position of the player's body, shoulder, and bat, as well as the stroke, and whether they hit or missed the ball. The position of the body, the shoulder, and the bat were recorded by the coders when the player first saw the ball. The body position was defined as a middle point between the top of the two iliac crests. The shoulder location was defined as the location of the greater tubercle tuberosity of the humerus. The shoulder position which was recorded was the one link, through the upper limb, to the bat when the player either attempted to return the ball, or when the ball reached its nearest point in relation to the player. The bat position was defined as the intersection point of two diameters of the "circular" part of the bat.

The categories of coding used for the five dependent variables are presented in Table 2.

Coding, Interobserver Agreement, and Validity

All the data were collected with a half-inch videotape system using a wide-angle lens. All of the coding was completed by the experimenter who used reference points on the table, the screen placed behind the table, and a plastic screen placed over the television monitor. This setup allowed the coder to judge the position of the body, the shoulder, and the player's bat at the time when the ball appeared on the television screen. Further, the videotape was momentarily stopped to record this data. This moment was selected because at this time the player first saw the ball. Measures of the type of stroke used and whether the ball was hit or not were recorded later in the sequence.

In order to investigate the validity of the data, 100 trials were randomly selected from the first five subjects in the study. Those trials were selected under the restriction that: (a) twenty trials were selected from each subject, (b) the ball landed on target 1 or 4, and (c) the ball landed the same number of times on each target. Later on a professional colleague was asked to look carefully at the videotape of these trials, and take body positions and postures identical to the ones used by the player on a given trial. During this period, two judges, using the above-mentioned coding system, directly observed the "player" and coded the position of the body, shoulder, and the bat. During this re-enactment the player's posture was simultaneously videotaped. The same procedure was repeated until 100 trials were coded. These trials were considered as validly coded and were used for both training the coders and to check for possible coder drift over time.

A block of 20 of the above trials, randomly selected from the pool of 100 available, was used to train the main and second coder. Another block of 20 randomly selected trials was used to assess the validity of the coding system. The results revealed that, at this stage, both the main coder and second coder had validity scores ranging from 95% to 100%. The validity of the main coder was then assessed each two weeks during the coding period; validity scores always ranged from 90% to 100%.

The assessment of interobserver agreement was done by randomly selecting 32 trials from each subject under the following restriction: (a) on these trials the ball landed only on target 1 or 4 and (b) the ball landed the same number of times on either target. As shown in Table 3, the percentage of interobserver agreement ranged from 93% to 98%.

Data Analysis

Body, shoulder, and bat. Data for each dependent variable were analysed with four-way analyses of variance (ANOVA) with repeated measures on two factors. The within subject factors were landing targets and condition while the between subjects factors included in these analyses were sex and IQ.

As noted earlier, this project focussed specifically on the relationship between knowledge and its effect upon the solution of movement problems. In the experiments completed, it is through the condition factor that knowledge was manipulated. Consequently, only statistical tests including the condition factor were of interest in the ANOVAs completed.

To control for the liberalization of the F test when the sphericity assumption is not met, the three-step decision making procedure recommended by Greenhouse and Geisser (1959) was employed. During the first step of this procedure, the value of the F statistic was compared to the critical value. When the observed F did not exceed the critical value, the analysis stopped; if F exceeded the critical value, then the second step of the Greenhouse-Geisser procedure was undertaken and a conservative F (F_{cons}) test was done (for details see Kirk, 1982, pp. 500-505). When the observed value exceeded the conservative critical value, the test was declared significant; if not, the third step of the Greenhouse-Geisser method was undertaken. At this stage, an estimate of the departure from sphericity called epsilon was obtained and used to correct more appropriately for the bias of the F test introduced by the lack of sphericity (for details see Keselman & Rogan, 1980). As before, usual decision making procedures were used by comparing the value of the F statistic to the critical value. In this dissertation the completion of the third step of Greenhouse-Geisser procedure will be indicated by F_{eps}.

The Tukey honestly significant differences (HSD) post-hoc test was used to test the simple effect means. The choice of the appropriate error term for these tests was determined by the following procedure: the components of the total sum of squares of the associated simple main effects test were found,[5] and if these components were themselves tested by different error terms, then a pooled mean square error terms was used. This pool mean square was equal to the sum of the relevant error sum of squares, divided by the sum of corresponding degrees of freedom (see Kirk, 1982, pp. 509-510).

The percentage point of the studentized range distribution was selected in a conservative manner. The

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[5]The same procedure was used in the case of simple main effect tests.

degrees of freedom used with the studentized range statistics was always the smallest value selected among the degrees of freedom used to calculate the appropriate pooled mean square. The use of this rather conservative procedure was justified by the large number of Tukey post-hoc tests completed in the dissertation.

When test of simple interaction effects were called for, a pooled mean square was used as the error term when components of the total sum of squares of the simple interaction effect test were tested by different error terms. In this case, the degrees of freedom of the error term were determined by the Satterthwaite procedure[6] (see Howell, 1982, pp. 381-382). The use of the symbols E_{sat} will notify the reader of the use of this procedure in this report.

<u>Stroke</u>. A visual analysis of the stroke data generated by each subject was completed to determine if subjects changed their stroke strategies during both conditions of this experiment.

<u>Ball</u>. The average number of balls hit were analysed with a five-way ANOVA with repeated measures on two factors (condition and landing targets). The between subject factors included in this analysis were sex, IQ, and order. Test of simple effect means and simple interaction effects were performed according to

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[6] The obtained value was rounded to the nearest integer for testing of the null hypothesis.

the rules described earlier.

CHAPTER 4

Experiment 1

Results and Discussion

This chapter is divided into three major parts in accordance with some of the central questions of this dissertation. The main concern of the first section is the relationship between knowledge about the future landing of the ball and its effect on the player's position. The relationship between knowledge and stroke strategies used is addressed in the second section. The question of improvement in performance is the object of the last part of this chapter.

Body, shoulder, and bat

As indicated in Chapter 3, each dependent variable (body, shoulder, and bat) used to assess the position of the player behind the table had three possible values (left, centre, or right). So, the Cartesian product of the three dependent variables by the three possible values of the dependent variables generated nine pairs. The frequency data for each of these nine pairs were analysed with a mixed model ANOVA 2 x 2 x 2 x 4 (sex x IQ x condition x landing target) with condition and landing target serving as repeated measures. For the sake of clarity, the results for the three dependent variables are presented together under each of the three coded positions.

Left. The ANOVAs done on the frequency data indicating how often the body, the shoulder, and the bat were behind the left side of the table revealed a significant two-way (condition x landing target) interaction for the body, $F_{cons}(1, 12) = 62.78$, $p < .001$, the shoulder, $F_{cons}(1, 12) = 54.17$, $p < .001$, and the bat, $F_{cons}(1, 12) = 113.60$, $p < .001$ (see tables 4, 5 and 6). For ease of understanding, Figure 4 shows these interactions for each dependent variable.

The Tukey post-hoc tests done on the cell means of the condition by landing target interactions revealed that, when the ball landed either on the left or left-centre part of the table, the body, the shoulder, and the bat were more frequently behind the left side of the table during the experimental condition than during the control condition. Conversely, comparisons across conditions revealed that the body was less frequently behind the left side of the table during the experimental condition when the ball landed either on the right-centre or the right target. Quite simply, these results mean that knowledge about the future landing location of the ball was used to select a position closer to the future landing location of the ball to return it during the experimental condition.

Centre. The four-way ANOVAs done on the frequency data indicating how often the body, the shoulder, and the bat were behind the centre part of the table revealed significant differences for the conditions by

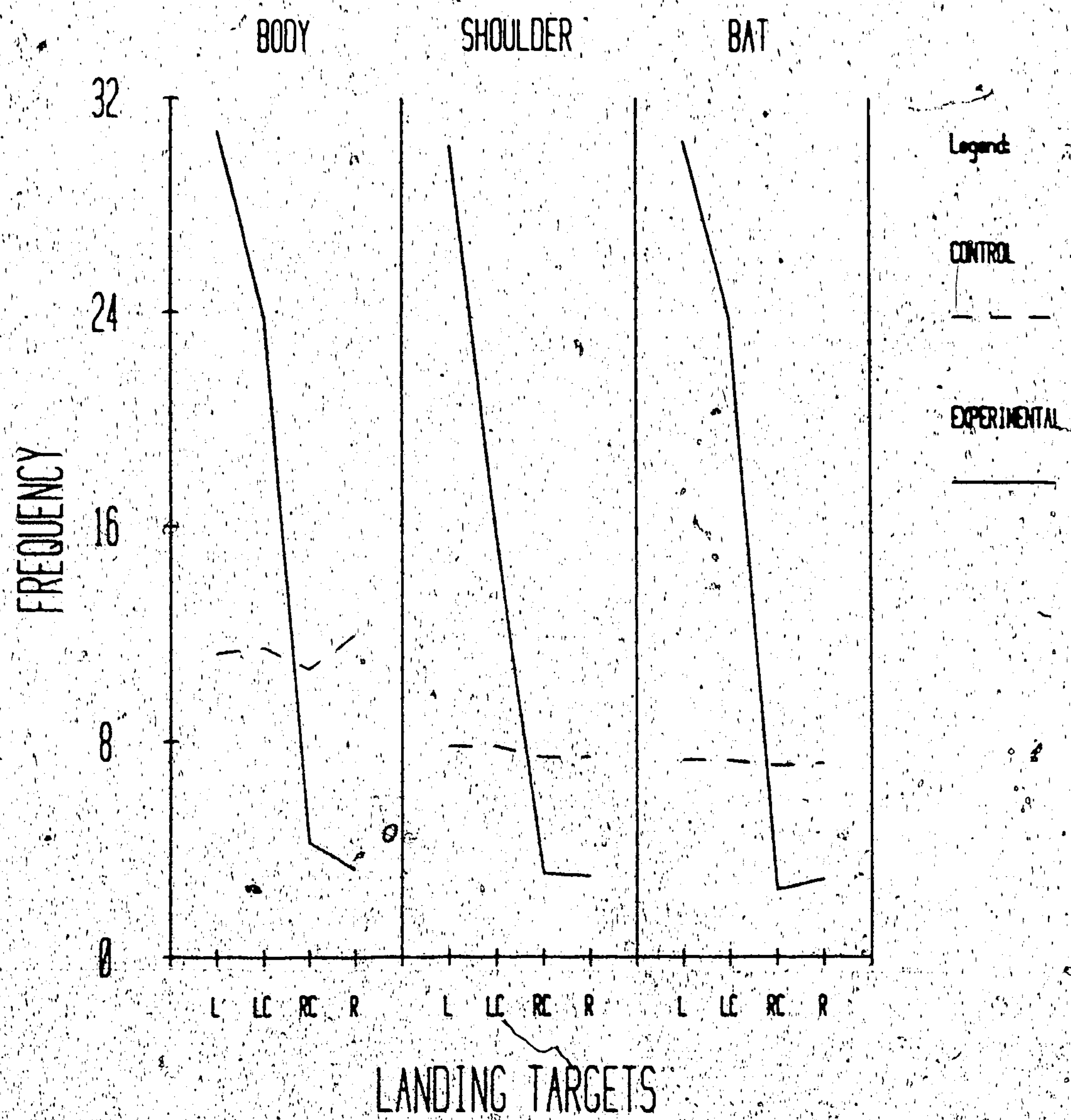

Figure 4. Average frequency indicating how often the body, the shoulder, and the bat were behind the left side of the table during Experiment 1, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

landing target interaction for the body, $F_{cons}(1, 12) = 9.27$, $p<.05$, the shoulder, $F_{cons}(1, 12) = 16.84$, $p<.01$, and the bat, $F_{cons}(1, 12) = 12.99$, $p<.01$ (see Tables 7, 8 and 9). For ease of interpretation, Figure 5 shows these two-way (condition x landing target) interactions for each of the three dependent variables.

The Tukey post-hoc tests done on the cell means of the condition by landing target interactions revealed no significant differences among all the landing target positions during the control condition for each dependent variable. However, identical comparisons revealed significant differences during the experimental condition. The body, the shoulder, and the bat were more often behind the centre of the table when the ball landed either on the left-centre or the right-centre part of the table than when the ball landed on either extreme targets (left or right). Moreover, the body was more often behind the centre of the table when the ball landed on the right-centre target compared to the left-centre target and vice-versa for the shoulder. In brief, these results indicate that the players did not change their position as a function of the landing target area of the ball during the control condition. However, knowledge about the future landing area of the ball during the experimental condition was used to select a position closer to the future landing location of the ball to return it.

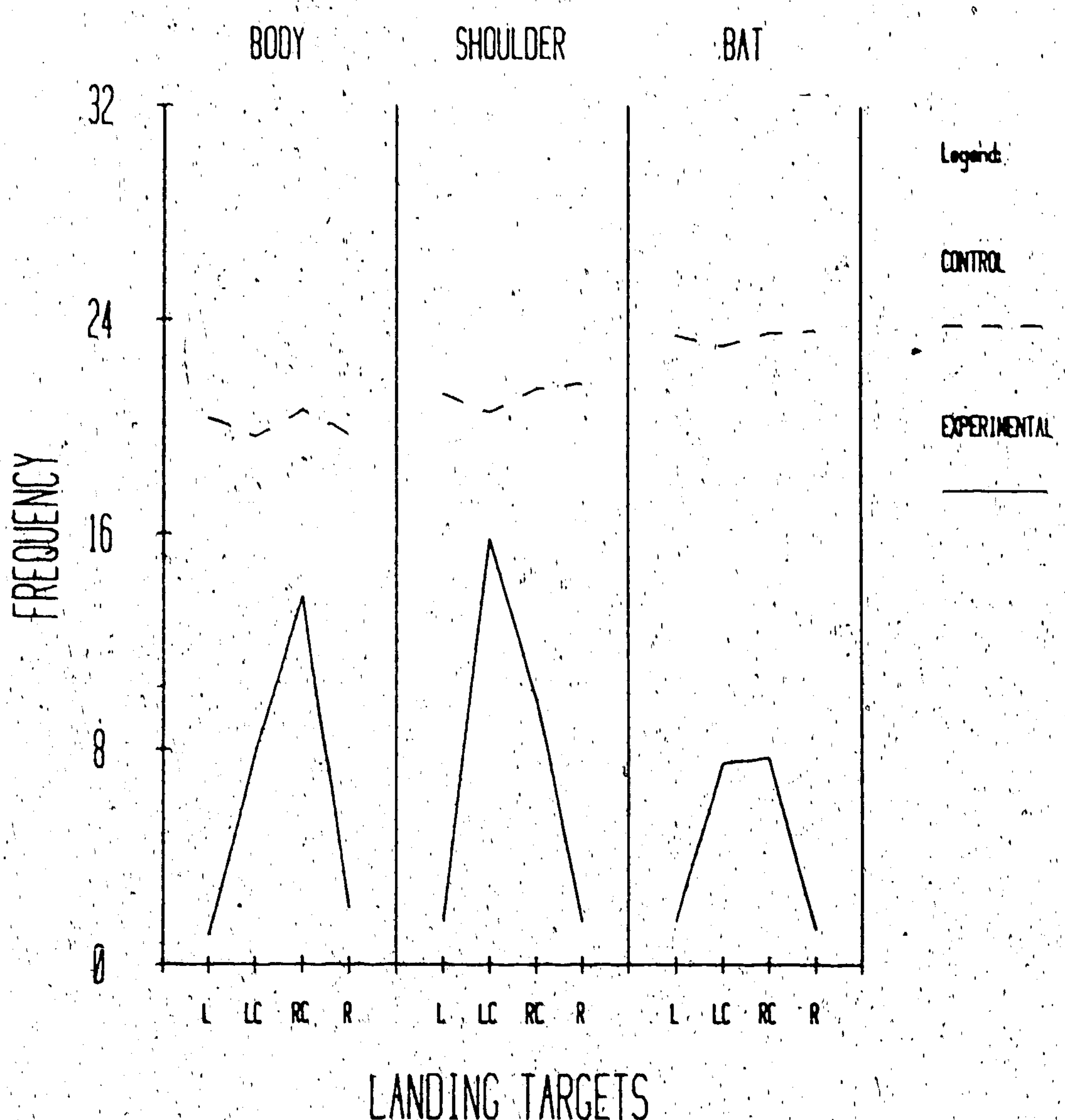

Figure 5. Average frequency indicating how often the body, the shoulder, and the bat were behind the centre of the table during Experiment 1, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

Right. The frequency data indicating how often the body, the shoulder, and the bat were behind the right side of the table were analysed in the same way as before. These analyses revealed different results for each dependent variable. Consequently, the results are presented separately for the body, the shoulder, and the bat.

Analysis of the data for the *body* dependent variable indicated two significant first order interactions. The condition by landing target interaction was, as usual, significant, $F_{cons}(1, 12) = 52.74$, $p<.001$. Moreover, a significant IQ by condition interaction also reached a significant level, $F(1, 12) = 4.84$, $p<.05$ (see Table 10). Cell means for these interactions are presented in Figures 6 and 7.

Subsequent post-hoc Tukey tests done on the cell means of the condition by landing target interaction indicated that, compared to the control condition, the body was more often behind the right side of the table when the ball landed either on the right-centre or the right target. No such differences were observed when the ball landed on the two leftmost targets. This again indicates that the players, on average, used the information about the future landing location of the ball to move closer to the ball to return it during the experimental condition.

Multiple comparisons done across IQ groups on the

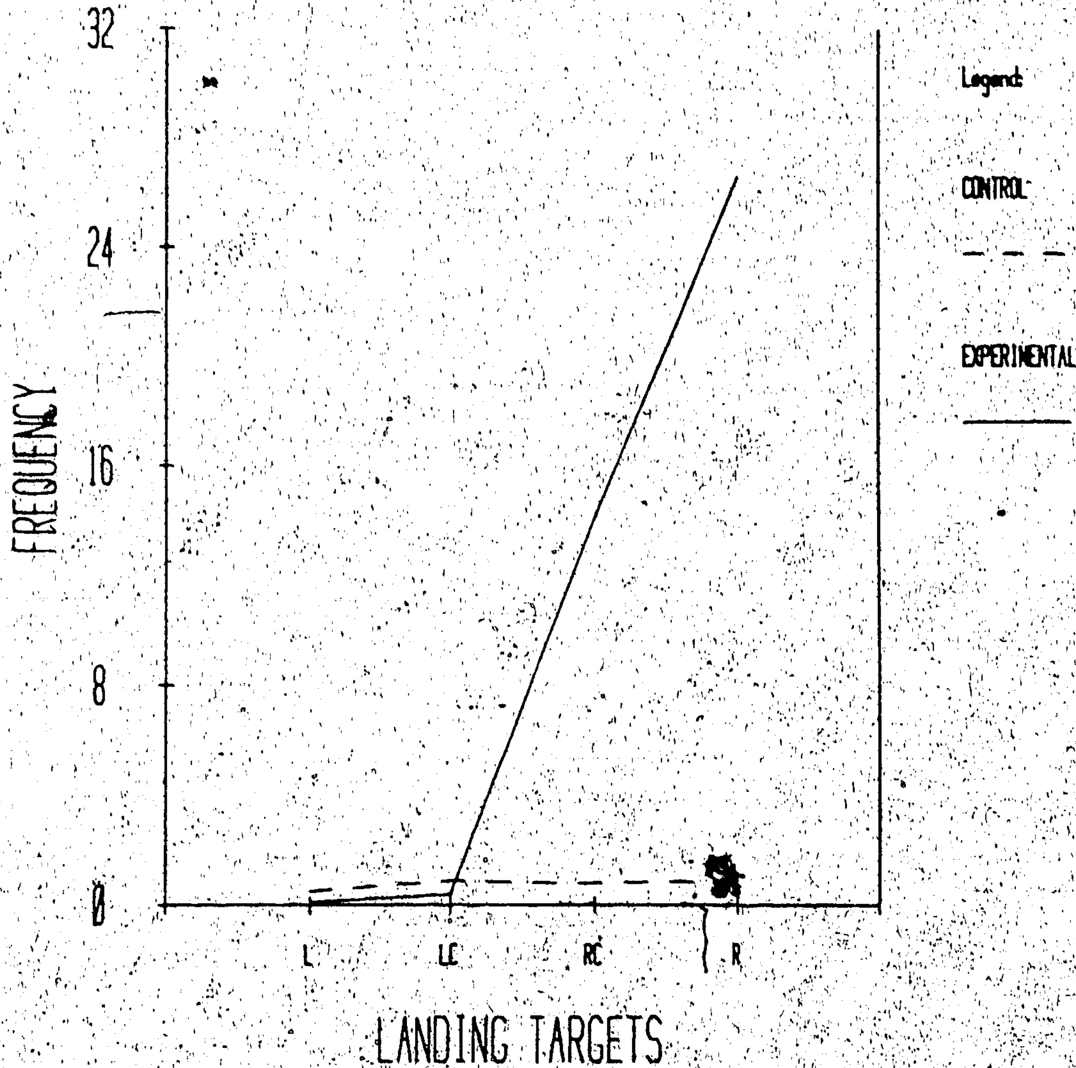

Figure 6. Average frequency indicating how often the body was behind the right side of the table during Experiment 1, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

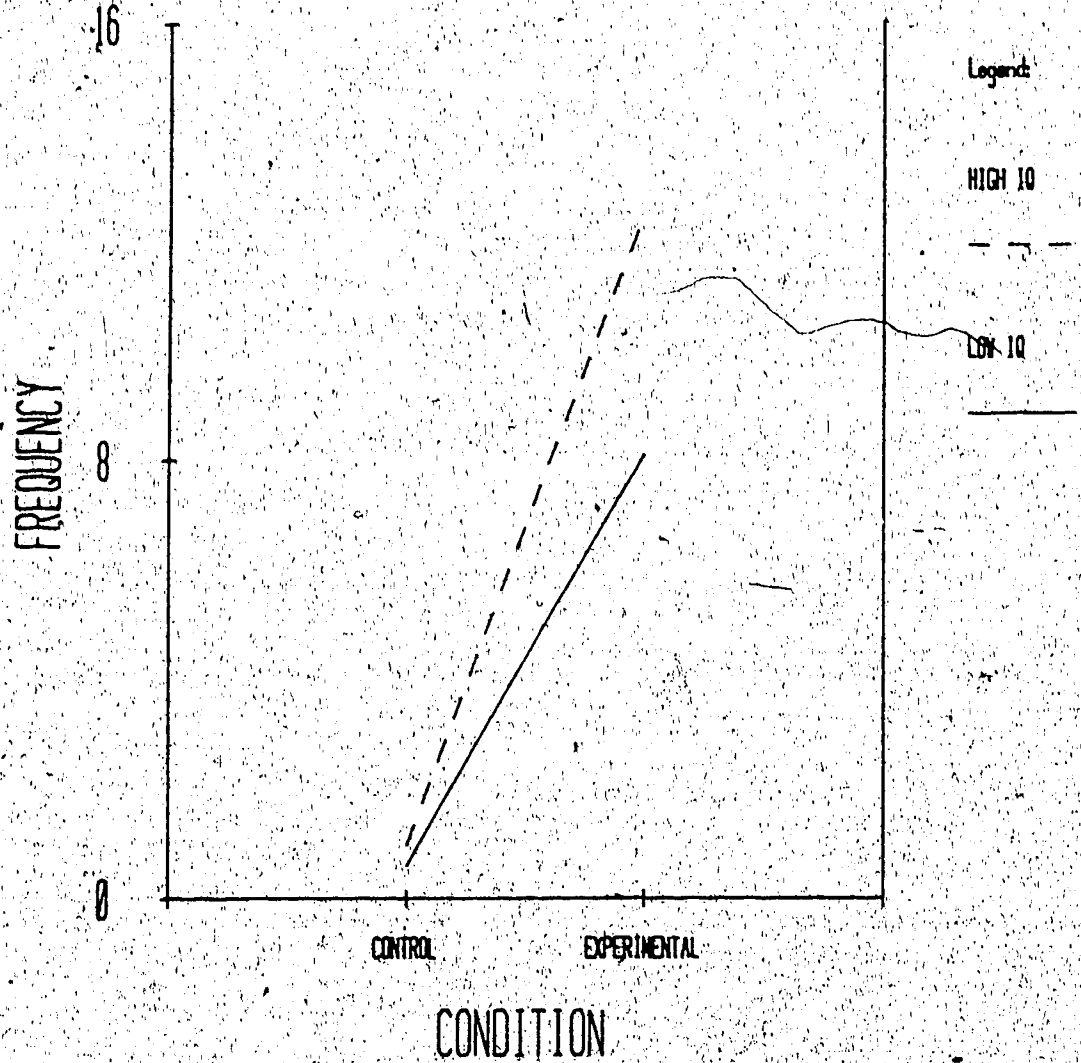

Figure 7. Average frequency indicating how often the body was behind the right side of the table during Experiment 1, as a function of IQ and condition.

cell means of the IQ by condition interaction (see Figure 7) revealed no differences during the control situation. Similar comparisons done on the cell means of the experimental condition indicated that the body of the high IQ group was more frequently than the low IQ group behind the right side of the table during the experimental condition. Similar trends were also observed for the shoulder and the bat dependent variables. The shoulder and the bat of the high IQ groups (mean values of 13.97 and 14.06 respectively) were more frequently behind the right side of the table during the experimental condition than the low IQ group (mean values of 9.66 and 10.81). Overall, these results reflect a tendency for the low IQ group to remain more frequently behind the left side or centre part of the table than the high IQ group during the experimental condition.

As shown in Table 11, the ANOVA done on the shoulder data revealed that a significant three-way interaction IQ by condition by landing target, $F_{eps}(2, 22) = 4.10$, $p < .05$, was obtained. Figure 8 shows the cell means of this three-way interaction.

Simple interaction effect tests (IQ x condition) done at each level of the landing target factor indicated that the only two way interaction that reached a significant level was the IQ by condition at the right-centre target, $F_{sat}(1, 33) = 5.20$, $p < .05$.

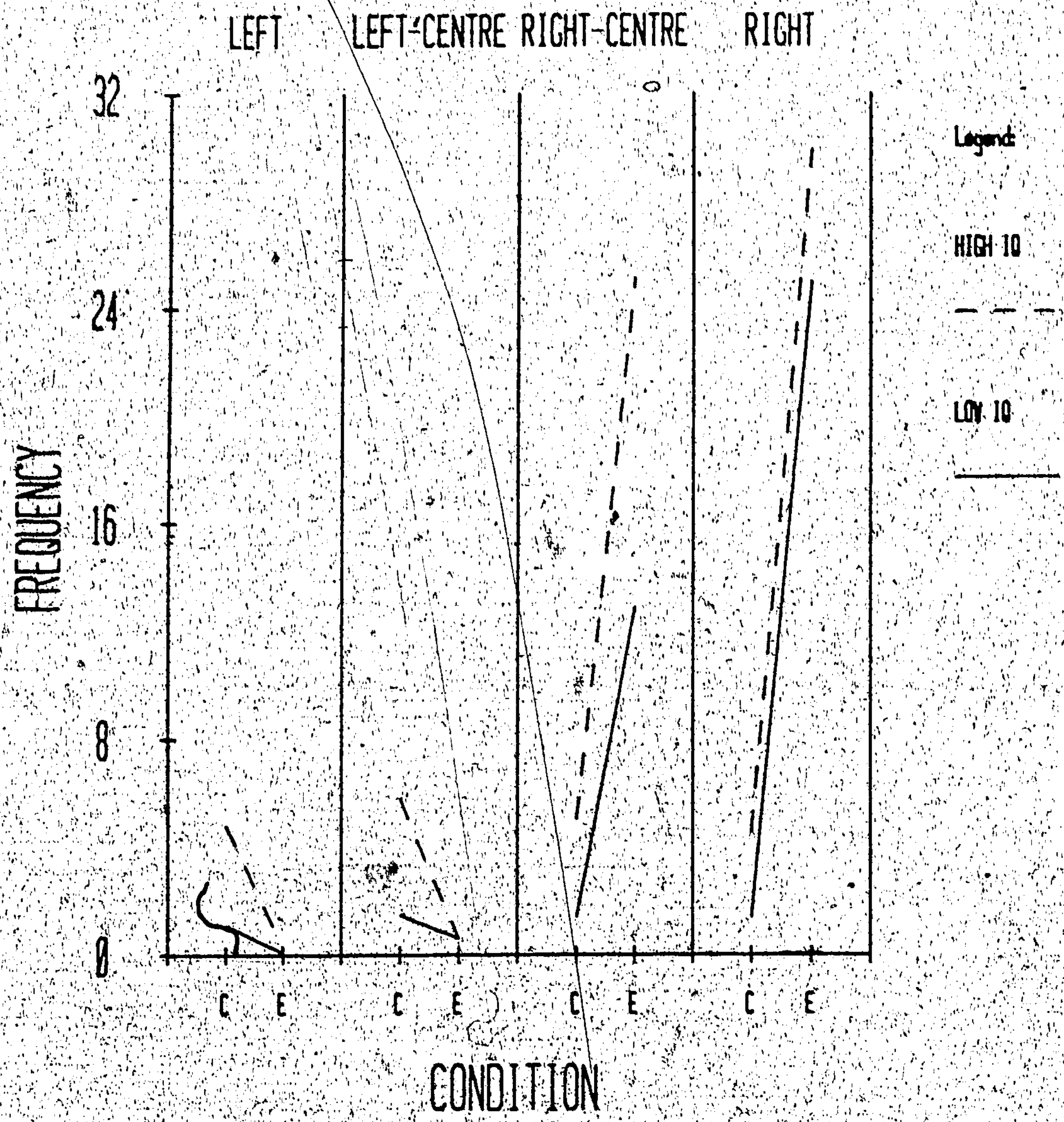

Figure 8. Average frequency indicating how often the shoulder was behind the right side of the table during Experiment 1, as a function of landing target area, IQ, and condition (C: Control; E: Experimental).

Subsequent Tukey HSD tests done across IQ levels revealed that the high IQ group of mentally retarded persons was more frequently behind the right-side of the table, compared to the low IQ group, when the ball landed on the right-centre target during the experimental condition. No other differences across IQ groups was significant. On the other hand, post-hoc comparisons across conditions, showed that for both IQ groups, subjects were more frequently behind the right side of the table during the experimental condition when the ball landed on the two rightmost targets. This again indicates that both IQ groups selected a closer position to return the ball during the experimental condition.

When the frequency data from the bat were analysed as before, a two-way interaction, condition by landing target, was again found to be significant, $F_{cons}(1, 12) = 123.85$, $p<.001$ (see Table 12). Multiple comparisons across landing positions indicated that the bat was more frequently behind the right side of the table during the experimental condition when the ball landed on the two rightmost targets (see Figure 9). As before, this indicate that both IQ groups used knowledge about the future landing location of the ball to return it.

In summary, the nine ANOVAs done and the subsequent analyses all converged toward the same conclusion; both IQ groups, on the average, used knowledge about the

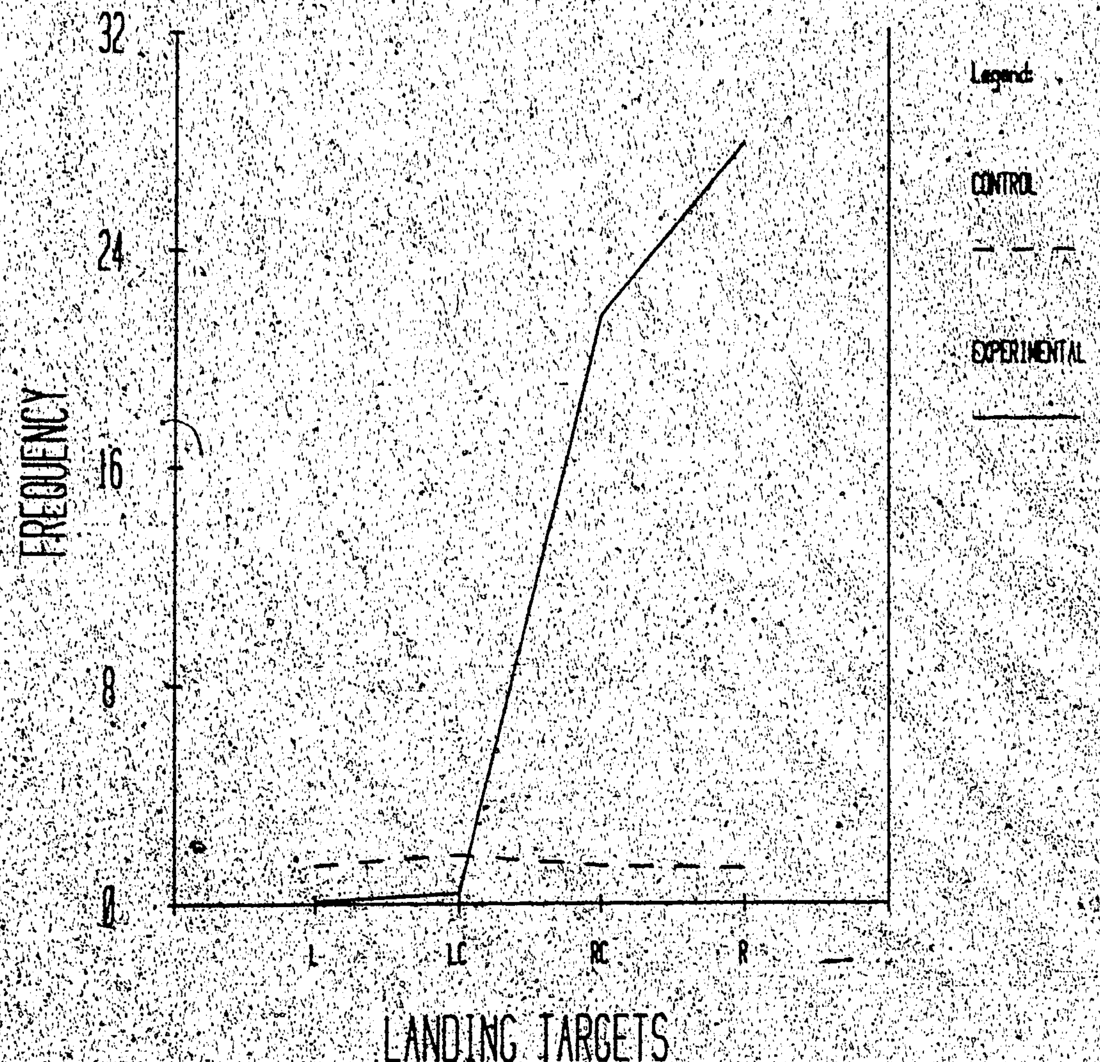

Figure 9. Average frequency indicating how often the bat was behind the right side of the table during Experiment 1, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

future landing location of the ball to take a position closer to the future landing area of the ball while in the experimental situation. This conclusion is not affected by the sex and the IQ level of the groups. Although a notable exception to this conclusion is presented later, a discussion of these results follow. To avoid lengthy statements, this exception is not considered in the next few pages.

Before going into the details of this discussion, it is useful to first do an analysis of the mover-environment relationships (Keogh & Sugden, 1985) used in this study. To be able to do the task effectively during the control condition, the players had to be able to perceive a letter presented verbally to them and then repeat it. A few seconds later, the players had to hit the ball. This action was constrained by the spatial and temporal characteristics of the ball. This implies that the skill required for this experiment was an open-skill (Gentile, 1972). Moreover, although the flight characteristics of the ball were rather consistent from trial to trial, the location of the next landing of the ball was unknown to the player. In fact, the uncertainty about the future landing target area of the ball on the table was always near 2 bits. The above analysis implies that, during the flight of the ball, the players had to perceive as well as anticipate the spatio-temporal characteristics of the flight of the ball, decide where to move their body and what type of stroke to use and, finally, initiate the selected response in due time.

During the experimental condition, all players were verbally told where the ball would land on the table approximately 3.5 s prior to its projection. Due to this change, the load on the decision mechanism was reduced. The players instead of being forced to decide, during the flight of the ball, where to move their body and what type of stroke to use, were allowed to make these decisions prior to the projection of the ball. In fact, as the results clearly showed, most players had not only decided, before the projection of the ball, where they wanted to stay behind the table, but they also had enough time to implement this decision, that is, to take a position closer to the future path of the ball. Using the classification system proposed by Gentile, Higgins, Miller, and Rosen (1975), this implies that the act of hitting the ball frequently required only limb manipulation because body transportation had occurred earlier. This is different from the control condition where the act of hitting the ball frequently required both body transportation and limb manipulation (especially when the ball landed on the <u>left</u> or the right target). The observed behavior of the subjects, implies that they believe that it is <u>better</u> to select a position closer to the future path of the ball to return it. This belief has, most likely, influenced their decision to be close to the ball.

Although some racquet sport experts may question the assertion that "closer is better" (e.g., J. Watkinson, personal communication, July 14, 1986), movement skill theorists like Bernstein (1967) and Kelso (1982) would likely qualify the observed behavior as intelligent adaptation. From their standpoint, any beginner[7] learning a movement skill must gradually master the degrees of freedom to be controlled. One way to decrease the level of individual demand in relation to the mover's resources (Keogh & Sugden, 1985) is to immobilize some joints and restrict the range of motion of some other joints. This is what the players did during the experimental condition. As noted by Kelso (1982), within this view of skill development:

> the performer is "curtailing" the degrees of freedom via completely immobilizing some joints (which later are used when the skill is performed expertly) and restricting the range of motion of some other joints. This is because he or she lacks the capability of

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[7]The players were questioned, before and after the experiment, about their level of experience as table-tennis players. Eight players had never played table-tennis before the experiment, three had most likely played this game less than 10 times in their life, and five more than 10 times. So, most players were beginners.

controlling the degrees of freedom in the manner demanded by the skill. It follows therefore that increasing skill level involves a lifting of the ban on degrees of freedom ... As Fowler and Turvey (1978) point out, increasing the number of controllable degrees of freedom is synonymous with improvement in skilled performance. (pp. 26-28)

If Kelso (1982) view of skill development is right, then the players spontaneously reduced the level of individual demand (Keogh & Sugden, 1985). Consequently, they made the task easier for them. This may be viewed as a better way to solve the movement problem.

Now that it has been established that the players plausibly used a better solution during the experimental condition, our main concern in the next few paragraphs is why did the players use information about the future landing of the ball to select a better position during the experimental situation.

The use of a different strategy during the experimental condition implies that the players used the declarative knowledge about the future landing location of the ball to either access and implement a solution (procedure) already stored in memory or that they generated a new solution to this problem.

Using Pea's (1982) views on planning, we can say that the players had an appropriate representation of the problem. The players understood that they had to hit the ball with the bat, they noted the differences between their position and the actual landing location of the ball during the control condition, as well as the differences between their position behind the table and the future landing area of the ball during the experimental situation. The players were also able to construct a more appropriate plan during the experimental situation; they were able to eliminate the differences between the problem representation and the goal state (Pea, 1982). In this study, it is impossible to know whether or not the subjects accessed a plan that was already available in memory or if they generated a new plan to meet the task demands. The players were also able to execute, prior to the projection of the ball, the part of the overall plan that required body transportation (walking) behind the table. It is more difficult to assess whether or not the players evaluated their progress toward the goal during this experiment (MacKay, 1985; Wessells, 1982). This could certainly be a subject for future study because the evaluation or monitoring of one's progress toward the goal (Brown, 1977) is certainly a crucial aspect of movement skill development. It could certainly shed some light on the capacity of mentally retarded people to self-modify or adapt their motor system to the requirement of the task. The analysis of subject's verbal reports (Ericsson & Simon, 1984) might be an interesting research strategy to use to develop a better understanding of the monitoring behavior of the mentally retarded while learning a new movement skill.

Considering the observed changes in behavior across movement situations, it seems that the players had some knowledge and understanding of their own capacities and weaknesses (Campione et al., 1982; Wall et al., 1985). They were likely conscious of their own limitations in relation to the particular end to be attained in both movement situations studied (Campione et al., 1982; Norman & Shallice, 1986; Wall et al., 1985). Stated anothe way, we think that the observed changes in behavior reflects metacognitive knowlege about action (Wall et al., 1985). More will be said about this hypothesis later.

The reader might also be concerned by the fact that no statistically significant differences of interest were found involving the IQ factor. One reason why no such differences was found might be the design of the study. The variance between IQ groups was not maximized because the players in the high IQ group had an estimated IQ between 60 and 70, and those in the low IQ group had a range of scores between 45 and 59. Hence the effect size (Cohen, 1977), if any, is probably small and difficult to detect. There are different ways around this problem. A first one is to determine the effect size of interest, choose the desired power, and then use the results found in this dissertation to determine the sample size required. Another way might be to increase the difference between the IQ groups. A third possibility would be to use a more precise scale of measurement; instead of coding the position of the body, the shoulder, and the bat as we did in this study, it would be better to measure the distance between these three units and a common frame of reference. Some information was lost due to the coding system used. A more precise measurement scale would allow for more accurate description and differentiation, if any, between groups.

Obviously, the generalizability of these results to lower IQ groups is unknown. It is quite likely that, as we go down the scale of IQ, people could no longer solve this problem. This could be the object of future studies.

As said earlier, an exception to the results presented before was found in this study. The presentation of these results as well as a discussion of them is done in the next section.

A Case Study

As shown in Table 13, a girl in the low IQ group (Subject 11) never used knowledge about the future landing area of the ball to select a better position to return it during the experimental situation. This player had no experience as a table-tennis player. Instead of looking toward the robot before the projection of the next ball, as the other players most frequently did, she was either looking to her right or all around the room. This behavior reflects an inappropriate allocation of attention by this person.

Due to her frequent perceived failure[8] to hit the ball she had to be frequently reinforced. Typically, we encouraged her by saying "Don't give-up. Just try to do your best". She also probed the main experimenter asking what she was doing wrong. The usual answer was "I can't help now. Just try your best".

This is the only person for which, clearly, the declarative knowledge about the future landing location of the ball was not used to take a position closer to its future landing area. The exact reasons for this lack of use of prior declarative knowledge about the future landing of the ball are unknown; however, they do invite speculations. One possibility is that she did not understand the meaning of 1, 2, 3, and 4 which were said approximately 3.5 s before the landing of the ball. This possibility appears unlikely because when the experimenter asked her, during the instruction period, a question of the form "show me where the ball will land if you hear 'such and such'", she accurately

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[8]She frequently said "What am I doing wrong?".

pointed toward the appropriate target each time. A possibility remains that she might have forgotten this information later on during the experimental condition. This is also unlikely because when we asked her, before the fourth block of trials, the same question, she was perfectly able to respond. A third possibility might be that she did not encode the number that was verbally given by the experimenter. Although she did not repeat the numbers on a few trials, she generally verbally reproduced the number perfectly, so we argue that at this stage (approximately 3 s before the landing of the ball) she had, most of time, encoded the appropriate number. Another possibility is that the "memory trace" of the number disappeared rapidly from the content of the conscious memory system. Although this fading had to be faster than values usually accepted, information could be lost from short-term store within a matter of seconds if it is not rehearsed. It should be remembered that this adolescent was looking to her right or all over the room while in the experiment, suggesting inappropriate allocation of attention. She was also upset by her frequent failure to hit the ball. Under these circumstances it seems plausible, in our view, that the knowledge of the number disappeared rapidly from the conscious memory system and, if so, can no longer be used to generate, consciously, a position closer to the future landing of the ball. A fifth possibility is that she did not understand that she had to hit the ball with the bat. This explanation is unlikely because she attempted to hit the ball at least 95% of the time while in the experimental condition; this percentage does not differ from the values usually found for other players. Finally, another possibility is that, due to her misunderstanding of the instructions, she inferred that the experimenter asked her to keep the same place behind the table during the experiment. Although nothing like this was said during the instruction period, this possibility cannot be entirely ruled out with the information we have.

To clarify this issue, this subject came back to the laboratory ten days later to do the same experiment again. This time she did the experimental condition first. In this session she immediately used prior information about the future landing area of the ball to select a position more suitable to return the ball. Observing this fact, the experimenter asked her "Did you do something different today compared to last time?". She simply replied "No". The experimenter paraphrased the question again and received the same answer. Although this player had generated a better solution the second time, she did not seem to be aware of it.

<u>Stroke</u>

A second question of interest in this study is "Did the players use different stroke strategies to return the ball during both conditions?". We now turn to a presentation of the results related to this question and a discussion of them.

The type of stroke used by each player was tabulated onto contingency tables and a visual analysis of the data was completed on it. For each subject, a comparison of the type of stroke used at each of the four landing targets was completed; hence, for each subject, four frequency distributions were compared. In doing so, the evaluator attempted to differentiate non-significant associations from those that were either strong or very strong. The results of this process are presented in Table 14.

In general, subjects 2, 5, 6, 9, and 15 more frequently used their backhand when the ball landed on the right side of the table. Conversely, subjects 4, 7, 10, 14, and 16 more frequently used their forehand when the ball landed on the two leftmost targets. Exceptions to this tendency to use only the forehand or the backhand during the experimental condition were: (a) subject 1 who used only a penholder grip during the entire experiment, (b) subject 3 who almost exclusively used his forehand during the control condition and used both types of strokes during the experimental condition, (c) the only left-handed player, subject 8, who more frequently used her forehand when the ball landed on the two rightmost targets, (d) subject 12 who did not alter the type of stroke used, and (e) subject 13 who more frequently used his forehand during the experimental condition when the ball landed on the left target and his backhand when the ball landed on the right side of the table. Finally, it is of interest to note that subject 11, who never used the information given during the experimental condition, did not change the type of stroke used.

In view of these results, our conclusion is that most players altered the type of stroke used in this experiment. However, the decision about what type of stroke should be used appears to be a personal one. It is our suspicion that the decision is based on an assessment, by the player, of their ability to use different types of strokes in relation to a movement situation. If so, the use of either the forehand or the backhand should reflect metacognitive knowledge about action that each player has about his or her stroke. Metacognitive knowledge about action "is a higher type of declarative knowledge about action that develops as children become consciously aware of what they can or cannot do in thousands of action situations" (Wall et al., 1985, pp. 31-32).

Some players may know only one way to hit the ball, others may know different methods but may be more confident with a particular stroke. Some players might believe that their forehand is a better stroke than their backhand, or vice-versa. This personal conviction that a particular type of stroke is likely to produce a better outcome has, most likely, influenced the behavior of the players.

Although the above discussion is admittely speculative, it should be possible to test these hypotheses. By measuring the degree of perceived competence that the player has in his forehand and his backhand, we would predict that the player will use their perceived best stroke in a performance situation. If both strokes are perceived as equally good, then other factors specific to the mover-environment relationship will influence the decision. It is important to underscore that we make these predictions in a performance situation; in a learning context the learner may simply decide to upgrade his weakest stroke, hence leading to an apparent rejection of our hypothesis.

<u>Balls Hit</u>

Another question of interest in this study is "Does prior knowledge of where a ball will land improve a player's ability to hit the ball across the table?". The results and discussion related to this question are presented in this section.

The number of balls hit was analysed with a five-way ANOVA with repeated measures on two factors.

The between subject factors were sex, IQ, and order of conditions (experimental or control first). The two within subjects factors were, as before, condition and landing target area of the ball.

The analysis revealed that the IQ by order by condition interaction, $F(1, 8) = 6.07$, $p<.05$, and the IQ by condition by landing target interaction, $F_{eps}(2, 17) = 4.67$, $p<.05$, were both statistically significant (see Table 15).

As suggested by Figure 10, simple interaction effect tests done on the IQ by order by condition interaction revealed that the order by condition simple interaction effect test was significant only for the low IQ group, $F(1, 8) = 15.54$, $p<.01$. Tukey post-hoc tests revealed that subjects in the low IQ group always hit more balls in the second half of this experiment. This effect was not observed for the high IQ group.

Visual inspection of the plotted cell means of the IQ by condition by landing target interaction (see Figure 11) suggested that this three-way interaction was due to the difference of differences in slopes observed by comparing data from the right target to the data from the other three targets. This hunch was followed by using three-way interactions post-hoc tests. For each of these tests, all the levels of the IQ and condition factors were included in each analysis, but only two levels of the landing factor were considered at each

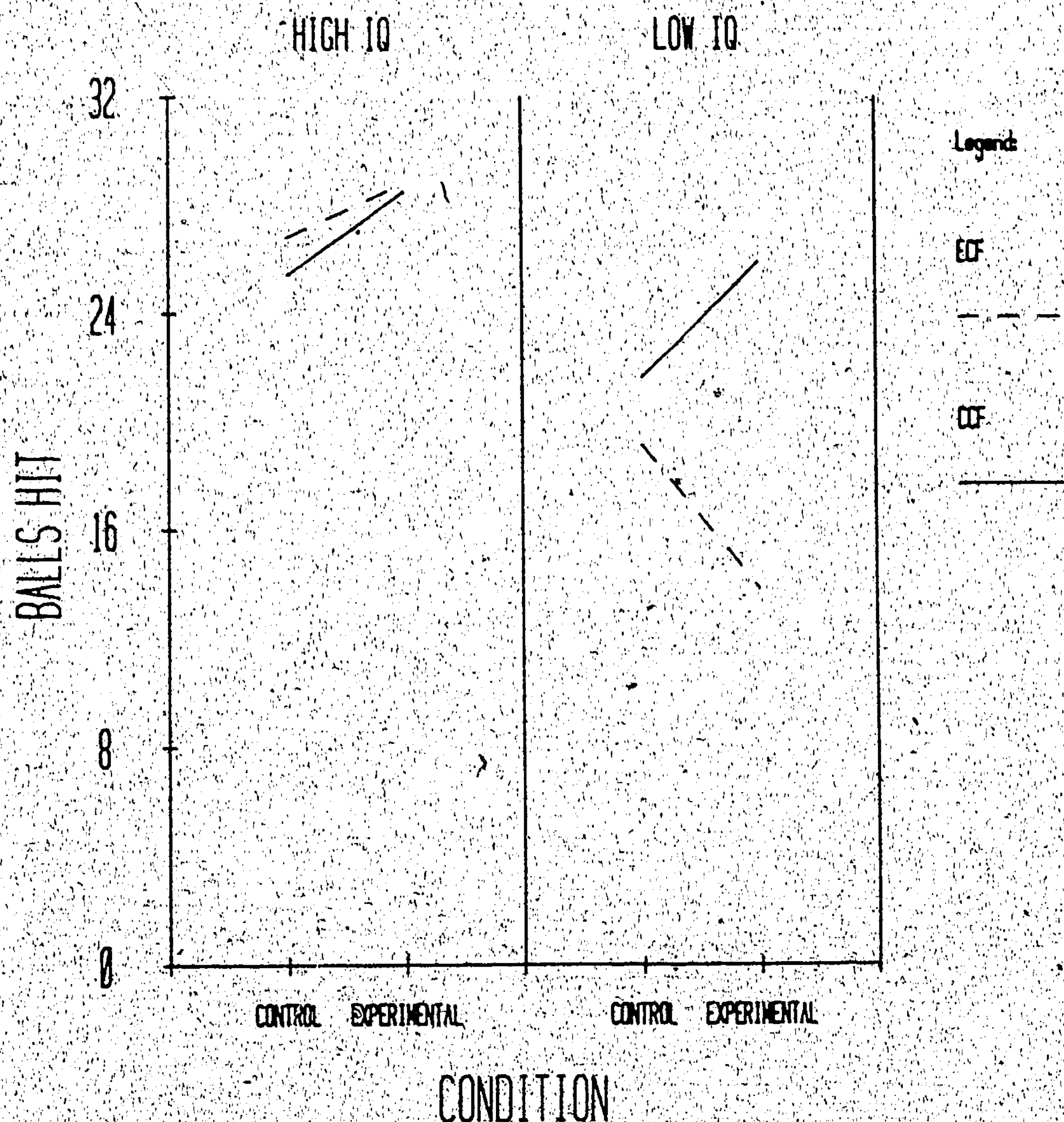

Figure 10. Number of balls hit during Experiment 1, as a function of IQ, order, and condition (ECF: Experimental Condition First; CCF: Control Condition First).

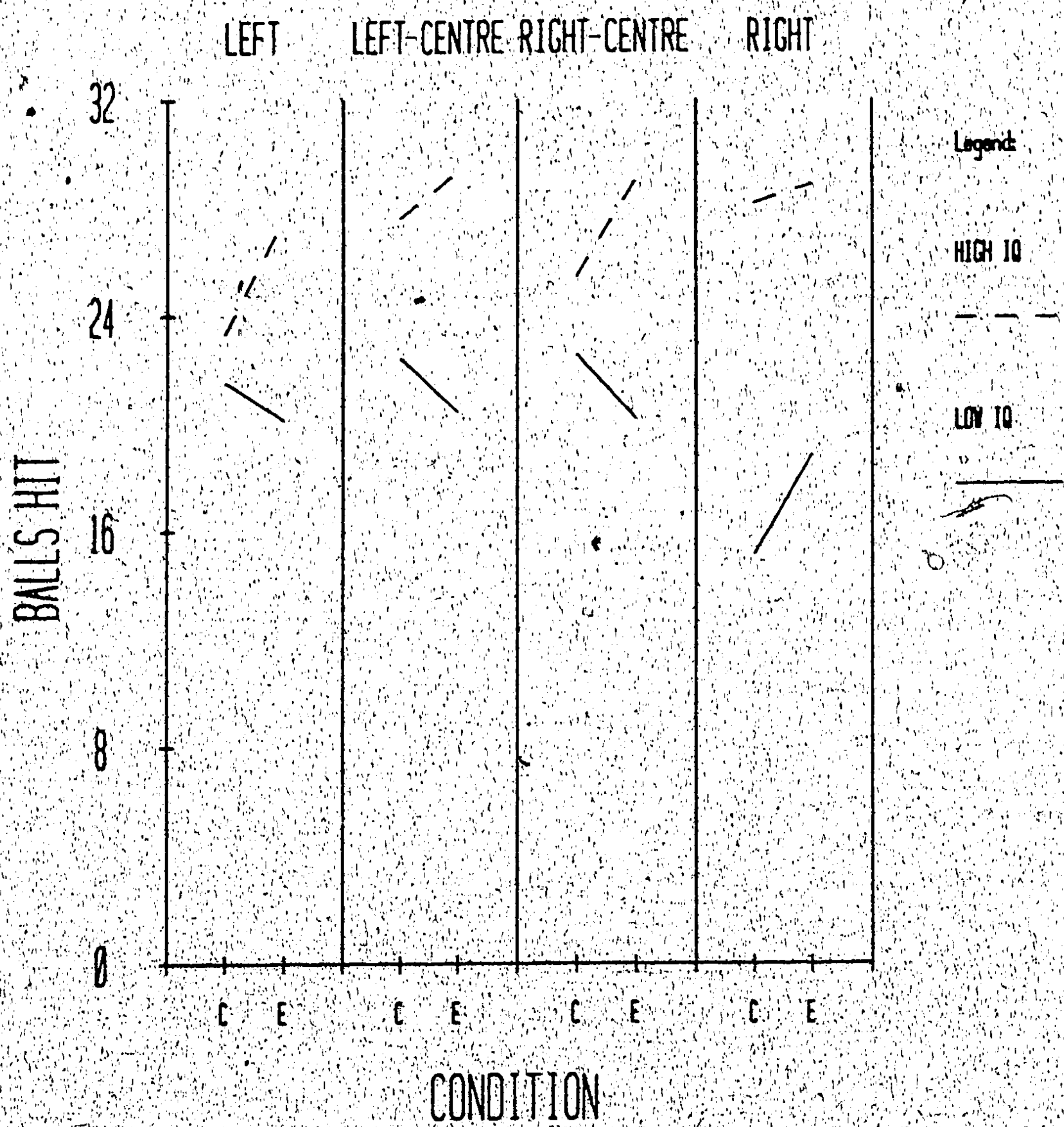

Figure 11. Number of balls hit during Experiment 1, as a function of landing target area, IQ, and condition (C: Control; E: Experimental).

time. This set of six post-hoc test supported our hunch. The interactions of IQ by condition by landing target, L against R, $F(1, 12) = 10.19$, $p<.01$, LC against R, $F(1, 12) = 5.83$, $p<.05$, and RC against R, $F(1, 12) = 10.78$, $p<.01$, were all statistically significant. Moreover, Tukey HSD test across conditions revealed only two significant differences: the high IQ group performed better during the experimental condition when the ball landed on the left target or the right-centre target. It is our suspicion that the lack of improvement of the high IQ group when the ball landed on the left-centre or the right target is due to a ceiling effect: it was too easy for them to hit the ball.

If our suspicion about a possible ceiling effect is true, then our tentative answer to the question "Does a prior knowledge about the future landing location of the ball lead to better performance?" is yes for the high IQ group, but no for the low IQ group. Despite the fact that both groups used a better positioning, prior to the projection of the ball during the experimental condition, the knowledge about the future landing target area of the ball did not induce a better performance in the low IQ group.

The existing body of knowledge about movement skill development can help us to explain why the performance of the low IQ group was always better during the second half of this experiment and why the high IQ group was the only one to benefit from a prior knowledge about the future landing area of the ball on the table. It is well documented that as we go from mildly to moderately mentally handicapped individuals, the quality of motor performance becomes inferior (Watkinson & Wall, 1982). As noted in the introduction, unskilled people have rather unstable and inconsistent kinematic responses (Magill, 1985; Marteniuk & Romanow, 1983; Tyldesley, 1980; Tyldesley & Whiting, 1975). Consequently, we suggest that, as the low IQ subjects practiced, they developed more consistent kinematic motor pattern and, hence, they were able to hit more balls. On the other hand, it is likely that the high IQ group had developed a more consistent kinematic response before this experiment. Consequently, we suggest that it is only when a rather consistent kinematic motor pattern is developed that knowledge about the future landing location of the ball is beneficial; otherwise, the players frequently miss the ball even if they are close to it. Hence, a priori knowledge does not induce better performance unless a minimal level of movement consistency has been developed.

CHAPTER 5

Experiment 2

Method

Subjects

All the new subjects in this experiment met the same criteria as that used in Experiment 1, except for one girl who had an estimated IQ of 44 and one boy who had an estimated IQ of 57 based on the Stanford-Binet intelligence test. None of these subjects participated in the first experiment. Some of their characteristics are presented in Table 16. All but one player (subject 31) were right-handed.

Apparatus

A number of modifications were made to the equipment used in Experiment 1. The letters A, B, C, and D, that were placed on the player's side of the table were removed. A Barbie doll figure (30.5 cm x 1[illegible]7 cm) in the posture of a table-tennis player was mounted above the robot (see Figures 12 and 13). For a player placed at 50 cm behind the centre of the table, this figure sustained approximately a visual angle of 4.1^{o} and an horizontal angle of 1.7^{o}. The degree of Barbie's rotation when the ball landed on adjacent targets was 10.4^{o}. A rotation of 2 x 10.4^{o} implied a landing two targets away; and a rotation of 31.2^{o} indicated landing on the most extreme targets. During the control condition, this figure was fixed

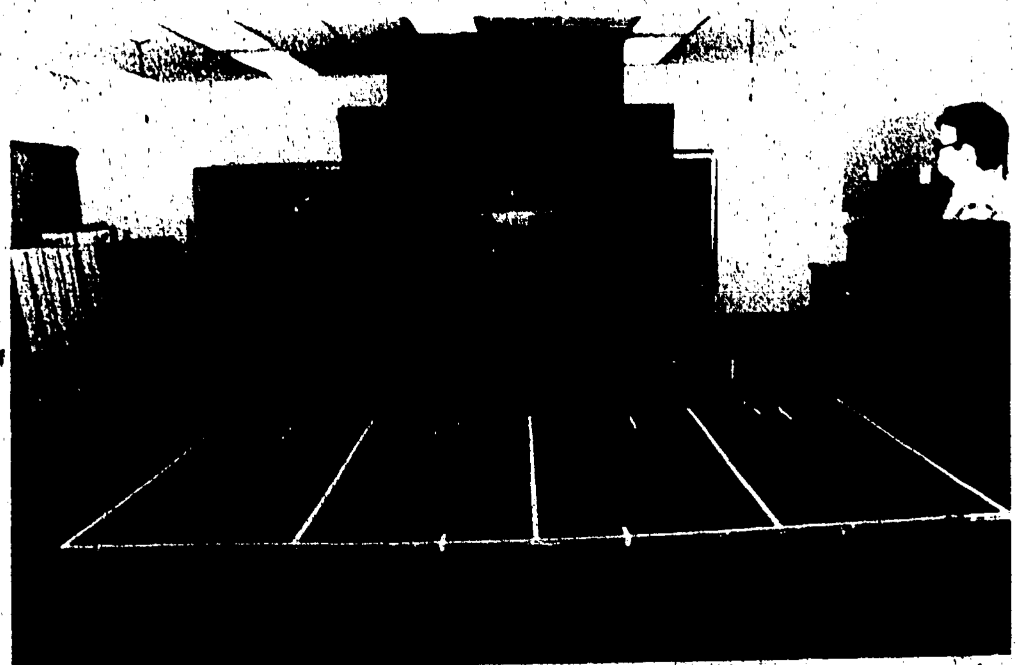

Figure 12. View of the display offered to the players during Experiment 2.

Figure 13. View of "Barbie" and its posture.

Procedure

Each condition had three major parts: (a) initial practice, (b) prediction period and, (c) play. During the practice part each player was taught the rules for a good return and was then allowed to practice returning 16 balls, all shot at the left-centre target. Immediately after the practice period, the player's understanding of the rules for a good return were assessed according to the procedure described in Experiment 1.

During the prediction period each player was trained to predict where the ball would land on the table without actually returning the ball with his or her bat. Before the experimental condition the players were told that Barbie could help them to guess where the ball would land and that they had two things to do: (a) look at Barbie, and then, (b) guess where the ball will land on the table. Before the control situation players who had done the experimental situation first were also told that Barbie could not help them to guess where the ball would land.

The players were next trained to predict where the ball would land on the table; this took from two to five blocks of 16 balls depending on the player's facility to make acceptable predictions before the delivery of the ball. At this stage, to ensure that the predictions trained with balls shot in 4 s interval. Due to the inability of subjects 20, 21, 24, and 27 to make their predictions within the time delay allowed, the time period between the landing of each ball was increased up to 10 s and then progressively reduced to the 4 s rate.

When the players were sufficiently trained, they were told that they could guess as many times as they liked before seeing the ball for only their last guess would count. To ensure familiarity with the requirements of the task, they then practiced on another block of 16 balls before the play part of the experimental sequence.

Before the experimental condition, players were told that they had three things to do: (a) look at Barbie, (b) say quickly where they guessed that the ball would land, and (c) then attempt to hit the ball with the bat, over the table-tennis net, such that the ball would land on the far side of the table. They were then asked to say verbally the three things they had to do; feedback was provided after each part of the response. They were also reminded that they could guess many times before the delivery of the ball and that only their last guess before seeing the ball would count. The instructions before the control condition were identical except that players were not instructed to look at Barbie.

forget" the nature of the task were reminded to "Look at Barbie" if in the experimental condition and to "guess" if they were too slow. If judged useful, between each block, subjects were reminded of the nature of the task and asked to say verbally the two or three things they had to do depending on whether they were in the control or the experimental condition. Feedback about the accuracy of their response was always provided.

The rest of the procedure and the design were the same as for Experiment 1. It took about two hours per subject to complete this experiment.

Coding, Interobserver Agreement, and Validity

One dependent variable was added to the ensemble used in Experiment 1: the predictions of the players were coded for each condition. Numbers 1, 2, 3, and 4 were coded respectively as category left, left-centre, right-centre, and right. For the rest of the coding, the system was identical to Experiment 1.

The method used to estimate the interobserver agreement and the validity of the coding were the same as for Experiment 1. The only difference was that, due to technical difficulties, estimates of interobserver agreement were not obtained from three of the 16 players participating in this experiment. Estimates of interobserver agreement ranged from 92.8% to 97.1% (see Table 17). The validity of the coding of the main and

Data Analysis

Forty-four trials out of 4096 were not considered for analysis in this experiment. The reasons for their rejection were (a) the player did not guess where the ball would land before the delivery of the ball; (b) the player's prediction was not audible; (c) an inappropriate prediction was made, e.g., they said "five", "six", or "nine"; and (d) equipment errors; the ball was not shot to the appropriate target five times in the experiment.

The method used to analyse the data in Experiment 1 was also used in this experiment except for some analyses based on the accuracy of the subject's predictions while in the experimental condition.

CHAPTER 6

Experiment 2

Results and Discussion

The results of this experiment will be presented in much the same manner as was done in Experiment 1. However, two changes must be noted. The first section will present the results of the ANOVAs completed on the data obtained during the prediction phase of this experiment. The second major change is related to the accuracy of the predictions of each subject during the experimental condition. The main reason for this change was to study the relationship between the degree of accuracy of the predictions and the appropriateness of the observed solutions. For this particular analysis, an index of accuracy of the predictions called del_p proposed by Hildebrand, Lang, and Rosenthal (1976, 1977a, 1977b) was calculated from the prediction data obtained from each subject during the experimental condition. The del_p values were then used to block the subjects into four homogeneous prediction groups. The prediction group factor was then considered a between subject factor in three-way ANOVAs with repeated measures on two factors (condition and landing target). The error terms obtained through these ANOVAs were then used for planned comparisons across conditions. Finally, whenever possible, a comparison and discussion of the results of Experiment 1 against the results of

Experiment 2 will be done.

Predictions

The results of the prediction data were analysed with four-way ANOVAs with repeated measures on two factors. As in Experiment 1, sex and IQ were the between subject factors while condition and landing target were within subject factors.

Left. As presented in Table 18, the ANOVA done on the frequency data indicating how often the players predicted that the ball will land on the left target showed a significant condition by landing target interaction, $F_{cons}(1, 12) = 30.82$, $p < .001$. As suggested by Figure 14, the results of Tukey HSD post-hoc analyses done across conditions indicated that these subjects were more accurate in their predictions during the experimental condition than during the control condition. On the average these players predicted that the ball would land more often on the left side target when in fact it did, and they also made fewer prediction errors when the ball landed on the two right side targets.

Left-centre. The four-way ANOVA done on the frequency data indicating how often the players predicted a landing of the ball on the left-centre target showed a significant condition by landing target interaction, $F_{cons}(1, 12) = 8.50$, $p < .05$, (see Figure 14 and Table 19). Subsequent post-hoc tests across

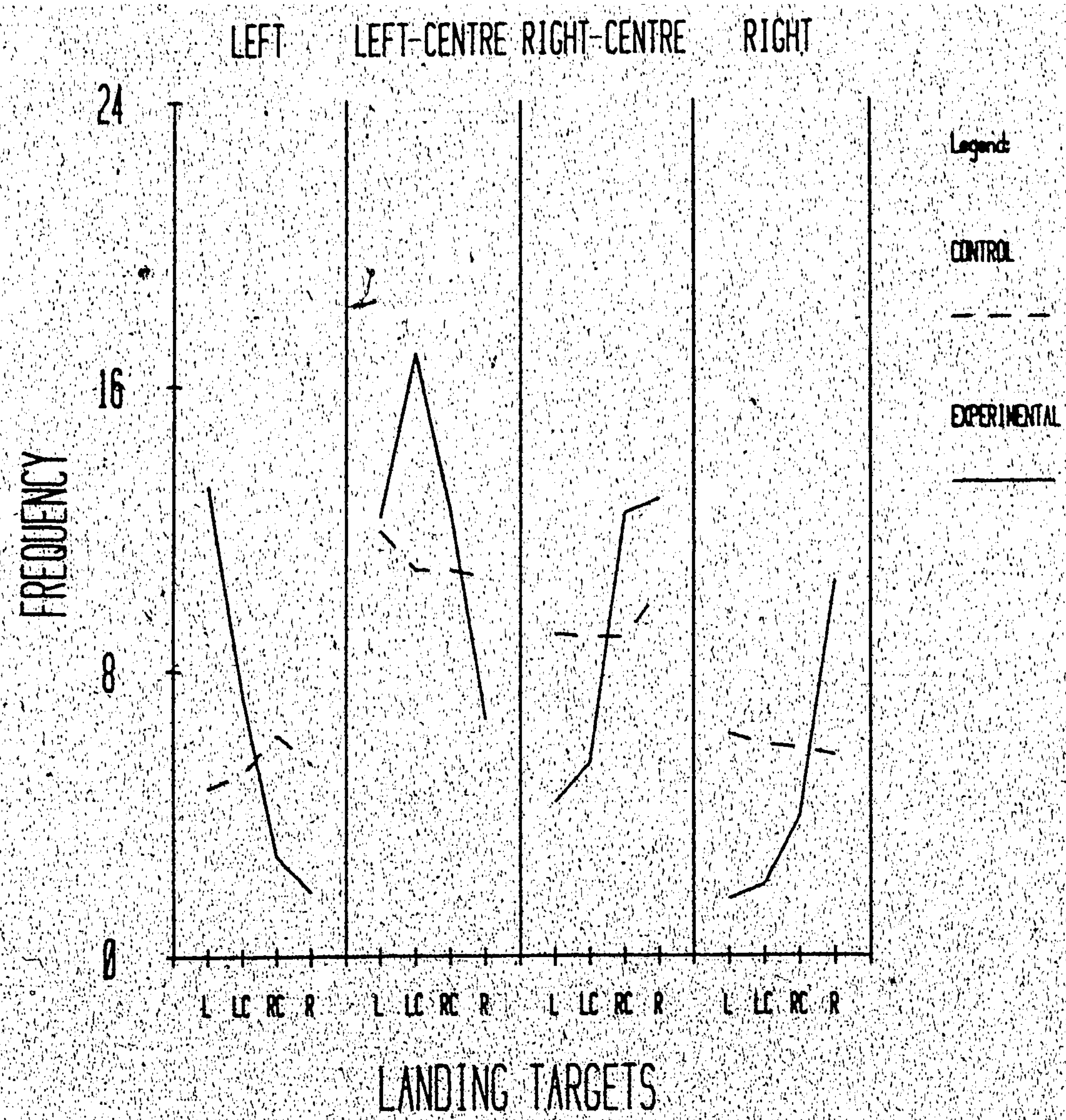

Figure 14. Average frequency indicating how often subjects predicted where the ball would land on each target as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

conditions showed that during the experimental condition, these players more often predicted that the ball would land on the left-centre target when it was landing there and they made significantly fewer prediction errors when the ball landed on the right target. As before, these results indicate that the players were more accurate in their predictions during the experimental condition.

Right-centre. As shown in Table 20, the analysis of the predictions that the ball would land on the right-centre target indicated a significant condition by landing target interaction, $F_{cons}(1, 12) = 11.47$, $p<.01$. As suggested by Figure 14, the post-hoc analyses done on the cell means of this interaction revealed that the subjects were again more accurate during the experimental condition than during the control situation. Compared to the control condition, the subjects predicted less frequently that the ball would land on the right-centre target when in fact the ball landed on the two left side targets and, conversely, they predicted more frequently that the ball would land on the right-centre target during the experimental situation when, in fact, the ball landed either on the right-centre or the right target.

Right. As suggested by Figure 14, the ANOVA done on the predictions that the ball would land on the right target resulted in another significant condition by landing target interaction, $F_{cons}(1, 12) = 14.36$, $p < .01$ (see Table 21). Comparisons across conditions using the Tukey HSD procedure showed that, during the experimental condition, these players predicted more often that the ball would land on the right target when in fact it did, and they less frequently predicted a landing of the ball on the right side target when the ball actually landed on either of the two left side targets. This again indicates that, on the average, the players were more accurate in their predictions during the experimental situation.

In summary, the above results indicate that the players, on the average, were better predictors during the experimental condition than during the control condition. This implies that they were able to use Barbie's rotation to gain some knowledge about the future landing location of the ball on the table. As will be shown later, this does not imply that all the players were better predictors during the experimental condition.

From the standpoint of this study, it was important to establish that the players were better predictors during the experimental condition; otherwise, the relationship between knowledge and the solution of movement problems could not have been studied.

To start the discussion of these results, it is useful to first do an analysis of the mover-environment relationship used in this study. To do the task during the control condition, the players had first to guess where the ball would land on the table and then attempt to hit the ball with the bat over the table-tennis net, such that the ball would land on the far side of the table. Although the subjects were forced to guess, no clues were given that would facilitate their prediction. As a consequence of this, the act of hitting the ball had to be based upon perception as well as anticipation of the spatiotemporal characteristics of the flight of the ball (Gentile, 1972; Keogh & Sugden, 1985). This implies that the players had to decide, during the flight of the ball, what type of response to use and when to initiate the response. Due to the nature of the experimental setting, feedback was available to the subjects approximately 500 ms after hitting the ball.

During the experimental condition, the players had to look at Barbie, guess where the ball would land, and then attempt to hit the ball. Clearly, the results showed that the subjects were, on the average, better predictors during the experimental condition than during the control condition. Based on our observations of the subjects reactions, these significant results were obtained through the conscious efforts of the subjects. Before the delivery of the ball, during the experimental condition, most subjects spent all the time available looking at Barbie and then guessed one or more times. Some subjects seemed to allocate all of their attention all of the time on Barbie: in fact they often constantly looked at Barbie and did not even try to track the flight of the projected ball. Thus it seemed they only used peripheral vision to hit the ball.[9] The main point here is that the attentional demands of the task prior to the projection of the ball were much greater during the experimental condition than during the control condition. Furthermore, for some subjects, after the projection of the ball, the tasks required divided attention (Kahneman, 1973; Schneider, Dumais, & Shiffrin, 1984): central vision was used to look at Barbie, and peripheral vision was used to obtain information about the flight pattern of the ball, anticipate its spatial-temporal characteristics, decide what type of stroke to use and when to initiate the response.

In summary, the type of strategy used by the subjects was beneficial in the sense that it allowed them to gain information about the future landing target area of the ball; on the other hand, relevant information during the flight of the ball was sometimes disregarded. As the task of hitting a ball requires the

[9]Unfortunately, the equipment used did not allow us to study the eye movements strategies used by the subjects. These comments are based on observations made by the experimenter during the experiment.

the ability to select and attend to relevant cues in the environment, it is unlikely that the gain of information about the future landing location of the ball, obtained by looking at Barbie, could compensate for the loss of specific information about the flight of the projected ball. More will be said later about this point.

Now that it has been established that the players were better predictors during the experimental condition, the reader is invited to look at its effect on the player's position before the projection of the ball.

Body, Shoulder, and Bat

Left. The frequency data indicating how often the body, the shoulder, and the bat were behind the left side of the table were analysed, as in Experiment 1, with four-way ANOVAs with repeated measures on two factors. These analyses revealed significant condition by landing target interactions for the body, $F_{cons}(1,12) = 22.97$, $p<.001$, the shoulder $F_{cons}(1, 12) = 23.97$, $p<.001$, and the bat, $F_{cons}(1, 12) = 25.08$, $p<.001$ (see Tables 22, 23, and 24).

The Tukey HSD tests completed across conditions on the cell means of the condition by landing target interactions presented in Figure 15, revealed that the body, the shoulder, and the bat were more frequently behind the left side of the table, during the experimental condition, when the ball landed on the left

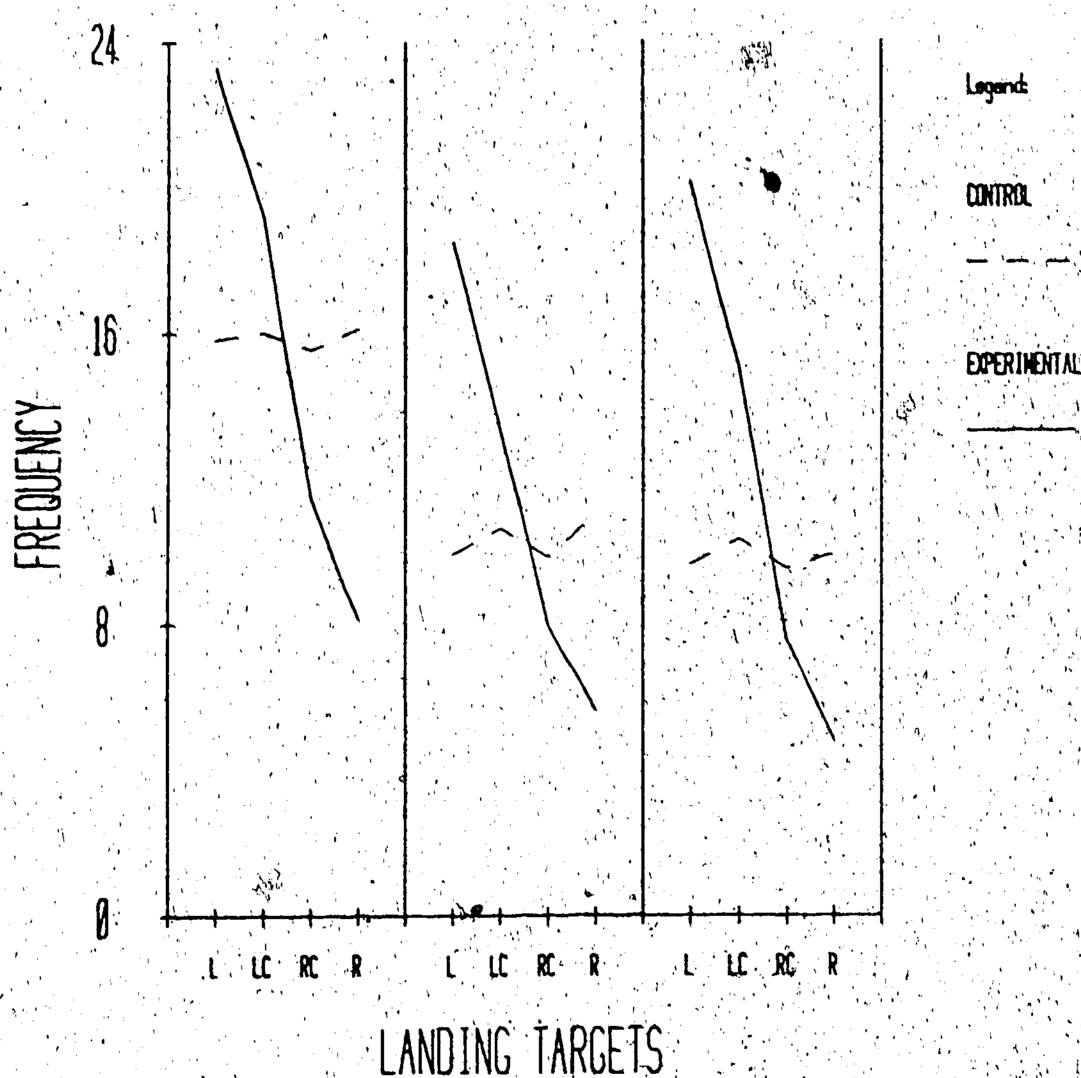

Figure 15. Average frequency indicating how often the body, the shoulder, and the bat were behind the left side of the table during Experiment 2, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

table when th ball landed on the right target. This pattern of results, similar to those obtained in Experiment 1, indicates that the players used the knowledge gained by observing Barbie to select a closer position to return the ball during the experimental condition.

Centre. As shown in Tables 25, 26, and 27, the ANOVAs done on the frequency data indicating how often the body, the shoulder, and the bat were behind the centre of the table revealed that the usually significant condition by landing targets interaction was significant only for the body, $F_{cons}(1, 12) = 6.77$, $p<.05$, and the bat, $F_{eps}(2, 30) = 4.74$, $p<.05$. Tukey post-hoc tests completed across conditions on the cell means of the condition by landing target interactions presented in Figure 16, revealed that the body was less frequently behind the centre of the table when the ball landed on the left target during the experimental condition. Similar comparisons done on the bat data revealed that this implement was less frequently behind the centre of the table during the experimental condition when the ball landed on the two outside targets.

Right. As shown in Tables 28, 29, and 30, the ANOVAs done on the frequency data indicating how often the body, the shoulder, and the bat were behind the

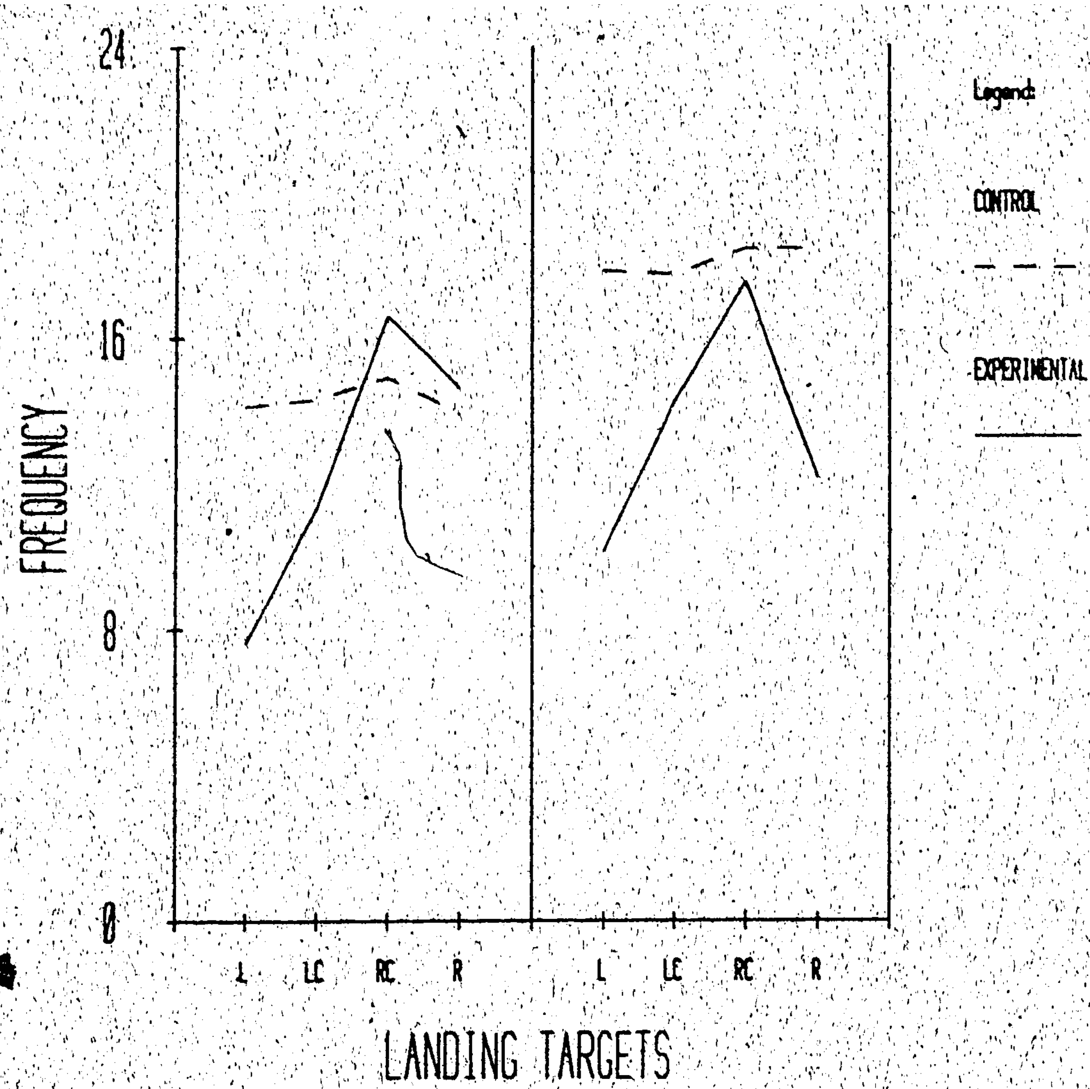

Figure 16. Average frequency indicating how often the body and the bat were behind the centre part of the table during Experiment 2, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

significant condition by landing target interaction for the body, $F_{cons}(1, 12) = 9.91$, $p<.01$, the shoulder, $F_{cons}(1, 12) = 20.75$, $p<.001$, and the bat, $F_{cons}(1, 12) = 28.64$, $p<.001$. As suggested by Figure 17, the post-hoc tests done across conditions in the condition by landing target interaction indicated that the body was more frequently behind the right side of the table during the experimental situation when the ball landed on the right target. Indentical comparisons done on the cell means of the shoulder data indicated that the shoulder was more frequently behind the right side of the table during the experimental condition when the ball landed either on the right centre or the right target (see Figure 17). Furthermore, identical comparisons on the cell means of the bat data indicated that the bat was less frequently behind the right side of the table during the experimental situation when the ball landed on the left target and more frequently behind the right side of the table when the ball landed on the two rightmost targets (see Figure 17).

Overall, the results of Experiment 2 show that the declarative knowledge about the future landing location of the ball on the table was used to select a position closer to the future trajectory of the ball to return it. These results are, in a sense, a replication in a different movement situation, of the results obtained in

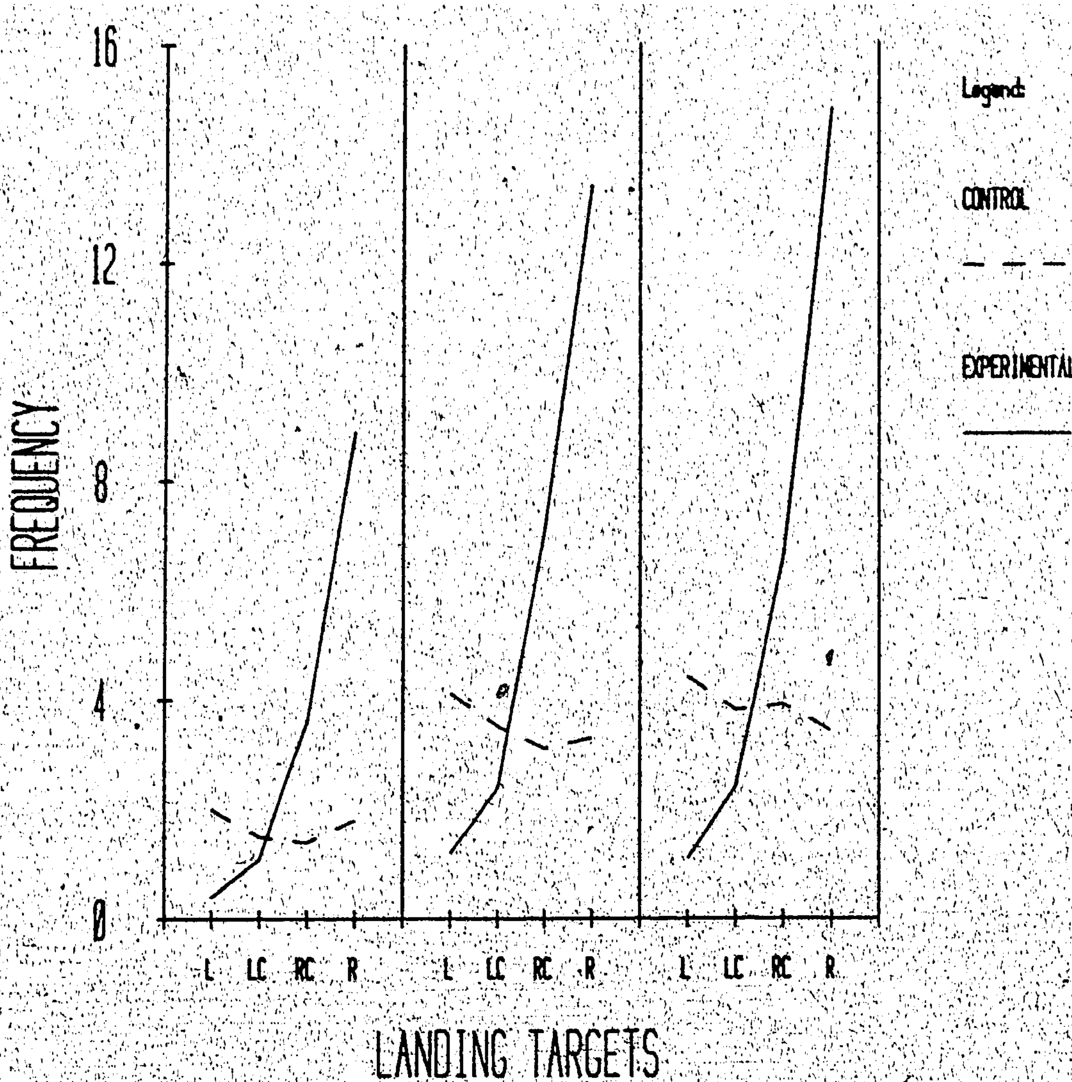

Figure 17. Average frequency indicating how often the body, the shoulder, and the bat were behind the right side of the table during Experiment 2, as a function of condition and landing target area (L: Left; LC: Left-Centre; RC: Right-Centre; R: Right).

will not be replicated here. Instead, some of the differences between the results of the two experiments will be highlighted.

A comparison of Figures 4 to 9 and 15 to 17, show that the players did not select as frequently a position closer to the future landing area of the ball during the experimental condition of Experiment 2 when the ball landed on the left or the right target. As Figures 5 and 16 show, the players stayed more frequently behind the centre of the table during the experimental condition of the second experiment when the ball landed on the left or the right target.

Although we do not know exactly how these decisions were made, they were appropriate in each movement situation. The relative inaccuracy of the declarative knowledge was, most likely, taken into account by the players during both conditions of the first and the second experiment. The subjects, as a group, applied different rules during both experiments. These rules can be represented by theoretical constructs call production systems (Anderson, 1982, 1985; Newell & Simon, 1972). Productions are condition-action rules which specify what act should occur and when that act should occur (e.g., if a set of conditions are met, then do such and such).

The rules or strategy used by the players during categories: absence of preparation for one particular event, total preparation for one particular event, and biased preparation for one particular event. An example of absence of preparation for one particular event was given by the control condition in both experiments. The players, as a group, used a rule of the form:

> P1: IF you play table-tennis and your goal is to hit the ball and you do not know where the ball is going to land
> THEN stay behind the centre part of the table.

An example of a total preparation strategy for one particular event was given during the experimental condition of Experiment 1, when all but one subject applied the following rule:

> P2: IF you play table-tennis and your goal is to hit the ball and you know where the ball will land and you detect that you are far from the future landing location of the ball
> THEN move your body into the vicinity of the future location of the ball.

Finally, an example of biased preparation for one particular event was given by the subjects during the experimental condition of Experiment 2. Although this rule is more complex to infer, it can be represented as:

> P3: IF you play table-tennis and your goal is to hit the ball and you can predict rather well

you are far from the predicted future
location of the ball

THEN move your body toward the anticipated
location of the ball but make sure that you
can recover from errors of anticipation.

It must be noted that the above rules are only general: the condition part of the productions are likely to be more complex than P1, P2, and P3 described above. The condition part of each production is most likely a function of the experience of the player, his knowledge, beliefs, personality, the type of task, the social context, the motivation of the subject, as well as the feedback received (Cavanaugh, Kramer, Sinnot, Camp, & Markley, 1985). Futhermore, P1, P2, and P3 are based upon average group behavior. They are somewhat analogous to an ANOVA in the sense that they represent a central tendency across people but they are not necessarily applicable to each individual. More will be said about this when we will consider the accuracy of the predictions of each of the subjects and its effect on the position selected behind the table before the projection of the ball.

The fact that different solutions (rules) were spontaneously used by the players under different movement situations underlies the player's sensitivity to the movement context. This makes plausible a certain number of inferences: (a) the players were able to characterize the current problem, (b) they were aware of the subroutines available, (c) they were able to recognize their limitations in relation to the task and the environmental conditions (Campione & Brown, 1977) and, (d) they were able to select and use more appropriate subroutines. Stated another way, we argue that these results reflect conscious metacognitive knowledge and skills of the players in a racquet sport situation. If the players had not been aware of their own limitations as well as the spatial and temporal constraints of the task, the environmental conditions, and the subroutines available then they can hardly be expected to modify their behavior across settings (Campione et al., 1982). Furthermore, the orchestration of different subroutines across settings underlies their metacognitive skills about action (Wall et al., 1985).

For now, we turn to the results and discussion of the number of balls hit.

<u>Balls Hit</u>

As in Experiment 1, a five-way ANOVA was done on the number of balls hit. The between subject factors included in this analysis were sex, IQ, and order of the conditions while the within subject factors were condition and landing target area. This analysis, presented in Table 31, revealed a significant four-way interaction of IQ by order by condition by landing [illegible] eps [illegible] A visual inspection of Figure 18 suggested the possible reasons for this four-way interaction. As the reader may note by looking at the results for the left target, the lines for the low IQ groups are almost parallel while the lines for the high IQ groups diverge. For the two right side targets, the lines for the high IQ groups are almost parallel while the lines for the low IQ groups now, in fact, diverge; this is exactly the opposite of what was observed for the left target. Quite simply, this visual analysis suggested that difference of differences in slopes involving the left target and the two rightmost targets was the reason for this significant four-way interaction. This hunch was followed up by four-way interactions post-hoc tests. For each of these tests, all the levels of the IQ, order, and condition factors were included in each analysis, but only two levels of the landing target factor were considered at each time. Of these six tests, only the IQ by order by condition by landing target interaction L against RC, $F(1, 8) = 6.65$, $p<.05$, and L against R, $F(1, 8) = 8.42$, $p<.05$, were significant and supported the hunch obtained through visual analysis. In plain words, a description of what happened is this: for the ball landing on the left target the difference between the number of balls hit during both conditions is about the same for the low IQ groups whatever the order of the conditions; however,

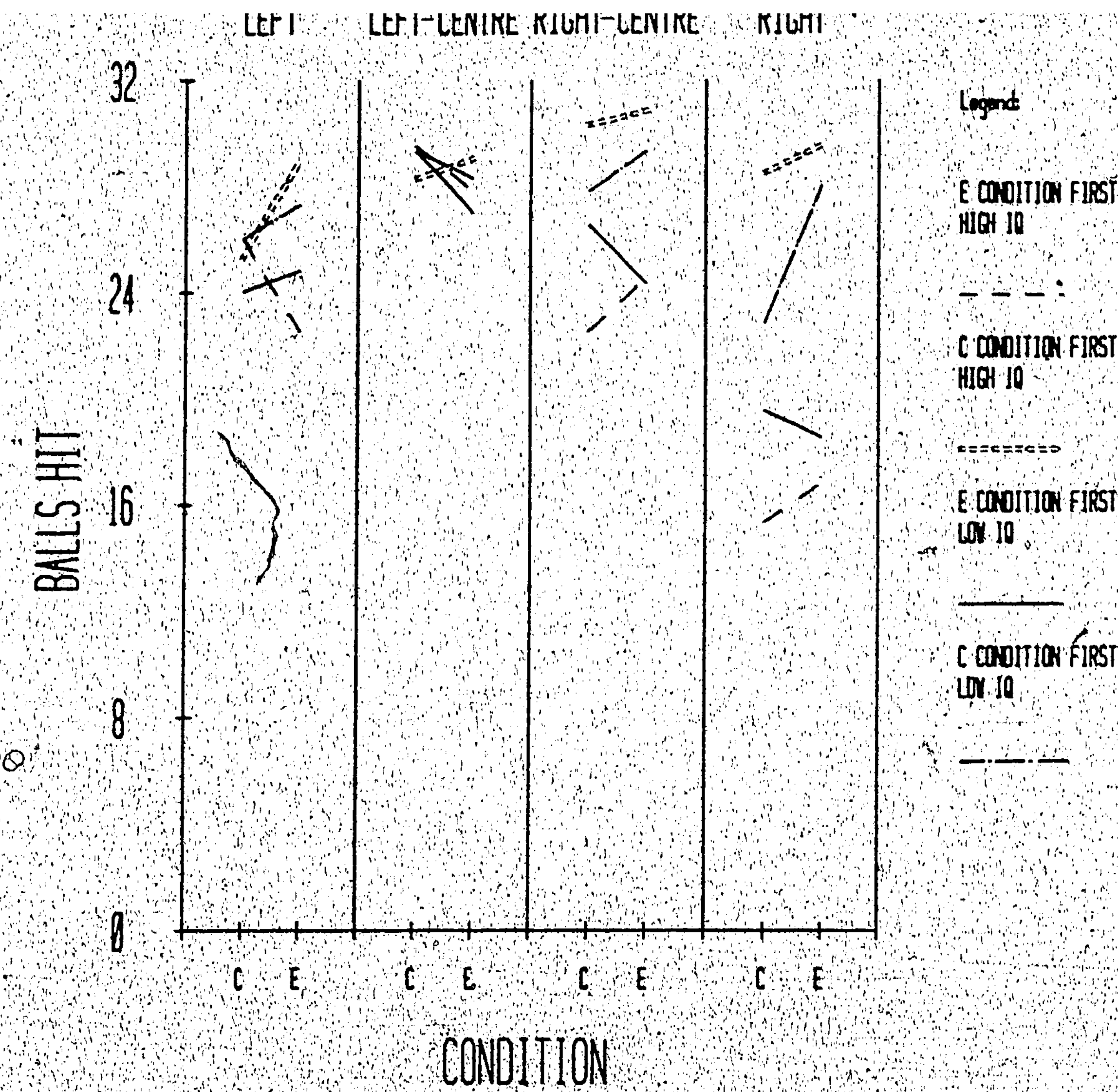

Figure 18. Number of balls hit during Experiment 2, as a function of landing target area, IQ, order, and condition (C: Control; E: Experimental).

these differences are not the same for the high IQ groups. The converse is true for the two rightmost landing targets: the difference between the number of balls hit during both conditions is about the same for the high IQ groups whatever the order of the conditions, however, these differences are not equal for the low IQ groups. Furthermore, the Tukey HSD tests done across conditions revealed only one significant difference: the low IQ group who did the control condition first hit more balls during the experimental condition when the ball landed on the right target. No other differences reached a statistically significant level.

Overall, the above results indicate that, although the players had a better idea about where the ball would land during the experimental condition, the subjects were not able to use this information to more frequently hit the ball. These results are slightly different from those obtained in Experiment 1 where it was found that (a) the high IQ groups hit more balls during the experimental condition when the ball landed on the left and right-centre target and (b) when we argued that a ceiling effect might be responsible for the lack of significant differences when the ball landed on the left-centre and the right target.

As mentioned earlier, the attentional demands during the experimental condition were higher than during the control situation. The subjects allocated their attention mainly to the prediction part of the task. As a consequence of this, they did not carefully track the ball and, most likely, did not have enough attentional capacity available (Kahneman, 1973) to select and execute the response, as well as process the feedback resulting from the act of hitting the ball. In brief, the increased attentional demand combined with the relative lack of movement consistency (Keogh & Sugden, 1985; Marteniuk & Romanow, 1983) discussed earlier could explain the lack of significant improvement.

At this moment in the discussion, it is important to underscore that the movement situation used in this experiment was, most likely, new to the players. In fact, all the players were questioned about their level of experience as a table-tennis player prior to this experiment. Two players (subjects 19 and 31) said that they had been playing this sport on a regular basis during the last year, and five players (subjects 20, 21, 25, 28, and 29) had already played table-tennis earlier in their life. Furthermore, nine players had never played this game before the experiment. So, we argue that being forced to look at Barbie, guess where the ball will land, and hit the ball was, most likely, a new movement situation for the players.

This implies that most players were either in the cognitive or associative (Fitts & Posner, 1967) phase of movement skill acquisition. For most, if not all players, the autonomous phase was not reached yet. During the early (cognitive) phase of skill acquisition the learner is generally concerned with some very specific, cognitively oriented problems (Anderson, 1982; Fitts & Posner, 1967; Magill, 1985). This phase is characterized by a large number of errors and high performance variability. Moreover, although beginners may know that they are doing something wrong, they generally do not know what should be done to solve the movement problem (Anderson, 1982; Fitts & Posner, 1967; Magill, 1985). During the associative phase, the number of errors is reduced and performance variability has decreased. Typically, the performer is more aware of errors produced and can use this information to implement a solution to solve the movement problem. Finally, with a tremendous amount of practice, the autonomous phase of skill acquisition is reached. Here, the movement skill has become almost automatic and habitual; some attentional capacity is available so that the performer can usually attend to other aspects of the movement situation that will permit optional performance.

Consequently, we argue that the players were simply overloaded by the amount of information to be processed during this experiment. Confronted by this problem, most players spontaneously allocated all of their attention capacity available to the prediction part of the task. Hence, they did not carefully track the ball and important regulatory stimuli (Gentile, 1972) useful to hit the ball were disregarded.

It is usually accepted that as humans practice movement skills, less and less attentional capacity is required for the same level of performance and a better allocation of processing resources is made (Wickens & Benel, 1982). So, different results might be obtained with mentally retarded adolescents that have more experience with this type of task. In this context, the declarative knowledge about the future landing location of the ball obtained by observing Barbie might help to more efficiently hit the ball across the table. An empirical answer to this hunch awaits further studies.

<u>Prediction Accuracy of Each Subject</u>

An important aspect of this project was to determine the degree of accuracy of the declarative knowledge of each subject about the future landing location of the ball on the table. It was expected that only players that were able to predict relatively accurately the place where the ball would land might use this information more efficiently to select a closer position behind the table to return the ball.

As the type of analysis used to determine the prediction accuracy of each subject is not frequently used, the next few pages include relatively more details than is usually given in a research report.

To facilitate communication, let X be a discrete random variable that represents the place where the ball landed, and Y be a discrete random variable that represents the prediction of a subject. Furthermore, let P be the proposition made by a researcher that a subject is a perfect predictor. To check the accuracy of P, the researcher analyses a contingency table that includes both X and Y. If P is true, then the contingency table must have non-zero values only in the main diagonal and zeros elsewhere. Non-zero values observed out of the main diagonal would contradict the proposition that P was a perfect predictor. Stated another way, the conditional probability of Y given X must equal 1 for cells in the main-diagonal and 0 elsewhere. In other words, if P is true, then the prediction success of P should be better when the investigator knows the location of the independent variable X, rather than having only the unconditional probabilities of the various independent states.

Furthermore, in the case of this experiment, some prediction errors are more serious than others. For example, it is a relatively more serious error if a player predicts that a ball will land on the left target when, in fact, it lands on the right target than predicting that the ball will land on the left target when, in fact, it lands on the left-centre target.

Hence, the performance is more seriously impaired the greater the difference between prediction and landing area of the ball.

In agreement with the above rationale, the statistic del_p proposed by Hildebrand, Lang, and Rosenthal (1976, 1977a, 1977b) was used to assess the prediction accuracy of each subject. This measure of proportional reduction in error is defined as:

$$del_p = 1 - \frac{\sum_{i=1}^{R} \sum_{j=1}^{C} w_{ij} \; P_{ij}}{\sum_{i=1}^{R} \sum_{j=1}^{C} w_{ij} \; P_{i.} \; P_{.j}}$$

Where: w_{ij} : error weights

P_{ij} : the probability of an observation in cell ij

$P_{i.}$: the marginal probability of row i

$P_{.j}$: the marginal probability of column j

The error weights used for this analysis are presented in Table 32, and reflect the rationale presented earlier.

The predictions of each subject as a function of the landing area of the ball on the table during the experimental condition were cross-tabulated and the del_p statistic calculated for each of these contingency tables. The results of this process are shown in Table 33. While looking at this table, the reader is reminded that values close to 1 support the proposition P that a player is a perfect predictor, while values close to 0 do not support P. As the reader can see, these results suggest the existence of a relatively heterogeneous population: the accuracy of the declarative knowledge about the future landing of the ball on the table ranged from 0.04 to 0.70.

The results of this subject by subject analysis again underscore that measures of central tendency are not always good descriptors of each member of the population. The reader is reminded that, at the beginning of this chapter, it was found that the players were, on the average, better predictors during the experimental condition. However, the del_p results show us that this superiority during the experimental condition was not due to better prediction accuracy of each of the subjects.

These results indicate that within this population, some people have much better perceptual ability than others. What could account for these findings? In an attempt to answer this question, the square multiple correlation using del_p as criterion and sex, IQ, and order as predictors was calculated. The obtained value ($R^2 = 0.212$) was not statistically significant, $F(3, 12) = 1.08$, $p>0.25$. This indicates that, within the population studied, the predictors used cannot accurately estimate the criterion. The small R^2 value obtained suggests that factors not included in the above analysis are likely to account for a large portion of the observed variance in the prediction accuracy that was observed. In brief, further studies are needed to determine the reasons for these individual differences.

As mentioned earlier, it was expected that only players who were able to predict relatively accurately the landing location of the ball would use this information to select a better position from which to return the ball. To test for this prediction, the subjects were blocked into four relatively homogeneous groups according to the del_p values obtained. The four best predictors were included in the first group, the next four best predictors were included in the second group, and so on. For communication purposes, these groups were labeled very good predictors (VGP), good predictors (GP), bad predictors (BP), and very bad predictors (VBP).

To test for our expectations, we used planned comparisons that compared the values obtained by each group during both conditions for each landing target area of the ball on the table. Due to the large number of comparisons done, we followed the advice given by Kirk (1982, p. 106) to use a rather conservative test. The Tukey HSD test was selected for this purpose. The error terms used for these tests were obtained through the completion of nine three-way ANOVAs with prediction group serving as the between-subject factor and condition and landing target as within subject factors. These ANOVAs were completed on the frequency data indicating how often the body, the shoulder, and the bat were behind the three areas of the table. The summary of these nine ANOVAs are presented in Tables 34 to 42. The pooling precedure and the determination of the degrees of freedom associated with the studentized range statistic were both done according to the rules described in Chapter 3.

The cell means for each group as a function of condition and landing target area of the ball on the table are presented in Figures 19 to 27. To facilitate the assimilation of the important information, Table 43 shows which Tukey tests were declared significant for each dependent variable as a function of prediction group and landing target area of the ball. An inspection of Table 43, revealed that the Tukey HSD reached a statistically significant level 11 times for the very good predictors group and 15 times for the group of good predictors. On the other hand, the bad predictors group had only three significant differences and, more importantly, no significant differences were observed for the very bad predictors group. Furthermore, inspection of the cell means for the left and right target areas presented in Figures 19 to 27, show that each time the Tukey test was declared

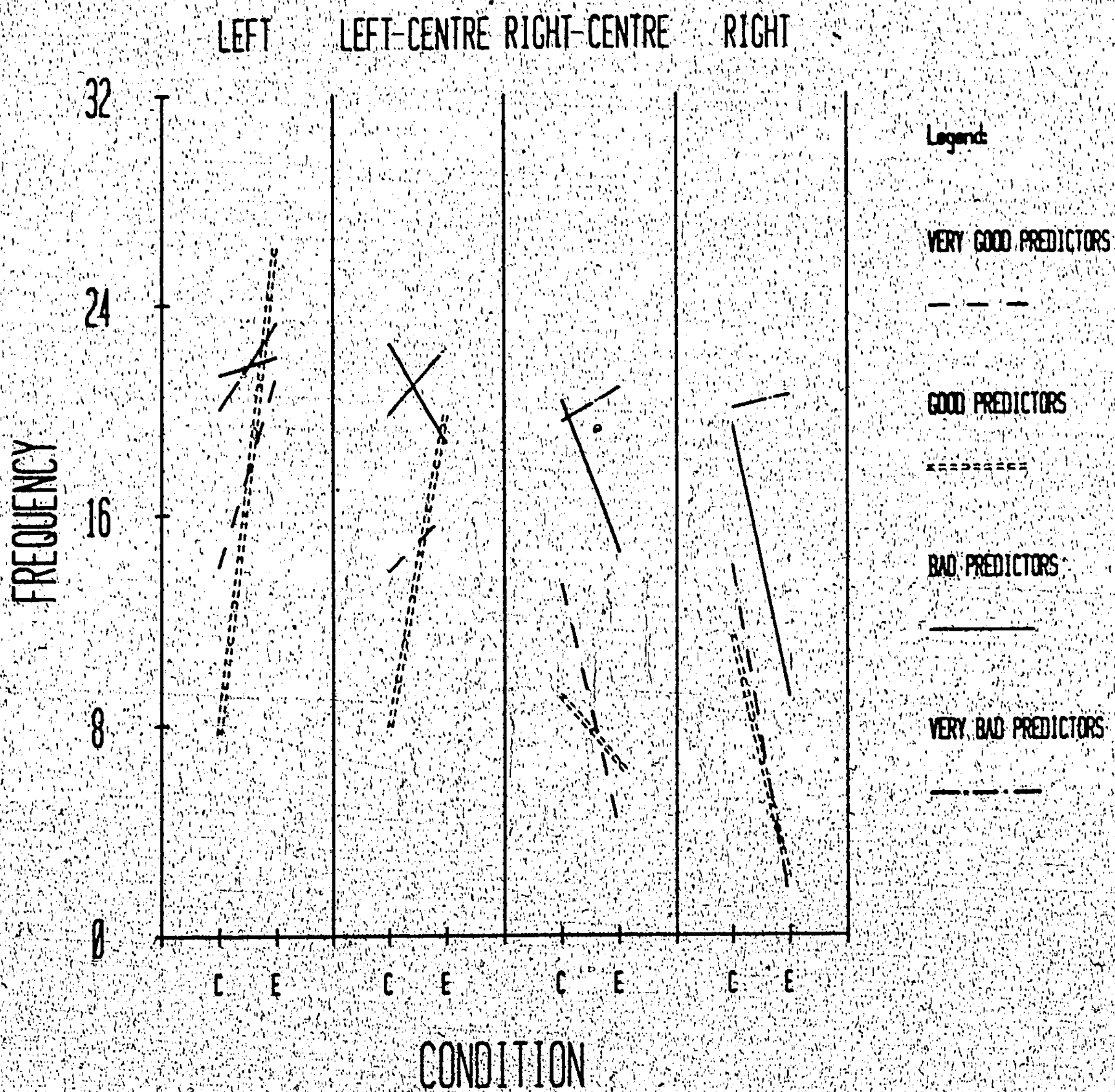

Figure 19. Average frequency indicating how often the body was behind the left side of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

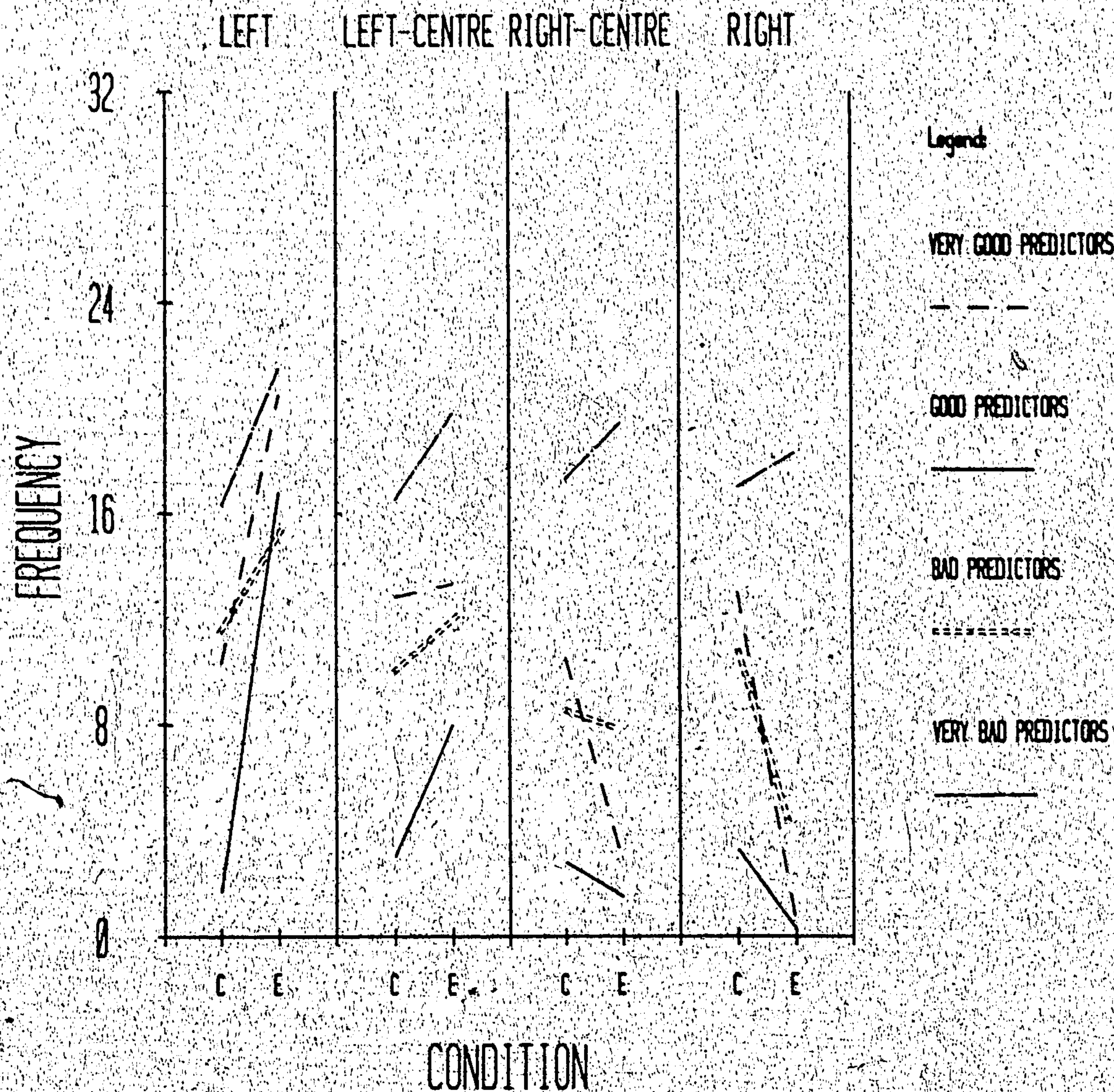

Figure 20. Average frequency indicating how often the shoulder was behind the left side of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

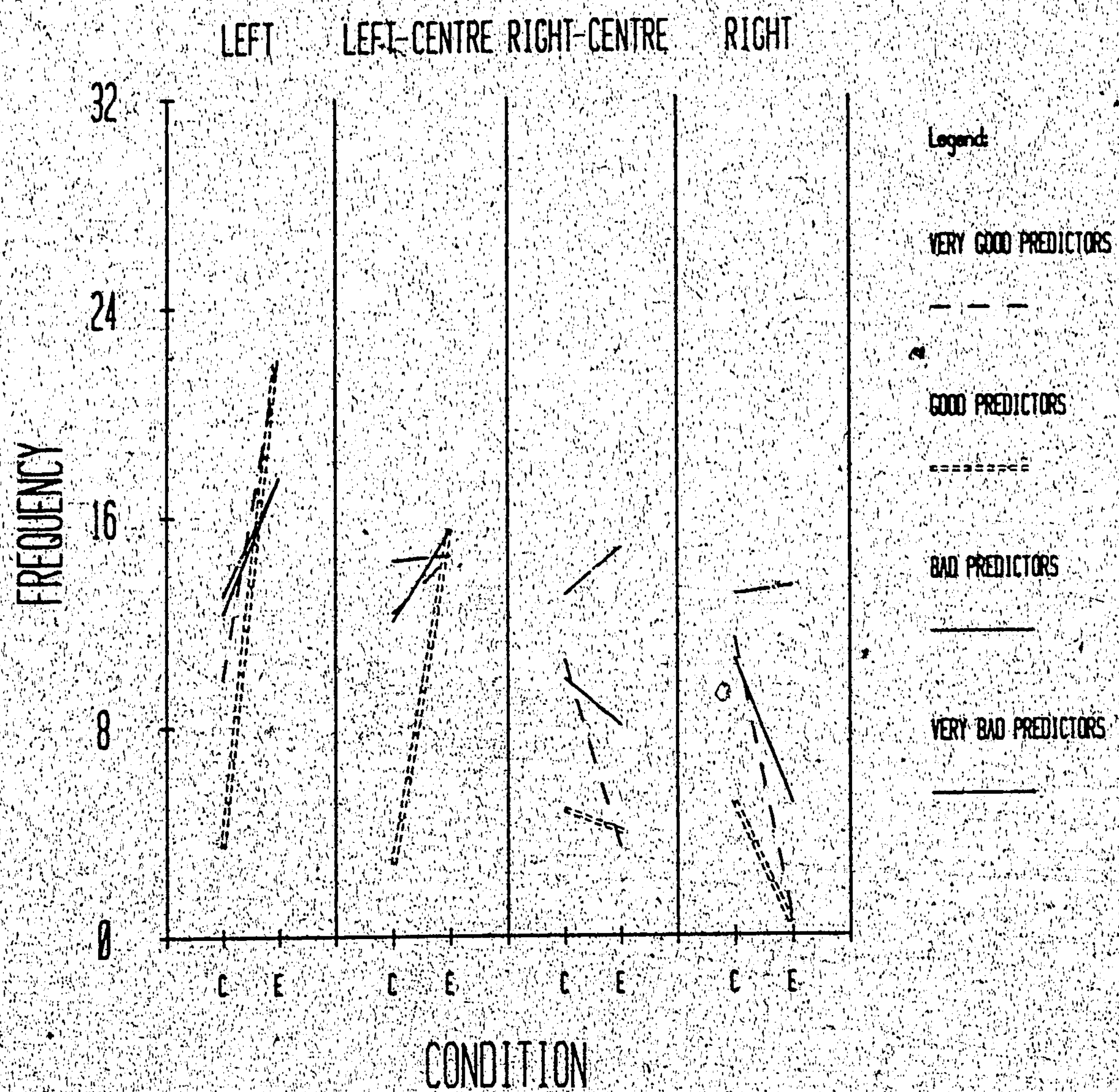

Figure 21. Average frequency indicating how often the bat was behind the left side of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

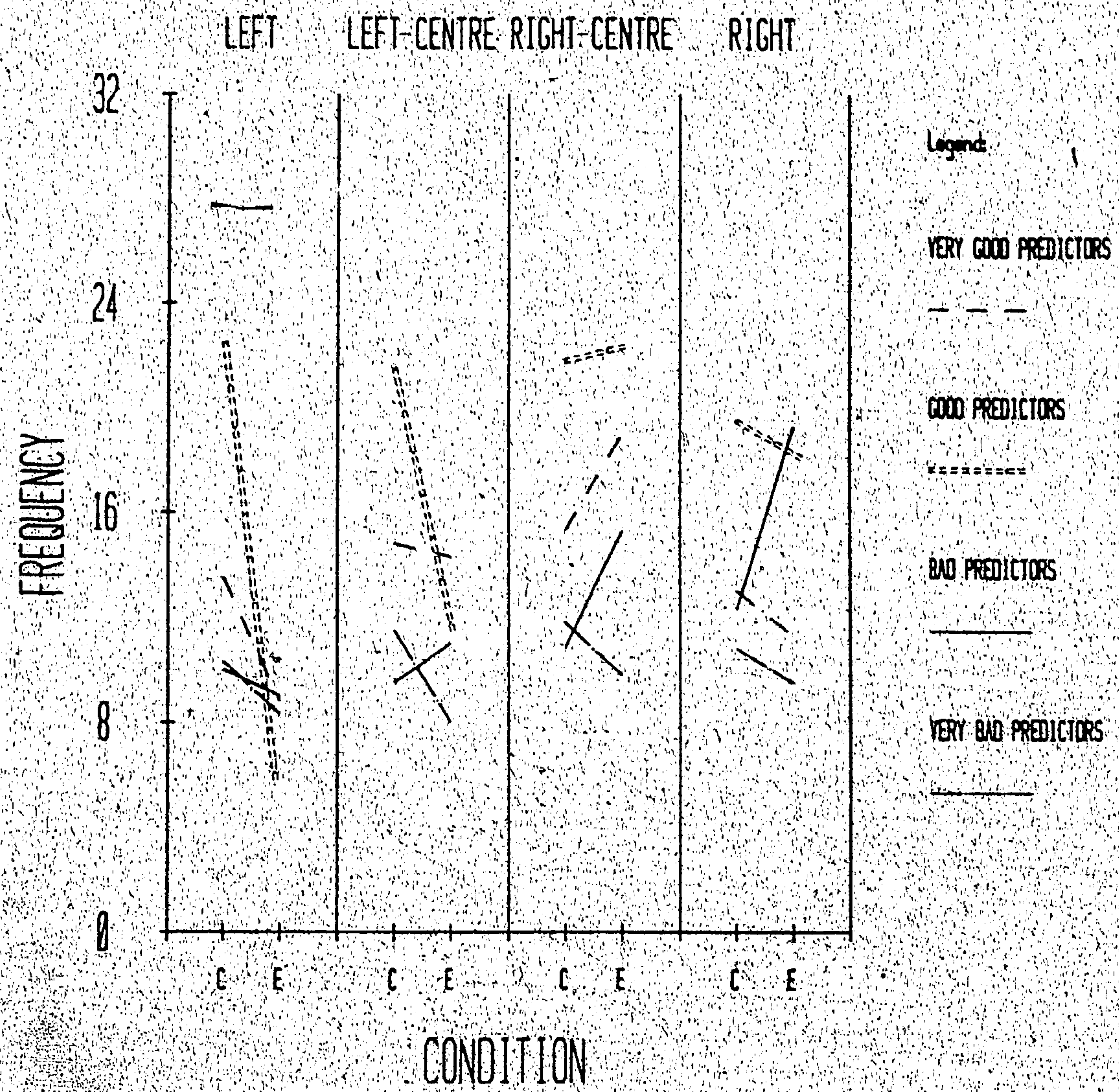

Figure 22. Average frequency indicating how often the body was behind the centre of the table during Experiment 2, as a function of landing target area, *group*, and condition (C: Control; E: Experimental).

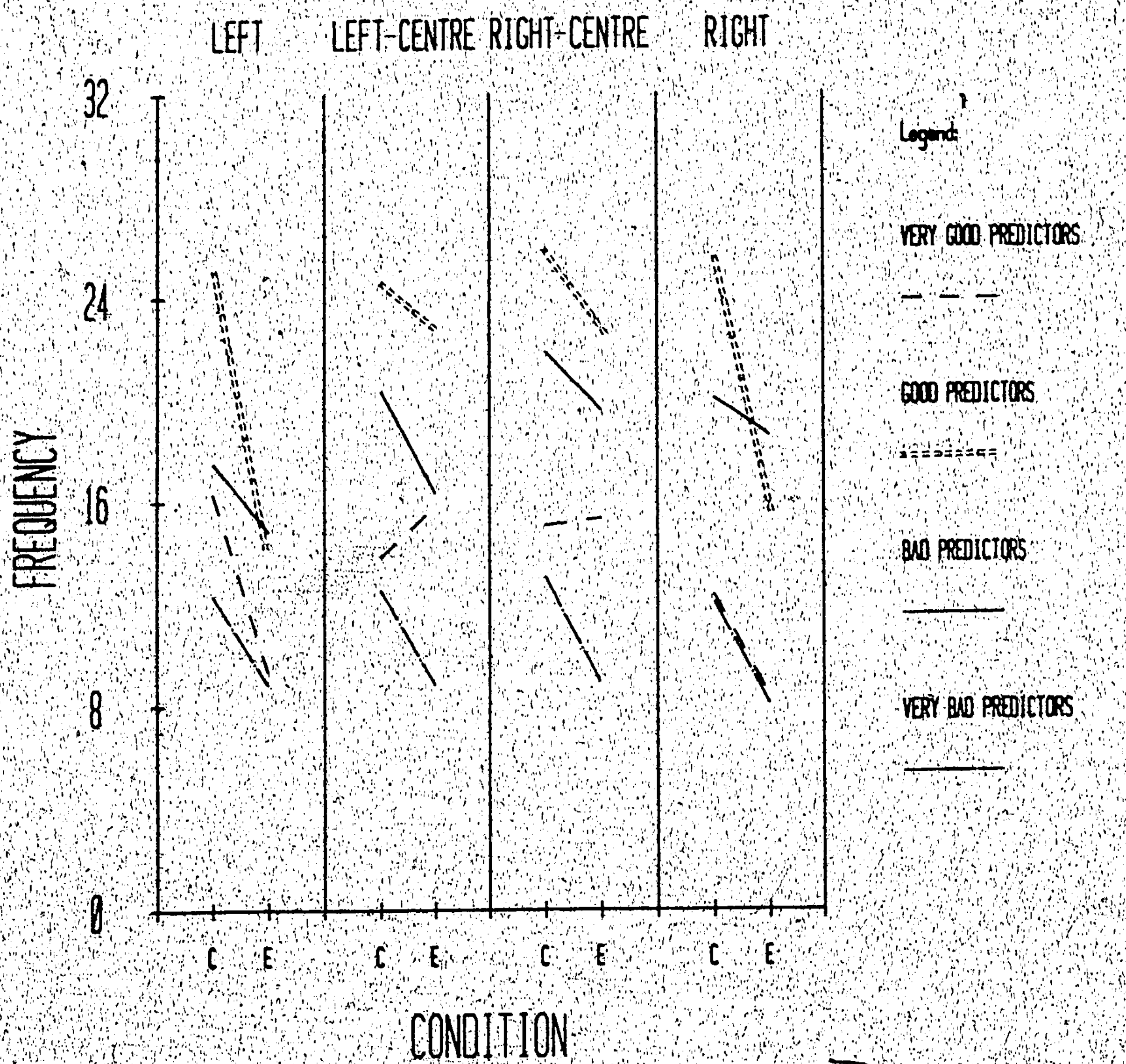

Figure 23. Average frequency indicating how often the shoulder was behind the centre of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

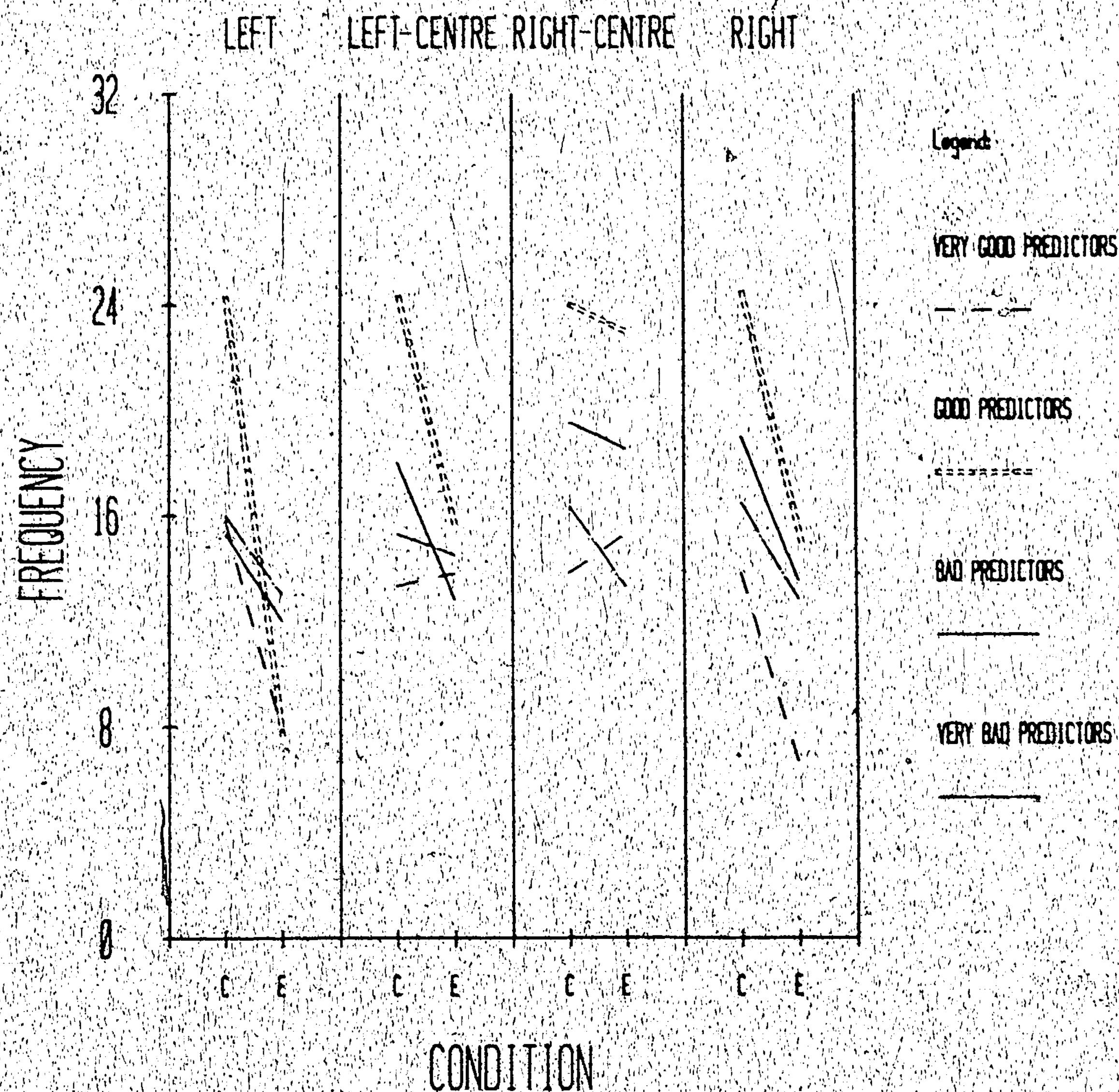

Figure 24. Average frequency indicating how often the bat was behind the centre of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

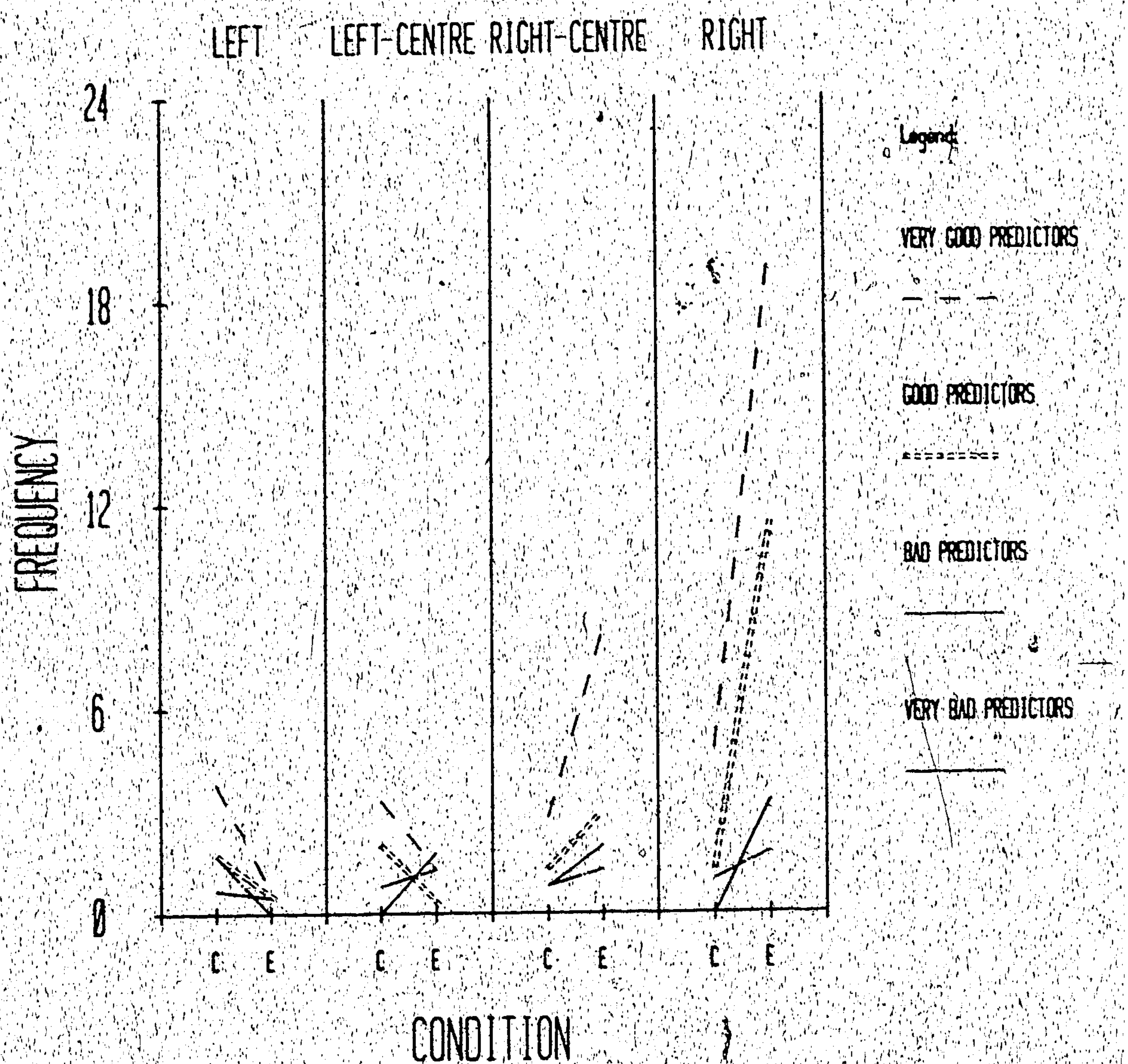

Figure 25. Average frequency indicating how often the body was behind the right side of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental)

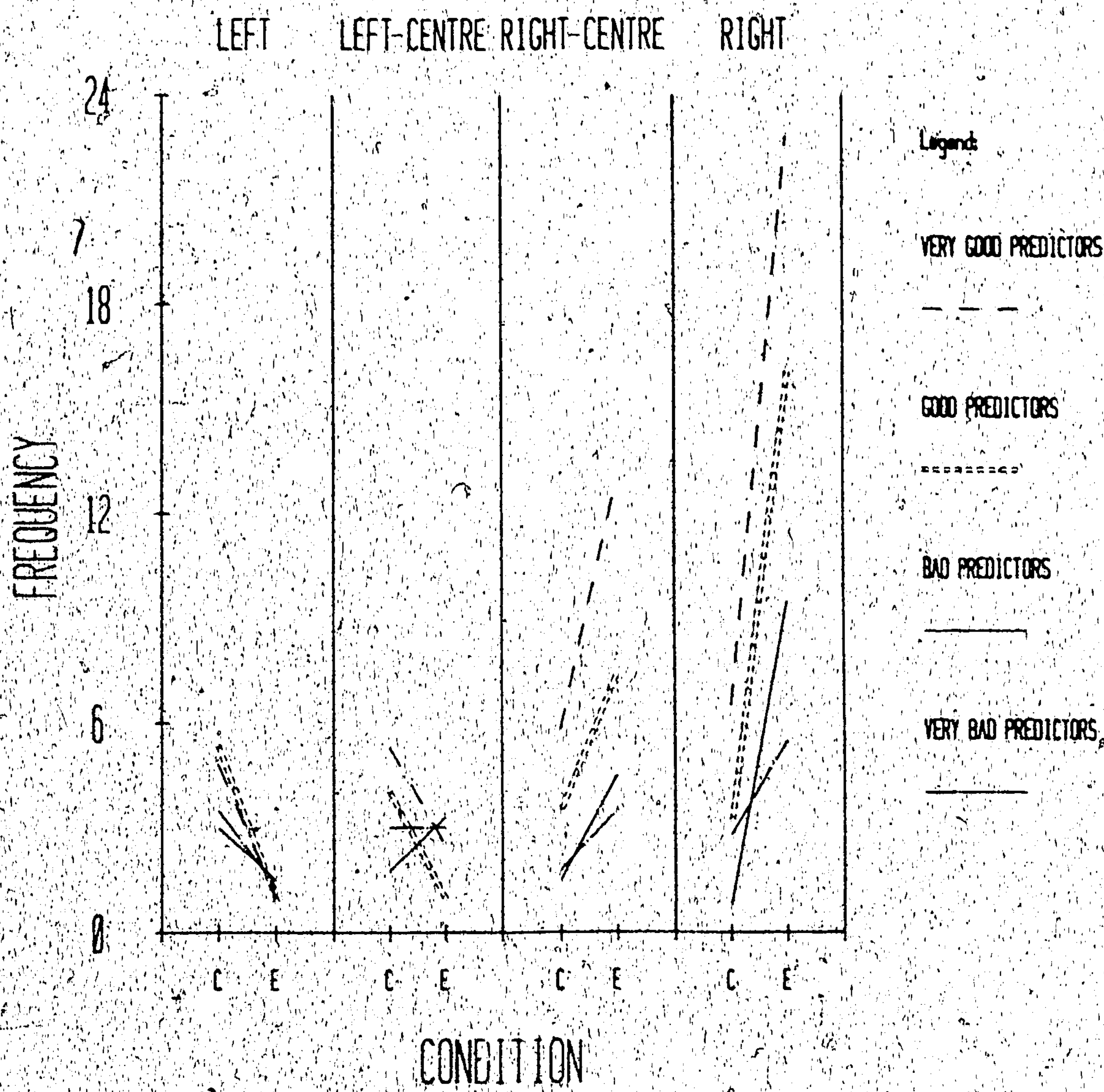

Figure 26. Average frequency indicating how often the shoulder was behind the right side of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

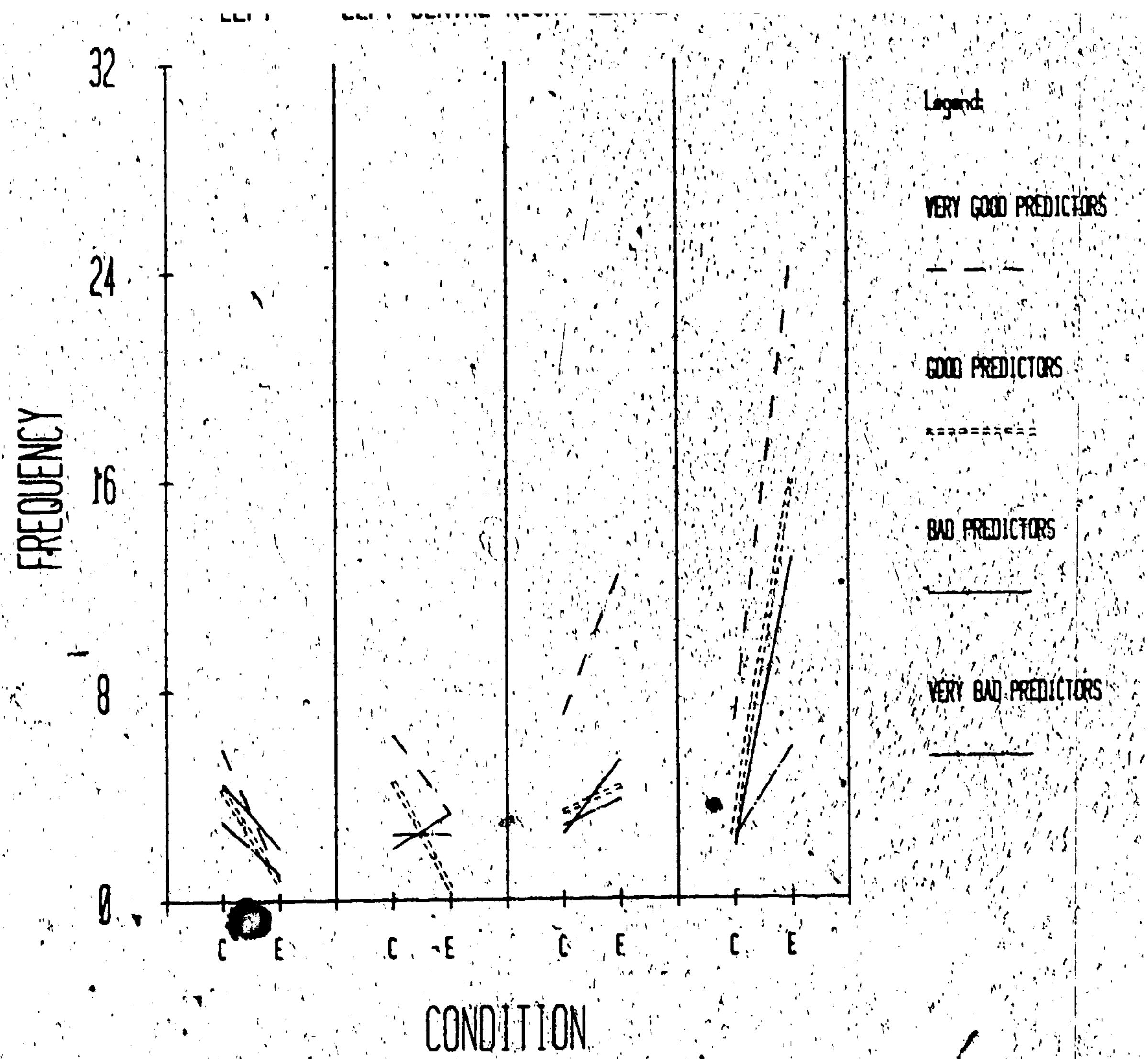

Figure 27. Average frequency indicating how often the bat was behind the right side of the table during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

closer to the future landing area of the ball on the table during the experimental condition.

These results, combined with those of Experiment 1, do not only suggest that this population could, on the average, use a priori information to select a better position behind the table to return the ball, but that the accuracy of the declarative knowledge is essential to the intelligent use of this information. Quite simply, the positioning strategy used by the players is a function of knowledge (Wall et al., 1985).

Now that all the results related to the positioning of the players before the projection of the ball have been presented, it is appropriate to do an overall summary and discussion of these results. Briefly, in the first experiment, all but one subject used a priori information about the future landing location of the ball on the table to select a closer position to return it during the experimental condition. During the second experiment the players, on the average, were able to detect and use the information generated through Barbie's rotation to select a closer position to return the ball. However, when the subjects were blocked according to the accuracy of their predictions during the experimental condition, it was found that the association between accuracy of predictions and selection of a closer position to return the ball was adolescents having an IQ between 45 and 70 can spontaneously generate different solutions to the poblems studied in these experiments, and that the type of solution selected depend upon the accuracy of the declarative knowledge about the future landing location of the ball.

This flexibility of behavior demonstrates, we think, the player's sensitivity to the movement situation. It is unlikely that these observed changes in behavior could have occurred without an awareness of the movement situation (Campione et al, 1982; Wall et al., 1985). As well, the use of different responses underscores that different subroutines were available and selected in due time (Marteniuk, 1976). The appropriate selection of subroutines was, most likely, guided by general knowledge about these subroutines, what they can do, and when to use them (metacognitive knowledge). Furthermore, the appropriate orchestration of the subroutines, underscore the intelligent use of executive functions (Campione et al., 1982) or metacognitive skills (Wall et al., 1985).

Stroke

The stroke results were analysed in much the same manner as was done in Experiment 1. As noted earlier, the evaluator compared the frequency distributions obtained during the control and the experimental non-significant associations from those that were either strong or very strong.

Contrary to the results of Experiment 1, where most subjects used different stroke strategies to return the ball during both conditions of the experiment, the results presented in Table 44 do not show such a tendency. For only nine subjects, the associations were judged to be significant and none of these was judged to be very strong. For subject 17 and 21, who were very bad predictors, these assocations cannot be attributed to the accuracy of their knowledge about the future landing of the ball. For subject 26, who was a bad predictor, the observed differences reflect mainly the fact that this player attempted to hit more balls during the control condition than during the experimental situation. Subject 27, who was the best of the bad predictors (see Table 33), decided to use more frequently the forehand stroke during the experimental condition when the ball landed either on the left or the left-centre target. For subjects 20, 24, 25, and 32, who were either good or very good predictors, the observed distribution shift reflects a tendency to use more frequently the backhand stroke during the experimental condition. Finally, for subject 28, the observed changes can be explained by the fact that this subject hand, on the average, a position located more frequently behind the centre of the table during the experimental condition.

As said earlier, the decision to change or not the type of stroke strategy used is personal to the player and based upon numerous factors. Assuming that the random process used to allocate subjects to experiments produced equivalent groups, then a comparison of the results obtained from both experiments suggests that the accuracy of the declarative knowledge about the future landing location of the ball is an important determinant of the type of stroke used (Wall et al., 1985). In the first experiment, where the information given to the players was always true, most players altered the type of stroke used while in the second experiment, these changes were either minor or not accounted for by the accuracy of the guesses. It seems likely that, as the accuracy of the predictions becomes better and better, people start to use more and more frequently a total preparation strategy. This would be in agreement with the results obtained by Alain and Proteau (1980) who found that "the ratio of the probabilities of two events must reach the value of .1/.9 in order to elicit a reaction time faster than the one obtained if the two events were equiprobable" (p. 465). The faster reaction time was presumably due to a reduced response selection time because the subjects knew that one response was more likely to be required. It is our hunch that the type of stroke strategy used, as well as the position selected behind the table, are functions of the degree of uncertainty of the stimulus. The smaller the degree of uncertainty, the more mildly and moderately mentally handicapped adolescents are likely to use their prefered stroke and a total preparation strategy in a performance situation. This could be tested by varying the degree of uncertainty of the stimulus, assessing the type of stroke perfered by the player, and observe how our hypothesis stands. As we move closer to perfect certainty, then we should observe almost exclusively the use of the preferred stroke and a total preparation strategy. If the above hypothesis is supported, this would show, in another movement situation, that mentally handicapped people could evaluate some movement situations and respond flexibly and adaptively to these situations.

Balls Hit by Each Prediction Group

As shown in Table 45, the number of balls hit by each prediction group was analysed first with a three-way ANOVA with repeated measures on two factors. The Tukey planned comparisons done across condition on the cell means presented in Figure 28, did not reveal any significant differences. Although a ceiling effect might partly account for these results, there is no overwhelming evidence to suggest that the very good or the good predictors hit more balls during the

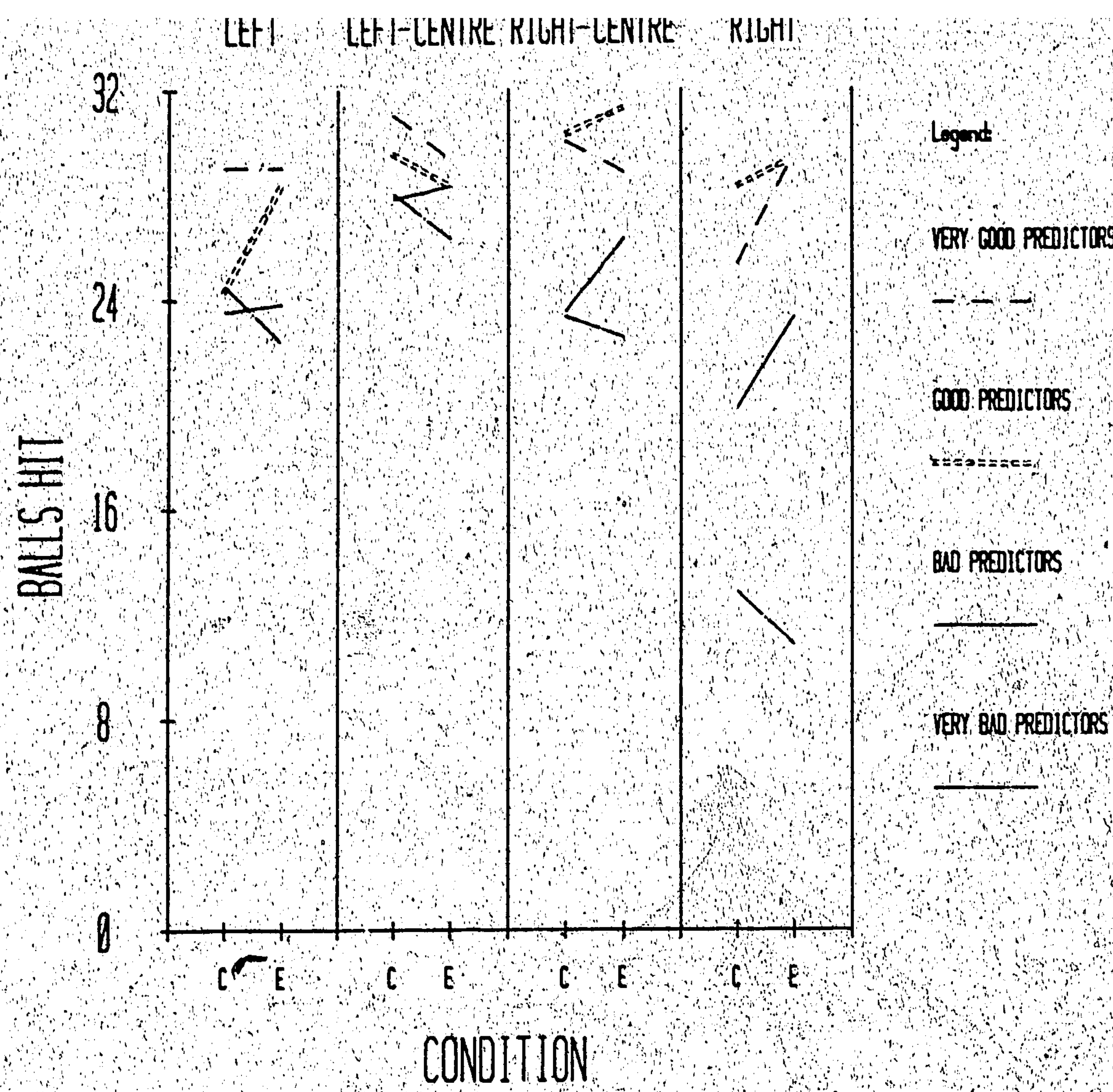

Figure 28. Number of balls hit during Experiment 2, as a function of landing target area, group, and condition (C: Control; E: Experimental).

experimental condition. Although a more definite conclusion on this question must await the use a task with more difficult balls to hit, our suspicion is that the attentional demands required to guess where the ball will land are so high that the potential benefit of better knowledge is annihilated by the increased attentional demand in the early learning of such tasks.

However, as noted earlier, it is possible that different results might be obtained with more experienced mentally retarded adolescents players because (a) the responses are likely to be more consistent and more automatic and (b) a more efficient allocation of processing resources might be made by the players (Wickens & Benel, 1982). Stated another way, an interaction is likely to exist between declarative knowledge and level of experience of the player: Early in learning the declarative knowledge about the future landing location of the ball will not allow the players to hit more balls. However, as movement consistency, automaticity, and possibly better allocation of processing resources develops, then the declarative knowledge about the future landing location of the ball will lead to better performance.

Summary, Conclusions, and Recommendations

Summary and Conclusions

The ability of mildly and moderately mentally handicapped adolescents to solve movement problems was studied in a simulated racquet sport situation. Like many researchers (e.g., Adams, 1976; Fitts & Posner, 1967; Gentile, 1972; Glencross, 1978; Keogh & Sugden, 1985; Newell & Barclay, 1982; Schmidt, 1975, 1976; Wall et al., 1985), our main thrust was to view movement skill development from a problem solving perspective. Due to the lack of empirical studies done on the problem solving behavior of the mentally retarded in movement situations, we first developed a theoretical framework from which the movement skill acquisition problems of the mildly and moderately mentally retarded could be studied. In brief, we proposed that three major categories of knowledge underlie the capacity to solve movement problems: declarative knowledge, procedural knowledge, and affective knowledge. Declarative knowledge refers to the representation that people have about something; it includes the representation of facts. An important type of declarative knowledge has been labeled metacognitive knowledge. This "cluster is roughly concerned with a person's knowledge about his own cognitive resources and the compatibility between himself as a learner and the learning situation" (Brown includes skills, rules, algorithms, strategies, heuristics, and procedures. A particular type of procedural knowledge has been referred to as executive functions (Brown & Campione, 1981) or metacognitive skills (Wall et al., 1985). This category of knowledge is concerned primarily with self-regulatory functions during an attempt to solve a problem. Metacognitive skills include activities such as checking, monitoring, testing, planning, revising, and evaluating. Finally, affective knowledge refers to the subjective feelings that people develop during or after participation in movement situations.

It was proposed that the solution of movement problems depends not only on the knowledge available to the learner in a movement situation but, as well, on its accessibility. The lack of access to relevant knowledge among mentally retarded people has been reported so frequently that "welding" is considered a key characteristic of this population (Campione et al., 1982). Consequently, if relevant knowledge is not accessed flexibly across situations, then it might be expected that mentally handicapped people would have difficulty solving movement proplems. Consequently, in the two studies reported, we focussed more specifically on the ability of mildly and moderately mentally handicapped people to use knowledge to solve movement

In Experiment 1, eight males and eight females, between 13 and 15 years of age, without known neuromuscular disorders or behavioral problems, were randomly selected from a vocational school in Edmonton, Alberta. The subjects were asked to return table-tennis balls with a regular bat. A ball projection machine, hidden behind a screen from the player's view, was used to project balls at four different target areas on a table enlarged for the purpose of this study. During the experimental condition the players were told, 3.5 s prior to the projection of each ball, a number representing the future landing target area of the ball on the table. No such information was available during the control condition. The design of the study included five factors. The three between subject factors were sex, IQ (45 to 59 and 60 to 70), and order of the conditions (control first or experimental first). The within subject factors were conditions (control or experimental) and landing target area of the ball on the table (L, LC, RC, and R). The dependent variables used were the position of the players when they first saw the ball, the type of stroke used (forehand or backhand), and the number of balls hit.

All but one subject used the information given during the experimental situation to select a position closer to the future path of the ball. The players, on declarative knowledge about the future landing target area of the ball on the table to better solve the movement problem. Comparison of the data across conditions showed that most players used different stroke strategies to return the ball. The solutions selected were personal to each player and appear to be guided by metacognitive knowledge about the strokes. Only the high IQ groups hit more balls during the experimental condition. These results suggest that it is only when movement consistency has developed that the players can benefit from the information given about the future landing location of the ball to hit more balls.

In Experiment 2, eight males and eight females were randomly selected according to the criteria used for Experiment 1. Furthermore, none of the subjects had participated in the first experiment. The equipment used was the same as described earlier excepted that a "Barbie" doll figure, holding the posture of a table-tennis player, was rotated above the ball projection machine during the experimental condition. Barbie was fixed during the control condition. During the experimental condition, the players were asked to look at Barbie and to guess where the ball would land on the table. On the average the players were better predictors during the experimental condition. Furthermore, they selected, on the average, a location experimental condition replicating, in a different movement situation, the results of the first experiment. However, they did not hit more balls; the processing demands required to look at Barbie and guess were too high. Consequently, the tracking of the ball, the response selection and execution, as well as the processing of feedback was impaired. The players were also blocked according to the accuracy of their predictions during the experimental condition. A high association was found between accuracy of predictions and the selection of a better position to return the ball. These results underscore the importance of knowledge to the solution of movement problems. However, comparisons across conditions provided no strong evidence that better predictors hit more balls during the experimental condition. Again, the amount of available attention allocated to signal detection and predictions was most likely very high and, consequently, impaired other cognitive processes related to the task of hitting the ball. Finally, no strong evidence was found that the players changed the type of stroke used. This could be explained by the partial preparation strategy used by the subjects.

In conclusion, the results show that mildly and moderately mentally handicapped adolescents can respond flexibly and adaptively to the type of movement generate different solutions adapted to different movement problems. In fact, three different preparation strategies were identified in the two experiments. The no preparation strategy was used during the control condition of both experiments where no information about the future landing target area of the ball was available. In this movement situation, most subjects stayed behind the centre of the table before the projection of the ball. The total preparation strategy was used by all but one subject during the experimental condition of the first experiment. In this situation most subjects moved very close to the future path of the ball before they could see it. Finally, the partial preparation strategy was used mainly during the experimental condition of the second experiment. In this situation, the subjects moved slightly toward the anticipated landing location of the next ball but, at the same time, they did not move too far to avoid missing balls due to errors of prediction.

The use of different solutions to different movement situations required, by the player, a conscious assessment of the movement situation, the knowledge that different subroutines were available (metacognitive knowledge), as well as the ability to orchestrate the subroutines available (metacognitive skills).

Recommendations

Based on the results of this investigation, the following recommendations are made:

1. The measurement of the location of the player behind the table should be done using a more precise measurement scale. Instead of coding the position of the body, the shoulder, and the bat as we did in this study, it would be better to measure the distance between these three units and a common frame of reference. Some information was lost due to the coding system used and a more continuous measurement scale would allow for more accurate description and differentiation, if any, between groups.

2. The task of hitting the ball should be slightly more difficult. In a few occasions, the lack of improvement across conditions may have been due to a ceiling effect. A more difficult task would avoid this problem and permit a more definite answer to the question of whether or not people hit more balls during the experimental condition.

3. Faster ways to do the coding should be found. It took almost three months of full time work by the main coder to generate the 45,056 codes required for statistical analysis of the data. Computerizing the coding would provide a much more efficient and convenient way to do this mammoth task.

4. More precise measurement of eye movements

should be made. The study of eye fixations would provide a better description of their information intake as well as the possibility to know whether different or better attention allocation strategies emerge with practice.

TABLES

Table 1

Characteristics of Subjects Selected for Experiment 1

Subject	Sex[a]	Age		IQ[b]		
		Years	Months	VS	PS	FS
1	M	14	1	65	68	64
2	M	13	1	46	66	52
3	M	14	11	72	52	59
4	F	13	8	72	64	66
5	F	13	3	60	73	65
6	F	13	8	59	69	61
7	F	14	2	64	63	59
8	F	14	4	49	54	47
9	M	14	0	67	75	70
10	M	13	3	68	68	66
11	F	14	8	58	64	52
12	M	14	4	58	54	52
13	M	14	6	57	72	62
14	F	14	7	62	49	52
15	F	14	10	55	75	64
16	M	15	0	58	63	56

[a]M:male; F:female

[b]The IQs were all estimated with the Weschler Intelligence Scale for Children Revised edition (WISC-R).

VS:verbal scale; PS:performance scale; FS:full scale.

Table 2

Categories of Coding Used for Each Dependent Variable

Dependent Variable	Category	Operational Definition
Body, shoulder, and bat	L (Left)	The left side of the table from the subject's view.
	C (Centre)	Behind the centre of the table, i.e., in an area having a width of 45.7 cm.
	R (Right)	The right side of the table from the the subject's view.
Stroke	N (No response)	No movement of the bat toward the ball was observed in close temporal contiguity with the passage of the ball near the player.
	F (Forehand)	When attempting to return the ball, the major part of the hand was oriented in a forehand manner in which the palm was facing the ball.
	B (Backhand)	When attempting to return the ball, the major part of the hand was oriented in a backhand manner in which the palm was facing away from the ball.

Table 2 (continued)

Categories of Coding Used for Each Dependent Variable

Dependent	Category	Operational Definition
Ball	M (Missed)	The player missed the ball with the bat.
	H (Hit)	The player legally hit the ball with the bat.

Table 3

Percentage of Interobserver Agreement for Each Dependent Variable of Experiment 1

Variable	Condition: Control	Condition: Experimental
Body	94.5	97.3
Shoulder	94.9	96.1
Bat	96.1	97.3
Stroke	93.0	98.0
Ball	97.7	96.5

Table 4

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Left Side of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	0.20	0.00
I (IQ)	1	736.32	2.21
SI	1	285.01	0.85
Blocks w. SI	12	333.91	
C (Condition)	1	556.95	3.20
SC	1	7.51	0.04
IC	1	187.70	1.08
SIC	1	7.51	0.04
C x Blocks w. SI	12	174.31	
L (Landing Target)	3	1545.32	62.78[ccc]
SL	3	13.84	0.56
IL	3	26.34	1.07
SIL	3	6.65	0.27
L x Blocks w. SI	36	24.62	
CL	3	1553.80	78.03[ccc]
SCL	3	1.74	0.09
ICL	3	33.47	1.68
SICL	3	9.07	0.46
C x L x Blocks w. SI	36	19.91	

[*]$p<.05$ [**]$p<.01$ [***]$p<.001$ (Conventional F)

[c]$p<.05$ [cc]$p<.01$ [ccc]$p<.001$ (Conservative F)

[e]$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.59$ $\text{Epsilon}_{CL} = 0.62$

Table 5

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Left Side of the Table During Experiment I

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
S (Sex)	1	70.51	0.20
I (IQ)	1	951.57	2.73
SI	1	303.20	0.87
Blocks w. SI	12	347.96	
C (Condition)	1	908.45	5.06*
SC	1	10.70	0.06
IC	1	130.01	0.72
SIC	1	1.76	0.01
C x Blocks w. SI	12	179.64	
L (Landing Target)	3	1386.40	47.41ccc
SL	3	1.11	0.04
IL	3	16.76	0.57
SIL	3	7.80	0.27
L x Blocks w. SI	36	29.24	
CL	3	1287.05	54.17ccc
SCL	3	1.47	0.07
ICL	3	28.03	1.18
SICL	3	11.28	0.47
C x L x Blocks w. SI	36	23.76	

*p<.05 **p<.01 ***p<.001 (Conventional *F*)

cp<.05 ccp<.01 cccp<.001 (Conservative *F*)

ep<.05 (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.63$ $\text{Epsilon}_{CL} = 0.65$

Table 6

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Left Side of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	0.20	0.00
I (IQ)	1	285.01	1.36
SI	1	159.76	0.76
Blocks w. SI	12	209.46	
C (Condition)	1	1883.45	19.97***
SC	1	14.45	0.15
IC	1	110.63	1.17
SIC	1	31.01	0.33
C x Blocks w. SI	12	94.30	
L (Landing Target)	3	1655.53	113.60ccc
SL	3	3.52	0.24
IL	3	14.88	1.02
SIL	3	5.47	0.38
L x Blocks w. SI	36	14.57	
CL	3	1616.95	95.89ccc
SCL	3	5.45	0.32
ICL	3	42.26	2.51
SICL	3	3.80	0.23
C x L x Blocks w. SI	36	16.86	

*p<.05 **p<.01 ***p<.001 (Conventional F)

cp<.05 ccp<.01 cccp<.001 (Conservative F)

ep<.05 (Epsilon correction for lack of sphericity)

$Epsilon_L$ = 0.59 $Epsilon_{CL}$ = 0.48

Table 7

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Centre of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	11.28	0.05
I (IQ)	1	157.53	0.66
SI	1	190.13	0.80
Blocks w. SI	12	237.54	
C (Condition)	1	6132.78	29.20***
SC	1	28.13	0.13
IC	1	595.13	2.83
SIC	1	26.28	0.13
C x Blocks w. SI	12	210.02	
L (Landing Target)	3	291.52	8.19c
SL	3	13.80	0.39
IL	3	13.22	0.37
SIL	3	6.69	0.19
L x Blocks w. SI	36	35.58	
CL	3	254.22	9.27c
SCL	3	6.10	0.22
ICL	3	15.02	0.55
SICL	3	19.80	0.72
C x L x Blocks w. SI	36	27.42	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

c$p<.05$ cc$p<.01$ ccc$p<.001$ (Conservative F)

e$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.52$ $\text{Epsilon}_{CL} = 0.49$

Table 8

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Centre of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	120.13	0.51
I (IQ)	1	69.03	0.29
SI	1	60.50	0.26
Blocks w. SI	12	236.88	
C (Condition)	1	6244.03	26.88***
SC	1	1.13	0.00
IC	1	175.78	0.76
SIC	1	36.13	0.16
C x Blocks w. SI	12	232.33	
L (Landing Target)	3	343.64	9.35cc
SL	3	3.60	0.10
IL	3	54.22	1.47
SIL	3	7.56	0.21
L x Blocks w. SI	36	36.76	
CL	3	425.34	16.84cc
SCL	3	10.31	0.41
ICL	3	62.93	2.49
SICL	3	20.73	0.82
C x L x Blocks w. SI	36	25.25	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

c$p<.05$ cc$p<.01$ ccc$p<.001$ (Conservative F)

e$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.51$ $\text{Epsilon}_{CL} = 0.49$

Table 9

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Centre of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	5.70	0.03
I (IQ)	1	53.82	0.32
SI	1	64.70	0.38
Blocks w. SI	12	170.86	
C (Condition)	1	11381.63	94.28***
SC	1	59.13	0.49
IC	1	297.07	2.46
SIC	1	110.63	0.92
C x Blocks w. SI	12	120.72	
L (Landing Target)	3	95.65	10.73cc
SL	3	21.92	2.46
IL	3	5.72	0.64
SIL	3	1.22	0.14
L x Blocks w. SI	36	8.91	
CL	3	109.90	12.99cc
SCL	3	18.78	2.22
ICL	3	11.30	1.34
SICL	3	2.65	0.31
C x L x Blocks w. SI	36	8.46	

*p<.05 **p<.01 ***p<.001 (Conventional F)

cp<.05 ccp<.01 cccp<.001 (Conservative F)

ep<.05 (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.79$ $\text{Epsilon}_{CL} = 0.76$

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Right Side of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	14.45	0.27
I (IQ)	1	187.70	3.47
SI	1	4.88	0.09
Blocks w. SI	12	54.12	
C (Condition)	1	2897.51	104.56***
SC	1	2.82	0.10
IC	1	134.07	4.84*
SIC	1	10.70	0.39
C x Blocks w. SI	12	27.71	
L (Landing Target)	3	1307.50	51.57ccc
SL	3	3.59	0.14
IL	3	68.88	2.72
SIL	3	1.74	0.07
L x Blocks w. SI	36	25.35	
CL	3	1267.57	52.75ccc
SCL	3	7.63	0.32
ICL	3	73.01	3.04
SICL	3	5.38	0.22
C x L x Blocks w. SI	36	24.03	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

c$p<.05$ cc$p<.01$ ccc$p<.001$ (Conservative F)

e$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.65$ $\text{Epsilon}_{CL} = 0.66$

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Right Side of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	6.57	0.06
I (IQ)	1	508.01	4.65
SI	1	92.82	0.85
Blocks w. SI	12	109.21	
C (Condition)	1	2389.13	38.10***
SC	1	4.88	0.08
IC	1	3.44	0.05
SIC	1	21.94	0.35
C x Blocks w. SI	12	62.71	
L (Landing Target)	3	1452.34	87.30ccc
SL	3	0.78	0.05
IL	3	62.76	3.77e
SIL	3	1.70	0.10
L x Blocks w. SI	36	16.64	
CL	3	1515.22	87.92
SCL	3	8.84	0.51
ICL	3	70.70	4.10e
SICL	3	3.99	0.23
C x L x Blocks w. SI	36	17.23	

*p<.05 **p<.01 ***p<.001 (Conventional F)

cp<.05 ccp<.01 cccp<.001 (Conservative F)

ep<.05 (Epsilon correction for lack of sphericity)

$Epsilon_L = 0.57$ $Epsilon_{CL} = 0.60$

Table 12

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Right Side of the Table During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
S (Sex)	1	3.13	0.06
I (IQ)	1	112.50	2.34
SI	1	12.50	0.26
Blocks w. SI	12	48.09	
C (Condition)	1	3872.00	98.31***
SC	1	24.50	0.62
IC	1	60.50	1.54
SIC	1	15.13	0.38
C x Blocks w. SI	12	39.39	
L (Landing Target)	3	1602.81	106.14ccc
SL	3	10.35	0.69
IL	3	34.94	2.31
SIL	3	2.77	0.18
L x Blocks w. SI	36	15.10	
CL	3	1671.23	123.89ccc
SCL	3	9.81	0.73
ICL	3	30.27	2.24
SICL	3	8.56	0.64
C x L x Blocks w. SI	36	13.49	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional *F*)

c$p<.05$ cc$p<.01$ ccc$p<.001$ (Conservative *F*)

e$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.50$ $\text{Epsilon}_{CL} = 0.43$

Table 13

Frequency Data, for Subject 11, on Three Dependent Variables

		Dependent Variables								
		Body[a]			Shoulder[a]			Bat[a]		
Condition	Landing Area[b]	L	C	R	L	C	R	L	C	R
Control	Target L	27	5	0	26	6	0	24	7	1
	Target LC	25	7	0	26	6	0	23	9	0
	Target RC	28	4	0	29	3	0	23	9	0
	Target R	22	10	0	22	10	0	19	13	0
Experimental	Target L	31	1	0	29	3	0	25	7	0
	Target LC	32	0	0	30	2	0	25	7	0
	Target RC	32	0	0	32	0	0	25	7	0
	Target R	32	0	0	31	1	0	29	3	0

Note. Maximum score = 32.

[a]L:Left; C:Centre; R:Right.

[b]L:Left; LC: Left-Centre; RC:Right-Centre; R:Right.

Table 14

The Frequency With Which Each Type of Stroke Was Used by the Subjects in Experiment 1, as a Function of Condition and Landing Area of the Ball

Subject	Landing Target	Control[a]			Experimental[a]		
		N	F	B	N	F	B
1[b]	Left	1	0	31	0	0	32
	Left-Centre	0	0	32	0	0	32
	Right-Centre	0	0	32	0	0	32
	Right	4	0	28	1	0	31
2	Left	0	0	32	2	0	30
	Left-Centre	2	1	29	5	1	26
	Right-Centre	0	22	10	5	5	22*
	Right	5	20	7	4	7	21*
3	Left	0	29	3	0	2	30**
	Left-Centre	0	31	1	0	15	17*
	Right-Centre	0	32	0	0	28	4
	Right	4	28	0	0	32	0
4	Left	0	2	30	0	28	4**
	Left-Centre	0	19	13	0	31	1*
	Right-Centre	0	28	4	0	30	2
	Right	0	28	4	0	32	0
5	Left	0	0	32	0	1	31
	Left-Centre	0	1	31	0	2	30
	Right-Centre	0	31	1	0	7	25**
	Right	0	32	0	0	9	23**
6	Left	12	0	20	0	0	32
	Left-Centre	0	0	32	0	0	32
	Right-Centre	0	6	26	0	0	32
	Right	0	32	0	0	0	32**
7	Left	0	1	31	0	32	0**
	Left-Centre	0	13	19	0	32	0**
	Right-Centre	0	32	0	0	32	0
	Right	3	29	0	0	32	0
8	Left	0	32	0	0	31	1
	Left-Centre	0	14	18	0	23	9
	Right-Centre	0	3	29	0	21	11*
	Right	2	2	28	0	12	20*

Table 14 (Continued)

The Frequency With Which Each Type of Stroke Was Used by the Subjects in Experiment 1, as a Function of Condition and Landing Area of the Ball

Subject	Landing Target	Control[a]			Experimental[a]		
		N	F	B	N	F	B
9	Left	0	0	32	0	0	32
	Left-Centre	0	1	31	0	0	32
	Right-Centre	0	22	10	0	3	29*
	Right	0	31	1	0	13	19*
10	Left	0	0	32	0	26	6**
	Left-Centre	0	0	32	0	27	5**
	Right-Centre	0	22	10	0	32	0*
	Right	0	32	0	0	32	0
11[c]	Left	2	7	23	2	3	27
	Left-Centre	1	19	12	0	27	5
	Right-Centre	2	22	8	3	29	0
	Right	17	8	7	21	11	0
12	Left	0	8	24	1	2	29
	Left-Centre	0	11	21	0	4	28
	Right-Centre	0	31	1	0	27	5
	Right	0	31	1	1	30	1
13	Left	0	0	32	0	9	23*
	Left-Centre	0	8	24	0	15	17
	Right-Centre	1	28	3	0	13	19*
	Right	0	31	1	0	17	15*
14	Left	6	0	26	0	10	22*
	Left-Centre	0	[illegible]	31	0	14	18*
	Right-Centre	0	28	4	0	24	8
	Right	0	32	0	0	32	0
15	Left	0	0	32	0	0	32
	Left-Centre	0	0	32	0	1	31
	Right-Centre	0	5	27	0	0	32
	Right	0	32	0	0	0	32**

Table 14 (Continued)

The Frequency With Which Each Type of Stroke Used by the Subjects in Experiment 1, as a Function of Condition and Landing Area of the Ball

Subject	Landing Target	Control[a]			Experimental[a]		
		N	F	B	N	F	B
16	Left	0	0	32	0	32	0**
	Left-Centre	0	4	28	0	30	2**
	Right-Centre	0	31	1	0	29	3
	Right	1	31	0	0	32	0

Note. Maximum score = 32.

[a]N:No response; F:Forehand; B:Backhand.

[b]This player used only a penholder-grip.

[c]This subject never used the information given during the experimental condition.

*Strong association **Very Strong association

Table 15

Summary of Analysis of Variance on the Number of Balls Hit During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	1040.82	4.94
I (IQ)	1	1689.26	8.02*
O (Order)	1	334.76	1.59
SI	1	3.45	0.02
SO	1	250.32	1.19
IO	1	540.38	2.56
SIO	1	103.32	0.49
Blocks w. SIO	8	210.73	
C (Condition)	1	33.01	1.37
SC	1	92.82	3.84
IC	1	76.57	3.17
OC	1	233.82	9.67*
SIC	1	0.01	0.00
SOC	1	51.26	2.12
IOC	1	146.63	6.07*
SIOC	1	10.70	0.44
C x Blocks w. SIO	8	24.16	
L (Landing)	3	33.13	2.55
SL	3	5.24	0.40
IL	3	71.67	5.51[c]
OL	3	23.42	1.80
SIL	3	31.73	2.44
SOL	3	37.20	2.86
IOL	3	6.09	0.47
SIOL	3	36.82	2.83
L x Blocks w. SIO	24	13.00	

Table 15 (continued)

Summary of Analysis of Variance on the Number of Balls Hit During Experiment 1

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
CL	3	8.17	1.08
SCL	3	0.95	0.13
ICL	3	35.28	4.67[e]
OCL	3	6.28	0.83
SICL	3	10.42	1.38
SOCL	3	1.09	0.14
IOCL	3	1.38	0.18
SIOCL	3	1.40	0.19
C x L x Blocks w. SIO	24	7.56	

*$p<.05$ (Conventional F)

[c]$p<.05$ (Conservative F)

[e]$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.66$ $\text{Epsilon}_{CL} = 0.71$

Table 16

Characteristics of Subjects Selected for Experiment 2

Subject	Sex[a]	Age: Years	Age: Months	IQ[b]: VS	IQ[b]: PS	IQ[b]: FS
17	F	13	11	72	52	59
18	M	14	1	58	61	55
19	F	14	3	59	75	66
20	M	14	1	52	72	59
21	F	14	1	52	49	46
22	F	14	1	68	73	69
23	M	13	3	62	48	51
24	M	14	10	–	–	57[c]
25	M	14	3	69	65	65
26	F	13	9	58	71	62
27	F	14	9	54	45	44
28	F	13	11	57	58	53
29	M	13	6	67	65	64
30	M	13	8	69	65	65
31	M	13	10	72	72	70
32	F	13	9	59	75	66

[a]M:male; F:female.

[b]All but one subject had their IQ estimated with the WISC-R.

[c]This adolescent had its IQ estimated with the Stanford-Binet.

VS:verbal scale; PS:performance scale; FS:full scale.

Table 17

Percentage of Interobserver Agreement for Each Dependent Variable of Experiment 2

	Condition	
Variable	Control	Experimental
Predictions	94.2	97.1
Body	93.3	94.1
Shoulder	96.1	95.1
Bat	92.8	94.1
Stroke	94.2	93.1
Ball	96.6	94.6

Table 18

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Subjects Predicted that the Ball Would land on the Left Target

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	60.50	2.16
I (IQ)	1	9.03	0.32
SI	1	6.13	0.22
Blocks w. SI	12	28.01	
C (Condition)	1	28.13	2.52
SC	1	0.03	0.00
IC	1	8.00	0.72
SIC	1	0.78	0.07
C x Blocks w. SI	12	11.17	
L (Landing Target)	3	178.03	18.25[cc]
SL	3	1.92	0.20
IL	3	6.78	0.70
SIL	3	15.54	1.59
L x Blocks w. SI	36	9.76	
CL	3	262.21	30.83[ccc]
SCL	3	9.36	1.10
ICL	3	0.58	0.07
SICL	3	7.78	0.91
C x L x Blocks w. SI	36	8.51	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

[c]$p<.05$ [cc]$p<.01$ [ccc]$p<.001$ (Conservative F)

[e]$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.53$ $\text{Epsilon}_{CL} = 0.50$

Table 19

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Subjects Predicted that the Ball Would Land on the Left-Centre Target

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	328.32	8.76*
I (IQ)	1	51.26	1.37
SI	1	13.13	0.35
Blocks w. SI	12	37.48	
C (Condition)	1	17.26	1.57
SC	1	2.26	0.21
IC	1	1.76	0.16
SIC	1	2.82	0.26
C x Blocks w. SI	12	10.98	
L (Landing Target)	3	180.65	18.22cc
SL	3	11.51	1.16
IL	3	20.78	2.10
SIL	3	15.82	1.60
L x Blocks w. SI	36	9.91	
CL	3	109.78	8.50c
SCL	3	4.95	0.38
ICL	3	15.36	1.19
SICL	3	15.51	1.20
C x L x Blocks w. SI	36	12.91	

*p<.05 **p<.01 ***p<.001 (Conventional F)

cp<.05 ccp<.01 cccp<.001 (Conservative F)

ep<.05 (Epsilon correction for lack of sphericity)

$Epsilon_L = 0.72$ $Epsilon_{CL} = 0.83$

Table 20

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Subjects Predicted that the Ball Would Land on the Right-Centre Target

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	16.53	0.69
I (IQ)	1	7.03	0.29
SI	1	185.28	7.68*
Blocks w. SI	12	24.11	
C (Condition)	1	10.13	1.45
SC	1	10.13	1.45
IC	1	36.13	5.18*
SIC	1	6.13	0.88
C x Blocks w. SI	12	6.98	
L (Landing Target)	3	189.11	23.23ccc
SL	3	7.61	0.94
IL	3	13.03	1.60
SIL	3	7.78	0.96
L x Blocks w. SI	36	8.14	
CL	3	138.08	12.03cc
SCL	3	4.08	0.36
ICL	3	5.42	0.47
SICL	3	5.25	0.46
C x L x Blocks w. SI	36	11.48	

*$p<.05$ **$p\leq.01$ ***$p<.001$ (Conventional F)

c$p<.05$ cc$p<.01$ ccc$p<.001$ (Conservative F)

e$p<.01$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.63$ $\text{Epsilon}_{CL} = 0.81$

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Subjects Predicted that the Ball Would Land on the Right Target

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	42.78	1.72
I (IQ)	1	55.13	2.21
SI	1	50.00	2.01
Blocks w. SI	12	24.90	
C (Condition)	1	60.50	3.41
SC	1	28.13	1.58
IC	1	0.78	0.04
SIC	1	0.03	0.00
C x Blocks w. SI	12	17.76	
L (Landing Target)	3	122.55	14.37^{cc}
SL	3	10.05	1.18
IL	3	12.65	1.48
SIL	3	3.27	0.38
L x Blocks w. SI	36	8.53	
CL	3	151.94	14.37^{cc}
SCL	3	7.90	0.75
ICL	3	6.55	0.62
SICL	3	2.22	0.21
C x L x Blocks w. SI	36	10.57	

$^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$ (Conventional F)

$^{c}p<.05$ $^{cc}p<.01$ $^{ccc}p<.001$ (Conservative F)

$^{e}p<.05$ (Epsilon correction for lack of sphericity)

$Epsilon_L = 0.53$ $Epsilon_{CL} = 0.48$

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Left Side of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	717.26	1.52
I (IQ)	1	775.20	1.64
SI	1	1898.82	4.02
Blocks w. SI	12	472.05	
C (Condition)	1	4.13	0.03
SC	1	15.82	0.13
IC	1	106.95	0.90
SIC	1	37.20	0.31
C x Blocks w. SI	12	119.07	
L (Landing Target)	3	383.15	24.77[ccc]
SL	3	7.59	0.49
IL	3	1.65	0.11
SIL	3	3.65	0.24
L x Blocks w. SI	36	15.47	
CL	3	391.76	22.98[ccc]
SCL	3	29.40	1.72
ICL	3	1.40	0.08
SICL	3	8.36	0.49
C x L x Blocks w. SI	36	17.05	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

[c]$p<.05$ [cc]$p<.01$ [ccc]$p<.001$ (Conservative F)

[e]$p<.05$ (Epsilon correction for lack of sphericity)

$Epsilon_L = 0.44$ $Epsilon_{CL} = 0.46$

Table 23

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Left Side of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	399.03	1.55
I (IQ)	1	420.50	1.63
SI	1	4536.28	17.60**
Blocks w. SI	12	257.70	
C (Condition)	1	32.00	0.40
SC	1	0.03	0.00
IC	1	72.00	0.90
SIC	1	0.78	0.01
C x Blocks w. SI	12	80.12	
L (Landing Target)	3	245.85	27.12ccc
SL	3	3.05	0.34
IL	3	2.15	0.24
SIL	3	1.93	0.21
L x Blocks w. SI	36	9.06	
CL	3	290.52	23.97ccc
SCL	3	18.14	1.50
ICL	3	13.40	1.11
SICL	3	4.43	0.37
C x L x Blocks w. SI	36	12.12	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

c$p<.05$ cc$p<.01$ ccc$p<.001$ (Conservative F)

e$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.46$ $\text{Epsilon}_{CL} = 0.62$

Table 24

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Left Side of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	392.00	2.53
I (IQ)	1	98.00	0.63
SI	1	1512.50	9.76**
Blocks w. SI	12	154.93	
C (Condition)	1	128.00	1.20
SC	1	4.50	0.04
IC	1	36.13	0.34
SIC	1	2.00	0.02
C x Blocks w. SI	12	107.05	
L (Landing Target)	3	397.65	35.82ccc
SL	3	17.48	1.57
IL	3	14.69	1.32
SIL	3	1.73	0.16
L x Blocks w. SI	36	11.10	
CL	3	392.35	25.08ccc
SCL	3	36.56	2.34
ICL	3	5.31	0.34
SICL	3	2.65	0.17
C x L x Blocks w. SI	36	15.64	

*p<.05 **p<.01 ***p<.001 (Conventional F)

cp<.05 ccp<.01 cccp<.001 (Conservative F)

ep<.05 (Epsilon correction for lack of sphericity)

$Epsilon_L = 0.49$ $Epsilon_{CL} = 0.51$

Table 25

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Centre of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	318.78	0.97
I (IQ)	1	351.13	1.07
SI	1	2016.13	6.15*
Blocks w. SI	12	327.91	
C (Condition)	1	101.53	0.84
SC	1	63.28	0.52
IC	1	253.13	2.09
SIC	1	28.13	0.23
C x Blocks w. SI	12	120.87	
L (Landing Target)	3	138.28	7.31[c]
SL	3	4.86	0.26
IL	3	18.33	0.97
SIL	3	7.58	0.40
L x Blocks w. SI	36	18.93	
CL	3	110.53	6.78[c]
SCL	3	14.56	0.88
ICL	3	13.58	0.83
SICL	3	13.92	0.85
C x L x Blocks w. SI	36	16.31	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional F)

[c]$p<.05$ [cc]$p<.01$ [ccc]$p<.001$ (Conservative F)

[e]$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.61$ $\text{Epsilon}_{CL} = 0.72$

Table 26

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Centre of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
S (Sex)	1	120.13	0.53
I (IQ)	1	124.03	0.54
SI	1	3140.28	13.75**
Blocks w. SI	12	228.38	
C (Condition)	1	457.53	8.02*
SC	1	22.78	0.40
IC	1	112.50	1.97
SIC	1	4.50	0.08
C x Blocks w. SI	12	57.06	
L (Landing Target)	3	66.77	4.65[e]
SL	3	7.19	0.50
IL	3	6.01	0.42
SIL	3	4.05	0.28
C x Blocks w. SI	36	14.37	
CL	3	32.93	1.92
SCL	3	27.05	1.58
ICL	3	1.69	0.10
SICL	3	22.89	1.34
C x L x Blocks w. SI	36	17.15	

*$p<.05$ **$p<.01$ ***$p<.001$ (Conventional *F*)

[c]$p<.05$ [cc]$p<.01$ [ccc]$p<.001$ (Conservative *F*)

[e]$p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.61$ $\text{Epsilon}_{CL} = 0.69$

Table 27

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Centre of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	164.26	1.32
I (IQ)	1	1.76	0.01
SI	1	887.26	7.12*
Blocks w. SI	12	124.54	
C (Condition)	1	679.88	8.30*
SC	1	33.01	0.40
IC	1	67.57	0.82
SIC	1	0.63	0.01
C x Blocks w. SI	12	81.94	
L (Landing Target)	3	87.90	6.14[c]
SL	3	7.38	0.52
IL	3	2.26	0.16
SIL	3	4.38	0.31
C x Blocks w. SI	36	14.32	
CL	3	74.05	4.75[e]
SCL	3	10.30	0.66
ICL	3	0.74	0.05
SICL	3	16.09	1.03
C x L x Blocks w. SI	36	15.60	

*p<.05 **p<.01 ***p<.001 (Conventional F)

[c]p<.05 [cc]p<.01 [ccc]p<.001 (Conservative F)

[e]p<.05 (Epsilon correction for lack of sphericity)

$Epsilon_L$ = 0.59 $Epsilon_{CL}$ = 0.83

Table 28

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Right Side of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	84.50	1.32
I (IQ)	1	81.28	1.27
SI	1	0.78	0.01
Blocks w. SI	12	63.94	
C (Condition)	1	112.50	6.56*
SC	1	10.13	0.59
IC	1	42.78	2.49
SIC	1	5.28	0.31
C x Blocks w. SI	12	17.15	
L (Landing Target)	3	118.44	9.42^{cc}
SL	3	8.85	0.70
IL	3	27.76	2.21
SIL	3	1.05	0.08
C x Blocks w. SI	36	12.57	
CL	3	120.65	9.91^{cc}
SCL	3	13.31	1.09
ICL	3	17.01	1.40
SICL	3	0.80	0.07
C x L x Blocks w. SI	36	12.17	

$^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$ (Conventional F)

$^{c}p<.05$ $^{cc}p<.01$ $^{ccc}p<.001$ (Conservative F)

$^{e}p<.05$ (Epsilon correction for lack of sphericity)

$Epsilon_{L} = 0.39$ $Epsilon_{CL} = 0.45$

Table 29

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Right Side of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	86.13	0.63
I (IQ)	1	83.13	0.63
SI	1	138.20	1.02
Blocks w. SI	12	135.95	
C (Condition)	1	202.51	6.13*
SC	1	17.26	0.52
IC	1	9.57	0.29
SIC	1	20.32	0.62
C x Blocks w. SI	12	33.02	
L (Landing Target)	3	219.84	15.12cc
SL	3	17.65	1.21
IL	3	14.61	1.01
SIL	3	1.84	0.13
C x Blocks w. SI	36	14.54	
CL	3	271.20	20.75ccc
SCL	3	19.11	1.46
ICL	3	8.38	0.64
SICL	3	8.38	0.64
C x L x Blocks w. SI	36	13.07	

$^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$ (Conventional F)

$^{c}p<.05$ $^{cc}p<.01$ $^{ccc}p<.001$ (Conservative F)

$^{e}p<.05$ (Epsilon correction for lack of sphericity)

$\text{Epsilon}_L = 0.42$ $\text{Epsilon}_{CL} = 0.43$

Table 30

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Right Side of the Table During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	52.53	0.49
I (IQ)	1	124.03	1.16
SI	1	91.13	0.85
Blocks w. SI	12	107.02	
C (Condition)	1	175.78	5.95*
SC	1	8.00	0.27
IC	1	10.13	0.34
SIC	1	13.78	0.47
C x Blocks w. SI	12	29.53	
L (Landing Target)	3	273.50	22.06ccc
SL	3	15.61	1.26
IL	3	18.53	1.49
SIL	3	2.58	0.21
C x Blocks w. SI	36	12.40	
CL	3	344.28	28.64ccc
SCL	3	20.71	1.72
ICL	3	7.08	0.59
SICL	3	8.03	0.67
C x L x Blocks w. SI	36	12.02	

*p<.05 **p<.01 ***p<.001 (Conventional F)

cp<.05 ccp<.01 cccp<.001 (Conservative F)

ep<.05 (Epsilon correction for lack of sphericity)

$Epsilon_L$ = 0.49 $Epsilon_{CL}$ = 0.43

Table 31

Summary of the Analysis of Variance Done on the Number of Balls Hit During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
S (Sex)	1	435.13	1.74
I (IQ)	1	1.13	0.00
O (Order)	1	621.28	2.49
SI	1	318.78	1.28
SO	1	10.13	0.40
IO	1	55.13	0.22
SIO	1	52.53	0.21
Blocks w. SIO	8	249.98	
C (Condition)	1	5.28	0.24
SC	1	0.50	0.02
IC	1	0.50	0.02
OC	1	47.53	2.15
SIC	1	0.78	0.04
SOC	1	50.00	2.26
IOC	1	2.00	0.09
SIOC	1	81.28	3.67
C x Blocks w. SIO	8	22.14	
L (Landing Target)	3	221.86	8.90[c]
SL	3	22.67	0.91
IL	3	0.08	0.00
OL	3	129.28	5.19[e]
SIL	3	107.53	4.31[e]
SOL	3	8.08	0.32
IOL	3	21.42	0.86
SIOL	3	30.20	1.21
L x Blocks w. SIO	24	24.92	

Table 31 (Continued)

Summary of the Analysis of Variance Done on the Number of Balls Hit During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
CL	3	10.20	1.88
SCL	3	4.88	0.90
ICL	3	3.46	0.64
OCL	3	2.86	0.53
SICL	3	4.78	0.88
SOCL	3	2.21	0.41
IOCL	3	19.38	3.58[e]
SIOCL	3	1.95	0.36
C x L x Blocks w. SIO	24	5.41	

[c] $p<.05$ (Conservative F)

[e] $p<.05$ (Epsilon correction for lack of sphericity)

$Epsilon_L = 0.54$ $Epsilon_{CL} = .75$

Table 32

Error Weights Used to Calculate the del_p Statistic for Each Subject During the Experimental Condition of Experiment 2

	Predictions			
Landing Target	L	LC	RC	R
Left (L)	0.00	0.25	0.50	1.00
Left-Centre (LC)	0.25	0.00	0.25	0.50
Right-Centre (RC)	0.50	0.25	0.00	0.25
Right (RC)	1.00	0.50	0.25	0.00

Table 33

The Statistic del_p for Each Subject During the Experimental Condition of Experiment 2

Subject	del_p
17	.15
18	.44
19	.24
20	.55
21	.07
22	.28
23	.29
24	.38
25	.58
26	.30
27	.34
28	.61
29	.36
30	.04
31	.70
32	.69

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Left Side of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
G (Group)	3	690.65	1.19
Blocks w. G	12	582.00	
C (Condition)	1	4.13	0.04
GC	3	154.92	1.65
C x Blocks w. G	12	93.66	
L (Landing Target)	3	383.15	49.77
GL	9	35.39	4.60
L x Blocks w. G	36	7.70	
CL	3	391.76	59.72
GCL	9	55.02	8.39
C x L x Blocks w. G	36	6.56	

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Left Side of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
G (Group)	3	1004.56	2.22
Blocks w. G	12	452.88	
C (Condition)	1	32.00	0.47
GC	3	70.56	1.03
C x Blocks w. G	12	68.55	
L (Landing Target)	3	245.85	73.95
GL	9	25.33	7.62
L x Blocks w. G	36	3.32	
CL	3	290.52	39.74
GCL	9	31.22	4.27
C x L x Blocks w. G	36	7.31	

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Left Side of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
G (Group)	3	248.77	0.96
Blocks w. G	12	259.61	
C (Condition)	1	128.00	1.45
GC	3	88.56	1.00
C x Blocks w. G	12	88.46	
L (Landing Target)	3	397.65	62.87
GL	9	30.40	4.81
L x Blocks w. G	36	6.32	
CL	3	392.35	53.52
GCL	9	48.08	6.56
C x L x Blocks w. G	36	7.33	

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Centre of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
G (Group)	3	345.84	0.74
Blocks w. G	12	465.29	
C (Condition)	1	101.53	0.89
GC	3	140.05	1.22
C x Blocks w. G	12	114.57	
L (Landing Target)	3	138.28	9.89
GL	9	30.04	2.15
L x Blocks w. G	36	13.98	
CL	3	110.53	8.73
GCL	9	28.55	2.25
C x L x Blocks w. G	36	12.66	

Table 38

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Centre of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
G (Group)	3	855.06	2.88
Blocks w. G	12	296.65	
C (Condition)	1	457.53	7.45
GC	3	29.18	0.48
C x Blocks w. G	12	61.41	
L (Landing Target)	3	66.77	5.61
GL	9	15.67	1.32
L x Blocks w. G	36	11.89	
CL	3	32.93	1.89
GCL	9	16.02	0.92
C x L x Blocks w. G	36	17.45	

Table 39

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Centre of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
G (Group)	3	309.40	2.29
Blocks w. G	12	134.97	
C (Condition)	1	679.88	9.10
GC	3	62.67	0.84
C x Blocks w. G	12	74.71	
L (Landing Target)	3	87.90	8.22
GL	9	19.18	1.79
L x Blocks w. G	36	10.69	
CL	3	74.05	6.09
GCL	9	22.79	1.87
C x L x Blocks w. G	36	12.16	

Table 40

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Body Was Behind the Right Side of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	*F* Ratio
G (Group)	3	138.21	3.19
Blocks w. G	12	43.27	
C (Condition)	1	112.50	6.57
GC	3	19.50	1.14
C x Blocks w. G	12	17.13	
L (Landing Target)	3	118.44	16.56
GL	9	34.24	4.79
L x Blocks w. G	36	7.16	
CL	3	120.65	14.81
GCL	9	26.48	3.25
C x L x Blocks w. G	36	8.15	

Table 41

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Shoulder Was Behind the Right Side of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
G (Group)	3	150.30	1.21
Blocks w. G	12	124.24	
C (Condition)	1	202.51	6.28
GC	3	18.78	0.58
C x Blocks w. G	12	32.25	
L (Landing Target)	3	219.84	28.37
GL	9	38.51	4.97
L x Blocks w. G	36	7.75	
CL	3	271.20	26.83
GCL	9	23.80	2.35
C x L x Blocks w. G	36	10.11	

Table 42

Summary of the Analysis of Variance Done on the Frequency Data Indicating How Often the Bat Was Behind the Right Side of the Table for Each Group During Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
G (Group)	3	171.98	1.99
Blocks w. G	12	86.33	
C (Condition)	1	175.78	6.24
GC	3	16.01	0.57
C x Blocks w. G	12	28.18	
L (Landing Target)	3	273.50	40.59
GL	9	34.88	5.18
L x Blocks w. G	36	6.74	
CL	3	344.28	41.07
GCL	9	26.48	3.16
C x L x Blocks w. G	36	8.38	

Table 43

Table Indicating Which Tukey Tests were Significant (S) and Non-Significant (NS) as a Function of Dependent Variable, Landing Target, and Group.

		Group[a]			
Dependent Variable	Landing Target	VGP	GP	BP	VBP
Body (left)	Left	NS	S	NS	NS
	Left-Centre	NS	S	NS	NS
	Right-Centre	NS	NS	NS	NS
	Right	S	S	S	NS
Shoulder (left)	Left	S	S	NS	NS
	Left-Centre	NS	NS	NS	NS
	Right-Centre	S	NS	NS	NS
	Right	S	NS	NS	NS
Bat (left)	Left	S	S	NS	NS
	Left-Centre	NS	S	NS	NS
	Right-Centre	NS	NS	NS	NS
	Right	S	NS	NS	NS
Body (centre)	Left	NS	S	NS	NS
	Left-Centre	NS	S	NS	NS
	Right-Centre	NS	NS	NS	NS
	Right	NS	NS	NS	NS
Shoulder (centre)	Left	NS	S	NS	NS
	Left-Centre	NS	NS	NS	NS
	Right-Centre	NS	NS	NS	NS
	Right	NS	S	NS	NS
Bat (centre)	Left	NS	S	NS	NS
	Left-Centre	NS	NS	NS	NS
	Right-Centre	NS	NS	NS	NS
	Right	NS	S	NS	NS

Table 43 (Continued)

Table Indicating Which Tukey Tests were Significant (S) and Non-Significant (NS) as a Function of Dependent Variable, Landing Target, and Group.

Dependent Variable	Landing Target	2Group[a]			
		VGP	GP	BP	VBP
Body (right)	Left	NS	NS	NS	NS
	Left-Centre	NS	NS	NS	NS
	Right-Centre	S	NS	NS	NS
	Right	S	S	NS	NS
Shoulder (right)	Left	NS	NS	NS	NS
	Left-Centre	NS	NS	NS	NS
	Right-Centre	S	NS	NS	NS
	Right	S	S	S	NS
Bat (right)	Left	NS	NS	NS	NS
	Left-Centre	NS	NS	NS	NS
	Right-Centre	NS	NS	NS	NS
	Right	S	S	S	NS

[a]VGP: Very Good Predictors; GP:Good Predictors;

BP:Bad Predictors; VBP:Very Bad Predictors.

Table 44

The Frequency With Which Each Type of Stroke Was Used by the Subjects in Experiment 2, as a Function of Condition and Landing Target

Subject[b]	Landing Target	Control[a]			Experimental[a]		
		N	F	B	N	F	B
17 (VBP)	Left	1	4	27	0	11	21
	Left-Centre	0	15	17	0	28	4*
	Right-Centre	0	29	3	0	32	0
	Right	8	24	0	6	26	0
18 (GP)	Left	0	0	32	0	0	31
	Left-Centre	0	1	31	0	1	30
	Right-Centre	0	31	1	0	32	0
	Right	0	32	0	0	32	0
19 (VBP)	Left	0	1	31	1	0	30
	Left-Centre	1	0	31	1	2	29
	Right-Centre	0	28	4	0	29	3
	Right	1	30	0	0	32	0
20 (GP)	Left	4	1	27	1	0	31
	Left-Centre	2	6	24	2	5	25
	Right-Centre	0	25	7	0	26	6
	Right	8	24	0	4	20	7*
21 (VBP)	Left	1	0	31	3	0	28
	Left-Centre	0	11	21	1	19	12
	Right-Centre	6	24	2	9	23	0
	Right	17	15	0	31	0	0*
22 (BP)	Left	1	0	31	0	0	32
	Left-Centre	0	12	20	0	13	19
	Right-Centre	0	30	2	0	32	0
	Right	0	32	0	0	32	0
23 (BP)	Left	0	0	32	0	0	31
	Left-Centre	0	6	26	0	1	30
	Right-Centre	0	28	4	0	23	8
	Right	0	31	0	0	32	0
24 (GP)	Left	0	0	32	0	1	31
	Left-Centre	0	16	15	1	6	25*
	Right-Centre	0	32	0	0	26	5
	Right	0	32	0	0	28	4

Table 44 (Continued)

The Frequency With Which Each Type of Stroke Was Used by the Subjects in Experiment 2, as a Function of Condition and Landing Target

		Control[a]			Experimental[a]		
Subject[b]	Landing Target	N	F	B	N	F	B
25 (VGP)	Left	1	4	27	2	5	25
	Left-Centre	0	13	19	1	9	21
	Right-Centre	0	29	3	0	15	16*
	Right	1	31	0	0	26	5
26 (BP)	Left	0	0	32	6	1	24
	Left-Centre	0	15	17	0	9	23
	Right-Centre	0	31	1	1	31	0
	Right	6	25	0	17	15	0
27 (BP)	Left	0	11	21	0	23	9*
	Left-Centre	0	14	18	0	26	5*
	Right-Centre	0	31	0	0	32	0
	Right	2	30	0	0	30	0
28 (VGP)	Left	0	0	32	0	0	30
	Left-Centre	0	17	15	0	2	29*
	Right-Centre	0	28	3	0	19	10
	Right	7	25	0	0	32	0*
29 (GP)	Left	0	0	32	0	0	31
	Left-Centre	0	0	31	1	3	28
	Right-Centre	0	29	3	1	24	7
	Right	0	32	0	1	31	0
30 (VBP)	Left	0	0	32	1	0	31
	Left-Centre	0	26	6	0	27	3
	Right-Centre	4	28	0	0	31	0
	Right	19	13	0	23	9	0
31 (VGP)	Left	0	32	0	0	30	0
	Left-Centre	0	29	3	1	23	8
	Right-Centre	0	1	31	2	5	25
	Right	2	0	29	2	0	29

Table 44 (Continued)

The Frequency With Which Each Type of Stroke Was Used by the Subjects in Experiment 2, as a Function of Condition and Landing Target

Subject[b]	Landing Target	Control[a]			Experimental[a]		
		N	F	B	N	F	B
32(VGP)	Left	0	1	28	0	0	31
	Left-Centre	2	5	24	0	1	31
	Right-Centre	1	26	3	0	18	14*
	Right	2	30	0	0	32	0

Note. Maximum score = 32.

[a]N:No response; F:Forehand; B:Backhand

[b]VGP:Very Good Predictor; GP:Good Predictor; BP:Bad Predictor; VBP:Very Bad Predictor.

*Strong association

Experiment 2

Source of Variation	Degrees of Freedom	Mean Square	F Ratio
G (Group)	3	431.72	0.12
Blocks w. G	12	183.23	
C (Condition)	1	5.28	0.21
GC	3	18.43	0.73
C x Blocks w. G	12	25.37	
L (Landing Target)	3	221.86	9.08
GL	9	75.16	3.08
L x Blocks w. G	36	24.43	
CL	3	10.20	1.98
GCL	9	7.01	1.36
C x L x Blocks w. G	36	5.15	

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