FACTORS INFLUENCING THE ACQUISITION OF A SEQUENTIAL MOVEMENT

FACTORS INFLUENCING THE ACQUISITION OF A TIMED SEQUENTIAL MOVEMENT

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A Thesis
Submitted to the School of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree
Master of Science

McMaster University

December, 1986

MASTER OF SCIENCE (1986) McMASTER UNIVERSITY
(Adapted Human Biodynamics) Hamilton, Ontario

TITLE: Factors Influencing the Acquisition of a Timed Sequential Movement

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NUMBER OF PAGES: viii, 77

ABSTRACT

Two experiments are reported that assess the effect two types of training (phase and duration) have on the acquisition and transfer of timed sequential movements. The first experiment showed that phase-training (practicing segment movement time goals) facilitated phase transfer over duration-training (practicing overall movement time goals). When the kinematics of the phase transfer test were altered in the second experiment, no transfer differences were found between phase and duration-trained groups. These findings are discussed in reference to contextual interference effects and the learning of essential variables. Also, the importance of kinematics and segment relationships to essential variables are evaluated.

ACKNOWLEDGEMENT

Thank you to Larry Jacoby and Jan Starkes for serving as members of my committee.

A very special thank you to Digby Elliott and Tim Lee for their friendship and guidance over the past years. I am indebted to them both for the opportunities they have given me.

A final thank you to my parents, Clifford and Dora Carnahan, who have supported me in so many ways throughout my education.

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Introduction

Research assessing the time properties of sequential movement recently has been a popular area of study. One interesting finding that has emerged is that some features of well learned sequential movements remain consistent across many repetitions of a motor-skill while other features change across repetitions (Armstrong, 1970; Hollerbach, 1981; Shapiro, 1977; Shapiro, Zernicke, Gregor & Diestal, 1981; Summers, 1975, 1977; Terzuolo & Viviani, 1979; Viviani & Terzuolo, 1982). More specifically, research has demonstrated that the proportion of time required to complete each element within a sequential movement (i.e., "phasing") is an invariant feature of repetitive movements. That is, from trial to trial the phasing (or proportion of time from event to event) remains consistent despite changes in other variables such as overall movement duration, acceleration, force or limb selection. These features of movement that can be varied without altering the phasing of the movement are called "parameters" (see Schmidt, 1985 for a review).

Two major theoretical views have been advanced to explain invariant features and parameters of movement. The first perspective is the information processing view. Proponents of this view suggest that there are motor programs which serve as memory representations of movement and the invariant features of movement are stored within these motor programs (Pew, 1974; Schmidt, 1975). Thus, this theory proposes that a central structure exists that is capable of retaining and reproducing the invariant features of movement patterns (i.e., the phasing of a movement). But, before a movement can be generated, the representational pattern must be parameterized. Once a person decides _what_ to do, _how_ it will be done can then be specified.

A second theoretical view that has also been advanced challenges the information processing view. This approach, which has been referred to as the "action" or "ecological" perspective (Michaels & Carello, 1981; Reed, in press) assumes that the mechanism behind invariances found in skilled sequential movement is not a central entity, but rather, is located peripherally (Kelso, 1981; Schmidt, in press; Turvey, Shaw, & Mace, 1978). This peripheral system, called a "coordinative structure", refers to a group of muscles and joints that act together as a single unit. That is, the muscle system acting as a unit, is responsible for the temporal invariance found in many movements. The action view hypothesizes that once a central command is sent to the coordinative structures, the phasing of movement evolves from a system of biomechanical constraints (Kelso, Southard & Goodman, 1979). Within the framework of this view, the invariant features and parameters are referred to by the terms "essential" and "non-essential" variables respectively (Kelso, Putnam & Goodman, 1983). Essential variables determine, "the structural prescription of movement," whereas non-essential variables, "specify marked changes in the value of the [movement] but leave its topological properties essentially unchanged" (Kelso et al., 1983, p. 367). Thus, essential and non-essential variables can be identified by varying the metrics of a movement (e.g., velocity or force) and assessing which aspects of the movement remain constant and which become modified. For example, examining the coordination of two handed movements, Kelso et al. (1979) and Kelso et al. (1983) demonstrated that when the left and right hands moved to different targets, the times to peak velocity and acceleration for both hands were almost identical even though the hands moved at different speeds. They concluded that velocity is a non-essential variable and movement phasing (the proportion of time spent accelerating and decelerating), is an essential variable.

While there are differences between the generalized motor program and the "action" perspectives to movement invariance (the most obvious being the role of central representations) what is of most interest are the similarities between these two approaches. Both perspectives recognize that there are features of movement that remain invariant (e.g. phasing) across various manipulations of movement parameters (e.g., movement duration). Although for each approach a different mechanism (the generalized motor program and coordinative structures) is deemed responsible, the two views are indistinguishable at a behavioral level (Schmidt, in press).

The majority of studies examining invariances have been conducted on skilled movements. For instance, researchers have assessed the invariant performance of <u>well learned</u> motor-skills such as typing, writing, walking and jogging. Another approach to studying invariance however, recently has been adopted by Langley and Zelaznik (1984). These two researchers have been interested in how an invariant feature (phasing) and a parameter (duration) of a movement are acquired, and how training on these two types of variables affects learning. To address this issue, Langley and Zelaznik (1984) conducted a study in which training on an essential and a non-essential variable was compared in order to determine which type of training best facilitated learning. Langley and Zelaznik compared the acquisition and transfer performance of Phase-trained subjects (using an essential variable) and Duration-trained subjects (using a non-essential variable) on a sequential timing task. The task involved knocking down three equidistant wooden barriers that were arranged in a reversed "Z" pattern. Duration-trained subjects were required to knock down all three barriers in one specified total time. The duration was defined as the time from release of the start button to knocking over the final barrier. Phase-trained subjects also were required to complete the same movement pattern using a continuous motion. However, they were required to knock down each of the three barriers in specific time intervals that were different for each phase (i.e., each segment or "phase" of the movement had a distinct timing requirement). The sum of the three segment timing goals was equal to the total timing goal of the Duration group.

Using a double transfer design, half of the subjects from each of the Duration and Phase groups participated in a novel duration transfer task while the other half completed a novel phasing transfer task. Results showed that Phase-trained subjects and Duration-trained subjects performed equally well on the duration transfer task. However, Phase-trained subjects showed superior performance over the Duration group in the phasing transfer task. Thus, Phase-training facilitated both phasing and duration transfer whereas Duration-training facilitated only duration transfer.

Exactly why phase-training facilitated transfer however, is not clear. One possible explanation for the transfer results is that during acquisition the Phase-trained group received three times as many knowledge of results (KR) scores as the Duration-trained group. To assess whether or not the number of KR scores affected the outcome of their Phase and Duration-trained groups Langley and Zelaznik (1984) conducted a follow-up study that equalized the number of KR scores that each training group (Duration and Phase) received. The transfer results of this experiment however, despite the KR manipulations, were the same as in the first experiment. Equalizing the number of KR scores did not overcome the effect that Phase-training had on phase transfer. The Phase-trained group continued to demonstrate superior phase transfer performance over the Duration-trained group.

Langley and Zelaznik also assessed another possibility for their transfer findings. They suggested that the Phase-trained subjects experienced high intramovement contextual interference, leading to that group's superior transfer. Contextual interference has previously been created by increasing task difficulty through the manipulation of practice schedules (Lee & Magill, 1983; Shea & Morgan, 1979). Generally, contextual interference during training leads to poor acquisition performance and superior retention and transfer performance when compared to training without interference. There were three findings that led Langley and Zelaznik to conclude that the Phase groups were experiencing contextual interference. First, during acquisition the Phase-trained subjects continued to improve across all blocks of trials. However, the performance of the Duration-trained subjects reached a plateau very early in practice, thus revealing a pattern of results similar to the contextual interference effect (Lee & Magill, 1983; Shea & Morgan, 1979). Second, the Phase-trained subjects showed more variability in performance throughout acquisition when compared to the Duration-trained group (also similar to the contextual interference effect). Finally, despite the Phase-trained subjects' less accurate and more variable acquisition profile, they performed better than the Duration-trained subjects during the phase transfer. These observations led Langley and Zelaznik to suggest that the Phase-trained group had experienced more contextual interference during acquisition than the Duration-trained group. They argued that phase-training conditions required subjects to simultaneously encode and retain three time frames of information, whereas the Duration-trained subjects only dealt with a single time frame. Thus, when an essential variable within a movement was arranged unsystematically, high intramovement interference may have resulted, and this perhaps led to improved transfer.

The assumption made by Langley and Zelaznik is that training on an essential variable facilitates learning because contextual interference is created. The problem with this assumption is that Langley and Zelaznik have not clarified whether the learning of an essential variable is facilitated by contextual interference or whether the contextual interference effect itself is solely responsible for the superior transfer of the Phase-trained group. Is the Phase group's superior transfer the result of contextual interference created while training on movements with differing segment movement time goals? Perhaps encoding and retaining these three different segments created contextual interference during acquisition which in turn facilitated performance later during transfer. If this were true, then the superiority of the Phase group would be due to contextual interference and not due to training on an essential variable. However, another possibility is that learning a segmented movement can be aided by contextual interference. Perhaps subjects training on segmented movements with variable phasing (differing segment times) experienced high levels of interference which in addition to training on an essential variable, led to improved transfer performance.

The notion of <u>intra</u>movement contextual interference has received little attention in previous work on motor-skill learning. Past studies examining the contextual interference effect have varied <u>inter</u>movement interference by manipulating practice schedules in blocked or random orders (Lee & Magill, 1983, 1985; Shea & Morgan, 1979; Shea & Zimny, 1983). Blocked practice schedules (where all trials of a movement are completed before the next movement is practiced) are intended to create low levels of interference, whereas random practice schedules (where movements are practiced in an unsystematic order) are intended to create high levels of intermovement interference. However, the possibility exists that contextual interference within a movement can also facilitate learning. Theoretically, the existence of intramovement contextual interference has been previously considered by Shea and Zimny (1983). They contend that random practice facilitates learning due to greater within and between movement "elaborative" and "distinctive" processing. Shea and Zimny defined elaboration as repeated interactions with a particular movement resulting in enhanced retention. Distinctiveness refers to how movements, and elements within a movement contrast with each other. These processes, elaboration and distinctiveness, may be the source of the Phase-group's superior transfer performance.

Another potential explanation for their transfer results also was proposed by Langley and Zelaznik (1984). Although they did not investigate the possibility, they suggested that while the Duration group learned independent total times for each movement, the Phase group learned to estimate the relationships between the movement segments. That is, the Phase group learned how each segmented related to the previous or following segment. In contrast, Duration-trained subjects ignored segment relationships and instead learned only to estimate the total movement time (Povel, 1981; Wing & Kristofferson, 1973). When both groups performed a phase transfer test, only the Phase-trained group (which learned the necessary segment relationships) demonstrated superior transfer. To summarize, Langley and Zelaznik suggest that the reason essential variables facilitated learning is because processing of intersegment relationships was promoted. How these relationships might be represented and the manner by which they are formed is the focus of the present investigation.

EXPERIMENT 1

One limitation of Langley and Zelaznik's study is that phasing (an essential variable) is confounded with a potential contextual interference effect. Their Phase group's superior transfer performance could have been due to this group learning to use an essential variable where the Duration group only learned to use a non-essential variable. An alternative explanation for the transfer results is that the Phase group experienced more contextual interference during acquisition than the Duration group. If this were true then contextual interference, and not learning to use an essential variable is the source of the Phase group's superior transfer performance. The purpose of the present experiment is to unconfound these two possibilities.

To evaluate the validity of these explanations requires that contextual interference effects and essential variables be unconfounded. To accomplish this the present experiment contrasted three groups: a Duration and a (Variable) Phase group (similar to Langley and Zelaznik) plus a Constant Phase group. A Variable Phase group, is one in which subjects practiced movements consisting of segments with different movement times. This is identical to the Phase manipulation in Langley and Zelaznik's experiments. The Constant Phase group practiced movements consisting of segments with identical movement times. Essentially, variable phase-training is analogous to a random practice schedule because segments within a movement are arranged in an unsystematic order. However, constant phase-training is analogous to a blocked practice schedule because segment goals remain unchanged within a movement. Thus, the acquisition and transfer performance of a Duration, Constant Phase and Variable Phase group must be compared in order to differentiate between the contributions of essential-variables and contextual interference to phase transfer performance.

If contextual interference (and not the essential variable) is responsible for the superior performance of a Phase-trained group, then a Variable Phase-trained group (which would experience high levels of interference) would show better transfer performance than a Constant Phase-trained group (which would experience low levels of interference). Further, the Constant Phase group would be equal to the Duration group. However, if the learning of an essential variable accounts for Langley and Zelaznik's findings, then both the Variable Phase group and the Constant Phase group would be expected to be superior to a Duration group during phase transfer.

In the present experiment three groups performed sequential timing movements that were comprised of three phases. The performance of Constant and Variable Phase-trained groups and a Duration-trained group was compared during acquisition. Learning was then assessed by duration and constant and variable phase transfer tests. Thus, by comparing the transfer performance of the Duration, and both the Variable and Constant Phase-trained groups, the role of an essential variable and intramovement contextual interference was assessed.

Method

Subjects

Thirty-six right-handed McMaster University undergraduates (27 males and 9 females, mean age of 20 years) served as subjects. Each subject was assigned randomly to one of three groups with the restriction that each group was equally represented by gender. All subjects participated in exchange for course credit.

Apparatus

Three foam-covered hinged blocks (12 cm x 8 cm) were aligned linearly 21 cm apart and rested horizontal to the body plane on a table top (81 cm high). Each barrier was fitted with electromagnetic switches that provided a signal when tipped over. A start button was located 21 cm to the right of the first barrier. All switches were interfaced with an Apple II+ computer, situated to the right of the apparatus, which measured the movement time (MT) to complete each particular phase. A phase consisted of the distance between the start button and the first barrier as well as the distance between two barriers. The computer also was interfaced with the start button so decision time (DT) could be measured. DT included the interval from stimulus onset to the release of the start button. MT and DT were recorded on a floppy disk for later analyses. The stimulus light was mounted at subjects' eye level and indicated when the movements were to be initiated. Illustration on each of three cards indicated the temporal requirements of the three movements to be learned. Only the card that corresponded to the required movement on any particular trial was attached to the wall in front of the subject during the practice session.

Procedure

Subjects were assigned to one of the following groups: Constant Phase, Variable Phase or Duration. Each group was required to learn three movement timing patterns. For any one movement pattern, subjects were required to knock down all three wooden barriers. The goal of both Phase groups was to complete each phase of the movement pattern in specified MTs. The Constant Phase group performed three movements each comprised of three identical phase MT goals (movement 1 = 150 - 150 -150 msec, movement 2 = 200 - 200 - 200 msec, movement 3 = 250 - 250 - 250 msec). The Variable Phase group performed three movements, each comprised of three different phase MT goals (movement 1 = 150 - 200 - 250 msec, movement 2 = 200 - 250 - 150 msec, movement 3 = 250 - 150 - 200 msec). The Duration group was required to complete three movements in specified total MT goals (movement 1 = 450 msec, movement 2 = 600 msec, movement 3 = 750 msec). After subjects in the Phase groups completed each movement, KR with respect to actual MT for each phase was displayed on the computer screen. KR with respect to actual total MT was displayed for the Duration group. For all three groups, inter-trial intervals were held constant at six seconds.

Insert Table 1 about here

On each trial a warning tone was sounded at the completion of the intertrial interval. Following a variable foreperiod (1 - 3 seconds) the stimulus light was then illuminated. Movements were self-initiated after the illumination of the stimulus light, which lasted for one second. The subjects were not required to respond immediately upon the illumination of the light. Rather, subjects were encouraged to initiate movement when they felt ready. The three movements were practiced in a blocked fashion and the order in which movements were performed was balanced using a Williams square design. Each movement was practiced for 40 trials.

After a ten minute rest interval all groups performed common, no-KR transfer trials. The test was actually comprised of three subtests. Each subtest consisted of 8 trials and the subtests were administered in a random order. Three new cards representing the MT goals of the transfer movements to be performed were posted at the subjects' eye level. The appropriate movement was initiated by the subject when the corresponding light (red, green or yellow) was illuminated. The first subtest was performed when the green light was illuminated and consisted of constant phasing MT goals (215 - 215 - 215 msec). The second subtest was performed when the red light was illuminated and consisted of variable phasing MT goals (190 - 230-160 msec). The final subtest, performed upon illumination of the yellow light, consisted of a duration MT goal (675 msec).

Analyses

Acquisition and transfer data were reduced over blocks of eight trials. The dependent measures for the acquisition data were absolute constant error (|CE|), variable error (VE), and decision time (DT). |CE| served as a measure of performance accuracy whereas VE represented a measure of performance consistency (Henry, 1974; Schutz, 1977). DT served as a measure of voluntary preparation time (Lee, Magill & Weeks, 1985). This measure, although a rather crude index, reflected the planning time that subjects engaged in voluntarily before movement initiation. The movements in this experiment were self-initiated and had constrained MTs, thus a standard reaction time (RT) measure was not appropriate. Newell, Hoshizaki, Carlton, and Halbert (1979) explain that in this type of situation the DT measure is preferred over the RT measure because it overcomes the problem of reacting quickly and moving slowly. Considering the procedures used in this experiment, DT was the best possible measure of preparation time.

The acquisition |CE| and VE data for the phase groups were analyzed in a 2 (group) x 5 (block) x 3 (movement) x 3 (phase) mixed ANOVA. The |CE| and VE data for the Duration group was analyzed in a 5 (block) x 3 (movement) repeated measures ANOVA. The acquisition group effects were analyzed separately since the goal times for the various groups were different. Finally, the DT data for all groups was analyzed in a 3 (group) x 5 (block) x 3 (movement) mixed ANOVA.

The dependent measures for the transfer data were the same as those used in the acquisition analyses. Data for both the variable phase MT goal test and the constant phase MT goal test were analyzed in 3 (group) x 3 (phase) mixed ANOVAs. |CE| and VE for the duration movement test, and DT for all three transfer tests were analyzed in separate 3 - group, one-way ANOVAs. Significant ANOVA findings at $p < .05$ were analyzed further using the Tukey a procedure for comparison of means.

Results

Acquisition

Decision Time. In the acquisition DT analysis there was a main effect for group, $F(2,33) = 9.77$, $MSe = 242361.59$, $p < .001$. The Variable Phase group mean was slower (1243 msec) than both the Constant Phase (671 msec) and Duration (571 msec) trained groups. There was also a main effect for movement $F(2,66) = 6.11$, $MSe = 149148.34$, $p = .004$, in addition to a group by movement interaction *F*(4,66) = 3.99, *MSe* = 149148.34, *p*=.006. For the Variable Phase group, mean DT for movement one (1088 msec) was much faster than DT for movement three (1447 msec). DT for movement two was intermediate (1194 msec). Contrary to this, DTs for all three Constant Phasing and Duration movements were the same (see Figure 1). The final acquisition DT effect was a main effect for block, *F*(4,132) = 2.63, *MSe* = 51537.35, *p*<.04. Mean DT for block one (891 msec) was slower than blocks two (811 msec), three (817 msec), four (806 msec) and five (816 msec).

Insert Figure 1 about here

Phase Errors (|CE| and VE). When |CE| was used as the dependent measure in the Phase groups analysis, a main effect for group was found, *F*(1,22) = 14.00, *MSe* = 3543.22, *p*=.001. Mean |CE| for the Variable group (38.2 msec) was greater than for the Constant group (24.6 msec). A block main effect was also found, *F*(4,88) = 6.13, *MSe* = 529.40, *p*<.001. On the first block subjects exhibited more mean |CE| (36.3 msec) than on the third (31.2 msec), fourth (29.1 msec) and fifth (26.4 msec) block. Also on the fifth block subjects showed less error than on the second (33.9 msec). There was a main effect for movement, *F*(2,44) = 4.89, *MSe* = 1373.84, *p*<.02, in addition to a group by movement interaction, $F(2,44) = 5.37$, MSe = 1373.84, $p=.008$. For the Variable group, more error was demonstrated for movement three than for either movement one or movement two. However, for the Constant group all three movements were performed with similar amounts of error (see Figure 2).

Insert Figure 2 about here

The effects found for VE were very similar to those found for |CE|. A group main effect, $F(1,22) = 26.93$, $MSe = 2380.44$, $p<.001$, demonstrated that the Variable group experienced more VE (40.2 msec) than the Constant group (24.8 msec). A block main effect, $F(4,88) = 8.38$, $MSe = 487.70$, $p<.001$, was also demonstrated. Most of the improvement in performance occurred between the first (39.7 msec) and the second block (32.5 msec). On blocks three through five subjects exhibited less VE than on block one (30.6, 31.7, 28.0 msec). There was a main effect for movement, $F(2,44) = 15.56$, $MSe = 971.77$, $p<.001$, along with a group by movement interaction, $F(2,44) = 6.73$, $MSe = 971.77$, $p=.003$. For the Variable Phase group, more error was committed on movement three (52.2 msec) than on either movement one (33.8 msec) or two (34.6 msec). However, for the Constant group there were no differences between the three movements (20.7, 26.3, 27.3 msec). In addition to a phase main effect, $F(2,44) = 8.33$, $MSe = 915.81$, $p=.001$, a movement by phase interaction, $F(4,88) = 3.58$, $MSe = 719.40$, $p=.009$, was found. These effects were accompanied by a three way group by movement by phase interaction, $F(4,88) = 2.93$, $MSe = 719.40$, $p<.03$. This interaction follows the pattern found in recent work showing that error increases as movements are made more slowly (Newell et al., 1979). As may be seen in Figure 3, this interaction revealed that for the Variable Phase group, at segment one (150 msec) of movement one, subjects produced the least amount of error, while at segments two (200 msec) and three (250 msec) subjects performed with more error. At all three segments of movement two subjects produced equal amounts of error. At movement three, segment three (200 msec) subjects produced the most error, at segment one (250 msec) a secondary amount and at segment two (150 msec) the least. For the Constant group however, at all three movements and all three phases, subjects produced equal amounts of error. The 150 msec phase of the variable phase movements was generally performed with less error than the other phases. This is congruent with other studies that have found that fast movements result in less timing errors than slow movements (Newell & Hoshizaki, 1980). Thus, the interaction occurred because for the Variable Phase group, the 150 msec phase was in a different position in each different movement.

Insert Figure 3 about here

Total Time Errors (|CE| and VE). When |CE| served as the dependent measure a block main effect was evidenced, $F(4,44) = 11.15$, $MSe = 400.10$, $p < .001$. At block one subjects performed with more |CE| (42.11 msec) than at the other four blocks (19.3, 19.22, 17.1, 14.3 msec).

When VE was the dependent measure a block effect was again demonstrated, $F(4,44) = 20.33$, $MSe = 437.53$, $p < .001$. Again subjects exhibited more VE (73.8 msec) on block one than on the other four blocks (41.0, 42.1, 35.5, 37.9 msec). In the VE analysis there was also a main effect for movement, $F(2,22) = 6.69$, $MSe = 753.24$, $p = .005$. Movement three was performed with more VE (56.1 msec) than movement one (38.2 msec). Performance on movement two (43.9 msec), was not different from either movement one or three. Again this finding supports previous work which demonstrated that VE decreases as the MT goal becomes faster (Newell et al., 1979).

Transfer Data

Variable Phase Test (|CE|, VE and DT). For the Variable movement transfer test, a group main effect was demonstrated when |CE| was analyzed, $F(2,33) = 13.50$, $MSe = 9891.23$, $p < .001$. The Duration group performed with more

|CE| (149.0 msec) than both the Variable (39.1 msec) and Constant (48.7 msec) Phase groups which did not differ from each other.

A group main effect also was found for VE, $F(2,33) = 15.80$, $MSe = 1051.44$, $p<.001$. The Duration group again performed with more VE (74.9 msec) than either the Variable (37.9 msec) or Constant (37.6 msec) Phase groups. This analysis also revealed a phase main effect, $F(2,66) = 4.61$, $MSe = 799.82$, $p<.02$, and a group by phase interaction, $F(4,66) = 5.31$, $MSe = 799.82$, $p=.001$. On the first phase of the variable transfer movement all three groups performed with equal amounts of error. However, the Duration group committed more VE than either the Variable or Constant groups in the second and third phases (see Figure 4). Langley and Zelaznik found total error (TE) results very similar to these (see their Figure 2, p.282).

Insert Figure 4 about here

For the DT data there was a group main effect, $F(2,33) = 3.94$, $MSe = 939772.25$, $p<.03$, as evidenced by the Variable group having a longer mean DT (2194 msec) than the Constant group (1207 msec). The Duration group mean DT (1259 msec) was not different from either of the other two groups.

Constant Phase Test (|CE|, VE, and DT). A main effect for group, $F(2,33) = 7.46$, $MSe = 8457.43$, $p=.002$ was revealed by the |CE| analysis of the constant transfer movement. The Duration group again committed more |CE| (113.1 msec) than both the Variable (47.3 msec) and Constant (35.3 msec) Phase groups.

However, when VE was used as the dependent measure, the group main effect, $F(2,33) = 3.89$, $MSe = 5473.77$, $p<.03$, revealed that the Duration group committed more VE (79.7 msec) than the Constant Phase group (35.2 msec) but, the Variable Phase group (40.4 msec) was not different from either of the other two groups. No group differences were found in the DT analysis.

Duration Test (|CE|, VE and DT). During the Duration transfer, when |CE| was analyzed, all three groups performed with equal amounts of error. But, when VE was assessed a group main effect was found, $F(2,33) = 5.01$, $MSe = 1646.92$, $p<.02$. Post hoc analyses revealed that the Constant group (60.9 msec) performed with less VE than the Duration group (112.9 msec). The Variable group (81.3 msec) was not different from the other groups. When DT data were analyzed, no differences were found between the three groups.

Discussion

The purpose of Experiment 1 was to ascertain whether Langley and Zelaznik's (1984) phase transfer findings were due to training on an essential variable or to contextual interference. If contextual interference was responsible for the superior performance of a Phase-trained group, the Variable Phase group would have shown better transfer performance than the Constant Phase group. But, if the learning of an essential variable was responsible for the phase transfer findings then both the Variable Phase and the Constant Phase groups would have shown superior phase transfer performance over a Duration group. The findings of this study supported the second hypothesis. Both the Variable and Constant Phase-trained groups outperformed the Duration-trained group for both constant and variable phase transfer tests without being different from each other. As well, there were essentially no group differences at the duration movement transfer. These findings provide no support for the idea that contextual interference was responsible for the phase transfer findings in previous studies (Langley & Zelaznik, 1984). Rather, the results do support the hypothesis that training on an essential variable caused the transfer group effects.

Although acquisition performance does not necessarily correlate with transfer performance, there was some support for the first hypothesis in the acquisition results. During acquisition the Variable Phase group experienced more error and longer DTs than the other two groups. This supports Langley and Zelaznik's conclusion that the variable phase task required more difficult processing than the other tasks. Acquisition findings similar to these would be expected if contextual interference was the mechanism involved. Contextual interference studies (Lee & Magill, 1983; Shea & Morgan, 1979) have demonstrated that Random practice groups experience poor performance during acquisition when compared to Blocked practice groups. Essentially, this is what was found in Experiment 1. The Variable Phase group experienced more error and longer DTs than the Constant Phase group suggesting there was contextual interference. However, when the acquisition and transfer data are examined collectively, the presence of a contextual interference effect was not supported. The <u>transfer</u> findings of Experiment 1 were <u>not</u> compatible with a contextual interference interpretation of the results.

It is interesting that intramovement contextual interference was not demonstrated, even though Shea and Zimny's (1983) theory predicts that it should. One suggestion (R.A. Magill, personal communication, October 2, 1986) is that contextual interference effects might become larger when very simple movements are practiced. Perhaps the movements in this experiment were so difficult that random or variable compositions were not necessary to produce interference; the difficulty of the task itself provided adequate interference.

A final, and potentially interesting possibility is that the contextual interference effect can only be created <u>between</u> movements or motor programs, and not within a motor program. Assuming that the movements in this study were generated by single motor programs, perhaps contextual interference can only be created between movements and not within a movement. If this were true, then the locus of the effect could be during the intertrial intervals, not during movement production.

To summarize, contextual interference was not responsible for Langley and Zelaznik's (1984) transfer findings. Both constant and variable phase-training facilitated the learning of a timed sequential movement. The remaining alternative (training on an essential variable) appears to be the more plausible explanation for the results of Experiment 1. Some uncertainly still remains however, about how training on an essential variable facilitates motor-skill acquisition.

EXPERIMENT 2

Although Phase-training results in superior transfer over Duration-training, the specific nature of phase training that is responsible for this finding is unknown. Presumably there is some unique characteristic of an essential variable that is responsible for the phase transfer findings. One possible explanation for the phase transfer findings is explored in this second experiment. It is possible that the Phase groups learned "to estimate the segment time relationships" (Langley & Zelaznik, 1984, p. 290) between the movement segments, whereas the Duration group learned independent total times for each movement. The rationale is that the Phase groups learned how one segment related to the other as opposed to learning three independent segment times. Thus, learning about the relationships between elements within an essential variable could have facilitated learning.

Several previous studies have attempted to evaluate the importance of segment relationships in sequential movements. For example, Folkins and his associates (Folkins & Abbs, 1975; Folkins & Zimmerman, 1982) have assessed the relationship between segments of articulatory patterns by examining the effects of jaw perturbations during lip closure. These studies did not ascertain however, whether the response to perturbations was standardized or was related to the utterance being performed. Kelso, Tuller, Vatikiotis-Bateson and Fowler (1984) attempted to answer this question and provided evidence that speech is comprised of articulatory segments which are flexibly assembled. (The articulatory segments in speech are analogous to the timed movement segments in Experiment 1). In their study, Kelso et al. introduced perturbations while various different utterances were being produced. Their findings indicated that the reactions to the disturbances were unique to each different utterance, suggesting that each articulatory segment is generated in reference to the previous segment. Thus, evidence exists that in a highly practiced relative timing task (speech), skilled movement is characterized by the ability to relate movement segments. If this finding is extended to the movements in Experiment 1, perhaps for successful phase transfer, subjects must develop an awareness of segment time relationships.

The purpose of this second experiment was to assess whether learning segment relationships while training on a non-essential variable will facilitate acquisition to the same extent as training on an essential variable. If developing a relationship between the segments which comprise a movement instead of merely learning how to perform three independent segments is the key to the superior transfer performance of a Phase group, then a Duration group which also learns segment relationships should perform better than the standard Duration group and similar to a Phase group. However, if learning specific segment goals and not their interrelationships is the key, then this "Duration-Relationship" group should perform similar to a Duration group, with both groups being poorer than the Phase group.

Method

Subjects

Twelve male and 24 female right-handed McMaster undergraduates with a mean age of 20 years served as subjects. None of the subjects had participated in Experiment 1.

Apparatus

The equipment was identical to that used in Experiment 1.

Procedure

Three training groups were again compared. A Duration-trained group was required to perform two movements each in a specified total time (movement 1 = 670 msec, movement 2 = 560 msec). A second, Variable Phase-trained group, performed two movements in which each segment goal time became either progressively longer or shorter (movement 1 = 180 - 220 - 270 msec, movement 2 = 230 - 190 - 140 msec). These two groups were similar to the Duration and Variable-Phase groups used in Experiment 1. The third group followed a Duration-Relationship training procedure. Subjects in this group were required to complete each of the two movements in specified total times (movement 1 = 670 msec, movement 2 = 560 msec), similar to the Duration group. However, an added goal was that each phase was to be performed either slower or faster than the previous phase. This condition is termed a Duration-Relationship group because a particular relationship amongst the segments was to be achieved (speeding up or slowing down) although specific goal MTs for each phase were not required. Similar to Experiment 1, forty trials of each movement were practiced in a blocked schedule. During acquisition all three groups received both segment and duration KR.

Insert Table 2 about here

Following acquisition trials and a ten minute rest, all three groups performed 8 trials on each of two transfer tests. The trial order in which subjects performed these tests was blocked, with test order counterbalanced across subjects. One transfer test consisted of variable phase movement goals (250 - 200- 160 msec) and the other transfer test consisted of a Duration movement goal (585 msec). In the first experiment the transfer tests were presented in a random order because three movements were practiced.

Analyses

The dependent measures for this experiment were the same as in Experiment 1. The acquisition |CE| and VE data for the Phase group were analyzed in a repeated measures 2 (movement) x 5 (block) x 3 (phase) ANOVA. |CE| and VE for duration performance, and DT for all three groups were analyzed in separate 3 (group) x 2 (movement) x 5 (block) mixed ANOVAs.

The transfer |CE| and VE data for the variable phase movement test were analyzed in a 3 (group) x 3 (phase) ANOVA. DT, |CE| and VE for both the variable movement and duration movement transfer tests were analyzed in separate 3 - group one factor ANOVAs.

Results

Acquisition

Decision Time. In this second experiment there were no DT group differences. However there was a block main effect, $F(4,132) = 4.17$, $MSe = 33058.85$, $p=.003$, which showed that subjects were slower on the first block (821 msec) than on the third (722 msec), fourth (714 msec) and fifth (728 msec) blocks. Only on the second block (760 msec) was the subjects performance not different from the other blocks.

Phase Errors (|CE| and VE). A block effect was found $F(4,44) = 10.67$, $MSe = 431.85$, $p<.001$, for the Phase group when |CE| was analyzed. On block one (49.4 msec) |CE| scores were higher than on blocks two, (36.6 msec), three (30.3 msec), four (31.6 msec) and five (30.8 msec).

A similar block effect also was found for VE, $F(4,44) = 12.93$, $MSe = 577.82$, $p<.001$. On block one (53.3 msec) subjects showed higher VE scores than on all the other blocks (35.2, 30.3, 30.8, 28.5 msec). There was also a movement by phase interaction, $F(2,22) = 6.35$, MSe

= 1460.92, p=.006. Post-hoc analyses revealed that subjects at all three phases for movement one showed similar amounts of VE (28.8, 35.5, 45.9 msec). However, for movement two, at phase one subjects exhibited more error (46.8 msec) than at phase two (24.3 msec). Subjects' VE at phase three (32.5 msec) did not differ from the other two phases.

Total Time Errors (|CE| and VE).

When assessing the timing errors with respect to total MTs, a group main effect was found, $F(2,33) = 16.86$, $MSe = 2673.15$, $p < .001$. The Duration group was more accurate (|CE| = 28.5 msec) than both the Duration-Relationship (CE = 57.7 msec) and Variable Phase (|CE| = 65.1 msec) groups. A block effect, $F(4,132) = 4.06$, $MSe = 1669.17$, $p = .004$, and a group by movement by block interaction, $F(8, 132) = 2.24$, $MSe = 1871.55$, $p < .03$, were also evident. There were no differences between movements or blocks for the Duration group. However, for the Duration-Relationship group, at movement two, subjects committed more error on block one than any of the other blocks. Also, on block five there was more error at movement one than movement two. For the Variable Phase group on block one, subjects demonstrated more error at movement one than at movement two (see Figure 5). This interaction does not appear to be theoretically meaningful. Further, the small amount of variance accounted for (ω^2 = .023) raises questions as to its potential for replication.

Insert Figure 5 about here

When VE was analyzed there was a group main effect, $F(2,33) = 8.72$, $MSe = 2754.86$, $p = .001$. The Variable group demonstrated more VE (79.3 msec) than the Duration group (51.2 msec) with the Duration-Relationship group (67.5 msec) not being different from either of these two groups. As expected, there was a block main effect $F(4,132) = 16.39$, $MSe = 1360.82$, $p < .001$, with the major difference occurring between the first (97.1 msec) and second (61.7 msec) block of trials. Performances at blocks three (60.0 msec), four (55.0 msec) and five (55.6 msec) were also not different from performance at block two.

Transfer

Variable Phase Test (|CE|, VE, and DT).

When VE was analyzed there was a main effect for phase, $F(2,66) = 3.48$, $MSe = 410.32$, $p < .04$. More VE was committed on the first phase (35.6 msec) than on the second (23.0 msec). However, the third phase (29.6 msec) was not different from the other two. There were no group differences in performing phasing goal movements when |CE|, VE, and DT were analyzed (for all three dependent measures $p > .20$).

Duration Test (|CE|, VE and DT). There was a group main effect, $F(2,33) = 9.68$, $MSe = 1954.92$, $p < .001$, when |CE| was analyzed. The Phase group committed more |CE| (113.8 msec) than both the Duration (41.7 msec) and Duration-Relationship (49.0 msec) groups. However, no group differences were found for VE and DT.

Discussion

If developing a relationship between movement segments was responsible for the superior Phase group transfer in Experiment 1 then the Duration-Relationship group in this study should have shown transfer performance equal to that of the Phase group and better transfer performance than the Duration group. However, if learning specific segment goals is the reason why training on an essential variable facilitates learning, then the Phase-trained group in this study should have performed better than both the Duration, and Duration-Relationship groups. The transfer results of Experiment 2 do not support either hypothesis. In contrast to Experiment 1, where the Phase groups demonstrated superior transfer performance over the Duration group, the present experiment revealed essentially no transfer differences between the three training groups. On both the duration and phase transfer tests, no differences between Phase-, Duration- and Duration-Relationship-trained groups were found.

The acquisition data do suggest however that there are some similarities between the performance of the Phase- and Duration-Relationship-trained groups. The total time acquisition analysis revealed that the Duration group performed with less error than both the Duration-Relationship and Phase groups. The lack of a difference between the Duration-Relationship and the Phase groups was very interesting especially when there was a difference between the Duration-Relationship and the Duration groups. At least during acquisition, a Duration group was made to perform like a Phase group by introducing a small alteration in task demands. While the Duration-Relationship group maintained a total MT goal, they had the additional task of maintaining a non-specific timing relationship between the segments. Thus, by giving a Duration group the additional task of dealing with segment relationships, they performed with error similar to the Phase group. Based on these acquisition data then, one might speculate that processing segment relationships is an important difference between standard Phase and Duration training. However, since no transfer group differences were found, a solid argument in favour of the importance of establishing segment relationships can not be established.

This experiment's transfer results do not replicate Experiment 1, nor Langley and Zelaznik's findings.

Several methodological differences existed between Experiments 1 and 2 and it can be assumed that one of these differences was responsible for the discrepant results of the second experiment. In the first experiment, all subjects practiced three movements whereas in the second experiment subjects practiced only two movements. However, this should not have had an influence on the transfer results because in Langley and Zelaznik's studies only two movements were practiced and still they found Phase group superiority.

A second difference between Experiments 1 and 2 is the number of KR scores that subjects received. In the first experiment, Phase-trained subjects received three KR scores during acquisition and the Duration-trained subjects received only one score. However in Experiment 2, all three groups received four KR scores (segment and total times). If the number of KR scores, or the type of information they provided was at all responsible for the Phase group's transfer performance then equalizing the number of KR scores each group received could nullify group differences. This is probably not the mechanism behind the transfer findings either however, because in their third experiment Langley and Zelaznik demonstrated that the number of KR scores administered during training did not explain the Phasing groups' relatively good transfer performance.

A third difference between Experiments 1 and 2 is that in Experiment 1, the transfer test trials were given in a random order. In Experiment 2, the transfer tests were presented in a blocked order. In Langley and Zelaznik's (1984) experiments the scheduling of transfer tests was not an issue since each group received only one transfer test. The scheduling of transfer tests could explain why there was generally less error and faster DTs in the transfer tests of Experiment 2, but the scheduling should not have affected the pattern of results. Shea and Morgan (1979) demonstrated that when transfer tests were presented in a blocked schedule the magnitude of group differences was smaller than when the same tests were presented in a random schedule. Thus, although scheduling of transfer tests may alter the size of any group differences found, the direction of any group effects would not be expected to change.

A fourth difference between Experiments 1 and 2 was the type of phase movements on which subjects trained. I believe that this difference may be critical in evaluating the mechanism behind the transfer performance of the Phase-trained groups. In Experiment 1, and in Langley and Zelaznik's study, the phase movements were all comprised of segments that required various combinations of acceleration, deceleration and zero acceleration. Also, both phase transfer movements required differing accelerations for each movement segment. Contrary to this in Experiment 2, the Phase and the Duration-Relationship groups performed movements that either were entirely accelerating or decelerating, that is, little change in acceleration was required within a movement. Also, the phase transfer test was a constantly accelerating movement. After calculating the Duration group's average segment times it appears that this constantly accelerating pattern was very similar to how the duration movements were performed. The Duration group's average segment times (for the last two blocks of acquisition) adopted an approximate ratio of 1.5 : 1 : 1. This indicates that the self-imposed phasing of the Duration group was very similar to the requirements of the phase transfer test. (The transfer movement required an approximate ratio of 1.5 : 1.2 : 1). This similarity between self-imposed phasing and the phasing of the phase transfer task is perhaps the most plausible explanation as to why there were no transfer differences between the three training groups.

General Discussion

Together, Experiments 1 and 2 produce an interesting pattern of findings. The Duration/Phase group differences found by Langley and Zelaznik have been replicated in Experiment 1 and then eliminated in Experiment 2. Thus, some constraints to the generalizability of the effect have emerged. It appears that characteristics of the phase movements that subjects practice and transfer to, are important for Phase and Duration group differences to become evident. As well, some evidence has been presented to suggest that the constraint that limits the effect may be related to the kinematics of the movements on which subjects train.

Langley and Zelaznik suggested that all subjects are learning a time estimation skill since they are able to generate new durations (Povel, 1981; Wing & Kristofferson, 1973). More specifically, Phase-trained groups develop an ability to estimate segment time relationships since new sequential movements are accurately and consistently generated by these groups. Perhaps Phase-trained subjects are developing the ability to estimate segment acceleration relationships. The present experiments provide no direct empirical evidence to support this hypothesis but some indirect evidence exists, and in addition, other studies (Fowler & Turvey, 1978; Marteniuk & Romanow, 1983) have demonstrated the importance of acceleration in movement control.

An interesting finding from Experiment 1, which was found also by Langley and Zelaznik was that in the phase transfer all three groups were equally consistent and accurate on the first phase of the movement. It was only on phases two and three that group differences emerged. All three groups had practiced accelerating from the start position and this is reflected in the absence of group differences on the first segment. But, for phases two and three, the Duration group performed poorly because they had not practiced the variable accelerations characteristic of phase movements. Thus, while all three groups had learned to control the acceleration of their movement on phase one, only the Phase groups learned to control their movement accelerations for phases two and three.

Other researchers have demonstrated the importance of learning to control acceleration. Marteniuk and Romanow (1983) provided evidence that while learning to reproduce a complex arm movement pattern, subjects shifted from using displacement information early in learning to using velocity and perhaps acceleration information later in learning. This supported Fuchs' (1962) progression hypothesis and also Fowler and Turvey's (1978) theory that motor learning is a process characterized by the progressive adoption of higher sources of information for the organization of movement (Fitts, Bahrick, Noble & Briggs, 1961).

Several studies have been conducted that have examined the relative importance of MT and velocity in movements. These studies measured attention demands, accuracy and DT as a function of simple timing movements performed at different velocities. Newell and Hoshizaki (1980) have shown that when initiating movements, attention is demanded by average movement velocity, not MT. Newell et al., (1979) have also shown that velocity affects both the latency and accuracy of movement, indicating that average velocity is crucial in programing movements. Further, Falkenberg and Newell (1980) found that velocity and initiation time showed a high inverse relationship. They proposed that average velocity may be the prime kinematic parameter in determining movement initiation time. But, these researchers neglected to point out that associated with the larger velocities were greater accelerations. Thus, their findings could be extended to acceleration. If acceleration is as important as average velocity in programming movement, it would follow that learning to control acceleration is critical in the skillful performance of timed sequential movements.

To empirically investigate the constraint that variable acceleration may have on the effectiveness of training on an essential variable, a follow-up experiment that adopts the same training procedure as Experiments 1 and 2 is currently planned. Three groups will be compared in this experiment. The first group will be a Variable Phase group, which will practice two movements with segments of differing accelerations. The second group will be a Phase group which will practice two movements with constantly accelerating segments. The final group will be a Duration-trained group. All three groups will transfer to three different movements. The first test will consist of a constant accelerating phase movement, the second test will include a movement with differing accelerations and the third test will be a Duration test. If learning to control movement acceleration is important for Phase-trained subjects, then the Variable acceleration group should demonstrate superior transfer at a variable accelerating movement. Also, there will be no expected group differences on the other two transfer tests.

The phase transfer differences first found by Langley and Zelaznik (1984) and replicated in Experiment 1, were eliminated in Experiment 2. Movement kinematics appear to be the constraint that is responsible for eliminating the phase transfer group differences. However, despite constraints to the effect, training on an invariant movement feature (phasing) appears to be the most effective way to facilitate phase transfer performance.

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Table 1. Acquisition and transfer time requirements (in milliseconds) for movements in Experiment 1.

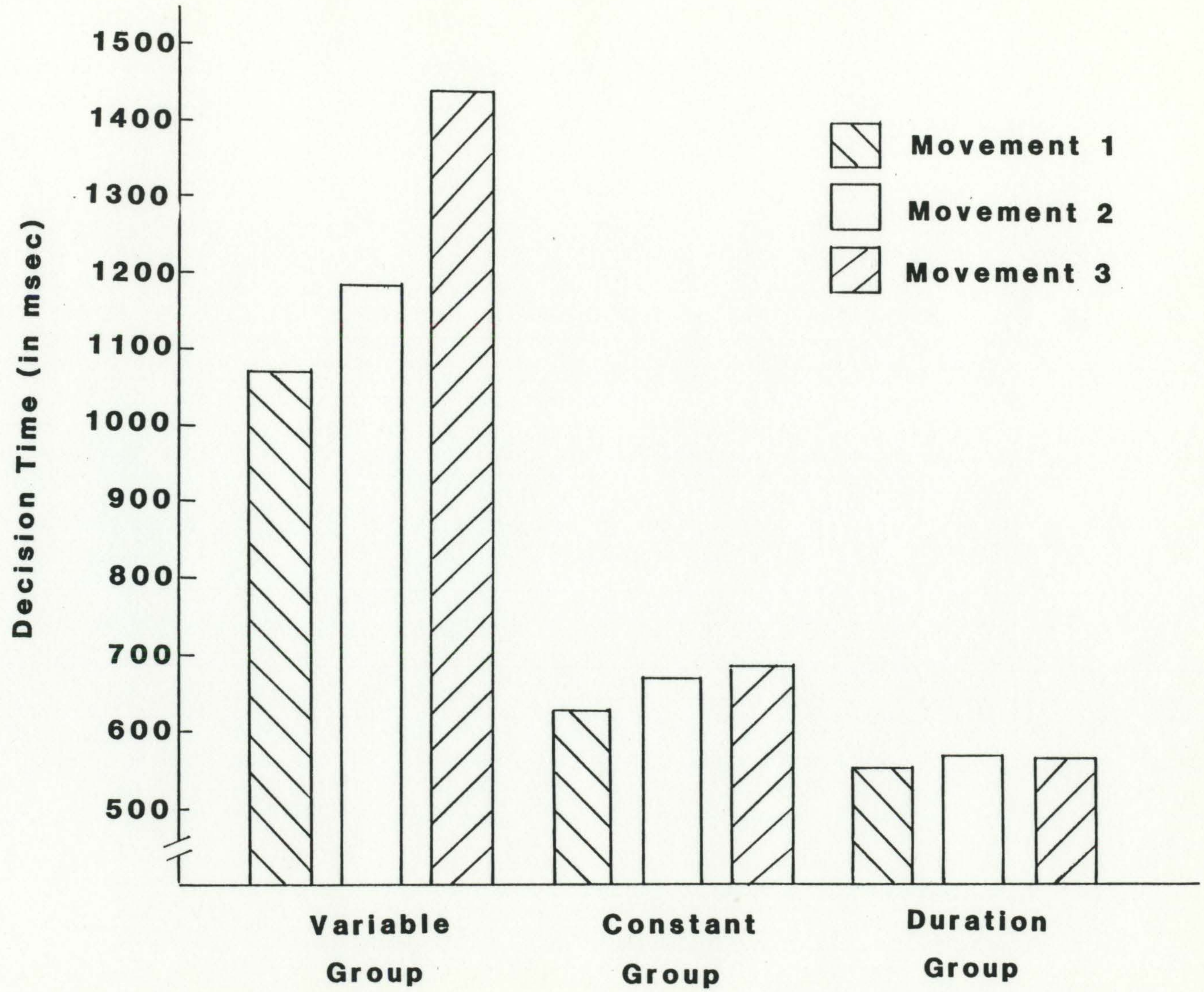
	Acquisition
Constant Phase Group	Movement 1 = 150 - 150 - 150 Movement 2 = 200 - 200 - 200 Movement 3 = 250 - 250 - 250
Variable Phase Group	Movement 1 = 150 - 200 - 250 Movement 2 = 200 - 250 - 150 Movement 3 = 250 - 150 - 200
Duration Group	Movement 1 = 450 Movement 2 = 600 Movement 3 = 750

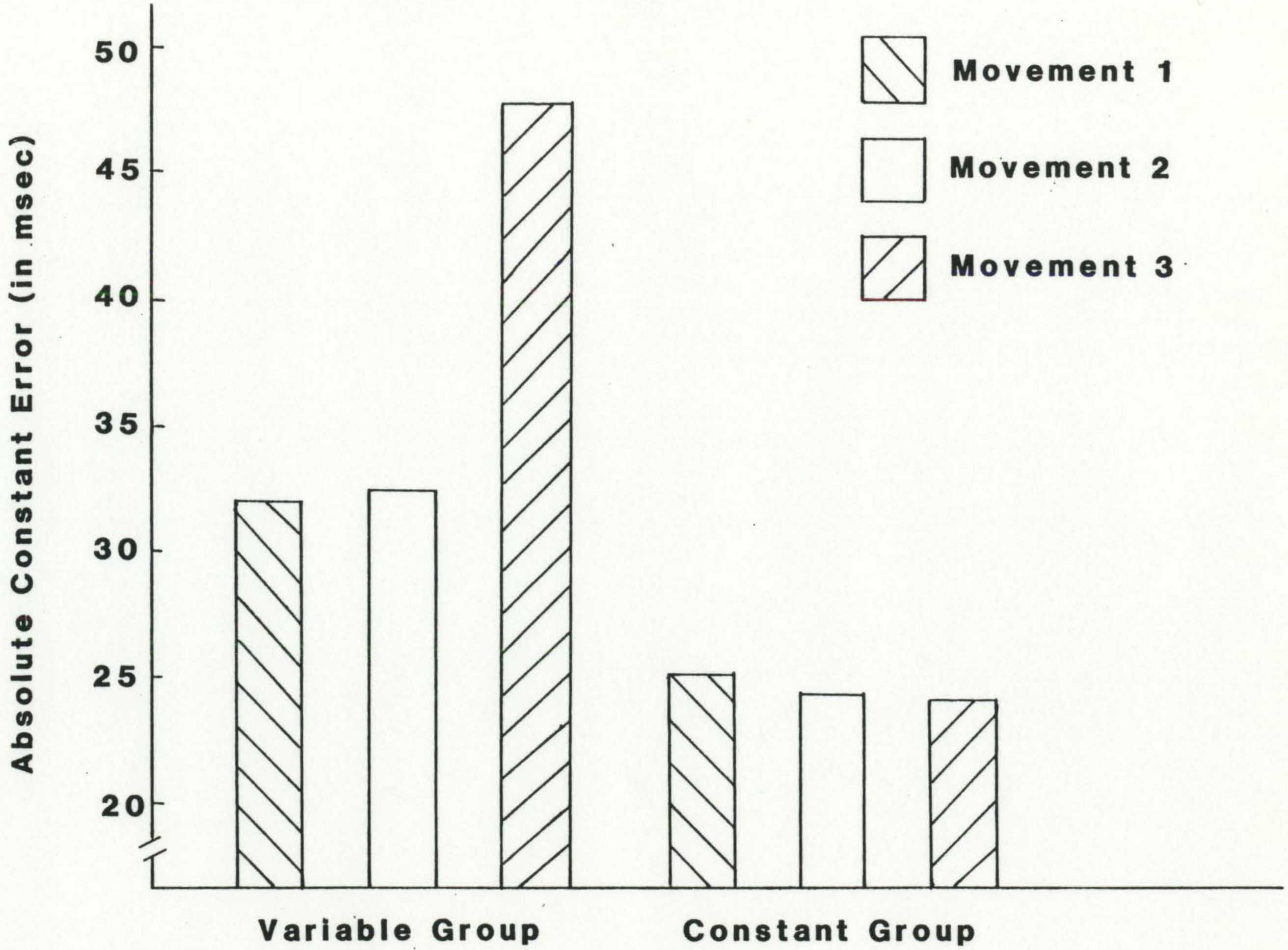
	Transfer
Constant phase test	215 - 215 - 215
Variable phase test	190 - 230 - 160
Duration test	675

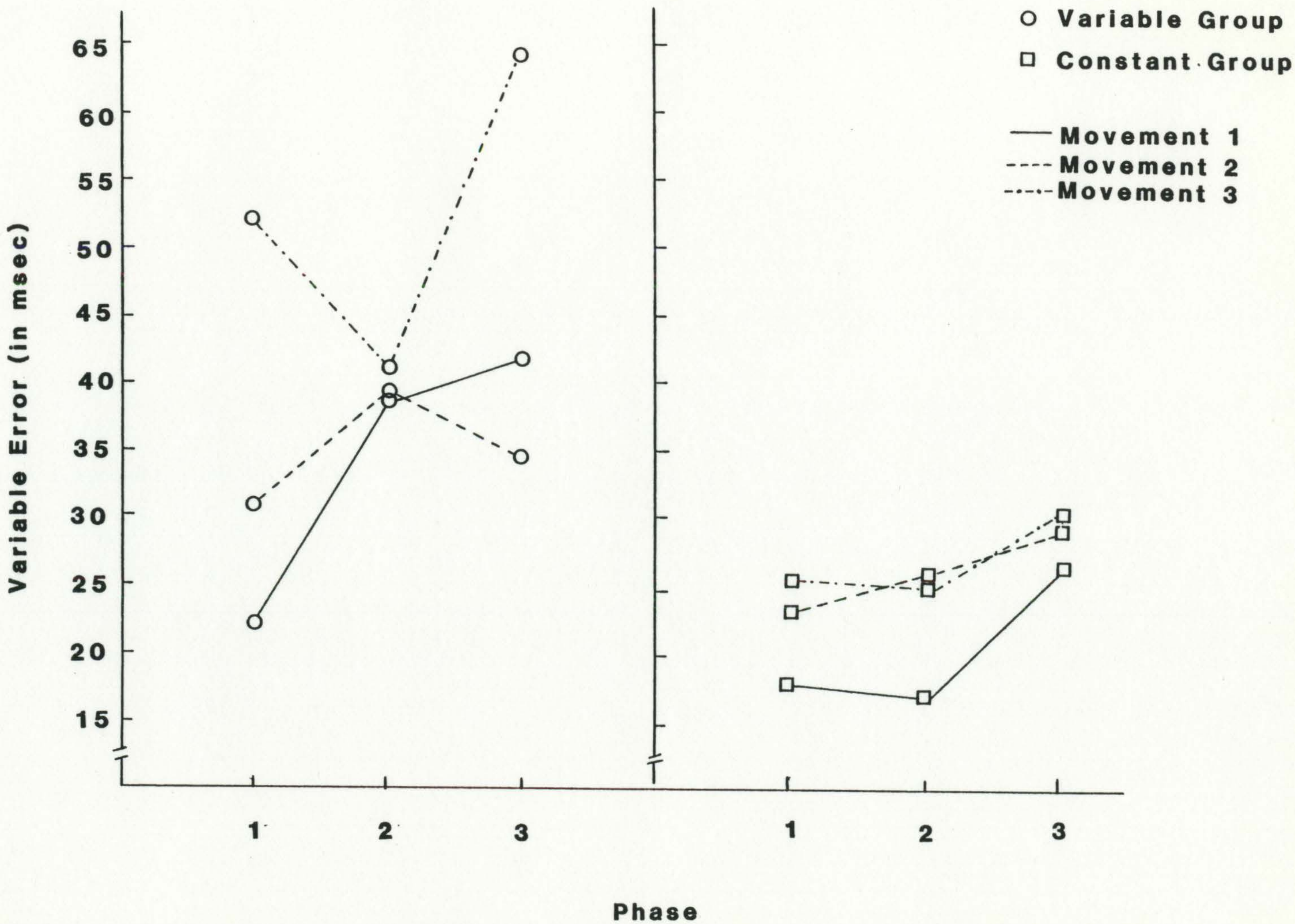
Table 2. Acquisition and transfer time requirements (in milliseconds) for movements in Experiment 2.

	Acquisition
Phase Group	Movement 1 = 180 - 220 - 270 Movement 2 = 230 - 190 - 140
Duration Group	Movement 1 = 670 Movement 2 = 560
Duration-Relationship Group	Movement 1 = 670 (decelerating) Movement 2 = 560 (accelerating)
	Transfer
Phase test	250 - 200 - 160
Duration test	585

Figure Captions


Decision Time (in msec)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
Movement 1
Movement 2
Movement 3
Variable Group
Constant Group
Duration Group


Absolute Constant Error (in msec)
50
45
40
35
30
25
20
Movement 1
Movement 2
Movement 3
Variable Group
Constant Group



Variable Group
Constant Group
Movement 1
Movement 2
Movement 3
Variable Error (in msec)
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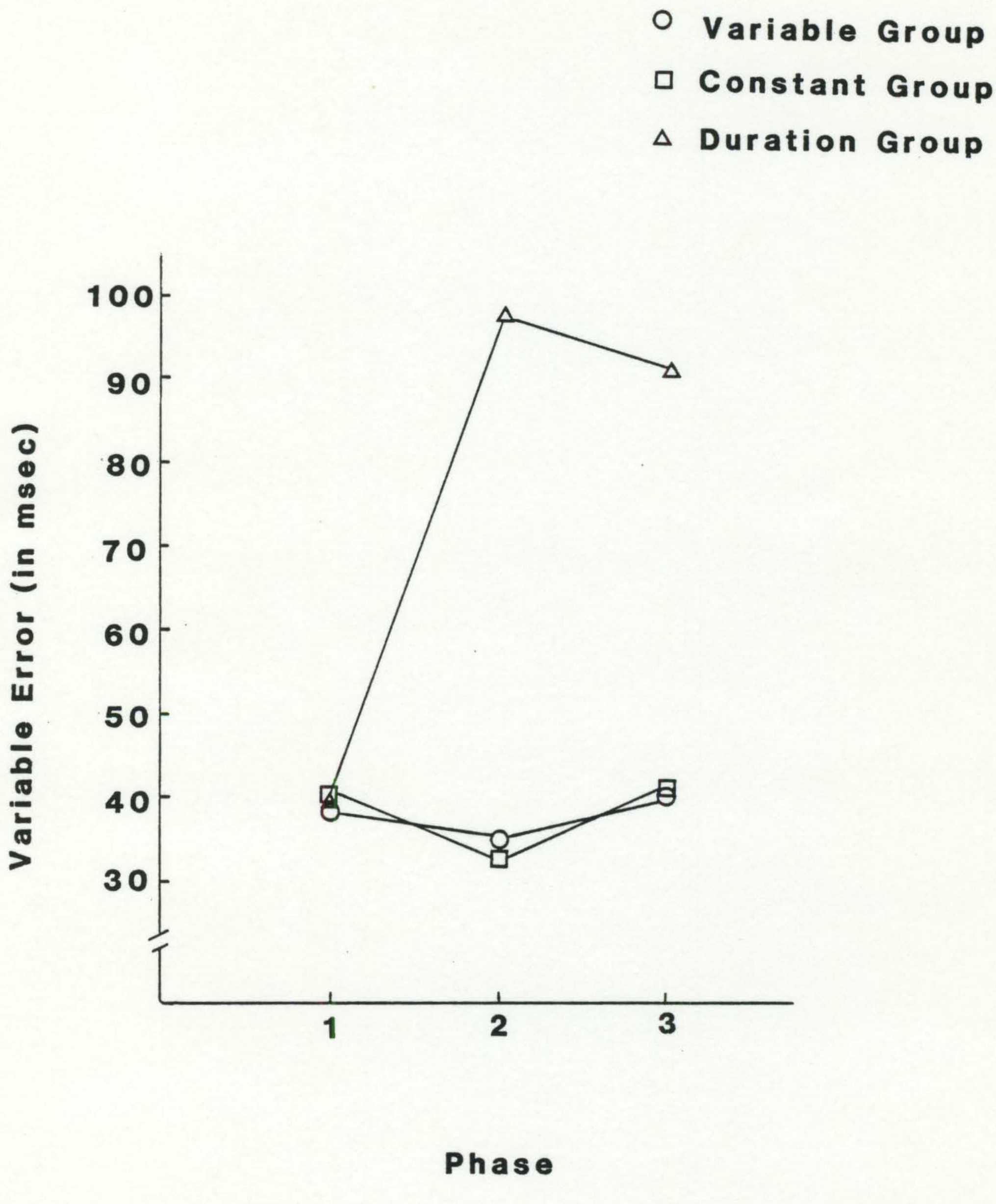
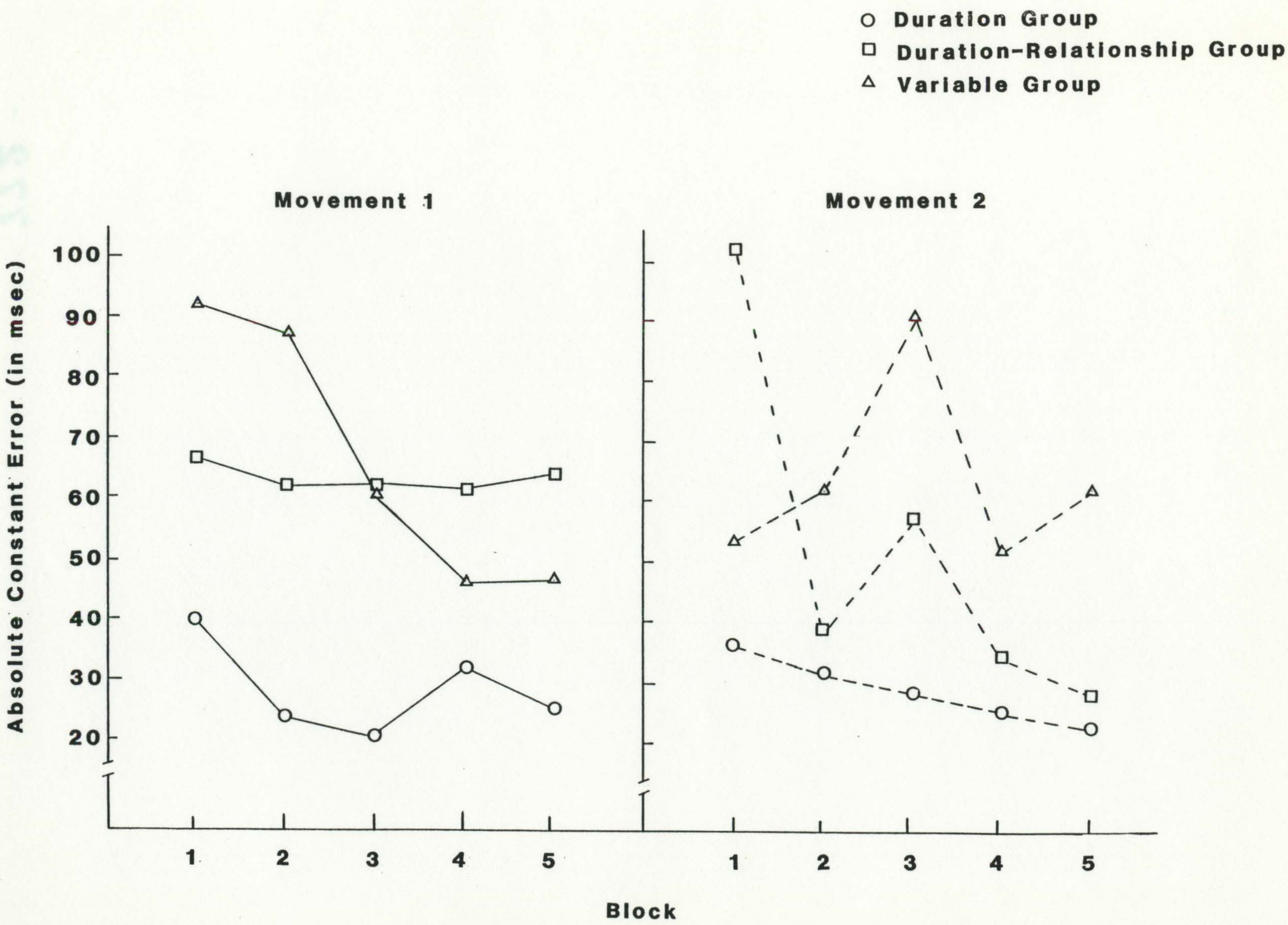
55
50
45
40
35
30
25
20
15
1
2
3
1
2
3
Phase



○ Variable Group
□ Constant Group
△ Duration Group
100
90
80
70
60
50
40
30
Variable Error (in msec)
1
2
3
Phase



Duration Group
Duration-Relationship Group
Variable Group
Movement 1
Movement 2
Absolute Constant Error (in msec)
100
90
80
70
60
50
40
30
20
1
2
3
4
5
1
2
3
4
5
Block

APPENDICES

APPENDIX A

ANOVA Tables

TABLE 3

Acquisition DT ANOVA for Experiment 1

Source	SS	df	F
Group	47337862.000	2	9.766 *
Error	79979380.300	33	
Movement	1822042.410	2	6.108 *
Grp x Mvt	2382736.220	4	3.994
Error	9843790.330	66	
Block	541476.657	4	2.627 *
Grp x Blk	682206.844	8	1.655
Error	6802930.570	132	
Mvt x Blk	363405.000	8	.864
Grp x Mvt x Blk	232834.500	16	
Error	13879201.100	264	
Total	163867866.000	539	

TABLE 4

Acquisition Phase Groups |CE| ANOVA for Experiment 1

Source	SS	df	F
Group	49613.331	1	14.002 *
Error	77951.376	22	
Block	12988.340	4	6.133 *
Grp x Blk	2570.253	4	1.214
Error	46587.586	88	
Movement	13446.487	2	4.894 *
Grp x Mvt	14773.269	2	5.377 *
Error	60449.001	44	
Blk x Mvt	5369.531	8	1.315
Grp x Blk x Mvt	3703.120	8	.907
Error	89866.361	176	
Phase	2724.864	2	.583
Grp x Pha	12865.403	2	2.753
Error	102802.623	44	
Blk x Pha	3693.460	8	1.194
Grp x Blk x Pha	2378.735	8	.769
Error	68028.018	176	
Mvt x Pha	9143.580	4	1.787
Grp x Mvt x Pha	2855.930	4	.558
Error	112544.796	88	
Blk x Mvt x Pha	8361.486	16	1.113
Grp x Blk x Mvt x Pha	10069.878	16	1.340
Error	165333.239	352	
Total	878120.667	1079	

TABLE 5

Acquisition Phase Groups VE ANOVA for Experiment 1

Source	SS	df	F
Group	64094.815	1	26.926 *
Error	52369.747	22	
Block	16354.396	4	8.384 *
Grp x Blk	1858.490	4	.953
Error	42917.160	88	
Movement	30245.515	2	15.562 *
Grp x Mvt	13071.123	2	6.725 *
Error	42757.676	44	
Blk x Mvt	4402.503	8	1.263
Grp x Blk x Mvt	3346.766	8	.960
Error	76711.744	176	
Phase	15262.425	2	8.333 *
Grp x Pha	1015.557	2	.554
Error	40295.798	44	
Blk x Pha	3293.093	8	1.282
Grp x Blk x Pha	1819.499	8	.708
Error	56529.625	176	
Mvt x Pha	10311.952	4	3.584 *
Grp x Mvt x Pha	8427.120	4	2.929 *
Error	63307.145	88	
Blk x Mvt x Pha	2720.892	16	.454
Grp x Blk x Mvt x Pha	5021.295	16	.838
Error	131784.940	352	
Total	687919.276	1079	

TABLE 6

Acquisition Duration Group |CE| ANOVA for Experiment 1

Source	SS	df	F
Blocks/Subjects	6467.711	11	
Block	17851.522	4	11.154 *
Error	17604.345	44	
Movement	1036.411	2	.855
Error	13331.189	22	
Blk x Mvt	1279.478	8	.311
Error	45234.255	88	
Total	102804.911	179	

TABLE 7

Acquisition Duration Group VE ANOVA for Experiment 1

Source	SS	df	F
Blocks/Subjects	17731.217	11	
Blocks	35582.521	4	20.331 *
Error	19251.480	44	
Movement	10082.099	2	6.692 *
Error	16572.034	22	
Blk x Mvt	1876.012	8	.404
Error	51093.186	88	
Total	152188.549	179	

TABLE 8

Variable Movement |CE| ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	267147.667	2	13.504 *
Error	326410.442	33	
Phase	1784.762	2	.248
Grp x Pha	28354.529	4	1.970
Error	237445.633	66	
Total	861143.043	107	

TABLE 9

Variable Movement VE ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	33223.414	2	15.799 *
Error	34697.593	33	
Phase	7369.139	2	4.607 *
Grp x Pha	16984.704	4	5.309 *
Error	52788.004	66	
Total	145062.854	107	

TABLE 10

Variable Movement DT ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	7402626.570	2	3.939 *
Error	31012484.200	33	
Total	38415110.800	35	

TABLE 11

Constant Movement |CE| ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	126256.782	2	7.464 *
Error	279095.304	33	
Phase	1296.094	2	.344
Grp x Pha	1244.654	4	.165
Error	124414.632	66	
Total	532307.566	107	

TABLE 12

Constant Movement VE ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	42606.874	2	3.892 *
Error	180634.306	33	
Phase	5922.907	2	.744
Grp x Pha	11852.272	4	.744
Error	262814.261	66	
Total	503830.621	107	

TABLE 13

Constant Movement DT ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	2870338.760	2	2.897
Error	16347550.200	33	
Total	19217889.000	35	

TABLE 14

Duration Movement |CE| ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	555.882	2	.021
Error	440403.047	33	
Total	440958.929	35	

TABLE 15

Duration Movement VE ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	16489.782	2	5.006 *
Error	54348.406	33	
Total	70838.187	35	

TABLE 16

Duration Movement DT ANOVA - Transfer for Experiment 1

Source	SS	df	F
Group	1140812.700	2	1.1888
Error	15840358.300	33	
Total	16981171.000	35	

TABLE 17

Acquisition DT ANOVA for Experiment 2

Source	SS	df	F
Group	918351.657	2	.307
Error	493777360.800	33	
Movement	189612.563	1	1.717
Grp x Mvt	182856.094	2	.828
Error	3644045.420	33	
Block	551719.594	4	4.172 *
Grp x Blk	280440.563	8	1.060
Error	4363767.590	132	
Mvt x Blk	63069.188	4	.577
Grp x Mvt x Blk	180808.875	8	.828
Error	3604211.700	132	
Total	63356244.000	359	

TABLE 18

Acquisition Phase Group |CE| ANOVA for Experiment 2

Source	SS	df	F
Blocks/Subjects	35385.764	11	
Movement	346.136	1	.094
Error	40675.832	11	
Block	18429.183	4	10.699 *
Error	19001.417	44	
Mvt x Blk	1453.239	4	.386
Error	41457.627	44	
Phase	5555.938	2	2.782
Error	21968.462	22	
Mvt x Pha	1758.539	2	.471
Error	41035.195	22	
Blk x Pha	2537.950	8	.484
Error	57679.650	88	
Mvt x Blk x Pha	1225.961	8	.236
Error	57058.971	88	
Total	345569.863	359	

TABLE 19

Acquisition Phase Group VE ANOVA for Experiment 2

Source	SS	df	F
Blocks/Subjects	19894.608	11	
Movement	442.226	1	.348
Error	13990.341	11	
Block	29878.678	4	12.927 *
Error	25423.987	44	
Mvt x Blk	2389.621	4	.807
Error	32577.977	44	
Phase	5984.317	2	2.182
Error	30165.350	22	
Mvt x Pha	18562.549	2	6.353 *
Error	32140.184	22	
Blk x Pha	4648.572	8	1.251
Error	40863.759	88	
Mvt x Blk x Pha	3618.063	8	.837
Error	47532.542	88	
Total	308112.775	359	

TABLE 20

Acquisition Duration Group |CE| ANOVA for Experiment 2

Source	SS	df	F
Group	90127.239	2	16.858 *
Error	88213.783	33	
Movement	1529.343	1	.591
Grp x Mvt	2499.706	2	.483
Error	85410.552	33	
Block	27118.738	4	4.062 *
Grp x Blk	14344.178	8	1.074
Error	220329.884	132	
Mvt x Blk	6509.462	4	.870
Grp x Mvt x Blk	33534.989	8	2.240 *
Error	247043.948	132	
Total	816661.821	359	

TABLE 21

Acquisition Duration Group VE ANOVA for Experiment 2

Source	SS	df	F
Group	48054.066	2	8.722 *
Error	90910.407	33	
Movement	3654.470	1	1.701
Grp x Mvt	5457.422	2	1.270
Error	70898.610	33	
Block	89211.574	4	16.389 *
Grp x Blk	19275.376	8	1.771
Error	179628.046	132	
Mvt x Blk	1128.404	4	.170
Grp x Mvt x Blk	13289.079	8	.999
Error	219439.518	132	
Total	740946.973	359	

TABLE 22

Variable Movement |CE| ANOVA - Transfer for Experiment 2

Source	SS	df	F
Group	188.222	2	.162
Error	19154.694	33	
Phase	1181.555	2	1.598
Grp x Pha	2042.722	4	1.381
Error	24397.722	66	
Total	46964.916	107	

TABLE 23

Variable Movement VE ANOVA - Transfer for Experiment 2

Source	SS	df	F
Group	1055.352	2	.614
Error	28382.056	33	
Phase	2853.018	2	3.477 *
Grp x Pha	2386.537	4	1.454
Error	27081.111	66	
Total	61758.074	107	

TABLE 24

Variable Movement DT ANOVA - Transfer for Experiment 2

Source	SS	df	F
Group	26354.045	2	.058
Error	7490547.150	33	
Total	7516901.200	35	

TABLE 25

Duration Movement |CE| ANOVA - Transfer for Experiment 2

Source	SS	df	F
Group	37860.667	2	9.683 *
Error	64512.333	33	
Total	102373.000	35	

TABLE 26

Duration Movement VE ANOVA - Transfer for Experiment 2

Source	SS	df	F
Group	704.667	2	.548
Error	21323.083	33	
Total	21936.750	35	

TABLE 27

Duration Movement DT ANOVA - Transfer for Experiment 2

Source	SS	df	F
Group	6376.383	2	.024
Error	4389643.900	33	
Total	4396020.290	35	

APPENDIX B

Cell Means

TABLE 28

Acquisition DT Cell Means for Experiment 1

Group	Movement	Block	DT
Variable	1	1	1094
Variable	1	2	1065
Variable	1	3	1084
Variable	1	4	1093
Variable	1	5	1106
Variable	2	1	1338
Variable	2	2	1132
Variable	2	3	1182
Variable	2	4	1134
Variable	2	5	1184
Variable	3	1	1675
Variable	3	2	1372
Variable	3	3	1448
Variable	3	4	1395
Variable	3	5	1345
Constant	1	1	593
Constant	1	2	616
Constant	1	3	615
Constant	1	4	668
Constant	1	5	677
Constant	2	1	642
Constant	2	2	704
Constant	2	3	664
Constant	2	4	700
Constant	2	5	733
Constant	3	1	686
Constant	3	2	710
Constant	3	3	724
Constant	3	4	650
Constant	3	5	681
Duration	1	1	622
Duration	1	2	556
Duration	1	3	546
Duration	1	4	542
Duration	1	5	556
Duration	2	1	675
Duration	2	2	570
Duration	2	3	545
Duration	2	4	555
Duration	2	5	532
Duration	3	1	695
Duration	3	2	575
Duration	3	3	545
Duration	3	4	521
Duration	3	5	531

TABLE 29

Acquisition Phase Groups Cell Means for Experiment 1

Group	Block	Movement	Phase	|CE|	VE
Variable	1	1	1	26.33	30.17
Variable	1	1	2	38.83	47.50
Variable	1	1	3	44.33	51.92
Variable	1	2	1	40.80	32.00
Variable	1	2	2	34.58	41.25
Variable	1	2	3	38.75	45.33
Variable	1	3	1	24.25	61.42
Variable	1	3	2	74.50	45.75
Variable	1	3	3	54.58	85.92
Variable	2	1	1	28.25	23.92
Variable	2	1	2	46.25	43.08
Variable	2	1	3	46.08	46.25
Variable	2	2	1	18.92	34.58
Variable	2	2	2	29.67	35.92
Variable	2	2	3	37.58	35.83
Variable	2	3	1	41.25	52.58
Variable	2	3	2	64.08	40.00
Variable	2	3	3	46.92	52.50
Variable	3	1	1	27.08	18.75
Variable	3	1	2	25.75	30.75
Variable	3	1	3	44.67	35.33
Variable	3	2	1	31.33	25.83
Variable	3	2	2	37.58	35.83
Variable	3	2	3	42.67	33.75
Variable	3	3	1	50.25	57.17
Variable	3	3	2	51.08	42.33
Variable	3	3	3	48.17	63.83
Variable	4	1	1	24.92	20.58
Variable	4	1	2	24.83	36.17
Variable	4	1	3	29.00	33.83
Variable	4	2	1	28.25	29.00
Variable	4	2	2	43.33	44.17
Variable	4	2	3	36.92	32.08
Variable	4	3	1	42.25	50.00
Variable	4	3	2	52.50	42.75
Variable	4	3	3	57.83	69.92
Variable	5	1	1	26.67	17.25
Variable	5	1	2	21.17	33.33
Variable	5	1	3	33.83	37.42
Variable	5	2	1	25.00	30.08
Variable	5	2	2	25.33	36.17
Variable	5	2	3	34.08	27.67
Variable	5	3	1	37.83	42.33
Variable	5	3	2	49.42	32.17
Variable	5	3	3	30.50	43.58

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Group	Block	Movement	Phase	|CE|	VE
Constant	1	1	1	45.33	18.75
Constant	1	1	2	16.08	23.33
Constant	1	1	3	42.75	45.25
Constant	1	2	1	26.83	27.08
Constant	1	2	2	39.58	36.92
Constant	1	2	3	32.83	30.00
Constant	1	3	1	25.42	26.08
Constant	1	3	2	27.08	32.25
Constant	1	3	3	21.42	33.17
Constant	2	1	1	33.83	19.83
Constant	2	1	2	18.33	21.50
Constant	2	1	3	35.17	29.08
Constant	2	2	1	23.92	18.75
Constant	2	2	2	27.67	24.17
Constant	2	2	3	25.67	26.83
Constant	2	3	1	32.50	26.00
Constant	2	3	2	27.75	22.50
Constant	2	3	3	25.92	31.67
Constant	3	1	1	26.17	15.25
Constant	3	1	2	16.17	15.92
Constant	3	1	3	29.58	21.33
Constant	3	2	1	15.92	18.58
Constant	3	2	2	19.42	25.50
Constant	3	2	3	20.83	28.92
Constant	3	3	1	32.33	25.08
Constant	3	3	2	22.67	26.58
Constant	3	3	3	19.83	29.33
Constant	4	1	1	23.92	18.92
Constant	4	1	2	15.25	12.58
Constant	4	1	3	18.75	21.25
Constant	4	2	1	26.50	22.92
Constant	4	2	2	14.33	24.00
Constant	4	2	3	24.50	34.92
Constant	4	3	1	23.75	24.33
Constant	4	3	2	15.42	23.92
Constant	4	3	3	22.25	29.67
Constant	5	1	1	23.50	16.42
Constant	5	1	2	12.83	14.83
Constant	5	1	3	18.33	16.33
Constant	5	2	1	29.92	31.75
Constant	5	2	2	21.50	22.25
Constant	5	2	3	16.17	22.17
Constant	5	3	1	23.00	24.00
Constant	5	3	2	24.50	23.50
Constant	5	3	3	22.08	32.08

TABLE 30

Acquisition Duration Group Cell Means for Experiment 1

Block	Movement	|CE|	VE
1	1	35.83	70.58
1	2	42.75	64.58
1	3	47.75	86.17
2	1	21.17	32.08
2	2	16.75	38.50
2	3	19.83	52.33
3	1	15.33	30.83
3	2	19.17	40.58
3	3	23.17	55.00
4	1	16.00	28.48
4	2	20.42	37.58
4	3	16.75	40.25
5	1	11.33	28.67
5	2	10.50	38.25
5	3	21.08	46.75

TABLE 31

Phase Transfer (|CE| & VE) Cell Means for Experiment 1

Group	Type of Transfer	Phase	|CE|	VE
Variable	variable	1	52.76	37.86
Variable	variable	2	31.08	35.72
Variable	variable	3	33.33	40.04
Constant	variable	1	56.24	38.88
Constant	variable	2	41.48	33.77
Constant	variable	3	48.30	40.15
Duration	variable	1	111.47	38.69
Duration	variable	2	167.60	96.69
Duration	variable	3	168.08	89.44
Variable	constant	1	56.23	62.78
Variable	constant	2	39.18	29.46
Variable	constant	3	46.46	28.98
Constant	constant	1	38.28	26.74
Constant	constant	2	30.20	23.40
Constant	constant	3	37.34	55.48
Duration	constant	1	115.07	84.98
Duration	constant	2	115.25	71.32
Duration	constant	3	108.88	82.80

TABLE 32

Phase Transfer (DT) Cell Means for Experiment 1

Group	Type of Transfer	DT
Variable	variable	2193.50
Constant	variable	1206.50
Duration	variable	1258.75
Variable	constant	1757.58
Constant	constant	1112.67
Duration	constant	1218.67

TABLE 33

Duration Transfer (|CE|, VE & DT) Means for Experiment 1

Group	|CE|	VE	DT
Variable	129.56	81.26	1468.67
Constant	121.34	60.90	1056.50
Duration	129.79	112.92	1139.33

TABLE 34

Acquisition DT Cell Means for Experiment 2

Group	Movement	Block	DT
Variable Phase	1	1	790.92
Variable Phase	1	2	717.67
Variable Phase	1	3	683.83
Variable Phase	1	4	647.17
Variable Phase	1	5	671.92
Variable Phase	2	1	896.08
Variable Phase	2	2	751.92
Variable Phase	2	3	828.00
Variable Phase	2	4	726.50
Variable Phase	2	5	851.33
Duration	1	1	713.25
Duration	1	2	668.50
Duration	1	3	646.00
Duration	1	4	647.00
Duration	1	5	652.25
Duration	2	1	693.67
Duration	2	2	740.42
Duration	2	3	683.50
Duration	2	4	694.83
Duration	2	5	667.50
Duration-Relation	1	1	952.50
Duration-Relation	1	2	776.00
Duration-Relation	1	3	745.33
Duration-Relation	1	4	776.83
Duration-Relation	1	5	781.08
Duration-Relation	2	1	878.00
Duration-Relation	2	2	902.50
Duration-Relation	2	3	753.83
Duration-Relation	2	4	766.50
Duration-Relation	2	5	741.17

TABLE 35

Acquisition Phase Group Cell Means for Experiment 2

Movement	Block	Phase	|CE|	VE
1	1	1	48.00	41.33
1	1	2	51.17	47.58
1	1	3	54.58	66.58
1	2	1	38.67	32.58
1	2	2	40.92	38.67
1	2	3	32.83	49.25
1	3	1	25.08	21.00
1	3	2	22.42	29.25
1	3	3	33.42	41.50
1	4	1	22.67	22.00
1	4	2	30.42	29.83
1	4	3	36.08	36.50
1	5	1	23.58	26.92
1	5	2	30.08	32.33
1	5	3	31.92	35.67
2	1	1	33.75	73.08
2	1	2	55.58	34.08
2	1	3	53.17	57.25
2	2	1	32.17	37.67
2	2	2	43.58	19.83
2	2	3	31.25	33.08
2	3	1	24.25	51.00
2	3	2	40.25	20.33
2	3	3	36.58	18.92
2	4	1	30.33	35.00
2	4	2	36.08	25.83
2	4	3	34.92	35.83
2	5	1	23.82	37.33
2	5	2	38.92	21.58
2	5	3	36.58	17.17

TABLE 36

Acquisition Duration Groups Cell Means for Experiment 1

Group	Movement	Block	|CE|	VE
Duration	1	1	40.25	66.25
Duration	1	2	23.42	54.42
Duration	1	3	20.00	46.67
Duration	1	4	31.17	51.42
Duration	1	5	24.92	53.75
Duration	2	1	35.52	69.92
Duration	2	2	31.92	48.25
Duration	2	3	29.17	36.83
Duration	2	4	25.33	45.00
Duration	2	5	23.00	39.08
Duration-Relation	1	1	66.50	113.92
Duration-Relation	1	2	62.75	64.42
Duration-Relation	1	3	62.42	73.25
Duration-Relation	1	4	60.92	68.92
Duration-Relation	1	5	64.33	56.25
Duration-Relation	2	1	100.75	75.83
Duration-Relation	2	2	39.33	59.17
Duration-Relation	2	3	57.58	58.00
Duration-Relation	2	4	34.67	48.00
Duration-Relation	2	5	27.75	57.00
Variable Phase	1	1	92.42	112.83
Variable Phase	1	2	87.00	83.42
Variable Phase	1	3	59.83	61.92
Variable Phase	1	4	45.08	53.08
Variable Phase	1	5	46.25	67.17
Variable Phase	2	1	53.83	113.67
Variable Phase	2	2	62.08	60.50
Variable Phase	2	3	90.25	85.08
Variable Phase	2	4	51.25	65.17
Variable Phase	2	5	63.08	60.58

TABLE 37

Variable Transfer Cell Means (|CE| & VE) for Experiment 2

Group	Phase	|CE|	VE
Variable Phase	1	27.33	44.17
Variable Phase	2	39.67	27.17
Variable Phase	3	34.25	29.83
Duration	1	26.17	26.92
Duration	2	34.75	20.33
Duration	3	33.00	37.00
Duration-Relation	1	39.75	35.67
Duration-Relation	2	39.00	21.50
Duration-Relation	3	24.33	22.08

TABLE 38

Variable Transfer Means (DT) for Experiment 2

Group	DT
Variable Phase	780.92
Duration	755.25
Duration-Relation	821.00

TABLE 39

Duration Transfer Means for Experiment 2

Group	|CE|	VE	DT
Variable Phase	113.83	55.42	661.50
Duration	41.67	44.58	692.33
Duration-Relation	49.00	50.25	667.75