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Procedural Knowledge and Movement Perception

by

Jeffrey I. Toward

A thesis
presented to the University of Ottawa
in fulfillment of the
thesis requirement for the degree of
Master of Science
in
Kinanthropology

Ottawa, Ontario, 1989

Dedicated
to
my Parents and
Louise

Whose love and support have made the completion of this thesis both more enjoyable and more satisfying

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I would also like to thank Mr. Don Bradley for his continuous computer support and for developing the apparatus (LEDMA) that was used in this investigation.

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Abstract

The performance on both a perceptual recognition and a movement reproduction task of a group (N=20) of subjects assessed as possessing higher levels of general procedural knowledge, relative to the detection and differentiation of various movement velocities, was studied and compared with the performance of a group (N=20) of subjects assessed as possessing lower levels of general procedural knowledge. Initially, 58 subjects were required to make judgements as to which of two visually presented moving light emitting diodes (LEDs) were travelling with the greatest velocity. The subjects completed 64 trials at this first task (Task One) with the number of incorrect responses being used to identify the level of general procedural knowledge possessed by each individual. Two groups of equal size and both varying perceptual ability and general procedural knowledge levels were then selected. Group one represented the 20 individuals who made the fewest number of errors on Task One and as a result were said to possess higher levels of general procedural knowledge, while group two represented the 20 individuals who made the greatest number of errors on Task One and as a result were said to possess lower levels of general procedural knowledge. Group one was found to be significantly different than group two with respect to the number of errors made at Task One. These same two groups were

then tested for their ability to physically reproduce the velocity of a previously observed moving LED through the manipulation of a hand held stylus pen. The subjects performed 96 trials at this task (Task Two). Group one subjects were found to perform significantly better than group two subjects at reproducing the velocity of the observed LED. These results suggested that a relationship does appear to exist between ones ability to visually perceive and physically reproduce movement velocities and that both abilities are greatly influenced by the level of general procedural knowledge possessed by the individual.

INTRODUCTION

Investigations concerned with the identification and labelling of perceptual and cognitive differences between individuals considered to be either expert or novice performers have traditionally focussed on such semantically rich domains as chess (Chase & Simon, 1973; DeGroot, 1965), bridge (Charness, 1979), computer programming (Adelson, 1984; McKeithen, Reitman, Rueter, & Hirtle, 1981), physics (Chi, Feltovich, & Glaser, 1981), and psychology (Murphy & Wright, 1984). Only recently has research begun to examine such expert/novice differences within the movement oriented domain of sport (Allard & Burnett, 1985; Allard, Graham, & Paarsalu, 1980; Borgeaud & Abernethy, 1987).

Experts within both the movement and non-motor domains have been found to differ from novices in their ability to perceive and process large amounts of meaningful information. The reasons for these apparent differences are many. Allard (1982) stated simply that the possession of more knowledge on the part of the expert may facilitate these differences, while McKeithen et al. (1981) extended this reasoning to suggest that experts represent, structure, and access this knowledge differently than novices.

With reference to the structural differences in the representation of knowledge between experts and novices Thomas, French, and Humphries (1986) believed it was

important to distinguish between the two main forms in which knowledge was said to be represented; declarative knowledge and procedural knowledge. The main distinction between these two forms of knowledge is one of content. Declarative knowledge emphasizes the storage of facts about the world, "knowing that", while procedural knowledge is a representation of our ability to perform a skill, "knowing how" (Anderson, 1976; Mitchell and Chi, ; Winograd, 1975). Procedural knowledge may exist as domain specifc procedures, or general interpretive procedures which are non-domain specific depending upon the extent of previous exposure to the event or action in question. One way in which procedural knowledge is believed to be enacted is through perceptual recognition where, according to Norman and Bobrow (1976), the appropriate procedure is automatically triggered through the recognition of relevant patterns of incoming information. Therefore, the use of a perceptual recognition task may prove beneficial when attempting to assess procedural knowledge levels as subjects may not always be able to verbalise this knowledge.

Glaser (1984) stated that the possession and utilization of an organized body of conceptual and procedural knowledge as well as the possession of accessible and useable knowledge differentiates thoses individuals who display more or less ability in thinking and problem solving. Therefore, it was hypothesized that changes in an individuals knowledge base

may result in changes in an individuals cognitive performance. Similarly, Wall, McClements, Bouffard, Findlay, and Taylor (1986) suggested that, in the motor domain, procedural knowledge about action underlies all aspects of action including the cognitive, perceptual, response initiation, and response execution phases. Consequently this may suggest that changes in an individuals knowledge base may also result in changes in an individuals motor performance.

When viewed in this manner, procedural knowledge about action appears to be closely associated with Rappaport's (1971) descriptive model of the perceptual processes involved in the integration of sensory information. Rappaport (1971) developed a five level model for the integration of sensory information, progressing from the identification and labelling of incoming information, through the organization of labelled information into distinct groups, the creation of mental images or percepts from the previously created groups, the categorization and organization of percepts into concepts, to the final cognitive level of "knowing" or "seeing" responses as being correct.

By using a visual perception recognition task to assess the level of general procedural knowledge for a group of subjects and then comparing their performance on a movement reproduction task it may be possible to determine how differences in an individuals knowledge base can affect the development and operation of both their perceptual (visual)

and motor abilities. Therefore, this investigation was designed to examine how differences in general procedural knowledge relative to the visual perception of movement velocities (as triggered through performance on a perceptual recognition task) relate to the ability to perform a movement velocity reproduction task. The majority of the research into expert novice differences has focussed on the extremes within each level of performance, and as a result could provide little insight into the processes by which a novice attains expertise (becoming an expert). Therefore, in an attempt to address this latter question, this investigation took the approach of focussing on different or intermediate levels of expertise rather than the extremes of expert vs novice.

The hypothesis tested in this investigation was that the group of individuals found to possess higher levels of general procedural knowledge relative to the detection and differentiation of various movement velocities would also possess superior motor abilities relative to the reproduction of movement velocities.

METHOD

Subjects

Fifty-eight male and female undergraduate students from within the department of Kinanthropology at the University of Ottawa served as subjects. Participation in the

investigation was voluntary, however, each subject did receive partial class credit for their participation.

Apparatus and Task

Two separate tasks were used in this investigation. Both tasks used are part of a larger apparatus called the Light Emitting Diode Movement Analysis apparatus (LEDMA) (refer to figure 1). Task one was a perceptual recognition task, as suggested by Norman and Bobrow (1976), and was used to assess each subjects level of general procedural knowledge as triggered through the visual perception of two LEDs moving in a successive manner down a computerized matrix board. The movement of the two LEDs differed in that they descended unequal distances in unequal times. The speed with which the LEDs travelled was based upon eight reference speeds (20, 30, 40, 50, 60, 70, 80, and 90 cm/s) built into the movement analysis program. One of the two LEDs always travelled at one of the eight programmed reference speeds while the second travelled at a percentage of the selected reference speed (66%, 100%, 150%, or 170%).

Performance on Task one (the perceptual recognition task) was felt to provide an accurate assessment of each subjects level of general procedural knowledge. It was believed that initial observation of the experimental apparatus combined with the task instructions would have resulted in the subjects activating information pertaining to

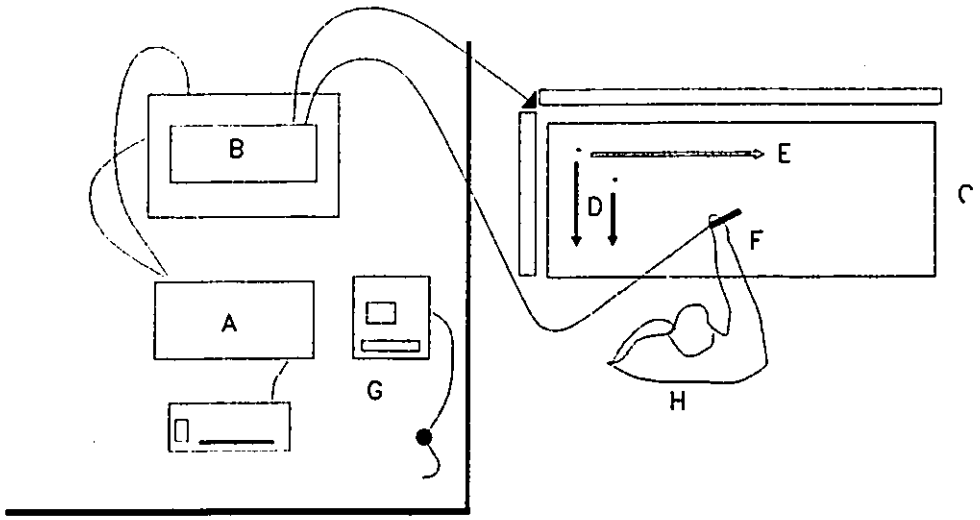

Fig 1: LEDMA apparatus experimental design: (A)Compac personal computer, (B)Sonic digitizer control unit, (C)Matrix board, (D)Task one(closed arrows), (E)Task two(open arrow), (F)Stylus (G)Tape recorder and microphone head set, (H)Subject

velocity (speed of movement, or velocity differentiation) in long term memory and/or in the temporary placement of this information in short term memory. Therefore, as the subjects performed Task one the appropriate procedures would have been automatically triggered through the perception and recognition of relevant patterns of incoming information (Norman & Bobrow, 1976). Given that procedural knowledge is said to be conceptualized as a series of IF-THEN rules (Anderson, 1976, 1982, 1983; French & Thomas, 1987; Mitchell & Chi, 1986; Neves & Anderson, 1981) the information obtained as a result of the observation of the LEDs movement would

have been compared to the activated information from long term memory to determine if the conditions required for velocity determination and differentiation were present in the observed movements.

Task two was used to assess each subjects ability to reproduce the velocity of a previously displayed movement. The first phase of this task, the visual display, consisted of the subject observing an LED travelling horizontaly, in either a left to right (forward) or right to left (reverse) direction, across the matrix board at a speed of either 20, 30, 40, 50, 60, 70, 80, or 90 cm/s for a distance of 40 cm. The plane of LED movement, vertical vs horizontal, differed for Tasks one and two respectively to help reduce any learning and/or transfer effects which may have occurred if both tasks were performed in the same plane. By performing each task in a different plane the subject was required to concentrate solely on the velocity of the LED movements, not the direction of travel. The second phase of Task two, the reproduction phase, consisted of each subjects attempt at physically reproducing the velocity of the visual display movement through the manipulation of a hand held stylus over one of three distances: 30, 40, or 50 cm. A computer then determined the velocity of the reproduced movement over the middle third of the distance travelled and compared it to the velocity of the visual display. For a complete description of the apparatus refer to appendix E.

Immediately after the completion of each Task (one and two) the subject was asked to participate in an interview designed to present the investigator with information relative to the strategies employed by each subject during testing. The responses were tape recorded for later analysis. At the end of the testing session each subject completed a questionnaire designed to provide relevant information about their personal history. Refer to Appendix A for a complete copy of the questionnaire and interview questions.

Procedure

Upon entering the laboratory each subject was shown the apparatus that was to be used during testing and was seated in front of the matrix board. Each subject participated in a single experimental session consisting of Tasks one and two, the background information questionnaire, and the subject strategy interview. The experimental session lasted approximately one hour.

Task One

The instructions were verbally presented to the subjects (see Appendix B) emphasizing that their responsibility was to determine, as quickly as possible, which of two LEDs was travelling with the greatest velocity, and to verbally communicate the answer (first, second, same) to the investigator. A microphone, worn by the subject, recorded the response issued and triggered a voice activated reaction time

mechanism which recorded the amount of time required by the subject to reach their decision. One and one-half seconds plus the amount of time required by the first LED to complete its run was allowed for each subject to communicate their answer or the trial was terminated and repeated later.

As each of the eight reference speeds was presented twice for the four subtasks that exist within Task one, each subject performed 64 trials. Prior to testing, each subject was presented with four practice trials, run at a slower speed than the actual test trials.

Task Two

Before initiating testing on Task two the instructions were verbally presented to each subject (see Appendix B) emphasizing that their responsibility was to attempt to move the stylus at the same speed as the movement observed in the visual display; not the same distance. As each of the eight velocities were presented twice in the visual display, for both directions of travel, and reproduced at each of the three reproduction distances, each subject performed 96 trials. A single trial began with the subject placing the stylus on an illuminated LED on the matrix board and then observing the movement of a second LED as it travelled either left to right or right to left. When the display movement was completed the subject responded by moving the stylus, attempting to reproduce the velocity of the display LED, to an illuminated LED located either 30, 40, or 50 cm to the

right of the initial stylus location. The location of both the display movement and the points used to guide the reproduction movement varied on the matrix board to prevent the use of location cues by the subject.

To ensure successful completion of each trial the subject had to; a) initiate the reproduced movement in response to an auditory signal from the computer, b) complete the reproduced movement in a specified time period, one and one-half seconds plus the amount of time required for the visual display to complete its run, and c) complete the movement within plus or minus two centimetres of the illuminated end-point LED. If the subject failed to comply with any of these guidelines the trial was terminated and repeated later in the series. For a more detailed description of the procedure refer to Appendix E.

Design

The preliminary analysis was concerned with identifying two distinct groups of subjects from the original 58. As a result of ranking the subjects based on the number of errors produced on Task one, two groups of equal size (N=20) and varying perceptual ability were selected. Two t-tests for independent groups were then used to test for significant performance differences on this task; both error scores and reaction times were used.

Group one consisted of those 20 individuals who

displayed a higher level of general procedural knowledge on the perceptual recogniton task, while group two consisted of those 20 individuals who displayed a lower level of general procedural knowledge on the perceptual recognition task.

Both groups were then analysed in terms of their ability to reproduce movements of various velocities. The values recorded during the performance of Task two represented the difference between the display movements velocity and the reproduced movements velocity. The absolute values of these scores were obtained and then averaged for the three distances of reproduction and two reproduction trials at each of the eight display speeds for both directions of the display LED's movement. These values were then labelled the Mean Velocity Errors (MVE's) and were analysed using a 2 X 2 X 8 (Group X Direction X Speed) ANOVA with repeated measures on the last two factors. Tukey post-hoc analyses and a simple main effect analysis were then used to describe the significant main effects and interactions.

The information obtained as a result of the interviews and questionnaires was analysed both descriptively and statistically, using a 2 X 2 (Group X Task) ANOVA with repeated measures on the last variable.

RESULTS

Task One

Table 1 illustrates the summary statistics for each of the two groups. For a complete listing of the raw error data for both group one and two on Task one refer to Table D-1 in Appendix D. The analysis of the number of errors produced by each group at Task one, using a t-test for independent

Table 1

Descriptive Statistics for the Reaction Times and Number of Errors produced at Task One

		Group One	Group Two
	N	20	20
Errors	Mean	11.40	22.10
	S.D.	2.39	4.15
R.T. (s)	Mean	0.99	1.12
	S.D.	0.11	0.18

groups, indicated that group one subjects significantly outperformed group two subjects on this perceptual recognition task, $t_{38} = 2.0354$, $p < 0.0001$. Analysis of the RT scores produced by each group at Task one indicated that group one subjects also performed significantly faster than group two subjects, $t_{38} = 2.0354$, $p < 0.05$. As group two subjects were found to respond marginally slower than group one subjects it was concluded that the observed

differences in the number of errors produced at this task were a result of knowledge base differences and not a speed accuracy trade-off. Consequently, the two groups were assessed as clearly possessing differing levels of general procedural knowledge.

Task Two

The 40 subjects that were identified as belonging to group one and group two in the preliminary analysis were then analysed in terms of their abilitiy to physically reproduce the velocity of the display LED in Task two. Table 2 displays the summary statistics for the MVE's for Task two.

Table 2

Summary Statistics for the MVE's at Task Two.

		Mean Velocity Errors (cm/s)			
		Group One		Group Two	
		Mean	S.D.	Mean	S.D.
Group		13.56	7.35	16.31	9.13
Direction	Forward	13.52	7.48	16.53	9.73
	Reverse	13.59	7.23	16.10	8.51
Speed (cm/s)	20	5.40	3.54	13.34	13.71
	30	7.46	2.79	13.55	11.34
	40	11.11	4.23	14.05	8.98
	50	13.00	4.80	13.39	6.24
	60	14.99	4.21	15.77	5.60
	70	16.34	5.77	18.75	5.86
	80	18.57	6.41	20.58	5.82
	90	21.56	8.58	21.09	8.16

For a complete listing of the MVE's for both groups one and

two on Task two refer to Tables D-2 and D-3 in Appendix D.

Analysis of the MVE's indicated significant main effects for: Group (F (1,38) = 4.19, p < 0.05); Speed (F (7,266) = 25.95, p < 0.05); and a significant Group X Speed interaction (F (7,266) = 2.96, p < 0.05). No significant effects were observed for Direction. Refer to Table 3 for the complete analysis results.

Table 3

Summary of the Analysis of Variance with Repeated Measures, One Grouping Factor (Group), Two Within Factors (Direction and Speed)

Source	SS	df	MS	F	Prob
Mean	142755.84	1	142755.84	490.40	0.0000 *
Group	1218.48	1	1218.48	4.19	0.0477 *
Error	11061.91	38	291.10		
Direct	4.88	1	4.88	0.22	0.6432
DG	9.86	1	9.86	0.44	0.5111
Error	851.15	38	22.40		
Speed	10284.45	7	1469.21	25.95	0.0000 *
SG	1171.97	7	167.42	2.96	0.0053 *
Error	15050.01	266	56.62		
DS	69.57	7	9.94	0.51	0.8254
DSG	109.92	7	15.70	0.81	0.5807
Error	5165.02	266	19.42		

* p < .05.

Observation of the MVE's indicated that as the speed of the visual display increased so to did the size of the error for both groups. The SD values for group one displayed a

similar tendency toward increasing as the speed of the visual display increased, indicating that the responses for the subjects within group one became more variable as the viusal display speed increased. For group two subjects the SD values steadily decreased as the speed of the visual display increased, indicating that their responses became less variable as the visual display speed increased. However, it was interesting to note that while an inverse relationship was seen to exist between the two groups in terms of their directional changes in response variability (i.e., SD's) both groups tended toward the same MVE and SD value at the highest visual display velocity (90 cm/s).

The significant group main effect indicated that group one was significantly more accurate in reproducing the velocity of the display LED than was group two. Thereby, suggesting that a relationship exists between the various levels of general procedural knowledge, as assessed on the perceptual recognition task, and the ability to physically reproduce movement velocities.

The tukey post-hoc analyses (see table D-4 in Appendix D) indicated that performance at velocity 90 cm/s was significantly different ($p < .05$.) than that at 20, 30, 40, 50, and 60 cm/s. Performance at velocity 80 cm/s was significantly different ($p < .05$.) than that at 20, 30, 40, and 50 cm/s, while performance at velocity 70 cm/s was significantly different ($p < .05$.) than that at 20 and 30

cm/s. Finaly, performance at velocity 60 cm/s was found to be significantly different ($p < .05.$) than that at 20 cm/s. These differences were mainly attributed to group one as no significant differences were observed between the eight speeds at group two.

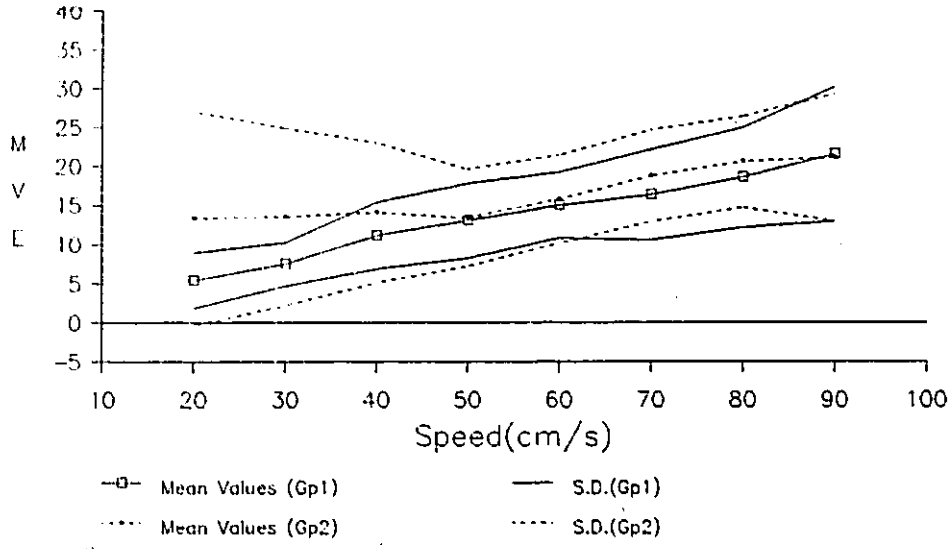

Fig 2: MVE at each speed
Group One & Group Two

A simple main effects analysis (see table D-5 in Appendix D) for the Group X Speed interaction revealed that there was a significant difference between the MVE's for group one and group two at the display speeds of 20 cm/s ($F(1,38) = 6.52$, $p < 0.05.$) and 30 cm/s ($F(1,38) = 5.63$, $p < 0.05.$). At both 20 and 30 cm/s group one was found to perform

significantly better than group two. Figure 2 graphically presents the differences observed between each group at all eight of the display speeds. Although the MVE's for group one were always less than those for group two, except at 90 cm/s, the only significant differences were observed at 20 cm/s and 30 cm/s indicating that group one subjects were significantly better at reproducing the slow speeds than were the group two subjects.

Interview

For group one, 82.5 % of the responses regarding task difficulty (question 1) indicated that both tasks were found to be difficult, while 17.5 % of the responses indicated that both tasks were found to be easy.

For group two, 62.5 % of the responses regarding task difficulty (question 1) indicated that both tasks were found to be difficult, while 37.5 % of the responses indicated that both tasks were found to be easy.

Questions 2a, 2b, and 2c as well as 3a and 3b were all designed to assist the subjects in their description of the procedures used to determine the velocity of the LEDs observed. Categorization of the responses offered by the subjects within each group indicated that both groups used similar strategies or focussed on similar elements when attempting to determine the velocity of the observed LEDs. Four out of the five most frequently cited strategies were

shared by both groups. These four common response categories were; 1) focussed on the LED and its pattern of movement, smooth vs rough, 2) counted the time required for the LED to complete its run and used that information to determine its velocity of travel, 3) was unable to verbally express how they arrived at their decisions and, 4) focussed on the centre of the matrix board, whether it was for Task one or two, and observed the LED movement across that point. For group one these four response categories accounted for 53.8 % of the responses given, while for group two they accounted for 47.9 % of the responses given.

Questionnaire

The Background Information Questionnaire provided some interesting information on the subjects within each group but did little to distinguish between groups. The subjects within both group one and group two were found to have little if any previous exposure to biomechanics courses. The subjects in both groups were also found to exhibit extensive participation in sports in both the past and present. Rarely did an individual in either group (five out of 20 in group one, and seven out of 20 in group two) indicate whether they believed there was something in their background that might have helped their performance on either task (question 3b). The responses for subjects in both groups centred on the possession of sport skills which they felt may have helped

their performance on either task.

There were two areas in which the subjects in both groups were found to differ. Group one subjects were found to have a more extensive physics background than group two subjects with group one subjects having taken an average of 1.95 courses compared to group two which averaged 1.15 courses. The most interesting information obtained from the questionnaire was the analysis of the data obtained from question 3a, which asked the subjects within each group to subjectively rate their performance on both Task one and Task two along a scale of 0, for very poor, to 10, for excellent. Analysis of the combined Task one and Task two rank performance values for group one and group two indicated a significant main effect for groups ($F(1,38) = 4.69$, $p < 0.05$). As the mean ranked performance values were 6.43 for group one and 5.65 for group two it was concluded that group one was significantly more confident in their performance than were group two subjects. For a complete listing of the raw data concerning the responses to question 3a refer to tables D-6 and D-7 in Appendix D.

DISCUSSION

The fundamental purpose of this investigation was to determine if a relationship existed between the ability to visually perceive and physically reproduce movement

velocities and differences in general procedural knowledge. Specifically, whether the group of individuals found to possess higher levels of general procedural knowledge, relative to the detection and differentiation of various movement velocities, would also possess superior motor abilities. This hypothesis was supported by the results obtained in this investigation in that the subjects assessed as possessing higher levels of general procedural knowledge (group one) demonstrated superior movement reproduction abilities when compared to the group of subjects assessed as possessing lower levels of general procedural knowledge (group two).

As group one subjects were assessed as possessing higher levels of general procedural knowledge, when compared to group two subjects, it was concluded that the schemata developed for movements and their subsequent velocities were more fully developed for group one subjects allowing them to more readily and more accurately differentiate between the velocities of the two LEDs presented. As Norman and Bobrow (1976) stated, schemata, which consist of a framework for tying together information about a given concept or event with specifications as to the types of interrelations and restrictions existing within the information, may activate procedures capable of operating on the information perceived.

With the strength of the schemata developed for movement and movement velocities believed to differ between the two

groups it appears reasonable to conclude that the manner in which the perceptual information provided by the moving LEDs was processed and analyzed also differed between groups. For group one subjects, possessing higher levels of general procedural knowledge and, therefore, more fully developed schemata it was hypothesized that the perceptual stimuli presented through the LEDs movements were processed and consequently identified as a result of what Norman and Bobrow (1976) termed top-down analyses. The first few indications of features relevant to the event in question, determining which of two LEDs was moving with the greatest velocity, drove the perceptual system to make conceptualizations about the perceptual input eventually resulting in the accumulation of sufficient evidence to accept the initial hypothesis which may have been that the first LED was travelling fastest. More simply stated, once it had been hypothesized that the first LED was travelling with the greatest velocity the appropriate features and relationships were then searched for by conceptually generated processes until the hypothesis was either accepted or rejected.

Group two subjects, on the other hand, possessed lower levels of general procedural knowledge and, therefore, less well developed schemata. Consequently, the perceptual stimuli presented through the LEDs movements may have been primarily processed and identified as a result of what Norman and Bobrow (1976) termed bottom-up analyses. In this type of data

driven analysis sensory information would have entered the sensory system activating different regions of the sensory memory as it did so. It would then be the responsibility of the sensory system to organize the activated structures into a meaningful and representative schema (Norman & Bobrow, 1976).

As the schema for group one subjects was believed to contain information about the relationships amongst its various parts, information which Norman and Bobrow (1976) stated as being essential for a schema representative of a given concept or event, these subjects were able to perform significantly better than group two subjects at Task one.

The fact that group one subjects were also found to perform significantly better than group two subjects at Task two indicated that the possession of higher levels of general procedural knowledge allowed group one subjects to more accurately assess and reproduce the velocity of the observed display LED. However, the advantage afforded by the possession of higher levels of general procedural knowledge appeared limited in that the only significant Group X Speed interactions were observed at the two slowest speeds of 20 cm/s and 30 cm/s. At these two slowest speeds only group one subjects were able to take advantage of the increased time afforded by the slow moving LED. As a result, group one subjects were provided with a greater opportunity to monitor their responses through the use of feedback and take

advantage of their more fully developed schemata when attempting to reproduce the previously observed movement velocity. This in turn meant that group one subjects had access to a larger more complete knowledge base when attempting to locate the procedures required to guide the movement reproduction portion of the task. Therefore, group one subjects were able to more accurately reproduce the velocity of the display movement lending support to Wall et al.'s (1985) contention that knowledge base differences may affect the accuracy and efficiency with which movements are controlled.

The differences observed between group one and group two with respect to the assessed general procedural knowledge levels and movement reproduction abilities may also be indicative of the possession of more highly refined visual perception abilities on the part of group one subjects. The performance of group one subjects on Task one suggests that these subjects were better able to discriminate between the velocities of the observed LED movements. On Task two these same subjects were then found to possess superior visual memory and integration abilities, both as defined by Williams (1983), as they were better able to recall the characteristics of the visual stimuli presented to them (the display movement) and coordinate this input with the required motor output (the reproduction movement) allowing for the more efficient monitoring of their responses.

This may serve to explain why no significant differences were observed between the MVE's at any of the eight display speeds for group two subjects. When examined in relation to Rappaports (1971) five level descriptive model for the integration of sensory information the lower levels of general procedural knowledge possessed by group two subjects may have prevented them from fully integrating the information obtained through the visual perception of the display movements velocity. The reason for this being that these individuals were more likely to proceed only as far as the third level for the integration of sensory information, the perceptual level, since they were, as a result of possessing lower levels of general procedural knowledge, unable to gain access to clearly defined concepts representative of both the group of perceptual tasks and motor tasks associated with velocity.

Group one subjects, on the other hand, were able to more accurately discriminate and reproduce the eight different velocities observed during the display movements due to the possession of higher levels of general procedural knowledge. Consequently, these subjects were able to proceed through to the fifth and final level for the integration of sensory information, the cognitive level, where the information condensed through the first four levels was used to identify a response seen as being correct by the subject. The process of integration, as stated by Kerr (1982), not only allows the

perceptual system to recognize visual stimuli, but allows it to do so at a faster rate and more accurately.

As group one subjects were found to perform significantly better than group two subjects on both Task one and Task two the question then arises as to why group one would rate these same tasks as being difficult more often than group two. Perhaps this finding may be related to those of Adelson (1984), Chi et al. (1981), Chi and Koeske (1983), and Murphy and Wright (1984) who found, while studying possible structural changes in the knowledge possessed by individuals labelled as expert or novice within a particular domain, that experts seem to form abstract conceptual representations of the problems presented to them allowing them to see the underlying similarities between problems, while the representations formed by novices tend to retain only the literal surface elements of problems. When applied to the tasks used in this investigation this may indicate that group two subjects relied primarily on the individually perceived elements of the LEDs movement such as the distance travelled by each LED or the time taken to complete each run and as a result perceived the velocity as being relatively easy to determine. The subjects within group one, while using essentially the same information as that used by group two subjects, formed more accurate representations of the LED velocities due to their ability to establish an abstract relationship between the information presented by the two

LEDs while ignoring the literal surface elements of the information presented. As this process appears more complex than that used by group two subjects it may provide the answer as to why group one subjects rated both tasks as being difficult more often than did group two subjects. Perhaps it may be said that as group one subjects were found to possess more highly developed procedures they in turn provided a more accurate assessment of the tasks difficulty than did group two subjects.

Not only were group one subjects able to more accurately assess the difficulty of both tasks, they were also found to possess more confidence in their actions for successfully meeting the imposed task demands. It may, as a result, be concluded that group one subjects were in possession of certain metacognitve knowledge variables not possessed, or not as fully developed, by group two subjects. Specifically, the subjects within group one were believed to possess higher levels of metacognitve knowledge about action which, as stated by Newell and Barclay (1982), represent an individuals awareness of the association between movement and its consequences.

Therefore, a relationship does appear to exist between an individuals ability to visually perceive and physically reproduce movement velocities and that both abilities are influenced by the level of general procedural knowledge possessed by the individual. Further, it was also observed

that the level of general procedural knowledge possessed by the subjects was related to their abilty to judge task difficulty and their resultant performance on both tasks.

If the results of this investigation are taken one step further one might conclude that a direct relationship exists between the functioning of an individuals perceptual abilities and their motor abilities, and that the functioning of both abilities is influenced by the general knowledge base possessed by each individual. However, further invesitgation must be undertaken before such broad conclusions can be made.

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Appendix A

BACKGROUND INFORMATION QUESTIONNAIRE

AND

SUBJECT STRATEGY INTERVIEW

NAME:

AGE:

SEX:

HANDEDNESS: R L

DATE OF BIRTH (dd/mm/yy):

1) Please indicate the extent to which you have received instruction in both physics and biomechanics courses (i.e., list the nuber of courses you have taken in each area, including highschool).

2) Please indicate any sports or hobbies which you have participated in for an extended period of time. If you have taken part in an organized or competitive sport please indicate at what level and for how long.

3a) How do you think you performed in these tasks?

TASK ONE

---

0 1 2 3 4 5 6 7 8 9 10

very poor excellent

TASK TWO

---

0 1 2 3 4 5 6 7 8 9 10

very poor excellent

3b) Is there anything in your background that might have prepared you for these tasks? If yes, what?

Subject Strategy Interview

At the completion of each task the following questions will be asked and the responses will be tape recorded;

1) How would you rate the difficulty of this task (i.e., easy, difficult, very difficult)?

FOR TASK ONE

2a) How were you able to determine which of the two LEDs was travelling with the greatest velocity?

2b) Did you try to prepare yourself to respond? If yes, how?

2c) What did you focus on during the task?

FOR TASK TWO

3a) How were you able to determine the velocity of the display LED?

3b) What did you focus on during the task?

Appendix B

TASK INSTRUCTIONS

TASK INSTRUCTIONS

Once the individual was seated in front of the matrix board the following instructions will be given.

There are two tasks that you will be tested on. The first task involves making judgements about the velocity of two LEDs moving in a vertical pathway down the screen toward a baseline of 11 illuminated LEDs. The first LED will appear at the top of the screen and travel down to the baseline and disappear. The second LED will then do the same. The distance travelled by the two LEDs will vary because they will start at different points near the top of the screen. Your job is to tell me which LED you think is travelling with the greatest velocity. If you believe that the first LED was travelling with the greatest velocity answer 'first'. If you believe that the second LED was travelling with the greatest velocity answer 'second'. If you believe that both LEDs were travelling with the same velocity answer 'same'. You will perform 64 trials at this task, preceeded by four practice trials. You are to try to respond as quickly and as accurately as possible. You will wear a small microphone during the performance of the task which will record your reaction time. At the completion of this task you will participate in a short interview which will be tape recorded.

The second task involves observing the velocity of an

LED moving in a horizontal pathway across the screen followed by an attempt at physically reproducing the velocity of the observed movement. You will see an LED appear on the screen. You are to respond by placing the stylus, which you hold in your preferred hand, on the LED. You will be allowed an error of plus or minus 1 sq cm when placing the stylus on the LED. You are to hold the stylus on the LED until instructed to do otherwise. Next you will see two LEDs appear 10 cm above the first LED. These two LEDs will always appear 40 cm apart. One of the two LEDs will then travel toward the the other, in either a left to right or right to left direction. After this movement is completed a number of events will occur simultaneously; you will hear a beeping sound, the LED which you are holding the stylus on will be turned off, and an LED will appear either 30, 40, or 50 cm to the right of where you are holding the stylus. Your job is to now move the stylus from where it has been held to the LED which has just appeared, attempting to move at the same speed as the LED you previously observed. You will be allowed an error of plus or minus 2 cm when completing this movement. If, when you have completed the movement, you are 2 cm short of the LED or 2 cm long the trial will be ignored and you will be asked to perform it again later in the series of trials. The trial will also be ignored and performed again if the movement takes longer than one and one half seconds plus the amount of time required for the display movement to be completed. You

will perform 96 trials at this task, preceeded by six practice trials. Remember that your job for this task is to attempt to move the stylus at the same speed as the LED in the observed movement. Try to keep the stylus in contact with the screens surface throughout each of the trials.

When the testing is completed on this task you will again be asked to participate in a short interview, as well as complete a short questionnaire providing some background information about yourself.

Appendix C

LETTER OF INFORMED CONSENT

Letter of Informed Consent

When a research project that studies individuals is undertaken by a member of the University of Ottawa, the Ethics Committee of the University requires the written consent of the participants. This does not imply that the project is risky; the intention is simply to assure the respect and confidentiality of the individuals involved.

This research project, conducted by Jeffrey Toward, is concerned with examining the perceptual and movement reproduction abilities of individuals possessing various levels of procedural knowledge.

Participation in the project will require the following:

1) I will be asked to sit in a darkened room in front of computerized matrix board and observe the movement of two LEDs as they travel from the top of the board to the bottom.
2) I will be asked to make judgements based on the speed of travel of the two observed LEDs.
3) I will be asked to physically reproduce the movement of a previously observed LED through the manipulation of a stylus across the matrix board.

All results will be kept confidential and I may address any questions that I have regarding my participation in the investigation to the investigator at any point before, during, or after my participation. I understand that at no point in the investigation will I be exposed to any risk. I understand that I may withdraw from the study at any time.

I give my informed, voluntary consent to particpate.

_____ _____

Date Participant's Name

_____

Participant's Signature

Appendix D

SUPPLEMENTARY RESULTS

Table D-1: Raw Data for Group One and Group Two at Task One

Group One			Group Two		
Sub#	GpSub#	Errors	Sub#	GpSub#	Errors
4	1	11	6	1	22
14	2	10	10	2	23
16	3	9	13	3	24
20	4	8	21	4	25
26	5	9	23	5	30
27	6	10	32	6	24
46	7	7	44	7	32
50	8	7	45	8	25
58	9	11	49	9	23
2	10	12	51	10	22
5	11	13	53	11	26
1	12	13	56	12	20
31	13	13	39	13	19
34	14	13	3	14	19
57	15	13	8	15	19
42	16	13	48	16	18
52	17	14	11	17	18
41	18	14	35	18	18
9	19	14	36	19	18
29	20	14	38	20	17

Table D-2: Raw Data for Group One at Task Two

Group	Direction	Speed (cm/s) 20	30	40	50	60	70	80	90
1	F	5.04	7.64	9.40	11.53	13.79	33.66	18.37	36.02
	R	2.83	5.66	11.37	14.26	18.47	13.50	23.79	28.33
1	F	8.09	12.16	4.71	16.77	15.03	15.82	14.65	13.77
	R	8.82	15.18	16.74	21.97	19.22	22.51	8.16	10.65
1	F	1.73	5.46	9.18	13.93	16.45	16.27	21.92	32.53
	R	2.89	4.52	10.47	12.80	11.51	18.91	24.61	36.20
1	F	2.19	9.12	9.03	21.61	16.28	17.75	19.87	5.97
	R	10.66	8.12	18.17	15.03	14.70	18.35	9.09	21.48
1	F	4.12	6.63	5.38	3.62	10.29	11.83	13.30	17.22
	R	2.50	10.93	4.96	7.69	12.90	11.13	12.01	11.17
1	F	14.61	11.32	10.01	10.57	8.89	7.85	17.41	17.65
	R	11.16	4.80	14.43	13.91	8.90	12.26	11.00	20.06
1	F	1.83	5.50	7.56	6.86	12.21	12.94	5.29	12.83
	R	3.21	6.42	8.24	12.25	7.78	10.98	15.58	15.43
1	F	3.92	4.69	7.94	7.86	17.87	18.66	13.25	30.70
	R	3.29	3.96	8.58	7.28	11.89	11.57	7.10	16.56
1	F	3.74	9.65	14.68	9.10	18.16	19.90	22.54	20.00
	R	4.90	9.83	8.29	22.29	19.22	27.19	25.43	18.81
1	F	7.79	8.80	10.52	10.35	13.81	7.71	14.25	13.24
	R	8.75	6.27	12.91	14.12	18.93	5.86	18.38	19.39
1	F	9.14	7.23	15.27	13.66	14.46	17.50	32.51	31.11
	R	9.40	8.47	14.43	21.94	22.19	8.59	22.34	20.56
1	F	17.09	14.06	17.57	7.81	5.93	13.18	12.10	16.94
	R	6.44	6.90	19.02	12.86	15.92	11.57	17.52	19.04
1	F	3.10	3.85	8.40	8.23	15.67	20.85	21.89	33.36
	R	3.94	4.56	6.96	10.65	16.69	16.13	24.64	33.36
1	F	4.22	6.11	9.14	9.41	15.61	16.90	23.97	20.97
	R	0.79	6.27	8.81	10.21	9.61	17.94	24.19	16.77
1	F	4.68	10.23	16.14	20.80	21.05	22.50	27.96	35.26
	R	5.43	7.48	9.85	19.06	22.58	23.41	27.97	27.72
1	F	4.38	6.81	10.55	7.21	17.55	18.30	18.68	19.17
	R	2.44	7.12	11.69	20.66	16.00	15.13	22.42	24.97
1	F	3.99	7.96	12.53	16.73	21.90	22.25	21.96	26.77
	R	3.64	7.68	11.39	14.43	20.73	20.97	16.54	35.88
1	F	5.52	6.53	11.77	15.25	14.19	13.55	13.17	8.31
	R	3.24	11.49	6.25	11.50	9.71	23.34	23.38	15.39
1	F	6.47	4.73	24.64	13.78	10.87	7.78	14.54	6.57
	R	3.05	6.24	7.63	10.89	11.79	12.40	11.84	22.29
1	F	3.22	5.25	11.20	11.89	18.25	17.22	25.06	30.01
	R	3.74	2.93	8.64	9.19	12.71	19.30	24.29	20.12

Table D-3: Raw Data for Group Two at Task Two

Group	Direction	Speed (cm/s) 20	30	40	50	60	70	80	90
2	F	5.07	4.04	9.22	12.17	12.64	23.16	24.73	37.39
	R	5.14	4.31	9.04	14.92	17.17	19.87	23.90	29.80
2	F	8.30	13.08	10.70	12.87	16.27	24.12	19.92	27.29
	R	16.10	12.73	12.10	13.66	16.06	19.39	25.77	29.59
2	F	9.89	9.11	7.09	13.81	12.81	15.53	15.68	22.31
	R	6.94	7.37	9.68	8.71	8.67	19.03	18.03	14.04
2	F	8.94	20.68	15.35	9.82	17.37	15.65	27.34	14.19
	R	5.15	18.42	3.18	11.50	18.61	13.79	16.85	11.83
2	F	9.91	19.66	24.63	14.39	17.36	15.80	11.50	8.99
	R	11.24	16.11	7.49	7.81	17.07	15.16	24.05	16.37
2	F	2.10	5.02	6.37	8.89	12.79	16.53	23.25	21.59
	R	6.97	8.38	7.74	17.36	12.49	11.71	22.10	22.73
2	F	13.32	6.29	20.94	15.54	9.48	17.30	22.07	12.52
	R	25.08	18.21	17.11	8.70	14.51	22.75	13.83	19.77
2	F	47.70	29.69	20.20	17.05	31.67	22.04	18.69	36.80
	R	41.48	25.38	18.96	9.57	19.83	26.43	14.91	21.07
2	F	23.90	27.57	34.17	25.40	27.53	11.69	34.38	13.55
	R	25.24	17.31	26.98	13.92	14.25	37.44	16.19	20.99
2	F	4.83	12.27	13.66	21.26	19.94	22.94	23.41	10.01
	R	4.86	7.26	17.33	8.50	19.72	10.90	14.72	16.87
2	F	27.46	23.03	12.14	12.86	9.86	18.54	14.51	8.46
	R	11.01	24.98	13.85	10.92	20.65	16.85	15.03	16.64
2	F	5.10	4.99	10.58	7.72	8.56	14.06	12.29	12.89
	R	4.33	5.86	6.22	9.60	11.99	16.54	14.62	13.01
2	F	8.71	6.89	6.18	14.69	14.25	10.08	20.74	14.63
	R	10.03	4.81	11.08	6.80	14.91	15.95	19.46	35.47
2	F	5.61	3.99	8.40	9.01	14.65	13.70	22.85	24.04
	R	5.84	7.96	11.97	10.19	8.63	20.35	16.84	14.75
2	F	3.28	4.78	9.87	13.76	20.61	26.15	34.02	33.62
	R	1.82	4.92	8.47	16.60	14.97	29.54	34.83	27.33
2	F	15.18	6.19	16.11	7.29	15.77	11.15	12.56	10.42
	R	6.71	14.10	15.77	20.51	21.25	16.31	22.47	17.14
2	F	2.64	4.97	6.20	12.54	11.18	21.28	21.57	29.29
	R	3.24	3.41	5.60	9.18	8.94	15.42	14.28	34.54
2	F	10.61	9.86	15.94	8.61	16.07	12.62	22.47	27.29
	R	11.65	8.11	13.42	11.56	11.28	20.04	24.12	24.08
2	F	4.17	7.27	8.37	7.06	10.22	17.40	20.20	25.53
	R	7.57	11.57	9.62	14.50	9.73	24.89	21.77	22.36
2	F	56.46	53.03	48.57	36.65	20.20	30.12	20.82	19.63
	R	49.94	48.31	31.80	29.82	30.78	17.87	26.37	24.68

Table D-4: Summary tables for the post-hoc analysis (Tukey Procedure) for the Eight Velocities of the Display LED

A) Group 1 & Group 2, forward and reverse combined

Means	1	2	3	4	5	6	7	8
1= 9.37	-	1.14	3.21	3.83	6.01*	8.17*	10.21*	11.96*
2=10.51		-	2.07	2.69	4.87	7.03*	9.07*	10.82*
3=12.58			-	0.62	2.80	4.96	7.00*	8.75*
4=13.20				-	2.18	4.34	6.38*	8.13*
5=15.38					-	2.16	4.20	5.95*
6=17.54						-	2.04	3.79
7=19.58							-	1.75
8=21.33								-

* indicates a significant difference at alpha = 0.05 level of signifigance

B) Group 1, forward and reverse combined

Means	1	2	3	4	5	6	7	8
1= 5.40	-	2.06	5.71*	7.60*	9.59*	10.94*	13.17*	16.16*
2= 7.46		-	3.65	5.54*	7.53*	8.87*	11.11*	14.10*
3=11.11			-	1.89	3.88	5.23	7.46*	10.45*
4=13.00				-	1.99	3.34	5.58*	8.57*
5=14.99					-	1.34	3.58	6.57*
6=16.34						-	2.24	5.23
7=18.57							-	2.99
8=21.56								-

* indicates a significant difference at alpha = 0.05 level of significance

C) Group 2, forward and reverse combined

Means	1	2	3	4	5	6	7	8
1=13.34	-	0.21	0.71	0.06	2.43	5.42	7.24	7.75
2=13.55		-	0.50	-0.16	2.22	5.20	7.03	7.54
3=14.05			-	-0.66	1.72	4.70	6.53	7.04
4=13.39				-	2.38	5.36	7.19	7.69
5=15.77					-	2.98	4.81	5.32
6=18.75						-	1.83	2.33
7=20.58							-	0.51
8=21.09								-

Table D-5: Summary Table for the Simple Main Effects for the Speed X Group Interaction

Effect	Statistic	F	df	Prob
SP20 X Group	MS = 1260.32	6.52	1, 38	0.0148 *
SP30 X Group	MS = 740.30	5.63	1, 38	0.0228 *
SP40 X Group	MS = 173.02	2.15	1, 38	0.1511
SP50 X Group	MS = 3.10	0.07	1, 38	0.7895
SP60 X Group	MS = 12.04	0.34	1, 38	0.5622
SP70 X Group	MS = 116.79	2.86	1, 38	0.0988
SP80 X Group	MS = 80.34	1.48	1, 38	0.2307
SP90 X Group	MS = 4.55	0.04	1, 38	0.8391

* significant at alpha = 0.05

Table D-6: Summary table for the Perceived Performance Ranking Values for Group One and Group Two, Question 3a

	Group One			Group Two	
Sub#	Task One	Task Two	Sub#	Task One	Task Two
1	6	7	1	5	4
2	8	7	2	6	6
3	6	7	3	8	7
4	4	5	4	8	8
5	5	5	5	5	7
6	8	6	6	5	5
7	6	7	7	5	3
8	7	6	7	3	5
9	6	6	9	5	5
10	8	6	10	6	6
11	7	8	11	5	6
12	9	7	12	7	7
13	6	5	13	6	4
14	8	6	14	6	4
15	5	4	15	7	6
16	5	6	16	5	3
17	7	8	17	8	6
18	7	8	18	7	6
19	7	6	19	3	5
20	7	5	20	7	6
Means	6.60	6.25		5.85	5.45
S.D.	1.27	1.12		1.46	1.36

Table D-7: Summary of the Analysis of Variance with Repeated Measures for the Subjects Perceived Level of Performance, One Grouping Factor (Group), One Within Factor (Task)

Source	SS	df	MS	F	Prob
Mean	2916.11	1	2916.11	1138.00	0.0000 *
Group	12.01	1	12.01	4.69	0.0367 *
Error	97.38	38	2.56		
Task	2.81	1	2.81	3.27	0.0784
TG	0.01	1	0.01	0.01	0.9047
Error	32.68	38	0.85987		

* significant at alpha = 0.05

Appendix E

CHAPTERS I, II, III

Chapter I

Introduction

Recently, a great deal of interest has been expressed concerning the identification of cognitive and perceptual differences between individuals labeled as being either an expert or a novice performer. The majority of the work performed in this area has investigated such semantically rich domains as chess (Chase & Simon, 1973; DeGroot, 1965), bridge (Charness, 1979), computer programming (Adelson, 1984; McKeithen, Reitman, Rueter, & Hirtle, 1981), physics (Chi, Feltovich, & Glaser, 1981), and psychology (Murphy & Wright, 1984). The results from investigations in these various domains have suggested that the differences between experts and novices are both qualitative and quantitative (Adelson, 1984). Not only do experts possess more knowledge than novices (Allard, 1982), they are also seen to represent, structure, and access this knowledge differently than novices. Experts have been shown to create abstract representations of problems presented to them while novices tend to observe and retain only the literal surface elements of problems (Adelson, 1984). These same representation and structural differences have also been observed between experts and novices within the sporting domain (Allard & Burnett, 1985; Allard, Graham, & Paarsalu, 1980; Borgeaud & Abernethy, 1987).

Often when discussing cognitve differences between experts and novices a distinction is made between the two main forms in which knowledge is said to be represented, these being declarative and procedural representations of knowledge. Declarative knowledge is said to represent our factual knowledge (i.e., knowing 'that'), while procedural knowledge provides information on how to perform various cognitive functions (i.e., knowing 'how'). The fact that experts have been shown to create more abstract representations of problems when compared to novices suggests that experts possess more procedural knowledge, relative to the domain being tested, than do novices. Experts have been said to possess both a rich network of declarative knowledge and a system of procedural knowledge allowing them to create abstract plans for solving problems with greater ease than novices (Thomas, French, & Humphries, 1986). Wall, McClements, Bouffard, Findlay, and Taylor (1985) suggested that, in the motor domain, procedural knowledge about action underlies all aspects of action including the perceptual, cognitive, response initiation, and response execution phases. One way in which procedural knowledge may be enacted is through perceptual recognition where, according to Norman and Bobrow (1976), the appropriate procedure is automatically triggered through the recognition of relevant patterns of incoming information.

The proposed investigation will utilize the information

described above in an attempt to determine if the perception of movement velocities is linked to the ability to reproduce movement velocities.

Statement of the Problem

This investigation was designed to examine how differences in procedural knowledge relative to the visual perception of movement velocities, as triggered through performance on a perceptual recognition task, relate to performance on a movement velocity reproduction task.

Rationale

Until recently the only criteria one could offer to distinguish between sport experts and novices was the possession of superior motor skills, relative to the sporting environment, on the part of the expert. However, recent investigations into both the sporting domain and those domains which require greater cognitive involvement (i.e. chess, computer programming, and physics) have established another criteria which can be used to distinguish between expert and novice performers. These investigations have suggested that performance differences may reflect the possession of a larger knowledge base specific to the performance domain. This larger knowledge base is felt to be reflective of the expert performers superior ability to visually perceive and encode structure present in the environment in which they perform (Allard, et al., 1980). Based on these findings one may conclude that experts within

the sporting domain possess not only superior motor skills, but that they also possess superior perceptual and cognitive skills, relative to the domain in question. This would also suggest that the visual perception of movement concepts and motor performance are linked and that both must be developed to their fullest to acheive maximal skill performance.

Statement of Hypotheses

The majority of the research into expert novice differences has focussed on the extremes within each class of performer, and as a result has provided little insight into the processes by which a novice attains expertise and becomes an expert. Therefore, this investigation took the approach of focussing on different levels of expertise rather than the extremes of expert versus novice.

The hypothesis tested in this investigation was as follows:

1. that the group of individuals found to possess high levels of general procedural knowledge relative to the detection and differentiation of various movement velocities will also possess superior motor abilities relative to the reproduction of movement velocities.

Delimitations

The recognized delimitations in the proposed investigation were as follows:

1. The sample of subjects used in this investigation

was limited to university students from a movement related discipline.

2. Although cognitive psychology proposes the existence of several different types of knowledge about action this investigation was limited to studying procedural knowledge differences as they relate to movement and movement velocity.

3. Although the perception of movement involves the utilization of many different types of sensory information (tactile, visual, kinesthetic, and auditory) this investigation was concerned solely with the use of information obtained through visual perception.

Definition of Terms

Visual Perception: The process by which an individuals visual system attends to, discriminates amongst, organizes, and integrates visual stimuli in the environment.

Knowledge: Representative of the product stored in memory of one's interaction with the environment and the people and objects in it.

Declarative Knowledge: Representative of an individuals knowledge of facts (i.e., knowing 'that').

Procedural Knowledge: Representative of an individuals knowledge of how to do something (i.e., knowing 'how').

General Procedural Knolwedge: Non-domain specific general interpretive procedures.

Higher levels of General Procedural Knowledge: Relative to this investigation, an individual who made relatively few

errors (< 15) on the perceptual recognition task was said to possess higher levels of general procedural knowledge relative to the detection of movement velocities.

Lower levels of General Procedural Knowledge: Relative to this investigation, an individual who made a relatively large number of errors (> 16) on the perceptual recognition task was said to possess lower levels of general procedural knowledge relative to the detection of movement velocities.

Superior Motor Abilities: Relative to this investigation, superior motor abilities were defined as the ability to accurately reproduce the velocity of a previously observed movement.

Inferior Motor Abilities: Relative to this investigation, inferior motor abilities were defined as the inability to accurately reproduce the velocity a previously obsesrved movement.

Chapter II

Review of Literature

The proposed investigation incorporates both theory and research from a number of different disciplines. To assist in the development of a relationship amongst the various theoretical and experiential information the review of literature was divided into four general sections.

The first section of the review addresses the characteristics of visual perception highlighting the processes involved in the visual perception of motion and velocity. The second section presents literature which is concerned with examining the role that knowledge plays in the acquisition and development of expertise. The third section differentiates and discusses declarative and procedural representations of knowledge, the two main forms in which knowledge is said to be represented. The fourth section of this review offers some insight into the various forms of knowledge about action. To conclude the review of literature, previous investigations which have made use of the Light Emitting Diode Movement Analysis program were reviewed and discussed.

Prior to begining the four main sections a brief overview of the information processing model will be presented serving as an introduction to the topic of perception.

Information Processing: A Brief Overview

Information processing theory views the human as a processor of information consisting of receptors, effectors, and a controlling central mechanism. It is the operations of the controlling central mechanisms that are of primary concern in information processing theory. Stelmach (1982) stated that the central tenet of information processing theory is that an individual must undertake a number of mental operations when attempting to solve a particular problem or perform a certain task.

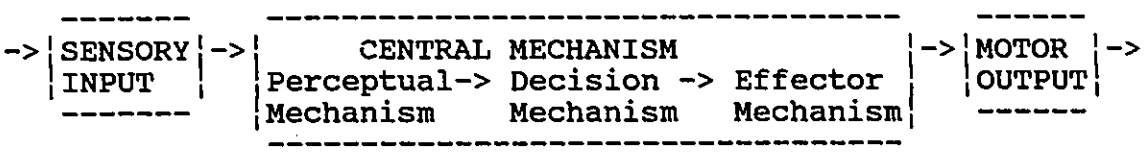

Fig 3. The Information Processing Model highlighting the Central Mechanism.

Figure 3 illustrates the three major components of the Central Mechanism as outlined by Kerr (1982). Stelmach (1982) identified the importance of each of these components as being the detection of a stimulus, the recognition of a stimulus, and the selection of a response relative to the stimulus. Stelmach (1982) stated that detection and recognition are important stages in the perceptual processing of information. For at the detection stage stimulus information is preserved in sensory storage allowing for the comparison of this information with descriptive information stored in memory. The association of the two types of

information would then lead to recognition (Stelmach, 1982). Information contained within sensory storage will persist for approximately 200-300 ms, as stated by Stelmach (1982), and it is during this interval that the features of information contained within sensory storage are compared with those in memory for recognition and identification purposes. Therefore, prior to its perception, sensory information is stored briefly indicating that perception is not instantaneous and may be disrupted (Stelmach, 1982).

Visual Perception

As defined by Roth (1986) the term perception refers to the method by which the bodies various sensory organs transform information obtained from the environment into experiences of objects, events, sounds, etc. As the proposed investigation is concerned with the visual perception of various movement velocities, this section of the review will concentrate on the visual perception and processing of objects and/or events.

The phenomenon of visual perception, as stated by Williams (1983), may be considered learned in as much as man learns to use his eyes, to attend to and discriminate amongst relevant visual stimuli in the environment, as well as to interpret and organize available cues in the environment based on past experiences. It is this process of perceptual organization that provides the basis for learning (Kerr, 1982).

Williams (1983) stated that the structure of visual perception consists of three major abilities: discrimination, visual memory, and integration. In terms of their appearance in the developmental sequence discrimination abilities are first, followed by integration, with visual memory being the last of the abilities to be highly refined (Williams, 1983). Discrimination was defined by Williams (1983) as the ability to identify similarities or differences in the characteristics of visual stimuli. Visual memory was said to represent the ability to recall the characteristics of visual stimuli, while integration was said to represent the ability to coordinate visual input with a specific motor output (Williams, 1983). The ability to integrate visual input with motor output allows the individual to reduce the amount of incoming sensory information to a manageable size (Kerr, 1982).

Rappaport (1971) developed a five level model for the integration of sensory information. The first level, the proprioceptive level, was said to provide for the initial identification and labelling of incoming information through any sensory modality. The second level, the preceptual level, was then responsible for organizing and combining related bits of labelled information received from a particular sensory modality into distinct groups. The third level, the perceptual level, then grouped the related information from the various sensory modalities into mental images or

percepts. The fourth level of the integration of sensory information involved the categorization and organization of percepts into concepts. At this level of integration, the conceptual level, a concept may represent the group of motor tasks associated with throwing, whether it be throwing a baseball, javelin, or paper airplane. The images associated with each motor task may be quite disparate, however, characteristics common to all three tasks allow them to be grouped together. At the final level of integration, termed the cognitive level, the information which has been reduced through the first four levels is then used by the individual to identify responses he/she sees as being correct. However, before an individual is able to function at the cognitive level three conditions should first be met. Palmer (1975) identified these conditions as being; 1) the stimulus should be well known as opposed to being novel, 2) the stimulus should appear in a familiar and appropriate context rather than an unfamiliar and inappropriate context, and 3) the stimulus should be typical of its representative category.

Kerr (1982) stated that it is the ability to function at the cognitive level that allows the decision making process to be simplified and operate more quickly. For at this level new situations and stimuli, belonging to a particular activity, need not be analysed in great detail, instead reference is made to common elements found within the existing concept. Therefore, the process of integration not

only allows the perceptual system to recognize visual stimuli, but allows it to do so at a faster rate and more accurately.

Perception of Motion

Although visual perception and visual processing involves the processing of many types of information, for the purpose of this investigation the review shall be limited to discussing the perception of motion. When discussing the visual perception of motion it is necessary to differentiate between two types of motion, real motion and apparent motion. The perception of real motion, occuring as a result of optical stimulation, consists of not only the motion of objects in the environment, but also motion of the subject himself in the environment (Gibson, 1958). Therefore, real motion is perceived when an individual moves about objects or objects move about the individual. Apparent motion, as described by Miller and Johnson-Laird (1976), is an impression of movement as is created when one watches television or a movie. It is the perception of apparent motion that is of concern in this investigation, therefore, theories and concepts related to this phenomenon will be discussed.

How is it that one is able to perceive motion on a television or movie screen? There are two phenomenon that allow individuals to perceive motion on such modalities. Kerr (1982) identified these phenomenon as being the persistence

of vision and the Phi phenomenon. The persistence of vision refers to the remaining sensation of a stimulus after it has been removed. The Phi phenomenon states that if two lights are switched on and off in a sequential synchronized manner the illusion of movement will be created. The shorter the interval between the switching on and off of the lights the more simultaneous the movement will appear.

Kolers (1972) stated that many of the theories used to explain the phenomenon of apparent motion can be grouped into two classes, figural theories, and excitation theories. The emphasis of the figural theories is placed on the assumption that the visual system resolves the disparity in perceived locations through the creation of a sense of motion. Kolers (1972) stated that the early interpretations of this theory stressed the importance of the figural identity of the forms observed. It was beleived that when an individual observed a form in one location then saw the identical form in another location the individual would use the identity of the figures and the differences in locations to create the perception of a single figure moving. However, the concept of figural identity was later disproved by a number of experiments using disparate figures which also resulted in the creation of a sense of motion amongst the subjects tested. Kolers (1972) stated that it is probably not the measurable aspects of a figures geometry that are most important to the visual system's perception of apparent motion, because, as so far as

the visual system's operations are concerned all shapes are members of the same class of object. The question was then raised, are well formed visual perceptions of figures in disparate locations the main requirements for the illusion of motion? The answer put forth by Kolers (1972) was no. However, it was agreed that they do exert an influence on the interpretation of the perception of motion.

Excitation theories differ from figural theories in that the emphasis is removed from the perception of figure and placed on the disparity of locations and the stimulation at these sites (Kolers, 1972). The best known of the excitation theories claimed that seperately stimulated retinal loci would generate regions of excitation in corresponding areas of cortex which, when properly timed, would electrically interact with each other creating the perception of motion (Kolers, 1972). However, this theory has also been proven wrong allowing Kolers (1972) to state that no theory of apparent motion has yet been developed that accounts for more than a few observations. The reasons given for this failure were that apparent motion is not an anatomically localized phenomenon as is believed by the Gestaltists, and that the role of time in the phenomenon of apparent motion has not been clarafied.

Perception of Velocity

Despite the large amount of work related to the visual perception of motion little attention has been directly focussed on the visual perception of velocity. Brown (1931) performed an investigation to measure the differences in phenomenal velocities, with phenomenal velocity defined as the perceived rate of movement, and concluded that velocity is perceived directly and is conditioned dynamically by the properties and structure of the visual field in which the movemement occurred. The velocity transposition phenomenon developed by Brown (1931) helped to illustrate this conclusion. This phenomenon stated that in order to maintain identical phenomenal velocity when a moving field in a homogenous surrounding field is transposed in its linear dimensions at a 1:2 ratio the stimulus velocity must also be transposed by the same 1:2 ratio.

Mandriota, Mintz, and Notterman (1962) stated that a problem associated with the measurement of velocity discrimination was that either spatial or temporal cues may regularly be related to the stimulus velocity. The method most frequently employed for velocity discrimination studies has made use of fixed and equal spatial dimensions for both the standard and comparison stimulus. However, Mandriota et al. (1962) stated that such a method may produce spurious results in that the relative velocity of the comparison stimulus may be inferred from the length of time it has spent

in the movement field.

Little research has been conducted that is solely concerned with the reproduction of movement velocity. However, a number of distance reproduction studies have indirectly addressed the subject while examining the cues utilized in the reproduction of distances. These studies, although utilizing perceptual information, have concentrated on the role that the kinesthetic system plays in providing information for the control of movement, and have excluded the role played by the visual system.

Marteniuk, Shields, and Campbell (1972) sought to obtain information as to whether the velocity of arm movements may be used as cues in the reproduction of movement. Subjects were required to either actively or passively move a lever to a physical stop, this serving as the standard movement. The subjects were then required to reproduce the movement as accurately as possible without the use of the stop. Microswitches placed at the starting position and 10 degrees short of each standard allowed the investigator to record the amount of time required to move the lever during either the standard movement or its reproduction. Examination of the times required to move the lever during the standard movement and the reproduction movement revealed that the subjects used the same relative velocity for both movements. However, when the average velocity of the standard and reproduction movements were correlated with the three accuracy measures

used in this investigation the correlations were found to be very low and tended toward zero. Therefore, Marteniuk et al. (1972) concluded that for the conditions of their study, the velocity of movement plays only a small role in movement reproduction.

Hall and Wilberg (1977, 1978) performed two very similar investigations designed in part to examine the effect which the velocity of movement has on the reproduction of various movement distances. Comparisons of the acceleration and deceleration phases of movement for the criterion and reproduction movements revealed no significant differences. In fact, Hall and Wilberg (1977) reported that the correlations for average velocity for the various short and long distance conditions were very high. The correlations for average velocity between the criterion and reproduction distances were also reported to be quite high for both investigations. However, in both investigations, the correlations for the average velocities with the different error scores measured (CE, AE, VE) were quite low. The velocity of movement correlated poorly with the accuracy and precision of the reproduced distance regardless of the movement distance, response strategy, or criterion movement endpoint. Therefore, Hall and Wilberg (1977, 1978) concluded that movement velocity has little influence on movement accuracy and precision. These results of course being specific to the reproduction of movement distances.

Knowledge and its Role in the Acquisition of Expertise

Recall that the final level of Rappaports (1971) five level model for the integration of sensory information was the cognitive level and that Palmer (1975) stated that the sensory stimulus being perceived must be typical of its representative category before an individual is able to function at this level. The question is then raised, how does an individual obtain knowledge that is representative of various facts, categories, and domains? The following section will address this question, concentrating on the development of knowledge, and how knowledge structures change as one acquires expertise. As Lesgold (1984) stated, comparing novices to experts allows us to discover what changes in ones knowledge take place as expertise is acquired.

Glaser (1984) stated that the possession and utilization of an organized body of conceptual and procedural knowledge as well as the possession of accessible and useable knowledge differentiates those individuals who display more or less ability in thinking and problem solving. Therefore, it was hypothesized that changes in an individuals knowledge base may result in changes in an individuals cognitve performance. Changes in ones knowledge base may take the form of an increase in the amount of knowledge one possesses. Chi and Koeske (1983) stated that the possession of more knowledge has been used as an explanation for better memory performance in individuals with greater skills. Differences in age have

also been used to explain discrepancies in the amount of knowledge that two or more individuals possess. The poorer memory performance of a child when compared with that of an adult is said to be reflective of the childs lack of knowledge (Chi, 1978; Chi & Koeske, 1983).

Reference is often made to structural change and representational change when discussing knowledge differences amongst individuals of different ages or skill levels. Chi and Koeske (1983) stated that the use of the term structure as something distinct from representation is unfortunate and suggested that structure refer to the properties of a representation. Although a theory of conceptual structure has yet to be agreed upon Murphy and Wright (1984) stated that many of the basic factors that affect concept acquisition are well established. One such factor states that the more alike the members of a category are the more easily learned the category. Likewise, the greater the distinction between members of one category as compared to the members of other categories the greater the advantages in terms of learning (Murphy & Wright, 1984). Basic categories contain examples which are similar to one another yet easily distinguished from members of contrasting categories (Murphy & Wright, 1984). These factors, although widely accepted, give rise to an important question about conceptual organization. How stable are these factors across different populations, across different levels of the same population or within a single

individual? More specifically, as Murphy and Wright (1984) asked; what conceptual differences can we expect to find between experts and novices?

In an attempt to explain what constitutes better knowledge structure as opposed to the possession of more knowledge, or representational change, Chi and Koeske (1983) performed an invesigation examining differences in the attributes of a knowledge structure within a single child. This was accomplished by assessing and comparing the knowledge structures of two aspects of a knowledge domain possessed by a child, dinosaur information, hoping to identify the attributes of a knowledge structure that make one subset of knowledge more structured than the other. For the purpose of this investigation the role of knowledge was defined as the knowledge of concepts, with concepts said to represent a semantic mapping of nodes and their related properties in a network of nodes and links (Chi & Koeske, 1983). The results of the investigation indicated that the mapping of nodes representing the subset of better known dinosaurs were more strongly interlinked than the nodes representing the subset of lesser known dinosaurs. It was also observed that the internal cohesiveness of the interconnections within each subset were different. For the subset of better known dinosaurs more linkages within a group of dinosaurs were observed than between groups. However, in the subset of lesser known dinosaurs there was no apparent

pattern of strong linkages within groups.

The results of the investigation performed by Chi and Koeske (1983) suggested that in the semantic mappings of the target subsets, the better known mapping had (1) a greater total number of interdinosaur links, (2) greater strength of linkages, and (3) greater cohesion of grouped dinosaurs, which was defined in terms of stronger within group and weaker between group direct and indirect linkages.

Murphy and Wright (1984) performed an investigation, similar in its methodology to the investigation performed by Chi and Koeske (1983), examining possible structural changes between experts and novices concepts of child psychological disturbances. Four groups of respondants, each varying in their clinical expertise (practising clinical psychologists, experienced child counselors, begining child counselors, and novice undergraduates) were asked to list the typical attributes of three diagnostic categories. Examination of the attribute lists revealed that both the richness of the diagnostic categories, as measured by the number of attributes listed, and the level of interrater agreement increased systematically with the increasing levels of expertise. However, category distinctiveness was seen to decrease as expertise increased. Murphy and Wright (1984) stated that the experts categories contained many attributes shared by two or more categories, while novices categories contained virtually no overlapping attributes. These results

being similar to those found by Chi et al. (1981) who, when examining the representation of physics problems in relation to the orgainzation of physics knowledge in experts and novices, found that experts initially abstract physics principles to approach and solve a problem representation, whereas novices base their representation and approaches on the literal features of the problem. Similarly, Adelson (1984) concluded, as a result of the examination of the representations of expert and novice computer programmers, that the representations of the experts were more abstract and contained more general information about what the program does, while the representations of the novices were more concrete and contained more information about how the program functioned. The results of these investigations support the suggestion that experts seem to form abstract conceptual representations of problems allowing them to see underlying similarities between problems, and that the representations formed by novices tend to retain the surface elements of problems which the novices, as a result, consider dissimilar.

The investigations presented above have illustrated structural differences in the knowledge of experts and novices through the use of verbal protocols. However, similar structural differences have also been observed when examining perceptual differences between novices and experts. Experts have been shown to differ from novices in their ability to perceive and process large amounts of meaningful information.

McKeithen et al. (1981) stated that a common explanation for this difference was that experts not only possess more information but that they are able to better organize this information into meaningful chunks, rather than perceiving and remembering individual bits of information as the novice does. McKeithen et al. (1981) stated that the expert is able to process meaningful groups of information which as a result make both the experts perception and recall of information more efficient.

Among the earliest investigations into the nature of perceptual differences between experts and novices were those concerned with isolating and studying the perceptual structures of games players in the semantically rich domains of chess (DeGroot, 1965; Chase & Simon, 1973) and bridge (Charness, 1979). In an attempt to understand the processess underlying skill in chess DeGroot (as cited in Chase and Simon, 1973) noted that neither master players nor novices think more than a few moves ahead, contrary to the previously held view of chess players. DeGroot observed that what seperated master chess players from novice chess players was the masters superior ability to perceive structure in relevant chess positions and to encode this structure in memory in the form of chunks (Trotter, 1986; Chase & Simon, 1973). As a result it was concluded that the ability to chunk information and build up a data base are the cognitive skills underlying the superior performance of the chess expert

(Allard, 1982).

Chase and Simon (1973) sought to expand upon DeGroots (1965) initial observations and investigated how many pieces of information typically constitute a chunk, what the relative sizes are of the chunks of masters and weaker players, and how many chunks players retain after a brief view of a chess position. The techniques used to isolate and define the chunks into which information was hypothesized to be encoded while playing chess were a perception task and a memory task. In the perception task subjects were asked to reconstruct a chess position while it remained in plain view, using the subjects successive glances at the board as an index of chunking. The memory task involved having subjects reconstruct a chess position from memory following a five second exposure to the position, using the timing or clustering in recall to segment the output into chunks. Three chess players, a master, a class A player, and a beginner served as subjects for the investigation.

In the memory task the results pertaining to the reconstruction of a chess position after a five second viewing period were very straight forward. Chase and Simon (1973) reported that for both midgame and endgame positions the master was able to perfectly reconstruct the board in three to four trials, with the A level player requiring one to two more trials, and the beginner requiring considerably more trials. Therefore, it was concluded that for both mid

and endgame positions, from actual games, the ability to retain information from a five second view of the board was closely related to playing strength.

Chase and Simon (1973) used the perception task to more closely investigate the chunking differences between the three levels of players. It was hypothesized that the subjects successive glances at the board could be used as an index of chunking and that the subject would only encode one chunk per glance during reconstruction. The time between successive pieces placed on the board was analyzed for both between glance intervals and within glance intervals. Within glance intervals were defined as the time intervals between pieces placed on the board without looking back at the original position, and between glance intervals were defined as the time intervals between the placement of two pieces seperated by a glance back at the original position (Chase & Simon, 1973).

Chase and Simon (1973) found, for all subjects, that within glance intervals rarely exceeded two seconds. However, for between glance intervals, there was a tendency for the better players to take less time. The mean latencies were 2.8, 3.2, and 3.5 seconds for the Master, A level, and beginner player respectively. When the results of the perceptual task were combined with those of the memory task Chase and Simon (1973) proposed the following two hypotheses about the nature of perceptual chunks; 1) the pieces placed

on the board by the subject in the perception task after a single glance correspond to a single chunk, with two seconds being required to recognize a chunk and store a label for it in short term memory which allow the contents in long term memory to be located and accessed, 2) a sequence of pieces placed on the board by the subject in the memory task with intervals of less than two seconds between successive pieces corresponds to a single chunk.

By confronting chess players of varying strength with both a perceptual task and a memory task Chase and Simon (1973) were able to show that the amount of information extracted from a briefly exposed position varies with the level of expertise. The data obtained suggested that the superior performance of master players derives from their ability to encode the position information into larger perceptual chunks, each consisting of a familiar subconfiguration of pieces.

The interaction between skill and stimulus information observed by Chase and Simon (1973) has since been demonstrated in the game of bridge by Charness (1979) and the domain of computer programming by McKeithen et al. (1981). Charness (1979) found that such tasks as planning the play of a contract, rapid bidding, incidental learning, and recall of briefly presented bridge hands depended to a large extent on the level of skill displayed by the players. McKeithen et al. (1981) observed that the classic expert-novice difference in

the short term recall of visually presented meaningful information was replicated in the domain of computer programming. Thus, it may be concluded that experts differ from non-experts in two basic ways. Experts are said to simply know more about their skill domain than non-experts, thus indicating that the experts data base is larger than the non experts (Allard, 1982). Secondly, experts are more efficient at relating environmental information to information stored in their data base enabling the expert to chunk information present in the environment into meaningful units that allow the expert to take in information much faster than someone who is unable to chunk.

Are the perceptual and cognitive skills shown by experts in the domains of chess, bridge, physics, and computer programming specific to these and other similarly rich semantic domains, or are they instead common to all experts regardless of the domain in which their expertise is held? This is a question that has recently been asked by both congnitive psychologists and sport scientists. Recent investigations have illustrated chunking and categorizing abilities for sport experts similar to those observed for experts in the traditional cognitive domains. The five second recall paradigm used by Chase and Simon (1973) and Charness (1979) to show experts superior chunking skills in chess and bridge has also been used to examine cognitive skill in sport experts.

Allard et al. (1980) performed an investigation designed to explore the relationship between skill in performing and skill in perceiving in the sport of basketball. Expert and novice basketball players were tested for their ability to recall information contained within briefly presented slides of both structured and unstructured game situations. The expert performers were found to be superior only in the recall of the structured basketball game slides. As a result, Allard et al. (1980) concluded that expert basketball players show the same benefit from structure when recalling structured game positions as do chess and bridge experts. However, whether the expert basketball player benefited from the ability to chunk information into meaningful units, as the chess expert was shown to, was still undetermined. Allard and Burnett (1985) tried to determine the nature of basketball chunks using an adaptation of the five second recall paradigm developed by Chase and Simon (1973). Expert basketball players and nonplayers were presented with a schematic diagram of a basketball play drawn on a piece of paper. All of the subjects were told to study the play for five seconds, after which time they attempted to reproduce as much of the play as possible. The subjects were allowed as many five second looks as needed, until the play was reproduced to the subjects satisfaction.

Experts took significantly fewer looks than the novices to complete the play. As a result, the number of

elements recalled per look was larger for the expert. Through examination of the elements recalled on each look, Allard and Burnett (1985) were able to identify how the two groups differed in their recall strategies. They reported that the only identifiable strategy employed by the nonplayers was the memorization of the players starting position on the first look, followed by filling in the rest of the information on later looks. The recall strategy employed by the experts was found to be much more consistent than that used by the nonplayers. On approximately half of their looks, expert players encoded information in terms of the meaning or purpose of the play. Allard and Burnett (1985), therefore, concluded that expert basketball players use their knowledge of the game in order to recall a briefly presented basketball play. The fact that the basketball experts recall was similar to the performance of experts in other skill domains suggested that basketball knowledge might well be organized in the same sort of semantic network proposed for experts in skill domains that more obviously require cognitive involvement.

In an attempt to determine if the role of perception varies across different sports, Allard and Starkes (1980) compared volleyball players and nonplayers for speed and accuracy of performance in a task involving the detection of a volleyball in a rapidly presented slide of a volleyball situation. The two volleyball situations depicted both game

action and nongame events. Unlike Allard et al. (1980) this investigation did not demonstrate any differences between experts and nonexperts in the recall of information from slides schematically depicting structured game situations. Borgeaud and Abernethy (1987) offered two reasons why the expected expertise X games structure interaction was not found. They stated that game structure may not be a relevant cue in both offensive and defensive contexts, and that the loss of temporal, directional, and sequential movement information through the use of a non-moving display may have negated any perceptual advantage held by the expert volleyball player (Borgeaud & Abernethy, 1987). However, despite the absence of differences in recall abilities, Allard and Starkes (1980) observed differences in the speed with which both groups responded. Volleyball players were found to be much faster in responding for both game and nongame slides. Further investigation indicated that volleyball players speed of response in ball detection was not a function of a simple athlete-nonathlete difference, or of volleyball players being fast at visual search in a nonvolleyball environment. Allard and Starkes (1980) stated that the perceptual skill shown by volleyball players was best described as a rapid visual search specific to the ball as target, ignoring for the most part any context information.

In an attempt to correct the observed weaknesses in the

study performed by Allard and Starkes (1980), Borgeaud and Abernethy (1987) conducted an investigation designed to reexamine the skill specific memory of volleyball players using a task which accounted for the structure of the game, using dynamic displays. In this investigation, expert and novice volleyball players viewed dynamic sequences of both structured and unstructured game information on video display. Each subject was asked to recall the position of each opposing player at the end of each video display sequence by reproducing the players position on a schematic representation of a volleyball court. The results of this investigation indicated that the expert volleyball players were superior to the novices in recalling structured game situations and that both groups recalled equally unstructured information. Therefore, it was concluded that expert volleyball players possess a perceptual advantage in terms of their memory for structural defensive elements of volleyball (Borgeaud & Abernethy, 1987).

Declarative and Procedural Knowledge

When examining structural differences in the representation of knowledge between experts and novices it is important to distinguish between two forms of knowledge (Thomas et al., 1986). The two main forms in which knowledge is said to be represented are declarative and procedural representations of knowledge (Anderson, 1976; Winograd,1975).

Examined at its most basic level, the main distinction between declarative and procedural knowledge is one of content. Declarative knowledge has been defined as ones knowledge of facts, 'knowing that', and procedural knowledge as ones knowledge of how to do something, 'knowing how' (Anderson, 1976). The distinction between declarative and procedural knowledge has been said to be analogous to the distinction made between data and program when discussing the operations of a computer. The declarative representation system, declarative knowledge, is analogous to data, while the procedural representation system, procedural knowledge, is analogous to the "program" or process. Anderson (1980) stated that some researchers have placed the emphasis on the data trying to have as few special purpose procedures as possible, while others have emphasized the process embedding the knowledge of the system within the processes.

In trying to more fully understand declarative and procedural knowledge, Anderson (1976) identified three criteria which serve to distinguish the two types of knowledge. The first of these being that declarative knowledge is obtained in an all or nothing manner, while procedural knowledge may only be partially obtained. To elaborate, an individual may not possess only partial knowledge of a fact, declarative knowledge, unless it is part of a related chain of facts. However, an individual may possess only partial knowledge of how to perform a certain

act, procedural knowledge. The second distinguishing criteria stated by Anderson (1976) was that declarative knowledge may be acquired suddenly while procedural knowledge may only be acquired slowly over time as a result of practice or continuous exposure through ones daily living experirences. The final distinguishing criteria offered was that an individual is able to verbally communicate declarative knowledge but not procedural knowledge. Stating a fact such as, "the Los Angeles Dodgers won the 1988 World Series", is a typical instance of declarative knowledge. An individual is able to verbally express this information because he/she is said to have conscious access to it. However, an individual has no such conscious access to procedural knowledge due to the nature in which it was acquired, through constant repetition and exposure throughout life as well as conscious and deliberate practice. Afterall, is it not the purpose of practice to allow the individual to perform various skills with little if any conscious involvement? An example of procedural knowledge that is very difficult to verbalize is attempting to describe the process of tying a necktie. Despite the fact that many individuals are able to tie a necktie, when asked to describe how the action is performed they are often at a loss for words and must resort to a visual demonstration.

Declarative Knowledge

A declarative representation of knowledge is one that

emphasizes the storage of an individuals knowledge of facts about the world (Anderson, 1976; Millward, 1980). Anderson (1980) proposed that all incoming knowledge is encoded declaratively, as a set of facts in a semantic network. These facts are then used by general interpretive procedures to help guide behavior. Millward (1980) stated that representing knowledge declaratively means storing it independently of the initial use made of it. As a result, a declarative representation of knowledge can be used in a large number of ways without changing its basic form, providing what Bobrow (1975) called economy of representation.

Mitchell and Chi (1986) have stated that the most commonly accepted model of declarative memory is an associative network model. An associative network model consists of nodes, representing concepts, and arcs representing the linkages between concepts (French & Thomas, 1987; Mitchell & Chi, 1986). The linkages between some nodes may vary in strength resulting in some concepts being more strongly associated than others. Mitchell and Chi (1986) stated that an activation process is responsible for the retrieval of information from a network model. The process involves the activation of specific nodes with the activation spreading to other linked nodes. If the activation threshold is exceeded at a specific node the contents of that node will be recalled. The activation of further nodes then depends on the strength of the association between the activated node

and the nodes with which it is linked. The nodes most strongly associated with the activated node are most likely to be activated next.

Representing knowledge in declarative forms has both advantages and disadvantages. Perhaps the greatest benefit of representing knowledge in declarative forms rests in the flexibility in using that knowledge (Anderson, 1980, 1982; Winograd, 1975). Declarative representations do not involve having to anticipate how a piece of knowledge will be used allowing the program to be more flexible in the type of deductions it will be able to make. Greater flexibility consequently results in economy in making multiple uses of a single declarative statement (Winograd, 1975). Anderson (1980) effectively illustrated the flexibility which declarative representations of knowledge afford procedures through discussion of the transitive rule of equality, which states that if A = B and B = C, then A = C. A declarative representation of this rule would allow the system to make a forward deduction through the use of one general interpretive procedure. Specifically, if statements AB = CD and CD = EF were given, then AB = EF could be declared. Through the use of a second general interpretive procedure the same declarative knowledge could be used to reason backwards from AB = EF to determine whether AB = CD and CD = EF are true.

A second advantage offered by declarative representations of knowledge is their ease of understanding

and their ease with which they may modify the body of knowledge within a system (Winograd, 1975). For example if a knowledge base consists of a set of facts then it can be changed by adding new ones or deleting old ones, with the implications of each statement lying in its logical content (Winograd, 1975).

The third advantage, as stated by Winograd (1975), of representing knowledge declaratively is that it may be easily accessed and communicated. This, as a result, has implications for adding new knowledge to the programs, and for communicating their content to other individuals. Winograd (1975) stated that natural language is primarily declarative, and that the usual way to communicate information to another individual is to break it into statements. This as a result of the fact that much of what we know is most easily stated as a set of declarative facts.

The representation and interpretation of knowledge in declarative forms has advantages in terms of its flexibility, ease of understanding, accessibility, and ease of communication. However, it also has serious costs in terms of its interpretive application time and working memory space (Anderson, 1980, 1982). Anderson (1982) stated that the process is slow because declarative information must be retrieved from long term memory for interpretation to occur. In order to achieve their generality the interpretive procedures are unable to take any available shortcuts in

applying the knowledge in a particular system. As a result, Anderson (1980) stated that many unnecessary and/or redundant tests and actions may be performed. The fact that declarative information must be represented in working memory for use in interpretive productions places a heavy burden on the capacity of working memory.

Mitchell and Chi (1986) stated that when measuring declarative knowledge it is important to make the distinction between its structure and content. Structure refers to how declaratively represented information is organized in memory, whereas content refers to how that information is encoded in memory (Mitchell & Chi, 1986). In a network model of memory the authors suggested that different measures of structure might include the number of knowledge structures (i.e., nodes) with no connecting linkages, or the number and pattern of connecting linkages associated with a particular node. The greater the number of links, or the stronger the assoication between links, the more tightly organized one would expect to find knowledge within a specific domain. Conversely, Mitchell and Chi (1986) stated that one would expect to find relatively few linkages between nodes if knowledge were loosely organized. Because individuals encode information differently, Mitchell and Chi (1986) suggested that one must also consider the pattern of linkages between nodes when discussing structure. Two individuals may have the same number of nodes and linkages ascribed to a specific topic,

however, the pattern of those linkages may vary.

In reference to the content of declarative knowledge Mitchell and Chi (1986) suggested that for some individuals information may be primarily episodic, made up of individual experiences, or it may be primarily semantic, relating to meaning.

Mitchell and Chi (1986) stated that the two most common methods for measuring declarative knowledge are word association tests and the traditional educational tool, a pencil and paper test. The paper and pencil test is designed to measure the different types of knowledge within a domain, primarily concentrating on the content of knowledge and doing little to illustrate its structure. The word association procedure, as described by Mitchell and Chi (1986), involves the presentation of a key word to an individual with the individual verbally responding with everything that comes to mind. It is hoped that by activating a specific node within the individuals memory all related concepts will be verbally expressed as a result.

Procedural Knowledge

Procedural knowledge, as defined by Mitchell and Chi (1986), is a representation of our ability to perform a skill. A procedural representation of knowledge stores knowledge as programs which act as specific routines that carry the function of the knowledge with them (Millward, 1980). The structure of procedural knowledge is generally

said to be conceptualized in terms of a production system consisting of a series of IF-THEN rules (Anderson, 1976, 1982, 1983; French & Thomas, 1987; Mitchell & Chi, 1986; Neves & Anderson, 1981). The IF statement is said to define a particular condition while the THEN statement defines a particular action that is executed when the condition is met. Mitchell & Chi (1986) stated that the conditions are generally based on the contents of short term memory or activated information from long term memory, while the actions consist of either actual behavior or the manipulation of contents within short term memory.

One way in which procedural knowledge is said to be enacted is through perceptual recognition where the appropriate procedure is automatically triggered through the recognition of relevant patterns of incoming information (Norman & Bobrow, 1976). In order for this to occur one must assume that an individuals past experience has created a vast repetoire of schemata that may be used to describe the characteristics of the propositional knowledge of any experience (Norman & Bobrow, 1976). If accomplished, the perceptual processess must then determine the appropriate schema and match it with the present perceived occurences. If the chosen schema is not appropriate a new schema must be selected or the chosen one reorganized (Norman & Bobrow, 1976).

Two types of analyses for the recognition of perceptual

stimuli are discussed by Norman and Bobrow (1976). The first, a bottom-up analysis driven by sensory input, functions under the premise that when information enters the sensory system it is operated upon automatically up through the process of feature extraction at which point the now active sensory memory is able to process the various feature sets (Norman & Bobrow, 1976). In this type of analysis each new sensory input initiates new activity while the structures which have already been activated must be organized by the sensory system into meaningful schema. The second analysis discussed by Norman and Bobrow (1976) for the recognition of perceptual stimuli is termed a top-down analysis which is driven by the conceptual organization of the perceived stimuli. Norman and Bobrow (1976) stated that a schema may be activated by either the individual sensory elements perceived or by the perception of the appropriate relationships amongst the elements. To help illustrate the processes involved in top-down analysis Norman and Bobrow (1976) discussed how an individual is able to perceive a human face from the observation of its various components. When not seen in relation to one another the various parts of the human face may be difficult to recognize as such. However, when put together the schema for the face may be activated due to the presence of one or more of the relationships that exist amongst the various facial features (eye-nose triangle, mouth to nose relationship, etc.). Norman and Bobrow (1976) stated

that once the face schema has been hypothesized, it then guides the processing for the rest of the facial features and relationships. The first indication of facial features will cause the system to make conceptualizations about what is being perceived eventually leading to the discovery of sufficient confirming evidence to support the hypothesis. The amount of actual perceptual evidence needed to perceive an object or event is said to decrease as the amount of conceptual evidence increases (Norman & Bobrow, 1976). Therefore, as Norman and Bobrow (1976) stated, the system is both data driven and conceptually driven.

The utilization of a production system is said to be representative of the second cognitive stage one passes through when learning a skill (Anderson, 1982). At the first stage, entitled the declarative stage, information is both received and encoded as a set of facts about how to perform the skill. These facts are stored in long term memory and must be used by an individual at this initial stage when performing a task requiring the skill. Anderson (1982) used the example of learning to drive a car to illustrate this process. When first learning to drive a standard car an individual learns exactly what physical actions must be performed to change gears and to maintain control of the car. When performing the task the individual must then continually access this declaratively represented knowledge. At this stage of skill acquistion the individual also has access to a

repertoire of general interpretive procedural knowledge which serves to interpret the new information received allowing for some form of the desired skill or action to be generated (Hughes, 1987). Quite often a begining driver, although possessing no specific procedural knowledge for driving a car, as a result of never having done so, may possess a pool of general procedural knowledge for basic driving mechanics which serves to assist the individual in developing the skills needed to drive a car.

As previously stated, at the second or procedural stage, the skill is now represented by a series of IF- THEN rules in a production system. It is at this stage that the individual may perform certain actions, such as shifting gears, without conscious selection of the series of actions that need to be performed. Anderson (1982) stated that it is at this point that individuals no longer have access to these specific procedures except when executing them.

Initially, a number of IF-THEN rules are used when performing a skill. However, as a result of continued practice a single IF-THEN rule will develop and become representative of that skill (Anderson, 1982). At this point the skill has become automatic requiring little conscious attention and time for its execution.

Between the declarative and procedural stages is a process called knowledge compilation which is responsible for the translation of declarative knowledge into procedural

knowledge (Anderson, 1982). The knowledge compilation process, as described by Anderson (1982) produces three phenomena; speed up, dropout of verbal rehearsal, and elimination of piecemeal application. These are accomplished through the two subprocesses of composition and proceduralization. Composition is responsible for taking sequences of productions that follow each other in solving a problem and combining them to create one single production sequence (Anderson, 1982). As a result, considerable speed up is created as a single production is produced that embodies the sequence of steps used in a particular problem domain. The second process, entitled proceduralization, builds new versions of the productions which no longer require the domain specific declarative knowledge to be entered into working memory because the essential products of the retrieval operations are now built right into these new productions (Anderson, 1982). How is it that the process of knowledge compilation produces the three phenomena of speed up, elimination of verbal rehearsal, and the elimination of piecemeal application? Anderson (1982) stated that the composition of multiple steps into one single production sequence produces the speed up effect and also leads to the unitary rather than piecemeal application of productions. The elimination of verbal rehearsal occurs as a result of the fact that proceduralization eliminates the need to hold information from long term memory in working memory.

Anderson (1982) stated that much learning still goes on after a skill has been compiled into a task specific procedure. One such type of learning is said to involve an improvement in the method chosen for performing the task. Anderson (1982) states that for most tasks there are many paths of steps which may be used to approach the problem, and the individual must, therefore, search amongst these paths in an attempt to solve the problem. A fundamental observation of much of the expert-novice research is that individuals possessing a high level of expertise within a particular domain are more judicious in their choice of paths and may alter the method of search if needed. Anderson (1982) refered to the learning underlying this selectivity as tuning.

Recall that in an earlier section of this review declarative knowledge was examined both in terms of its structure and content. This distinction may also be useful for discussing procedural knowledge. Mitchell and Chi (1986) suggest that for procedural knowledge structure refers to the number of production systems that would be used to solve a particular problem. It was suggested that one individual may require a series of production systems to solve a problem, while a second individual may require but one. In reference to the content of procedural knowledge, Mitchell and Chi (1986) suggested that this would refer to the differences in the condition-action statements used by individuals.

Mitchell and Chi (1986) suggest that the most common

method for measuring procedural knowledge is to give an individual a series of problems to solve and have him/her think out loud while solving these problems. These protocols may then be converted into a series of IF-THEN statements to provide an indication of the type of productions that are used to solve the problems. To determine how an individual categorizes problems within a particular domain, Mitchell and Chi (1986) suggest that you provide an individual with a number of problems and ask him/her to organize them into groups of similar problems. Next you ask the individual why he/she perceives the problems as being similar, using this information as an indication of how problems within a particular domain are categorized.

Knowledge about Action

Traditional definitions have stated that an individuals knowledge is representative of the product stored in memory of their organism-environment interactions. Newell and Barclay (1982) claimed that action, as well as knowledge, can be viewed in this manner. For knowledge, as stated by Wall et al. (1985), plays a crucial role in the control and execution of action. In reference to action, Newell and Barclay (1982) suggest that knowledge is acquired about the usefulness of various actions for meeting different task demands. The usefulness of the actions is based on whether or not they result in the successful completion of the task, or in the failure to meet the imposed task demands.

Newell and Barclay (1982) believed that one way to approach the theoretical issue of acquiring knowledge about action was through studying certain metacognitive knowledge variables. Metacognition, as defined by Newell and Barclay (1982), refers to a persons knowledge about his own or others psychological, social, and physical behavior and abilities. Metacognitive knowledge is acquired in the same manner as general knowledge, through purposeful interaction with the environment. Wall et al. (1985) stated that metacognitive knowledge about action is knowing about knowing how to move, or, as stated by Newell and Barclay (1982), represents an individuals awareness of the association between movement and its consequences. Metacognitive knowledge may be thought of as a higher type of factual knowledge about action that develops as individuals become conciously aware of what they can or cannot do in a number of action situations (Wall et al., 1985). Newell and Barclay (1982) suggested that developing an awareness about ones own actions involves two types of knowledge; sensitivity to situations requiring skilled action, and the knowledge of variables that affect the outcome of action. Sensitivity to different situations refers to knowledge of the fact that action is required, as well as an understanding of the movements required to successfully complete the act. The latter component of sensitivity, an understanding of the movements required to successfully complete the act, can itself be broken down into

two related elements. The first of these being an understanding of the nature of the problem to be solved, with the second refering to an individuals awareness of the specific situational cues which define the parameters of the task demands (Newell & Barclay, 1982).

The second major category of metacognitive knowledge, that being the knowledge of variables that affect the outcome of actions, is said to include three related variables; person, task, and strategy variables (Newell & Barclay, 1982). The person variable reflects an individuals knowledge of him/herself, or others, as being skilled in certain actions and exists in two dimensions (Newell & Barclay, 1982). The first dimension, entitled traits, consists of an individuals knowledge of his/hers or others enduring physical structures, whereas the second dimension, entitled states, refers to an individuals understanding of his/her present ongoing action (Newell & Barclay, 1982). This understanding will allow the individual to determine if the action should be terminated or continued depending on whether or not the perceived goal of the action was reached. The task variable, as desrcibed by Newell and Barclay (1982), refers directly to an individuals knowledge of the task constraints which affect the difficulty of the action to be performed. Finally, the strategy variable refers to the way which an individual approaches a task. The type of strategies employed during problem solving are felt to be representative of an

individuals level of knowledge concerning that particular task. Newell and Barclay (1982) conclude that the understanding of skilled action requires an analysis of the interrelationship of the sensitivity and variable categories of metacognition.

The sensitivity and variable categories, as have been described by Newell and Barclay (1982), appear analogous to the two types of knowledge discussed previously; declarative and procedural knowledge. In fact, metacognitve knowledge about action is said to refer to an individuals awareness of the three major types of acquired knowledge; declarative, procedural, and affective (Wall et al., 1985). Affective knowledge, as described by Wall et al. (1985), refers to the attachment of subjective feelings to an action by an individual. Affective knowledge about action is acquired in much the same way as general knowledge, through continuous interaction with ones environment and the people in it.

Procedural knowledge about action is seen as underlying all aspects of action including the perceptual, cognitive, response initiation, and response execution phases (Wall et al., 1985). Declarative knowledge about action, on the other hand, is said to refer to factual information stored in memory which may influence the development and execution of skilled action (Wall et al., 1985). Metacognitive knowledge about action, as stated by Wall et al. (1985), is seen as a form of declarative knowledge because it is knowledge about

the three major types of knowledge (affective, declarative, and procedural) about action. Metacognitive skill, on the other hand, is said to be representative of procedural knowledge about action because it refers to the application and use of metacognitive knowledge about action (Wall et al., 1985). As an individual develops and/or refines their declarative, procedural, affective, and metacognitive knowledge about action, higher level metacognitive skills will emerge and will be used to procedurally control cognitive activity within skill learning situations (Wall et al., 1985).

The Light Emitting Diode Movement Analysis Program

The Light Emitting Diode Movement Analysis Program (LEDMA) is an apparatus that was developed at the University of Ottawa (for a description of its operation see the methodology). This apparatus has been used successfully in previous investigations to assist in the determination of procedural knowledge rankings amongst two groups of subjects (Hughes, 1987).

The LEDMA apparatus is used as a tool to assess procedural knowledge levels within individuals and requires subjects to perform many trials within each experimental session. It is important that no learning effect occur across trials or testing sessions. Analysis of the data generated by Hughes (1987) led to the conclusion that there was no learning effect across the four subtasks within each of the

main tasks utilized in the testing process. In a separate investigation, Toward (1988a) tested 21 subjects on the LEDMA apparatus on two separate days. A
period of seven days separated each testing session. Two 2 X 4 (day X subtask) ANOVA's were conducted, one for Task one error data and one for Task two error data. The analyses indicated that there were no significant differences between the number of errors produced on day one and day two for both Task one and Task two. Therefore, it was concluded that no learning effect occurred as a result of performance on the LEDMA apparatus and that the results obtained on this apparatus provide an accurate and reliable assessment of an individuals level of procedural knowledge relative to the monitoring of movement and movement velocities.

In an attempt to strengthen this last statement a Pearson Correlation Coefficient was calculated using the "odd-even" method as described by Schmidt (1982). The performance of 97 subjects was subjected to a Pearson Product Moment Correlation in which the number of errors produced on trail 1 (odd) were compared to the number of errors produced on trial 2 (even) in an attempt to determine the extent to which the odd and even sums tend to deviate from each other. The correlation between the odd and even trials, the reliability coefficient, was calculated to be +.547 and was found to be significant ($p < .05$) indicating that this apparatus is a reliable test of an individuals level of

procedural knowledge specific to movement and movement velocities.

A second investigation performed by Toward (1988b) determined the appropriateness of the eight speeds (20, 30, 40, 50, 60, 70, 80, 90 cm/s) used by the LEDMA apparatus at each of the four subtasks for Task One, to assess an individuals level of procedural knowledge relative to the monitoring of movement and movement velocities. The purpose of this investigation was to ensure that none of the eight speeds were a) so difficult that subjects were forced to guess which LED was travelling with the greatest velocity, indicated by an error rate of greater than 50 %, or b) so easy that subjects rarely made an error in judgement with regards to determining which of two LEDs was travelling with the greatest velocity, indicated by an error rate approximating 0 %. Observation of the error rates produced by the 39 subjects tested at Task One indicated that the eight speeds used in this investigation were neither too easy nor too difficult at each of the four subtasks. The error rates were seen to range from a low of 2.4 % (15 errors out of 624 total responses) for the speed of 50 cm/s at subtask D to 22.0 % (137 errors out of 624 total responses) for the speed of 20 cm/s at subtask B.

Chapter III

Method

Subjects

A total of 58 undergraduate students from the Kinanthropology department at the University of Ottawa served as subjects in this investigation. Participation in the investigation was voluntary, however, each subject did receive partial class credit for their participation.

Apparatus

Two tasks were used in this investigation, one to provide an assessment of each subjects perceptual abilities and level of procedural knowledge, relative to the visual perception of movement velocities, and a second to provide an assessment of each subjects ability to reproduce movements relative to the reproduction of various movement velocities.

The apparatus that was used to assess each subjects perceptual and reproduction abilities was a perceptual recognition task entitled the Light Emitting Diode Movement Analysis Program (LEDMA). This apparatus encorporates the use of a computerized matrix board, a microphone and voice activated reaction time recorder, a stylus pen used to reproduce LED movement, and a COMPAC personal computer. The matrix board consists of 42 rows of 121 light emitting diodes (LEDs), located 1 cm apart, covered with a dark red transparent plastic top. The matrix board was connected to the personal computer which during the testing phase ran the

Movement Analysis Program (MAP). MAP was designed to evaluate an individuals ability to make quick and accurate judgements about movements and their velocities. Therefore, this perceptual recognition task was designed to tap each subjects procedural knowledge relative to making judgements about movements and their velocities.

Task one, entitled Movements in Succession consisted of two LEDs being illuminated in a successive manner with the LEDs travelling vertically from the top of the matrix board down to an illuminated baseline of 11 LEDs, approximately 40 cm away. The first LED appeared near the top of the matrix board, followed quickly by the successive illumination of the LEDs beneath to create the impression of a light travelling down toward the baseline of 11 LEDs. Approximately one second after the first LED had completed its run the second appeared and operated in the same manner as the first. The movement of the two LEDs differed in that they descended unequal distances in unequal times. Four subtasks operated within Task one with the speed and distance of LED movement varying for each subtask. The speed with which the LEDs travelled was based upon eight reference speeds included in the MAP. The eight reference speeds that were used in this investigation were 20, 30, 40, 50, 60, 70, 80, and 90 cm/s. One of the two LEDs always travelled at one of the eight programmed reference speeds while the second LED travelled at a percentage of the selected reference speed. The percentage

values that were used for Task one were 66%, 100%, 150%, and 170% of the reference speed. Each two speed movement combination was randomly selected by the MAP. The four subtask conditions that operated within Task one were (a) movements in equal time and equal distance, (b) movements in equal time and unequal distance, (c) movements in unequal time and equal distance, and (d) movements in unequal time and unequal distance.

Task two, entitled Movement Reproduction, was used to assess each subjects ability to physically reproduce the velocity of a previously displayed movement. This task existed in two phases, the first being a visually displayed movement and the second being an attempt at reproducing the velocity of the visual display. The visual display consisted of an LED (point A) being illuminated on the matrix board followed by the successive illumination of adjacent LEDs in a horizontal pathway until an endpoint was reached (point C); creating the impression of single light travelling along a horizontal pathway. The distance between point A and point C was 40 cm. The direction of travel for the LED was either left to right or right to left with the distance travelled always being a constant 40 cm. The LED travelled at one of the following eight programmed speeds; 20, 30, 40, 50, 60, 70, 80, or 90 LEDs/s.

In the reproduction phase each subject was asked to reproduce the velocity of LED movement observed in the visual

display over one of three distances (30 cm, 40 cm, or 50 cm). The direction of movement for the reproduction phase was always left to right. A stylus pen which emitted an electrical current was used to reproduce the movement of the LED observed in the display phase of Task two. Each subject was asked to move the stylus pen, using his/her preferred hand, across the matrix board covering one of the three distances. The personal computer then determined the velocity of the reproduced movement over the middle third of the distance travelled allowing the velocity of the reproduced movement to be compared with the velocity of the visually displayed movement.

At the completion of both tasks each subject was asked to fill out a confidential questionaire as well as participate in a short interview. The questionnaire, entitled the Background Information Questionnaire, indicated each subjects sex, age, educational history, and level of participation in sport and/or recreation activities. The interview consisted of six questions designed to present the investigator with information relative to the strategies employed by each subject as the test was being performed. Unlike the questionnaire, which was completed once at the conclusion of testing on both tasks, each subject responded to the interview questions twice, once at the completion of Task one and again at the completion of Task two. Refer to Appendix A for a complete copy of the questionaire and the

interview questions.

Procedure

Each subject participated in a single experimental session consisting of Tasks one and two of the LEDMA program, the background information questionnaire, and the subject strategy interview. The entire session lasted approximately one hour per subject.

Upon entering the laboratory each subject was shown the apparatus that was used during the testing session. The subject was then seated in front of the matrix board which was tilted at a 30 degree angle toward the subject so that he/she did not have to alter his/her body position during testing to see the LEDs.

Task One

The instructions were verbally presented to the subjects (see Appendix B) emphasizing that their responsibility was to determine which of two LEDs was moving with the greatest velocity, and to verbally communicate their answers to the investigator. A microphone located near the subject picked up the verbal response triggering a voice activated reaction time mechanism which recorded the amount of time required by the subject to make a decision. The subjects were allowed one and one-half seconds, plus the amount of time required for the second LED to complete its movement toward the baseline, to communicate their answer. If this time period was exceeded the trial was terminated and a

new trial begun.

The subjects responses were recorded by the investigator, immediately after they were given, on the COMPAC personal computer. After each response was entered the computer issued a beeping signal to alert the subject that the next trial was about to begin. To further enhance the subjects awareness of the LEDs all tests were performed in a darkened room to eliminate any glare which may have appeared on the matrix board.

Each subject was tested once at Task one. Task one consisted of four subtasks, and within each of the subtasks the subject had to perform 16 trials as each of the eight reference speeds was presented twice. Therefore, each subject performed 64 trials at Task one. Prior to the actual testing each subject was presented with four practice trials, one at each of the four subtasks, to ensure total understanding of the instructions. Each of the four practice trials was performed at a speed of 25 cm/s. When the testing on Task one was completed each subject was asked to respond to the interview questions and was then given a five minute rest, so that their eyes did not become fatigued, before proceeding to Task two.

Task Two

Prior to testing on Task two the instructions were verbally presented to the subjects (see Appendix B) emphasizing that their main responsibility was to attempt to

move at the same speed as the movement observed in the visual display, not the same distance. Each subject was asked to perform 96 trials at Task two, 48 trials reproducing the speed of movement of the left to right visual displays, and 48 trials reproducing the speed of movement of the right to left visual displays.

The sequence of events for one trial has been broken down into five steps. Step one consisted of a single LED (labelled point B1) being illuminated on the matrix board. The location of B1 varied within a 10 cm horizontal bandwidth so that the subject was unable to constantly focus on the same begining location. Step two consisted of having the subject respond by placing the activated stylus, held in the preferred hand, on point B1. An error of plus or minus one square centimetre was allowed when placing the stylus on B1. When the stylus was placed on B1 the stylus was deactivated. There followed a one second delay then step three began. Step three consisted of two more LEDs (labelled A and C) being illuminated 10 cm above B1. This distance remained constant throughout the investigation, regardless of the location of B1. An LED then travelled from point A to point C, assuming the movement was left to right. The point of origin for point A varied within a 10 centimetre horizontal bandwidth to assist in the elimination of any location cues that the subject may have used, forcing him/her to focus on the velocity of the LEDs movement. Throughout the

first three steps the subject held the stylus on the illuminated B1. At step four a number of events occurred simultaneously. These consisted of a beeping signal being issued by the computer, the stylus being reactivated, point B1 being turned off, and point B2 being turned on. Point B2 appeared either 30, 40, or 50 cm away from B1. If at this point in time the stylus was detected as having moved outside of the one square centimetre allowable error range on point B1 the trial was terminated and a new trial begun. The reason for terminating the trial when such a movement had occurred was to prevent the subject from initiating his/her movement before the signal to move was provided, and to prevent the unconscious movement of the stylus while watching the A to C display movement. Step five consisted of having the subject move the stylus along the matrix board in a horizontal pathway, approximating the speed of the LED observed in the visual display, until the endpoint B2 was reached. A horizontal error of plus or minus two centimetres was allowed when placing the stylus on B2. If this error range was exceeded the trial was terminated and a new trial begun. The subject was allowed one and one-half seconds, plus the amount of time that was required for the LED to travel from point A to point C, to complete their movement. If this time period was exceeded the trial was terminated and a new trial begun. If steps one through five were successfully completed point B1 would reappear and the next trial began. As previously

mentioned, each subject had to perform 96 trials at this task. Each of the eight speeds (20, 30, 40, 50, 60, 70, 80, and 90 cm/s) were presented twice in the visual display, for both directions of travel, and were reproduced at each of the three distances (30 cm, 40 cm, and 50 cm).

When the testing on Task two was completed each subject was asked to respond to the interview questions and then to answer the background information questionnaire.

Design and Analysis

The data obtained in this investigation was analysed in three ways. The initial analysis, concerned with identifying two distinct groups of subjects from the original 58, was used to provide an assessment of each subjects perceptual abilities and level of procedural knowledge. Both were related to the differentiation of visually perceived velocity. From the ranking of subjects based on the number of errors produced on Task two, two groups of equal size (N = 20) were selected. Group one represented the 20 individuals who made the fewest number of errors on Task two, while group two represented the 20 individuals who made the greatest number of errors on Task two. These two groups were then tested for significant differences in the mean number of errors produced through the use of a t test for independent groups. Once the two groups were identified the data representing the remaining individuals was discarded.

The purpose of the second analysis was to determine

whether or not the two groups identified in the first analysis differed signficantly in their ability to reproduce movements of various velocities. The values recorded during the performance of task two were illustrative of the differences between the display velocity and the subjects reproduced velocity. These values were recorded as either a positive or negative difference in velocity. For the purpose of further analyses the absolute values of these scores were obtained then averaged for the three distances of reproduction and two reproduction trials at each of the eight display speeds. These values were then labelled the Mean Velocity Errors (MVE's) and were analysed using a 2 X 2 X 8 (Group X Direction X Speed) analysis of variance with repeated measures on the last two factors. Tukey post-hoc analyses and a simple main effect analysis were then used to describe the significant main effects and interactions.

The information obtained as a result of the interview and questionnaire was analysed so that the investigator could gain some understanding of the strategies employed by the subjects while they were being tested, as well as how each subjects performance was influenced by their personal history.

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