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SINGLE AIMING AND RECIPROCAL TASKS: A COMPARISON

University — Université
UNIVERSITY of ALBERTA

Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée
M.Sc.

Year this degree conferred — Année d'obtention de ce grade
1982

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Single Aiming and Reciprocal Tapping: A Comparison

by

Ian Humphreys

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF Master of Science

in

DEPARTMENT Physical Education

EDMONTON, ALBERTA

Fall, 1982

THE UNIVERSITY OF ALBERTA

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Single Aiming and Reciprocal Tasks:
A Comparison

submitted by Ian Humphreys
in partial fulfilment of the requirements for the degree of
Master of Science

R. B. Wilberg
Supervisor

Rick Alderman

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Date June 9th 1982

ABSTRACT

Two experiments were conducted in order to compare characteristics of single aiming and reciprocal rapid aiming tasks. It was hypothesized that the two movement classes, reciprocal and single aiming, differed in the demands they placed on attentional processes. The result of this proposed difference in attentional demand was thought to account for the observation that the performance of reciprocal tapping tasks was predicted by Fitts (1954) Law, while the performance of single rapid aiming movements was not. Conversely, performance of single aiming tasks was predicted by the Schmidt et al (1978, 1979) formulation which could not accomodate reciprocal tasks. Experiment One provided some evidence to support the theory that when subjects operated below the capacity of the motor processing system the performance characteristics of the aiming movements whether single or reciprocal may be predicted by the Schmidt et al formulation. When subjects operated beyond the capacity of the motor system then characteristics of the aiming response may be predicted by Fitts' Law. Experiment Two was an attempt to manipulate the demands placed on a subjects attention when performing a reciprocal movement aiming task. The object of the experiment was to demonstrate a move from situations predicted by the Schmidt formulations to situations predicted by Fitts Law as demands on attention in the reciprocal movement task increased. Due to methodological problems this experiment failed to provide useful data.

ACKNOWLEDGEMENTS

My sincere thanks and appreciation goes [illegible] Dr. R.B. Wilberg, for his patient help and advice during the course of my program and in the writing of this thesis. Even in his absence his presence could always be felt. My thanks also go to Dr. R. Alderman and Dr. J. Bishop for their insight during the defence of my thesis.

Most of all, I would like to take this opportunity to express my deepest love for my wife, Sally, who has worked for so long to support us both while this thesis was completed. No thanks could ever be enough.

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The earliest mathematical relationship between the speed and accuracy of movement was provided by Fitts (1954). Fitts demonstrated experimentally that movement time (MT) was a linear function of the index of difficulty (ID) which was defined in information terms as:

$$\log_2 2A/W$$

where A was the amplitude of movement and W the width of the aimed for target. This relationship, celebrated as Fitts' Law, accomodated data from numerous experimental sources (Knight & Dagnall, 1967; Fitts & Peterson, 1964; Fitts & Radford, 1966). Although attempts were made to improve upon Fitts' equation, none resulted in any significant change (Welford, 1966). Stated simply, Fitts proposed that if movements of average amplitude were speeded up then each movement could provide less information and, as a result, movement variability would be increased by a specified amount.

Crossman and Goodeve (Note 1) and later Keele (1968) put forward a theory to account for Fitts' findings. In this theory the authors proposed a system of movement control based on the continued monitoring of feedback information and the subsequent issuance of movement corrections. However, research aimed at examining movement patterns for evidence of corrections was equivocal. Annett, Golby and Kay (1958) and Brown and Slater-Hammel (1949) demonstrated the presence of movement corrections, while Langolf, Chaffin and Foulke (1976), in a microminiature task, failed to uncover evidence of within movement corrections. Furthermore, the theory of feedback control could not accomodate movements which were completed within a simple reaction time. Such rapid movements allowed insufficient time for processing of feedback information and the subsequent issuance of corrections based on this information (Hick, 1952; Welford, 1952; Schmidt, Zelaznick, Hawkins, Frank and Quinn, 1979).

Howarth and Beggs (1970) and Beggs and Howarth (1972) proposed a visually mediated intermittent feedback mechanism as the basis for the control of aimed movements. They proposed that the error on target was related to the velocity of limb movement during the terminal phases of the movement. Error on target was thought to be proportional to the distance from the target at which the last correction was made. However, the theory was equally unable to account for movements completed within one reaction time.

Schmidt et al (1978, 1979) proposed an alternate theory based on the observation that the motor system appears to be contaminated by noise, (within subject variability). They proposed that this variability was related to parameters of the movement i.e. amplitude and speed. Central to the theory was the notion that movements could be centrally organized by a motor program which, when executed, could complete a movement without the involvement of peripheral feedback.

The Schmidt theory related the variability in target accuracy, effective target width (W_e), to the within subject variability of velocity, at the end of acceleration. Schmidt reasoned that if movement velocity was directly proportional to the magnitude of the impulsive forces, then variability in movement velocity must also be proportional to the variability of the impulsive forces. Therefore, as movement velocity increased, variability in the magnitude of the impulsive force and the time over which the force was acting also increased. This resulted, according to Schmidt, in greater error in achieving the aimed for target.

The basic statement of the model is given by:

$$W_e \propto A/MT$$

This formulation seems to describe rapid movements (less than 200 msecs duration) but cannot account for slower movements of longer duration. The lack of a single formula which accomodated both rapid and slow aiming movements prompted Klapp (1975) to suggest that movements of long duration were under feedback mediated control, while rapid short duration movements required control by motor programs.

Much evidence favoring the central control of movement was based on the observation that responses to feedback information were often in excess of the duration of many movements (Lashley, 1951; Keele, 1968; Glencross, 1975, 1977; Keele & Posner, 1968). Lenneberg (1967) argued that the many hundreds of coordinated muscular movements required in the production of a relatively few seconds of speech could not be under feedback mediated control. Taub and Berman (1968) studied the performance of gross movements in rhesus monkeys following deafferentation of the monkey's limbs (surgical elimination of afferent feedback). Taub and Berman found that monkeys could use deafferented limbs in a reasonably coordinated manner following deafferentation. Laszlo (1967, 1968, 1969) duplicated the results of Taub and Berman in human subjects by employing ischemic nerve block techniques. However, doubts about the complete efficiency of such techniques (Glencross & Oldfield, 1975) cast doubt on the importance of such research.

While much evidence has been cited to favour centrally programmed control of movement, the importance of feedback information cannot be discounted. Smith (1962) reported that deafferented specimens could make only jerky uncoordinated movements in the absence of feedback information. Fine graded manipulative movements were not possible. Glencross (1975) believed that even centrally generated movements must be integrated with peripheral sensory information at some stage of execution.

In order to examine possible programmed features of movement Kelso Southard and Goodman (1979) employed a simultaneous two handed movement paradigm. They found that movement time was common to both hands (as measured by between hands correlation) while movement amplitude and height were independent. They postulated that movement time was a programmed feature of movements. Using a related procedure Schmidt et al (1979) demonstrated that only 1% of variability in movement endpoint (a measure of spatial accuracy) could be associated with incorrect program selection. However, high degrees of variability were related to selection of particular parameters. A high correlation between effective target width and the magnitude of the accelerative impulse supported the theory that impulse variability was a major determiner of W_e.

Schmidt et al proposed that movements could be programmed in advance and that certain parameters of the program specified the magnitude and duration of the accelerative impulse. Such a theory would predict that if a mass was added to a limb following the initiation of a programmed rapid movement that the limb would fall short of the aimed for target. This would be due to the inability of the system to modify the parameters of the program until the movement had been completed. Damaging evidence to this position was presented by Bizzi, Polit and Morasso (1976); Bizzi, Dev, Morasso and Polit (1978) and Polit and Bizzi (1979). Examining movement control in normal intact and deafferented monkeys they demonstrated that addition of mass to a limb following initiation of a movement did not alter the accuracy of the movement in either normal or deafferented specimens. Furthermore, displacement of the limb prior to the initiation of the movement did not affect the resultant accuracy of intended movement in deafferented specimens, even if the displacement carried the limb beyond the target.

It was subsequently proposed that the endpoint of the movement was achieved by the specification of a set of length and tension parameters in agonist and antagonist muscle groups. These defined an equilibrium point between agonist and antagonist muscles which correctly positioned the limb in relation to the target. This "mass-spring" view of movement control was first proposed by Bernstein (1967) and later by Crossman and Goodeve (1963). It can be interpreted as a system which displays von Bertallanfy's (1973) principle of equifinality.

While damaging to the Schmidt theory Bizzi et al (1976, 1978) and Polit and Bizzi (1979) viewed the mass-spring as the means of achieving end point location. They suggested that a number of processes, acting in parallel, are responsible for the overall performance of aiming movements. One such process, it was suggested, would be responsible for control of limb velocity. Falkenberg and Newell (1980) demonstrated that average velocity may be a programmed feature of movement. This gives rise to the possibility that the Schmidt et al theory may only speak to the control process underlying limb velocity.

The Fitts formulation was concerned with the outcome of performance and its relation to the parameters of the movement. The main emphasis was an examination of the outcome of behavior. The Schmidt theory, however, was concerned with identifying underlying control mechanisms of movement and as such was more process oriented. The two theories, while often taken as opposite views of the same problem, can be seen to be completely different in approach and application. The following experiments were designed to examine the fundamental differences between the Fitts (1954) and Schmidt et al (1978, 1979) formulations.

Examination of the reciprocal tapping tasks of Fitts and the single rapid aiming tasks of Schmidt et al resulted in the following differences being identified:

1. In the Fitts' task the independent variables were movement amplitude and target width, while movement time and error rate were dependent variables. In the Schmidt et al paradigm the independent variables were movement amplitude and movement time, while effective target width was the single dependent variable.
2. The reciprocal nature of the Fitts' task confounded errors on tap n with errors on tap n-1, and the impulse for stopping tap n-1 was the same as that for

starting tap n. Further, visual feedback was used in responses to an unknown degree and changed with the accuracy requirements of the task.

3. The Fitts' task required the subject to attend to two targets, whereas the Schmidt tasks required subjects to monitor only the movement endpoint. As such, the Fitts' task was bi-phasic in nature and the Schmidt tasks uni-phasic.

It is proposed that the variable application of the Fitts and Schmidt et al formulations may have been due to fundamental task differences which existed between the bi-phasic reciprocal tapping task and the uni-phasic single aiming movement. It is further proposed that such differences were attributeable to differential attentional demands of the tasks. Reciprocal tapping involved the monitoring of two targets separated by some distance, and thus required the switching of attention between targets. Single aiming, however, involved no peripheral monitoring and consequently all available capacity could be devoted to target acquisition.

The following experiment tested the null hypotheses that, no differences in the means of measured parameters of movement existed as a result of the nature of the uni-phasic and bi-phasic differences between single aiming and reciprocal tapping movements respectively, and, that no differences in the variability of the measured parameters of movements existed as a result of the previously described differences between single aiming and reciprocal tapping tasks.

EXPERIMENT I

An examination of the Fitts and Schmidt methodologies was conducted in order to determine which dependent variables might be used when comparing the two approaches. Appendix 1 (review of literature) gives a review of the Fitts and Schmidt formulations.

In the Schmidt experimentation the single dependent variable was effective target width (W_e). The theory of motor output variability was based, however, on a theoretical relationship between W_e and the magnitude and duration of the accelerative impulse producing the move. Schmidt proposed that variability in target accuracy at a given distance was a result of variability in the time and force production mechanisms in the accelerative phase of movement. The Schmidt methodology unfortunately did not assess either the impulse magnitude or the duration of the decelerative phase of movement. His results and interpretations were based almost completely upon those forces propelling the limb, and not those related to its deceleration. A full examination of the Schmidt methodology resulted in the identification of a number of alternate dependent variables. These were: duration of accelerative impulse and its associated variability, duration of decelerative impulse and its associated variability, magnitude of accelerative impulse and associated variability, magnitude of decelerative impulse and associated variability, and effective target width (W_e).

Examination of the Fitts methodology resulted in the addition of movement time to the list of dependent variables under consideration.

A question of fundamental importance in understanding movement control involves the relationship between initiation and execution stages of movement. Fitts and Peterson (1964) suggested that perceptual and motor processes could be considered as being independent of each other. Consequently the time required to initiate movement (reaction time minus stimulus processing time) was unrelated to the required accuracy of the movement. Movement time on the other hand, varies according to the required accuracy of movement. Crossman and Goodeve (Note 1) and Keele (1968) attributes this increase in movement time to an increase in the number of within movement corrections that could be required to achieve smaller targets.

The Crossman and Goodeve (Note 1) and Keele (1968) theories depended on the monitoring of sensory feedback. Schmidt supported the notion that whole movements could be organized or programmed in advance and executed without need for feedback information. Furthermore rapid single movements could be completed in times short enough (i.e. less than 200 msecs) to prevent the utilization of feedback information. More exacting movements, such as aiming movements requiring higher degrees of accuracy, could require a more precise program. Initiation time would therefore increase with the increased accuracy demands. Henry (1960) was able to demonstrate that initiation time did in fact vary in response to movement complexity. Further, Glencross (1972), and Norrie (1974) demonstrated that movements requiring a pause and reversal of direction on a definite target, in route to a final target require longer initiation times than simple forward movements. Reaction time was therefore added as the final variable of interest to be used in the comparison between single rapid aiming and reciprocal tapping movements. The former being considered to be programmed in advance and the latter dependent upon feedback information for error correction.

The eight dependent variables in the following experiment were: reaction time, duration and variability of accelerative impulse, duration and variability of decelerative impulse, magnitude and variability of accelerative impulse, magnitude and variability of decelerative impulse, distance moved prior to correction, i.e. a standard deviation specifying the target width (W_e), distance moved following correction, and total movement time.

In order to compare the Schmidt and Fitts' formulations the following movement conditions were established which differed only in their mode of initiation. Condition One; involved a simple reaction time task followed immediately by a rapid aiming movement to a specified target. The reaction time task was used to control the subject's attention by forcing him to attend to an auditory stimulus. In Condition Two, a reciprocal aiming task was developed which required a single movement away from the body mid-line to a peripheral target; followed immediately by a rapid return aiming movement to acquire a specified target. This second phase of the reciprocal aiming task was considered to be identical to the rapid aiming movement specified under the first condition. A single rapid aiming movement, without a preceding reaction time task was used in Condition Three. The subject initiated the movement when he felt prepared to do so.

These three conditions were established for the following reasons. Conditions One and Three were identical single aiming movements of the Schmidt variety which differed only in their demands on attention. Condition One required attention to be directed towards an auditory stimulus while Condition Three did not. A comparison of these movements was in effect a comparison based upon differences in attention demands of each condition. Condition Two a Fitts type of task; embodied both the rapid aiming movements used in Conditions One and Three and an initial outward movement to a peripheral target; an important feature of reciprocal tapping. This condition required attention to be directed towards a peripheral physical stimulus and also a planned reversal of movement direction.

The three established conditions described a continuum of movement requirements. Condition Three, a single rapid aiming movement with no demand on attention, Condition One, a single rapid aiming movement with some demand on attention, and Condition Two, a rapid aiming movement following a planned reversal of movement direction requiring attention to be directed towards a physical stimulus which coresponded to the point at which the planned reversal had to take place.

The three conditions embodied all of the features of single aiming and reciprocal tapping movements allowing a comparison of such movements to be conducted.

Method

Subjects

Thirty male subjects, students at the University of Alberta, ranging in age from 19 to 32 years, volunteered for the experiment. All subjects wrote with their right hands.

Apparatus and Task

A PDP 11/10 computer was employed to control the experiment and collect data. The interaction between the apparatus and computer is shown in figure 1. The computer was used to control an auditory tone which acted as an event indicator to the subjects. The tone was activated by the computer by closure of a solid state switch via a signal from the computer's digital to analog converter. This switch activated an EICO audio wave generator to produce the tone. The computer was also employed to collect analog data from an accelerometer and potentiomater. These devices were connected to the A/D (analog to digital) channels of the computer. Analog data was subsequently digitized and stored on floppy disks.

Three target lights, Leecraft 3200 amber snaplights, were embedded in a plywood board which was first covered with heavy black paper and then overlayed with ¼ inch household window glass. The effect was to give three target lights which appeared as orange strip lights approximately 0.2 cm in width. The three lights were separated from a 1 cm wide metal start plate by distances of 10, 20 and 40 cm respectively. The three target lights could be individually controlled by the experimenter.

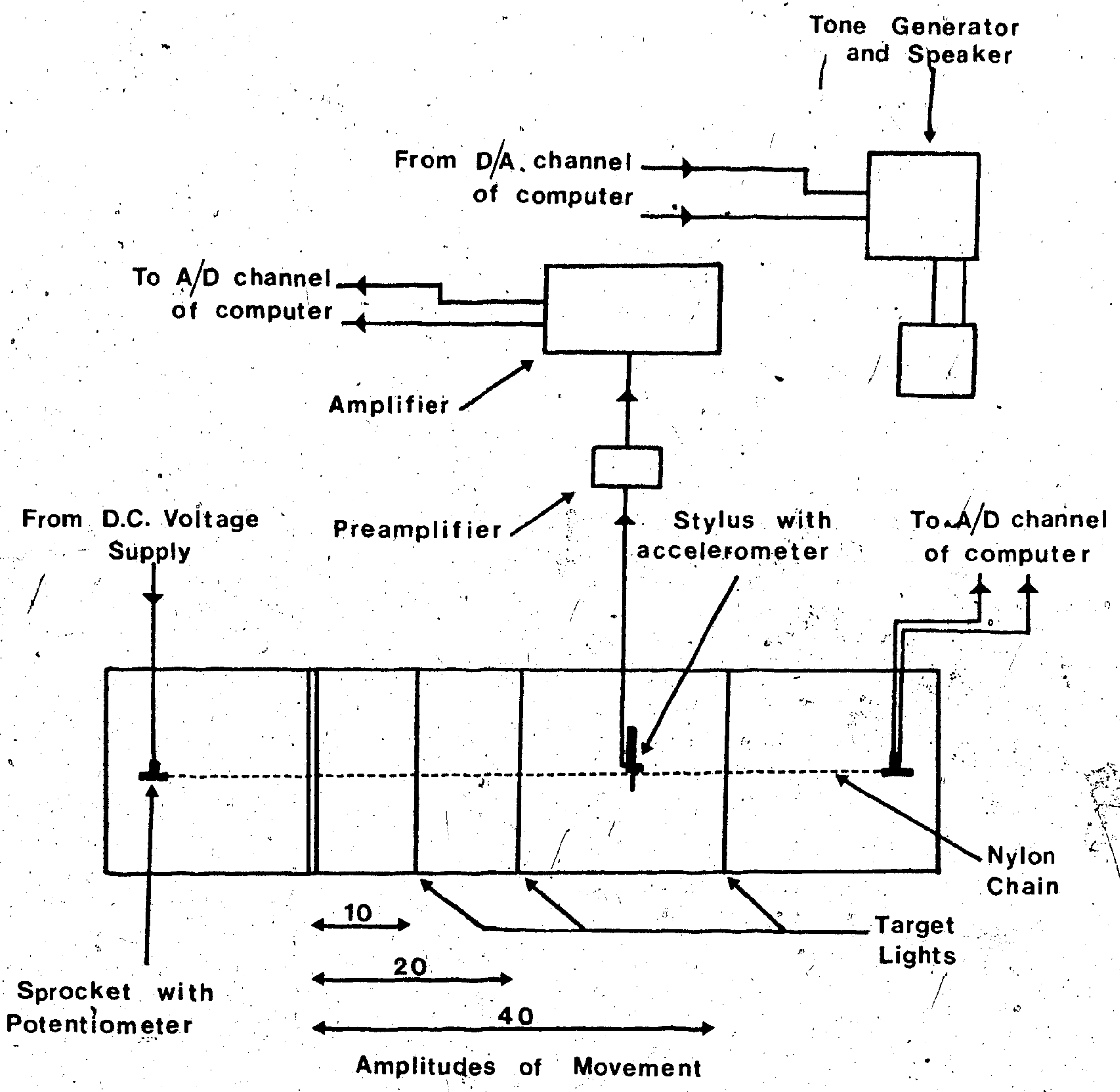


Figure 1. Plan of Apparatus and Interface with Computer

Two lightweight brass sprockets were mounted individually upon the spindles of two 10 Kohm ten turn potentiometers. The potentiometers were mounted on the table 100 cms apart from each other. They were situated centrally over either end of the plywood board. The potentiometers were mounted on uprights approximately 5 cm above this board allowing it to move freely beneath them. An Eveready heavyduty 6 volt battery was connected to the potentiometers. Only the output of one of the potentiometers was used as a source of analog signal for transmission to a digital channel of the computer.

A continuous nylon ladder chain ran between the two brass sprockets. Linear movements of the nylon chain caused rotation of the potentiometer spindles and a resultant change in resistance. Since the potentiometers were linear, movement of the nylon chain caused linear changes in output voltage. These changes in output voltage were sampled at a rate of 500 values per second.

A metal stylus, approximately 15 cm in length was fixed to the lower segment of the nylon chain. A piezoelectric accelerometer (Bruel and Kjaer Type 4332) was mounted on the stylus. The accelerometer was attached to a preamplifier (Bruel and Kjaer, Type 2616) which was mounted on the back of the subject's chair at the level of the shoulder. Output from the preamplifier was fed to a power amplifier (Hewlett Packard Type 467A). Output from that amplifier was then fed into a second A/D channel of the computer. Movements performed by displacing the stylus in the lateral plane, were therefore converted into voltage equivalents by the accelerometer and potentiometer and then digitized by the computer for immediate storage and eventual analysis.

An inclined wooden screen was fitted to the bench on which the equipment sat. The screen was of such length as to prevent subjects from viewing their arms or the equipment to the right of a line drawn perpendicular to the subject's mid-line. Since target lights could be illuminated individually and the position of the plywood board adjusted freely, the experimenter could make the target light visible to the subject while at the same time obscuring the start plate and right limb. Target lights coresponding to the amplitude of movement desired could be illuminated and correctly positioned by the experimenter relative to both screen and subject.

The task in Condition One required the subject to respond to an auditory signal by performing a single rapid aiming movement in the lateral plane. The movement, from initiation to target acquisition, was to be completed as rapidly and accurately as possible following the tone.

The subject was seated approximately eight inches from the bench such that the mid-line of the subject's body was directly opposite the target light. The metal stylus was fitted to the subject's right hand by taping it between the index and forefingers. The stylus was then attached to the nylon ladder chain and the subject positioned its tip on a cross point embossed into the metal start plate. The subject was allowed to view beneath the screen to acquire the cross point but following this was instructed to return to an upright position, in which only the target light was visible.

The computer was programmed to give a clearly audible tone of

500 msecs duration signifying that a trial could begin. When the subject felt he was ready he depressed a small switch with his left hand. After a three second delay following depression of the switch, the computer gave a second long tone of 500 msecs duration which, the subject was instructed, was a warning tone. The computer was programmed to create a random delay of between 500 and 3,500 msec following the warning tone. Following this delay the computer gave a signal of 50 msec duration which was the subject's signal to initiate his response. The subject was previously instructed that upon receiving this signal he was to move as rapidly and accurately as possible from the start plate to come to rest above the illuminated target without coming into contact with the glass.

On initiation of the signal tone the computer was programmed to sample and store the incoming data from the accelerometer and potentiometer. Sampling occured asynchronously at a rate of 1000 samples per second. Sampling lasted for 1000 msec, thereby providing 500 samples from the accelerometer and 500 from the potentiometer. Following a variable delay not exceeding 8000 msec during which acquired data was stored by the computer, the above procedure was repeated again. Subjects were given ninety such trials,divided into sixty training trials followed by thirty test trials.

The task in Condition Two required the subject to perform a rapid aiming movement to a target following the acquisition of a second target situated to the subject's right. The aiming movement required the subject to return, as fast and accurately as possible to the start position following the acquisition of the second target.

Subjects in Condition Two were seated as in Condition One and the stylus taped between the index and forefingers of the right hand. The subject began a trial by positioning the sylus on the glass directly on the target light. Following a 500 msec tone from the computer, the subject moved the stylus along the glass to the right until a change of context was perceived indicating contact with the start plate (this change of context was extremely obvious to the subject). Contact with the start plate was the signal that the subject was to move as rapidly and as accurately as possible back to the target light without contacting the glass.

The metal start plate and stylus were so arranged that contact between the stylus and the plate acted as the closure of a switch. Upon closure of this switch the computer began to sample for 1000 msec from the accelerometer and potentiometer. Following a delay during which sampled data was stored by the computer a second tone of 500 msec duration was given indicating the start of a new trial. Subjects were again given sixty training followed by thirty test trials.

The task in Condition Three required the subjects to perform a single rapid aiming movement to an illuminated target. This movement was self initiated by the subject.

Subjects were seated as in Conditions One and Two, with the stylus once again taped between the index and forefingers of the subject's right hand. The subject positioned the stylus so that it rested lightly upon the metalic start plate. The subject was allowed to view beneath the screen to position the stylus correctly, but once this was completed the subject was instructed to return to an upright position in which only the target light was visible. The computer was programmed to give a 1000 msec tone indicating that a trial could commence. The subject initiated a trial by pressing the stylus down firmly upon the metalic start plate. This action closed the switch lying beneath the start plate and caused the computer to commence sampling. The subject then moved as rapidly and accurately as possible to stop above the target light without coming into contact with the glass. Following a variable delay period not longer than 8000 msec during which sampled data was stored by the computer, a second tone of 1000 msec was given to indicate that a further trial could begin. Subjects were given sixty training followed by thirty test trials.

Ten subjects were randomly assigned to each treatment condition. Subjects in each condition were tested under all amplitudes, namely 10, 20, and 40 cm. The order for testing for amplitude was decided randomly, however, once this order was decided all subjects were tested in this order. The order for testing for amplitude was 20 cm, 10 cm, and 40 cm. The thirty subjects were tested at their convenience. Subjects were, however, tested only once per day to avoid fatigue effects.

Design

10 subjects were randomly assigned to each of the three treatment conditions, Condition One, Condition Two, and Condition

Three. Results were analysed using a three way factorial repeated measures design. The number of levels of the three factors were; 3 (treatment condition) X 3 (amplitude of movement) X 20 (trials). Following this analysis standard deviation data for each subject performing under each amplitude of movement were submitted to a two way factorial repeated measures analysis of variance. The number of levels of the two factors were; 3 (treatment condition) X 3 (amplitude of movement).

Data Analysis

On completion of the 30 test trials the computer indicated the end of the test session by giving four short tones. The computer was further programmed to analyse the stored digital data. Appendix B gives a graphical representation of the digital data collected during a single trial. The diagram shows how this data was used to obtain measures on the dependent variables of interest. Data from the potentiometers was used in the calculation of displacements and gave, therefore, distances moved prior to and following corrections. The accelerometer was used in the calculation of the magnitudes and durations of the impulsive forces as well as total movement time.

Only the first 20 acceptable trials from each test session were submitted to statistical analysis. Trials were considered to be unacceptable for the following reasons; responses were initiated prior to the required signal, movements were completed after the end of the computer sampling period and were not, therefore, completely sampled, subjects failed to respond to the signal, movements were performed at such speed that they failed to provide suitable acceleration data for analysis by the computer, these movements were not felt to have been performed as fast as possible.

Results and Discussion

Table 1 is a summary of the results of the three way factorial repeated measures analysis of variance performed on data obtained for each of the dependent variables in Experiment One. Table 2 is a summary of the results of the two way factorial repeated measures analysis of variance performed on standard deviation data obtained from Experiment One. For the purposes of the current discussion major consideration will be given to the variables of effective target width (standard deviation of distance moved prior to correction), variability of impulse duration (standard deviation of duration of accelerative impulse) and reaction time.

The major prediction of the Schmidt et al (1978, 1979) theory of motor output variability related variability of impulse duration to effective target width, W_e. The theory proposed that as variability in impulse duration increased there would be a proportional and linear increase in W_e. Examination of the results from the current experiment showed a significant main effect for treatment condition on the variable, variability of impulse duration, $F(2,27) = 7.74$, $p < .01$. No significant main effect for treatment condition was obtained for the variable, effective target width. For the main effect of amplitude, significant differences were obtained for the dependent variable effective target width, $F(2,54) = 1479.94$, $p < .000$, but no significant differences were obtained for variability of impulse duration.

Neither of these results would be predicted by the Schmidt theory. According to the theory, significant differences between

Table 1

F ratios obtained from the three way analysis of variance performed on raw data for each dependent variable of Experiment One.

Dependent Variable	Treatment Condition (C)	Amplitude (A)	C X A	Trials (T)	C X T	A X T	C X A X T
Reaction Time	22.00*	3.00	2.31	1.25	1.02	0.92	0.95
Time of Acceleration	5.94*	46.05*	0.69	0.97	0.72	1.08	0.81
Time of Deceleration	4.84*	8.21*	0.18	0.34	1.23	0.91	0.86
Distance moved prior to correction	0.93	1479.90*	0.18	1.25	0.91	1.15	0.11
Distance moved following correction	0.55	7110.10*	1.45	0.53	0.50	1.19	1.33
Magnitude of accelerative impulse	7.74*	60.32*	1.01	1.19	1.03	1.21	1.16
Magnitude of decelerative impulse	1.72	31.22*	0.21	0.56	0.79	0.84	0.77
Movement Time	4.95*	19.08*	0.54	0.57	1.01	0.71	0.96

*

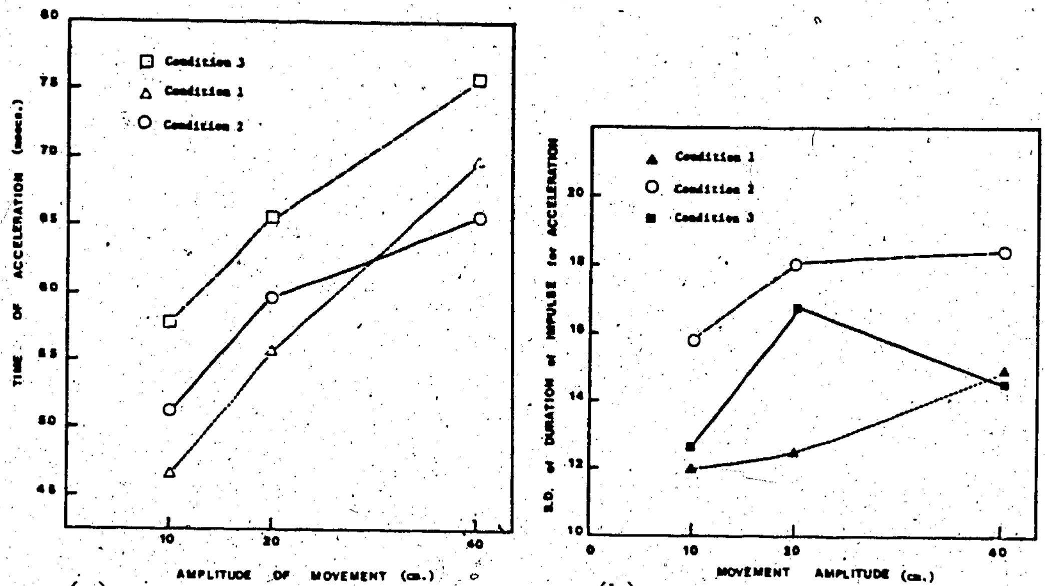
* indicates probability < .05

Table 2

F ratios obtained in analysis of variance performed on standard deviation data for each dependent variable in Experiment One.

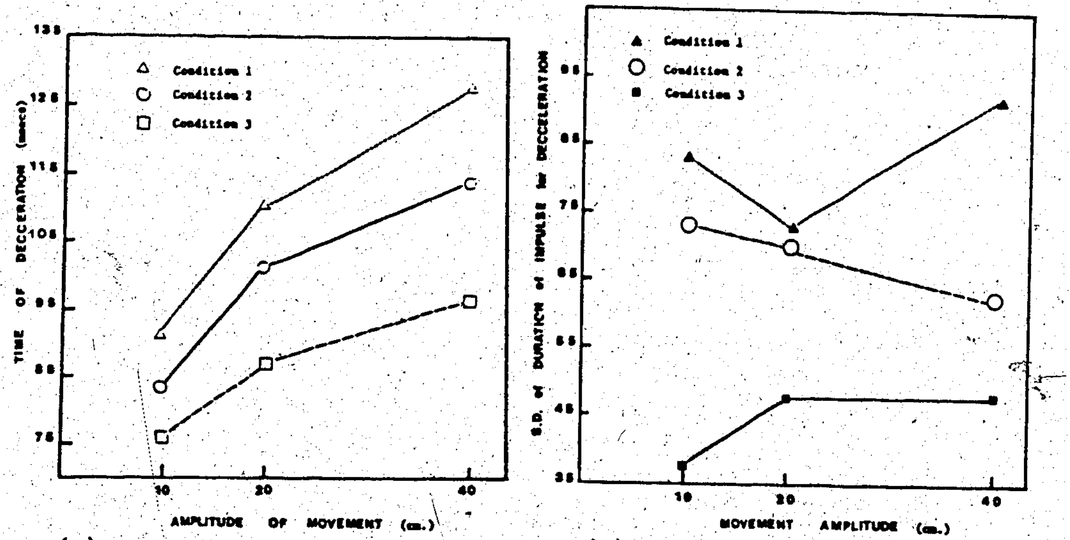
Dependent Variable	Treatment Condition (C)	Amplitude (A)	C X A
Standard deviation of duration of accelerative impulse.	5.83*	2.248	0.58
Standard deviation of duration of decelerative impulse.	4.90*	0.062	0.41
Standard deviation of magnitude of accelerative impulse.	2.04	9.482*	0.13
Standard deviation of magnitude of decelerative impulse.	1.37	4.981*	0.49
Standard deviation of distance moved prior to correction.	0.12	26.532*	0.95
Standard deviation of distance moved following correction.	0.23	20.926*	0.55

* indicates probability < .05



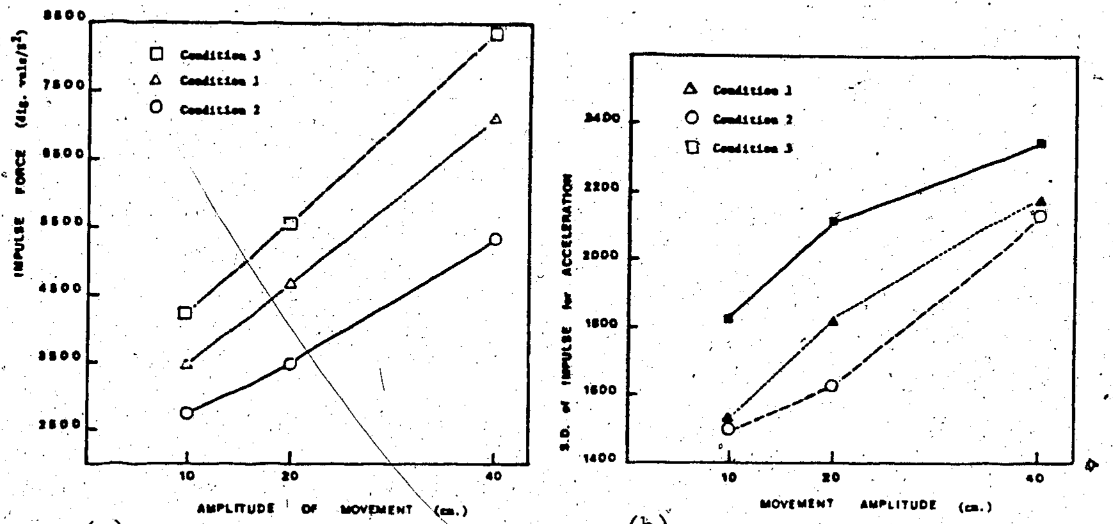
(a) (b)

Figure 1. Mean (a) and standard deviation (b) of duration of accelerative impulse as a function of amplitude and treatment condition



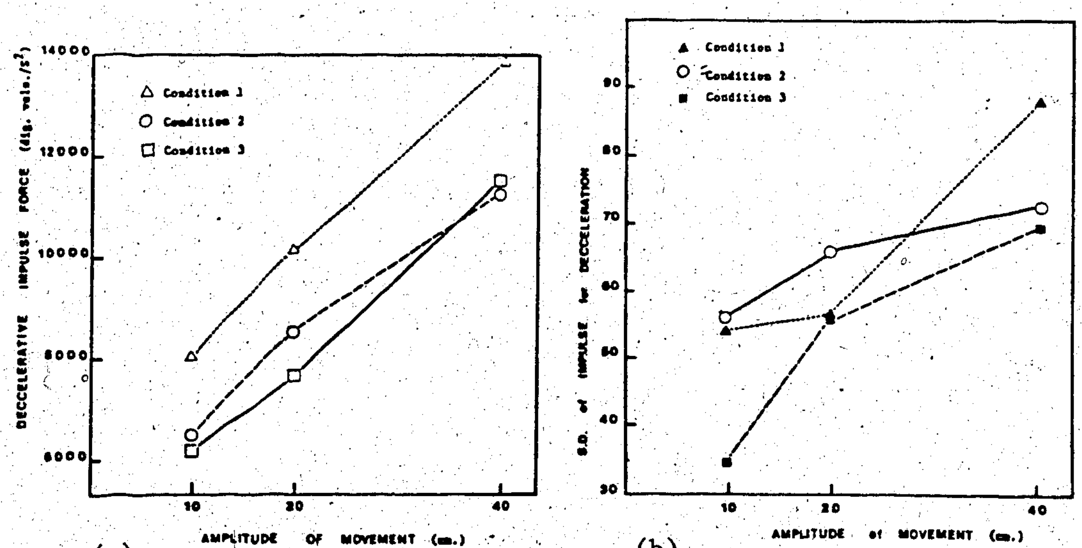
(a) (b)

Figure 2. Mean (a) and standard deviation (b) of duration of decelerative impulse as a function of amplitude and treatment condition.



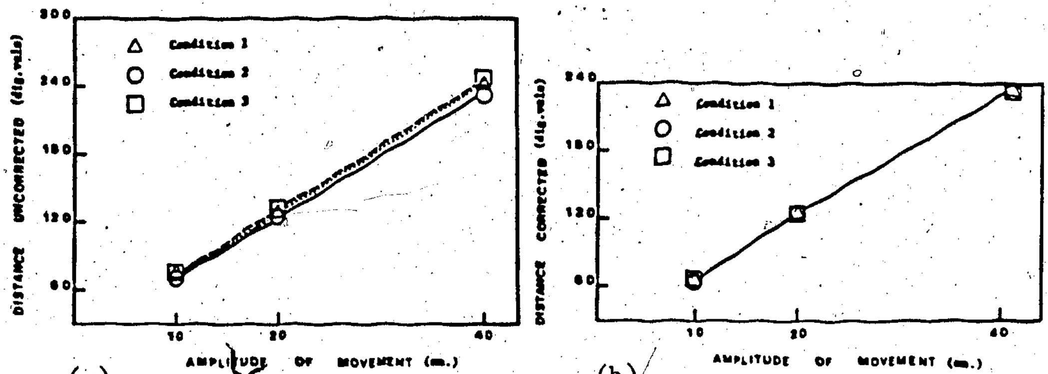
(a) (b)

Figure 3. Mean (a) and standard deviation (b) of magnitude of accelerative impulse as a function of amplitude and treatment condition.



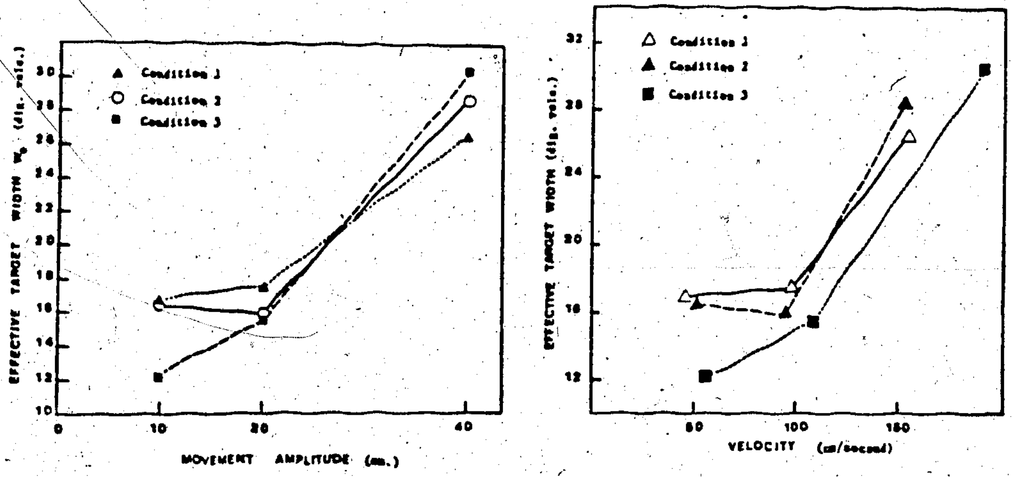
(a) (b)

Figure 4. Mean (a) and standard deviation (b) of magnitude of decelerative impulse as a function of amplitude and treatment condition.



(a) (b)

Figure 5. Mean distance moved prior to (a) and following (b) correction as a function of amplitude and condition.



(a) (b)

Figure 6. Effective target width as a function of movement amplitude and treatment condition (a) and movement amplitude and velocity (b).

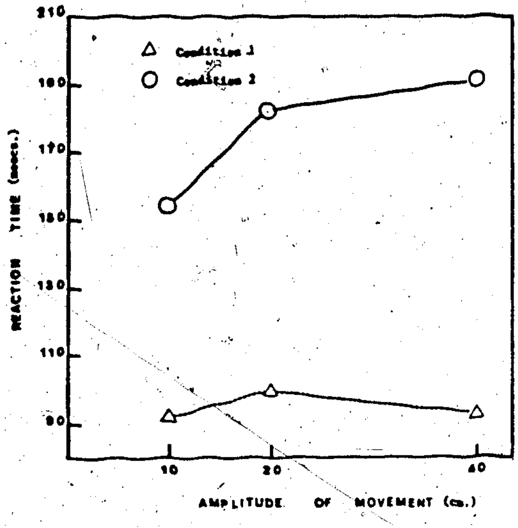


Figure 7. Reaction time as a function of amplitude for Conditions One and Two.

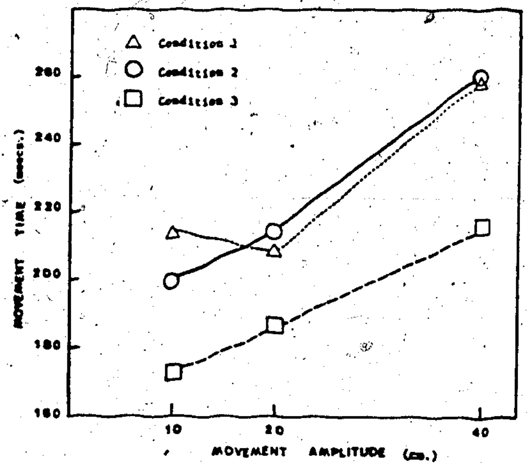


Figure 8. Movement time as a function of amplitude and treatment condition.

treatment conditions on the variability of impulse duration should have been accompanied by similar differences between treatment conditions for effective target width. Similarly within conditions, as amplitude increased, increases in effective target width should have been accompanied by a proportional increase in the variability of impulse duration. Neither of these results was obtained in the current experiment and therefore the experiment failed to support Schmidt's theory.

Fitts' (1954) theory predicted that as movements of a fixed amplitude were speeded there would be an increase in the variability of movement endpoint, W_e. Results of the current experiment demonstrated a significant main effect for treatment condition on the dependent variable movement time $F(2,27) = 4.95$, $p < .05$. Movements in the self-initiated condition (COndition Three) were performed significantly faster than movements in conditions One and Two. There was, however, no main effect for treatment condition on the dependent variable effective target width. This finding was contrary to the prediction of the Fitts' theory which would have required an increase in effective target width as movements became faster. It would appear in the current experiment that the mode of movement initiation affected the resultant accuracy and speed of movement. Self-initiated movements with limited attentional demands could be performed more rapidly than but with equal accuracy to movements requiring a response to a tone or a planned reversal of direction (Conditions One and Two respectively).

Figure 6(b) shows effective target width plotted as a function of movement velocity and treatment condition. No significant increase in effective target width was observed when movement velocity increased from 50 to 100 cm per second. A significant increase in effective target width was observed when movement velocities increased from 100 to 150 cm per second. In the first case both amplitude and velocity of movement were increased with no significant increase in W_e. These results suggested that effective target width did not increase until subjects operated at velocities which put them above the capacity of the motor system. It could be suggested that single aiming movements could be performed at greater velocities than reciprocal movements while maintaining the same degree of accuracy because less capacity had to be devoted to the monitoring of stimulus events. It could be suggested that Fitts' law holds in conditions in which subjects are performing at or beyond the capacity of the motor system while the Schmidt formulation would hold under conditions where subjects were operating below capacity. The performance of single aiming movements which required attention to be directed towards an extraneous stimulus event should by the previous argument, closer approximate performance of movements requiring planned reversals such as those in Condition Two, than the self-initiated movements of Condition Three. While insufficient data points are available figure 6 (b) lends some support to the previous argument. Condition Three (self-initiated single rapid aiming movement) demonstrates a near linear increase in effective target width with movement velocity while Conditions One and Two may well demonstrate logarithmic increases in effective target width with movement velocity.

The foregoing discussion is based on the assumption that within treatment conditions requiring response to a stimulus (Conditions One and Two) there was no trade off between complexity of movement, as represented by amplitude of movement, and reaction time. Henry et al (1960) proposed that the time required to program a movement, as reflected by reaction time, increased as the complexity of the movement increased. Analysis of variance performed on reaction time data from the current experiment showed no significant main effect for amplitude. Subjects did not take longer to plan movements of greater amplitudes. Data obtained for other dependent variables could not be attributed to subjects adopting a trade off strategy in which programming time was increased for longer amplitude movements. Observed differences on the dependent variables measured could more safely be attributed to the experimental manipulation which required attention to be directed towards particular stimulus events.

A significant main effect for treatment condition was obtained for reaction time $F(2,27) = 22.0$, $p < .05$. Reaction times for Condition Two were significantly longer than those for Condition One. Henry et al (1960) would suggest that this reflected the greater complexity of movements requiring a planned reversal of direction. This increased reaction time did not result in a more complete programming of the return aiming movement. Figure 5 (a) and (b) show that increased planning time in Condition Two did not result in greater accuracy of movement. Analysis of variance showed no significant main effects or interactions for the variables distance moved prior to correction or distance moved following correction.

Figure 3 (a) and (b) show the magnitude and variability of impulse for acceleration. Condition One shows greater accelerative impulse with greater associated variability than condition two. This is reflected in a significant difference obtained in analysis of variance for the dependent variable movement time for the main effect of treatment condition, $F (2,27) = 4.95$, $p < .05$. A similar result was obtained for the dependent variable decelerative impulse force. A significant main effect was obtained for the main effect of amplitude $F(2,54) = 31.22$, $p < .05$. Figure 4 (a) shows near linear increases in decelerative impulse for all conditions as a function of amplitude of movement. While no significant main effect for treatment condition was obtained it was interesting to note that Condition Three while demonstrating the largest accelerative impulses (figure 3) demonstrated the smallest decelerative impulses. This may be due to the more complete programming which may have taken place because no attention was required to be directed to any extraneous events. Figures 1 and 2 show that not only was the magnitude of accelerative impulse greatest for Condition Three it acted over the longest time of the three conditions while the decelerative impulse as well as being the smallest of all conditions also acted over the shortest time. These two results also seem to support the notion that more complete programming took place for movements performed by subjects in Condition Three.

In conclusion, the current experiment provided evidence to support the theory that single aiming and reciprocal tasks differ in their organization. The differences would appear to be related to the discrepent attentional demand between the three movement classes examined. One explanation would be that increased demands on attention resulted in decreased capacity for movement programming. The effect on programming of decreased capacity was not reflected in increased variability of movement endpoint. Accuracy of movement was maintained in all conditions while parameters related to movement velocity were effected. It would appear that rapid movements can be performed with the same accuracy as slow movements providing the attentional demands in the slow movement case were severe. If this was the case then the performance of reciprocal tasks such as those in Condition Two should vary according to the demands placed on attention by the task. As the attention demanded by the point of reversal is increased, perhaps by making the target plate at that point narrower, then the characteristics of the return aiming movement should be altered. According to the foregoing argument these changes should not be related to the effective target width, effective target width should be maintained for movements of equal amplitude regardless of demands placed on attention. Rather, the effect should be noted on parameters relating to the velocity of the movement. A second experiment was conducted to examine and test this prediction.

EXPERIMENT 2

Experiment One provided some evidence to support a tentative theory that single rapid aiming tasks and tasks of a reciprocal nature differed in their organization. The observed differences in the measured parameters between the two classes of movement appeared to be dependent upon the amount of attention subjects were required to direct towards events other than the aiming response. Acquisition of the peripheral plate in Condition Two and attending to the stimulus tone in Condition One appeared to demand capacity. Reductions in the capacity available for formulating the movement response did not lead to a reduction in accuracy of movement. Rather, differences were observed in factors relating to speed of movement. It was subsequently suggested that Fitts' law may hold under conditions in which subjects are required to operate beyond the limited capacity of the human motor system. Similarly it was proposed that the Schmidt formulation held under conditions in which the subjects operated below the limited capacity of the motor system.

The foregoing argument suggested that in reciprocal tasks subjects were required to attend to targets which marked the points of reversal in the movement task. Because attention was demanded by the points of reversal, reduced processing capacity was available for the formulation of the subsequent response. The effect on performance was not reflected in a reduction in accuracy but rather in factors related to movement speed such as magnitude of accelerative impulse. It was proposed, therefore, that reduction in attention demanded at the points of reversal in a reciprocal task would result in movements of increased velocity but not increased accuracy.

Experiment Two was an attempt to manipulate the attention required to be directed to the points of reversal in an aiming task which required a planned reversal of movement direction. This was accomplished by manipulating the width of a peripheral target plate which represented the point at which reversal of the movement was required. It was hypothesized that as the width of the reversal plate increased so the subject would be required to devote less attention to its acquisition. Greater processing capacity would be available for planning and execution of the return movement following acquisition of the reversal point. The result of decreases in the attention devoted to the peripheral plate would be return movements of increased velocity. All movements, regardless of the attention demanded by the point of reversal, which was theorized to be dependent upon its width, would be performed with equal accuracy. It was further hypothesized that as demands on attention were reduced, performance of the aiming response in a reciprocal task would more closely approximate that of a single aiming response.

The question of interest in the current experiment related to the effect of attentional demand on performance of aiming movements requiring a planned reversal of movement direction. Performance was assessed by measurements obtained on the eight dependent variables detailed in Experiment One. Since attention demand in the task was thought to be dependent on the width of the plate representing the point of movement reversal, movements in the following experiment had to be visually guided.

Method

Subjects

Five male subjects, students of the University of Alberta, ranging in age from 21 to 29 years, volunteered for the study. All subjects wrote with their right hands.

Apparatus and Task

A number of modifications were made to the apparatus described in Experiment One. The screen which prevented subjects from viewing the course of movements was removed in order to allow for visually guided movements. The peripheral start plate which acted as the starting point for all movements was also removed. Three metal plates were constructed of widths 10, 20, and 40 mm respectively. These plates could be inserted by the experimenter into the position previously occupied by the peripheral start plate. When any of the plates were in position, the distance between the centre line of the plate and the three target lights remained 10, 20, and 40 cm. There were, therefore, nine possible combinations of peripheral target width (PTW) and amplitude of movement.

The task in Experiment Two required the subject to perform a visually guided single rapid aiming movement to a visually illuminated target following the acquisition of a metal plate situated to the right of the target light. This task required a planned reversal in movement direction at a predetermined point prior to the acquisition of the target.

A PDP 11/10 digital computer was used to control the experiment.

The interaction between the apparatus and the computer was identical to that described in Experiment One Condition Two. The computer was used to control an auditory tone which acted as an event indicator to the subjects. The tone was activated by the computer by closure of a solid state switch via a signal from the digital to analog channel of the computer. This switch operated an EICO audio wave generator to produce the clearly audible required tones.

The subject was seated for each test session as in Experiment One such that the mid-line of the subject's body was aligned with the target light. Prior to the arrival of the subject, the experimenter selected the appropriate amplitude of movement and width of peripheral plate and adjusted the equipment accordingly. The stylus, bearing the accelerometer, was taped between the index and forefingers of the subject's right hand. The stylus was attached to the lower segment of the nylon ladder chain and this arrangement allowed for movements only in the lateral plane. The subject was instructed that each trial would begin with the stylus resting lightly upon the target light.

The computer was programmed to give a long tone of 1000 msec duration to indicate that a trial was to begin. After a fixed period of 3000 msecs the computer was programmed to give a tone of 500 msec duration which acted as a warning tone. After a delay of 500 msec a very short tone of 50 msec duration sounded to indicate to the subject that the movement out to the peripheral plate was to begin.

Speed of movement out to the peripheral plate was controlled by a further tone which acted in metronome fashion. The subject was instructed that his movement to the peripheral target plate should be evenly paced ~~and~~ in time with the pacing tone. This provided a relatively constant velocity of movement to the periphery for all amplitudes of movement since the duration of the pacing tone was proportional to the amplitude of the movement, 250 msec for 10 cm movements, 500 msec for 20 cm movements and 1000 msec for 40 cm movements. Upon initiation of the pacing tone subjects began the horizontal movement to the right towards the peripheral target plate.

Upon contact with the peripheral plate the subject was instructed to move as fast and accurately as possible to a position above the target light without coming into contact with the surface. Contact between the sylus and the peripheral plate acted as an event indicator to the computer. The computer commenced sampling data from the accelerometer and potentiometer for 1 second at a rate of 1000 samples per second.

Upon achieving the target the subject was instructed to remain there until the computer issued a further long tone indicating that the next trial would begin following a delay interval. During the delay the computer stored collected data for later analysis.

All subjects received 60 training trials followed by 30 test trials. Subjects were tested under all combinations of amplitude and peripheral plate size giving a total of 9 test sessions per subject. The order of testing for each subject was decided randomly by drawing the 9 combinations from a hat. Subjects were tested once per day for 9 days.

Design

The 5 subjects were tested under all combinations of amplitude and peripheral target width. Mean and standard deviation data were submitted to a two-way factorial repeated measures design with repeated measures on both factors. The levels of the two factors were; 3 (amplitude) X 3 (peripheral target width). Of the 30 test trials the first 20 acceptable trials were submitted for analysis. A trial was considered unacceptable for the following reasons; the subject failed to make contact with the peripheral plate, the subject failed to complete the aiming response within the sampling time of the computer, movements were performed at such speed that they failed to provide suitable acceleration data for analysis by the computer, these movements were not felt to have been performed as fast as possible, the subject failed to respond to the pacing tone and did not move to the periphery.

Table 3

F ratios obtained from analysis of variance performed on mean data obtained for each dependent variable in Experiment Two

Dependent Variable	Amplitude (A)	Peripheral Target Width (PTW)	A X PTW
Reaction Time	2.10	1.129	1.816
Duration of accelerative impulse	18.915*	5.985	1.344
Duration of decelerative impulse	7.029*	1.137	2.820
Movement Time	5.213*	1.232	0.578
Magnitude of accelerative impulse	45.920*	2.789	1.481
Magnitude of decelerative impulse	6.864*	1.746	3.252*
Distance moved prior to correction	159.290*	3.102*	2.928
Distance moved following correction	239.430*	1.813	2.403

* indicates probability < .05

Table 4

F ratios obtained from analysis of variance performed on standard deviation data obtained for each dependent variable in Experiment Two

Dependent Variable	Amplitude (A)	Peripheral Target Width (PTW)	A X PTW
Standard deviation of duration of accelerative impulse	1.276	2.375	2.039
Standard deviation of duration of decelerative impulse	5.539	1.746	2.215
Standard deviation of magnitude of accelerative impulse	4.680*	3.47	1.87
Standard deviation of magnitude of decelerative impulse	6.53*	1.16	2.24
Standard deviation of distance moved prior to correction	11.960*	5.05*	2.44

* indicates probability < .05

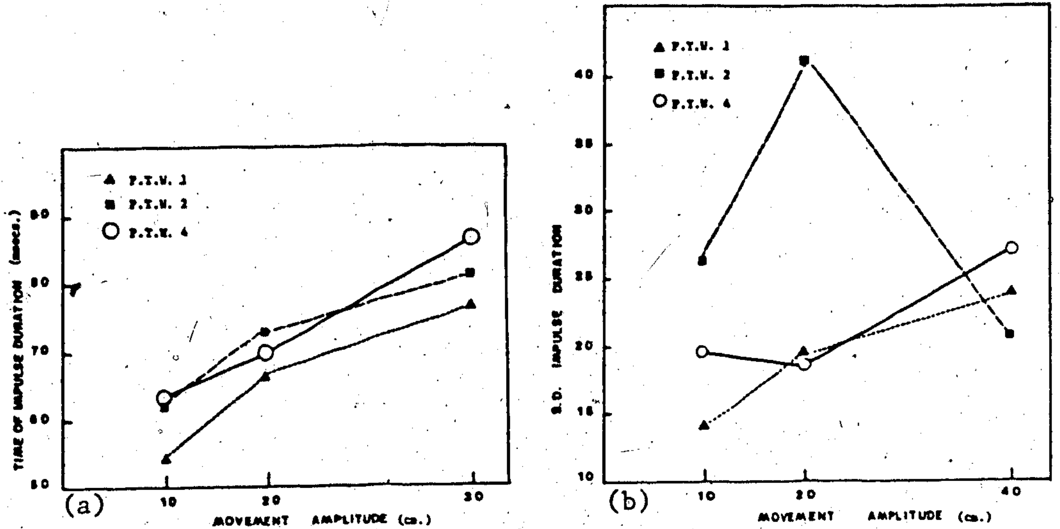


Figure 9 Mean (a) and standard deviation (b) of the duration of impulse for acceleration as a function of amplitude and peripheral target width (PTW).

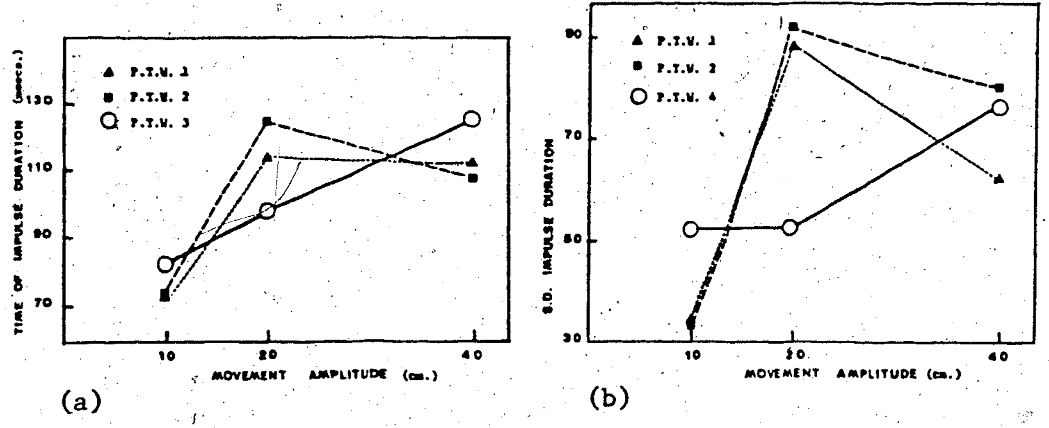
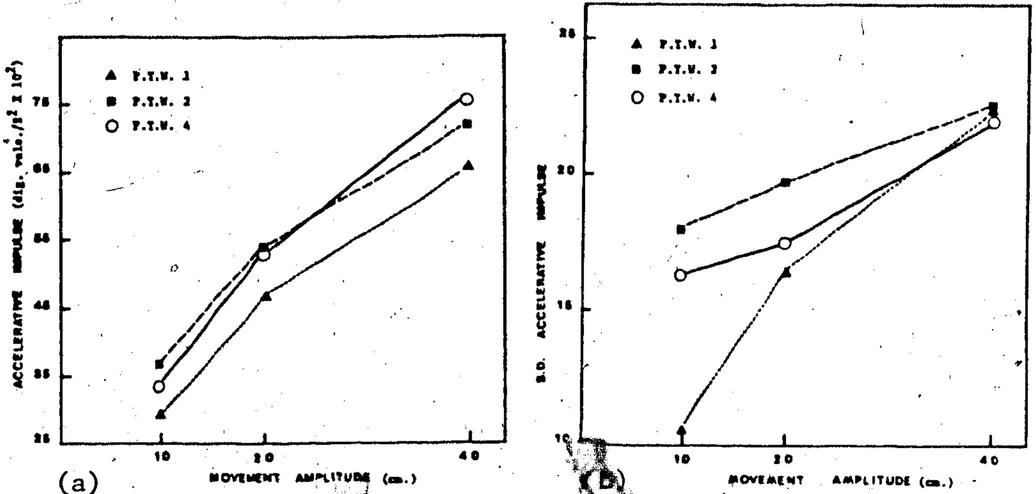
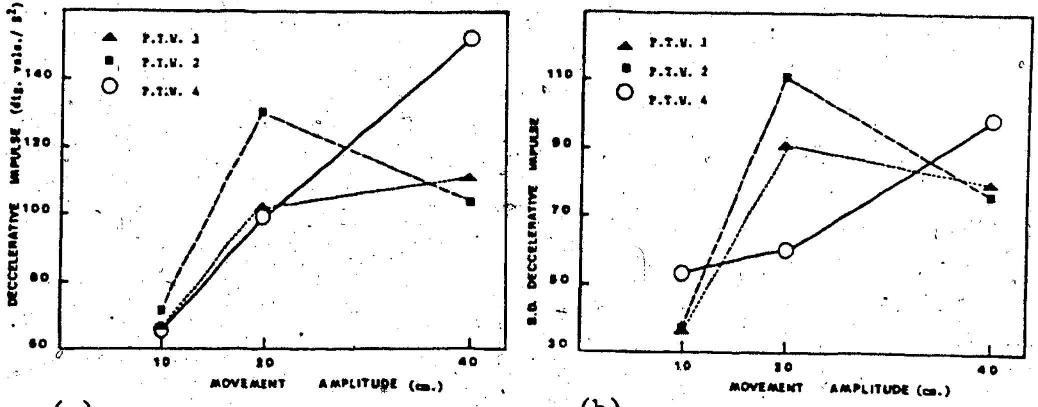


Figure 10 Mean (a) and standard deviation (b) of the duration of impulse for deceleration as a function of amplitude and peripheral target width.



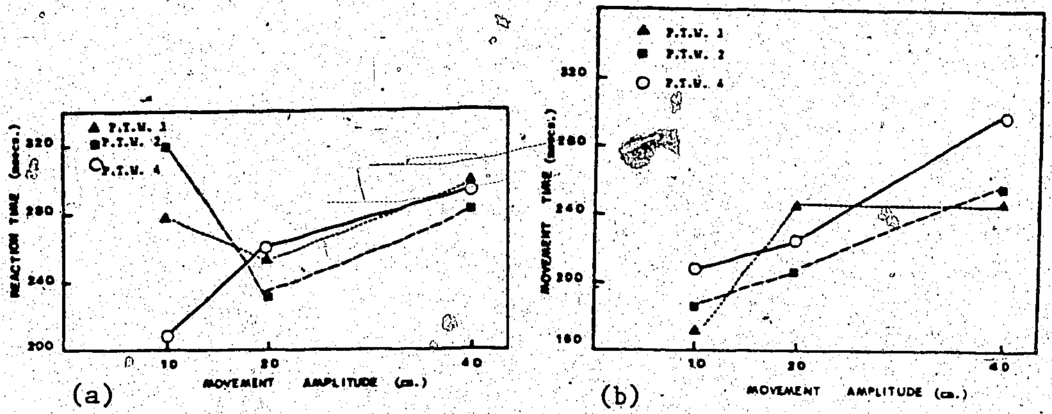
(a) (b)

Figure 11 Mean (a) and standard deviation (b) of magnitude of impulse for acceleration as a function of amplitude and peripheral target width.



(a) (b)

Figure 12 Mean (a) and standard deviation (b) of magnitude of decelerative impulse as a function of amplitude and peripheral target width.



(a) (b)

Figure 13 Reaction time (a) and Movement time (b) as a function of amplitude and peripheral target width.

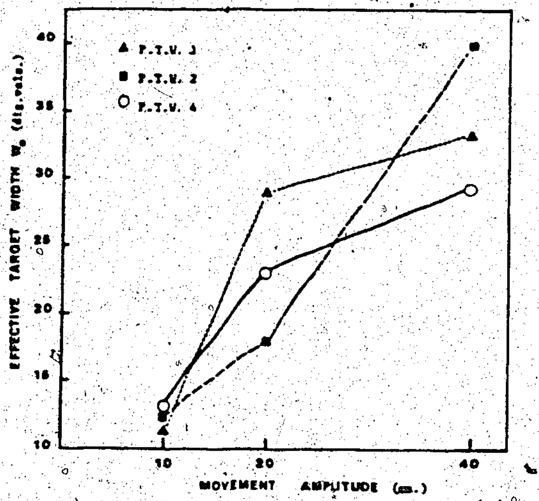


Figure 14 Effective Target Width as a function of amplitude and peripheral target width.

Results and Discussion

Tables 3 and 4 show the results of the two-way factorial repeated measures analysis of variance performed on mean and standard deviation data obtained from Experiment Two.

Figure 7 shows reaction time data for Conditions One and Two of Experiment One. The significant main effect of treatment condition was taken as an indication of differences in task complexity between Conditions One and Two. Henry (1960) and Klapp (1975) reported that more complex movements required increased processing time. In the current experiment no significant main effect or interaction was obtained for the dependent variable reaction time. For movements of fixed amplitude the manipulation of peripheral target width appeared not to increase the complexity of the response. The expected effect on attention of reducing the width of the peripheral plate did not take place.

Figure 14 presents effective target width (standard deviation of distance moved prior to correction) as a function of amplitude of movement and peripheral target width. Analysis performed upon this data demonstrated a significant main effect for both amplitude $F(2,8) = 11.96$, $p < .05$ and peripheral target width $F(2,8) = 5.04$. $p < .05$. Based on the findings from Experiment One it was proposed that no such differences in effective target width would be observed as a function of the manipulation of peripheral target width. Such a proposal could not be supported by the data obtained here. One reason for this failure may have been that no effort was made to observe whether or not the subjects made errors in reaching the peripheral target plate prior to initiation of the rapid visually guided movement to the target. As a result of the failure to partition the errors, the distance moved prior to correction and following correction of the rapid aiming movement, contained error at both ends of the movement and not merely at the final target as was assumed in the analysis. This problem did not arise in Experiment One since all movements were initiated from the same point and errors were not, therefore, confounded.

Examination of the mean distance moved prior to correction showed that for 40 cm movements to the 4 cm peripheral plate the distance moved on the return rapid aiming movement was greater than for similar movements to the 1 and 2 cm plates. Furthermore, this difference was maintained following correction of the rapid aiming movement implying that for the 4 cm peripheral plate the actual amplitude of movement was greater than 40 cm. However, this did not result in the greatest effective target width. The validity of this result must, however, be suspect since much of the error obviously occured at the periphery and as such was not accounted for in the calculation of W_e around the final target (see figure 14).

In the light of these findings it is difficult to comment upon the results for other dependent variables in the experiment.

A further methodological limitation related to the timing of the movement out to the peripheral plate. Long amplitude movements were given proportionally longer times for acquiring the peripheral plate than were short movements. This difference in time may have been sufficient for subjects to perform accurate movements to the peripheral plate. Calculation of effective target widths for movements to the

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peripheral plates may have demonstrated that for all peripheral target widths the effective target width of movements to the periphery were the same. Such a finding would suggest that the most important measure of peripheral attentional demand would not be the size of the peripheral plate given by the experimenter , but rather the effective target width calculated from the length of movements to the plate provided by the subject. Effective target widths can then be calculated using a method reported by Welford (1968) and employing a correction factor reported by Crossman (1957).

Equivalence of reaction time data for the three peripheral target widths may have been due to the fact that in movements to large peripheral plates, more time was taken in the preparation of the return rapid aiming response than in acquisition of the peripheral plate. In movements to narrow plates, however, the long reaction times recorded may have been reflective of increased time required to acquire the peripheral target and not in the time required to generate an adaquate response (see figure 13(a)).

Taken together the methodological limitations of the current experiment are so numerous that an interpretation of the obtained results would be meaningless. A possible experimental paradigm which could provide information relating to attentional demand in reciprocal aiming responses without the drawbacks of the current experiment could be performed as follows. subjects would be required to move alternately between targets of differing widths. The distribution of shots around each target would be indicative of the effective target width for that target. If the proposed theory was correct then no differences in effective target width would be obtained regardless of the size of the aimed for targets. However, differences would exist in parameters related to movement velocity.

Figure 9 shows mean and standard deviations for duration of accelerative impulse while figure 11 shows magnitude of accelerative impulse and its associated standard deviation. Both functions appear to demonstrate linear increases with amplitude for each peripheral target width. Although these results are inconclusive it is interesting to note that such results would be supportive of the Schmidt model even though the movements which produced these results were reciprocal in nature. Similar results were obtained for duration and magnitude of decelerative impulse, figures 10 and 12. The most strikingly linear relationship being for PTW 4 cm this being the peripheral target width which was predicted to show characteristics most similar to the single rapid aiming movements described by Schmidt.

General Discussion

Experiment One provided evidence which suggested that the variable application of Fitts' (1954) and Schmidt et al (1978, 1979) formulations was dependent upon the attentional demands of the tasks. Fitts law would appear to hold in conditions in which subjects were operating beyond the processing capacity of the motor system while the Schmidt relationship could conceivably hold in conditions in which subjects operated below that capacity. Experiment One indicated that the accuracy of movements could be maintained with increased velocity as long as the limited processing capacity of the motor system was not overloaded. This would suggest that when available capacity for the processing of movements is reduced, factors related to the speed of movement are affected before factors related to the accuracy of movement.

Polit and Bizzi (1979) comparing normal intact monkeys and monkeys with bilateral dorsal rhizotomy (C2 - T3) performing forearm positioning movements demonstrated that specimens performed the aiming responses with equal accuracy even when limbs were unexpectedly displaced prior to the initiation of the movement. Since visual feedback was not available to the monkeys, success in the task could not be credited to this source. Most importantly, the success of the aiming response was maintained even when the limb was displaced beyond the aimed for target and the response required changed therefore, from a forward to a reverse motion.

Accounting for these findings Polit and Bizzi postulated that the 'motor program' specified, through the selection of a set of length - tension parameters in the agonist and antagonist muscles, an equilibrium point which correctly positioned the limb in relation to the target. Final equilibrium was seen as a function of the passive elastic properties of the muscles in operation following a change in length or tension of the agonist or antagonist groups.

This 'mass spring' view of control has been criticised as it appears that muscle does not function according to the laws which govern the operation of normal springs. Houk (1976) demonstrated that the properties of muscles changed during movement and the critical variable in movement control was muscle stiffness, the function of length and tension. It would appear, however, that the motor system is capable by some means, of programming the end point of movements. Polit and Bizzi (1979) qualify this suggestion by proposing that the mechanism responsible for achieving final position must be paralled by a mechanism to control limb velocity, since movements acquiring the same target may differ in velocity.

The results of Experiment One may be interpreted as lending support to this modular view of movement control, since subjects in each of the three movement conditions acquired the targets with equal accuracy but with many differences in other measured parameters of movement. This may be expected if the acquisition of a target involved the execution of a program, a major component of which was responsible for the accuracy of the movement or the acquisition of the end point.

Combining this modular view of organization with a capacity view of the information processing system would suggest that as attentional demand of peripheral events increased then the capacity available for the formulation of the response program would be reduced. Such conditions existed in Conditions One and Two of Experiment One. The observed differences in the accelerative and decelerative impulse magnitudes and durations and their associated variabilities, together with differences in movement time and velocity may perhaps be attributed to differences in attentional demands of the tasks. Increased demands on attention result in incomplete or deficcient programming of certain response parameters due to decreased availability of processing capacity.

The concept that attention is required during the initiation phase of movement has recently been forwarded by Norman and Shallice (1980). They proposed that the production of movement sequences often involved accessing a number of resources or schemas and that attentional control dictates the relevance given to a specific component schema. In terms of the first experiment it could be argued that a component schema representing the movement endpoint was given maximum activation in all three movement conditions and as a result, all three conditions resulted in equally accurate movements. The activation levels associated with other component schemas varied according to the overall attentional demand of the task. According to Norman and Shallice, in times of high attentional activity the activation levels for certain component schemas or parameters of those schemas may fall below threshold and as a result fail to be executed. At the moment of initiation of the movement the source schema representing the required act would be composed of all the parameters required to perform the act accurately and as many of the parameters for velocity as could be fitted in the available capacity. Increased capacity therefore leads to more complete programming. The addition of further parameters occurs in an orderly fashion.

With reference to Experiment One, of particular interest is the comparison between Conditions One and Three (response to tone and self initiated). In both cases the required movement was identical and both were performed with equal accuracy. However, other measured parameters of the movements showed significant differences and it was proposed that these differences were due to the differential attentional demand at the initiation of the task. For movements requiring a planned change of direction, as in Condition Two, attention demanded was increased due to competition for processing capacity between the program controlling the movement out to the periphery and the program required to control the movement back to the target. However, the parameters resposible for accuracy of the movements are still given highest activation and the observed reduction in velocity is due to incomplete specification of velocity parameters.

It appears therefore, that attention demands of tasks critically affect the construction of response programs which resulted in the observed differences in the measured parameters of the movements.

In an earlier pilot study (Wilberg, Franks and Fishburne, note 2) results did not support a linear increase in effective target width with amplitude or movement time. Rather, subjects exhibited a bandwidth type of performance in that effective target widths could be maintained for a range of amplitudes and movement times. Incerasing the velocity of a movement did not by necessity result in an increase in effective target width. The current investigation also demonstrated this phenomenon. Interpretation of figures 6 (a) and (b) suggest that an increase in velocity from 50 to 100 cm per second or of amplitude from 10 to 20 cm was not associated with increased W_e for any treatment condition. However, an increase in amplitude from 20 to 40 cm and velocity from 100 to 150 cm per second resulted in a uniform increase in W_e for all conditions. Whether similar plateaus would be observed at increased amplitudes and velocities cannot be deduced from the data available. The current study does support the opinion that effective target width is related to a measure of movement difficulty. The bandwidth behavior also gave rise to the possibility that the difficulty of the movement is a perceptual phenomenon in that certain movements may have been perceived to be of equal difficulty even when the amplitude and velocity were increased. There was a possibility that the maximum information contained in a movement, the actual transmitted information and the perceived information differed and that perceived information is a more sensitive measure of task difficulty. Future experimentation may be directed towards this point and the application of Signal Detection Theory may offer a means of examining the question.

Kerr (1977) reported the presence of a 51 Hz frequency movement component in the accelerometer trace of subjects performing rapid aiming movements. This component apparently became evident with practice and may have been the result of learning. This was particularly true in movements with high terminal accuracy requirements. Although the current experiments did not speak to this point, future research may demonstrate that with practice the speed of reciprocal movements increases and this increase in speed is associated with the emergence of the 51 Hz movement component. This is a proposition which the author feels deserves further attention.

It reciprocal tasks, it has been suggested that many of the deficiencies in performance were related to the increased attentional demand of the peripheral target. Fitts (1954) demonstrated increased information transmission as a result of practice in reciprocal tasks. Such an increase may be interpreted as being the result of a decrease in attention demanded at periphery related to a decrease in the uncertainty both in the position of the peripheral target and also in the subsequently required aiming movement. It would be expected, therefore, that time spent in the transition phase of the movement would be reduced as a function of learning. This may result i reciprocal performances approaching those of single aiming responses. A further study would examine the duration of the transition phase and changes in the duration of the phase with practice and its effect on the measured parameters of movement.

The present experiments provided some evidence to support the theory that the differential application of the Fitts' and Schmidt formulations be due to differential demands on the attentional mechanisms. The locus of attention demand in reciprocal tasks appeared to be at the points of reversal in movement direction. In situations subjects operate below the capacity of the information processing system the author believes that the Schmidt formulation may hold. When subjects operate beyond the capacity of the processing system results may fit the Fitts' formulation.

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Notes

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APPENDIX A

Fitts' Law

The concept that the accuracy of rapid movements decreased with amplitude has been known for many years. However, the close relationship between speed, amplitude and accuracy of movement received little attention from early workers in the field of motor performance. Woodworth (1899), was one of the earliest experimenters to emphasize the importance of this inter-relation. In a variety of simple motor tasks, performed with and without the aid of visual monitoring, Woodworth demonstrated that for quick, visually controlled movements, variable error increased with both amplitude and speed. Subsequently, industrial engineers advocated the use of small amplitude movements in assembly work on the grounds that the time required to complete a unit of work increases as a function of its amplitude as well as of the precision demanded by the task, (Maynard, Stegemerten and Schwab, 1948).

The application of information theory to the study of sensory, perceptual and perceptual motor functions, allowed a more specific measureemnt of man's performance capacities, (Crossman, 1955; Hick, 1952). Fitts (1954) extended the theory to embrace the human motor system. Fitts stated that the information capacity of the human motor system is specified by its ability to produce: "one class of movement from among several alternative movement classes" (p.381). Further: "The greater the number of alternative classes, the greater is the information capacity of a particular type of response." (p.381). From this, Fitts concluded that since measurable aspects of responses such as amplitude and force are continuous variables, information capacity is limited only by the amount of variability that is characteristic of repeated attempts to produce the same response. Therefore, the information capacity of the motor system can be assessed from measures of variability of responses which are meant to be uniform.

Fitts' (1954) theory stated that, since the information transmission capacity of the motor system is fixed, it could be expected that if repetitive movements of average amplitude are 'speeded up' then each movement can provide less information and, therefore, movement variability will increase by a specified amount. Similarly, if the amplitude is increased then variability in the movement, and/or its duration, will also increase. Stating the specific hypothesis:

> "If the amplitude and tolerance limits of a task are controlled by E, and S is instructed to work at his maximum rate, then the average time per response will be directly proportional to the mimimum average amount of information per response demanded by the particular conditions of amplitude and tolerance." (p.383)

Fitts tested the hypothesis using a number of tasks, including: a reciprocal tapping task; a disc transfer task and a pin transfer task. In all cases Fitts found that: "The rate of performance of all the tasks studied increased uniformly as movement amplitude was decreased and as tolerance limits were extended." (p.387).

In order to test the results against a prediction that the information output of the motor system in any task is relatively constant over a range of amplitudes and accuracy requirements, Fitts formulated an index of difficulty which specified the minimum information required for organizing each movement. Minimum organization is the specifying of one from several possible amplitudes within which the movement is to terminate. In binary notation:-

$$ID = -\log_2 \frac{W}{2A} \text{ bits/response.} \qquad (1)$$

Where ID = Index of Difficulty

W = Tolerance range in inches

A = Average amplitude

The results of Fitts experiments confirmed that the movement time varied with task difficulty in such a way that ID was constant over a wide range of amplitudes and tolerances. That is to say, that movements of different amplitudes but of equal difficulty in terms of information, are of approximately equal duration. The average time per movement, MT, was related to A and W by the following relation:-

$$MT \doteq a + b \log_2 \frac{2A}{W} \qquad (2)$$

where a and b are empirically fitted regression parameters.

According to the information theory interpretation, the slope parameter, b, is the inverse of the motor system processing rate channel capacity. In the previous studies of arm movements b has been in the region of .100 bits/second. Fitts (1954) speculated that different limbs may show different information processing rates. Hancock, Langolf and Clark (1973) supported this showing an information processing rate of 20 bits/second for very small amplitude movements of the fingers and wrist. It was also shown that the times for a variety of microminiature assembly tasks, performed under microscopes, were proportional to the index of difficulty, ID. In general, Fitts' Law has been shown to hold in a variety of experimental situations and across a broad perspective of populations (Kerr, 1973; Welford, Norris & Shock, 1969).

Since the introduction of Fitts' Law there have been many attempts to modify the relationship to obtain more accurate descriptions of obtained data, but little or no improvement has resulted from this work. Welford (1960), using data from Fitts' (1954) reciprocal tapping task, formulated an equation which best fitted the data to a straight line:-

$$MT = K \log (A/W + .5) \qquad (3)$$

According to Welford: "This formulation makes movement time dependent upon a kind of Weber fraction in that the subject is called upon to distinguish between the distances to the far and near edges of the target." (p.147). Welford also identified situations in which the subject did not use the full target width. Under these circumstances the subject is transmitting more information than that calculated by equation three since the effective target width is narrower than the target. The narrowing of the target width, W, is reflected in a reduction in errors and, according to Welford, if this is allowed for then equation (3) holds reasonably well.

Crossman (1957) described a method for correcting for errors based on the fact that the information in a normal distribution is given by: $\log_2$ (2E), where is the standard deviation of the distribution. Since (2E) = 4.133 and plus or minus one half of this includes approximately 96% of the distribution, Crossman argues that if approximately 4% of shots fall outside the target that $\log_2 W$ is an accurate representation of the information contained in the distribution of shots. Also, if errors exceed 4% then the 'effective target width', W_e, is greater than W and, if errors are less than 4% W_e is less than W. Welford (1968) showed that Fitts' data, as plotted using equation (3) and corrected for errors using the Crossman method closely approximated a straight line passing through the origin.

Numerous experiments have produced results which are in striking agreement with Fitts. Knight and Dagnall (1967), using a task in which subjects had to align a pointer alternately between two targets, obtained results which closely fitted equation (3). Fitts and Peterson (1964) obtained results closely fitting equation (3) for 'single movements' carried out after a separate signal to move. Fitts and Radford (1966) demonstrated that accuracy improved as time taken to complete the movement increased, however, it was not affected by time taken to prepare, and the rate of gain of information was little affected whether the instructions were for speed or accuracy.

Theories Accounting for Fitts' Law

The most widely accepted explanation for the phenomenon described by Fitts was that presented by Crossman and Goodeve (1963), and later represented by Keele (1968). The theory is based on two assumptions: (a) that the subject is able to detect errors in movement and subsequently issue corrections; and (b) that the initial movement and subsequent corrections have a fixed relative accuracy. Crossman and Goodeve demonstrated that movements were not smooth but showed evidence of acceleration and deceleration with fixed periodicity, suggesting that movements consisted of a series of impulses, taking approximately the same time, but differing in velocity. The first movement may, for example, cover half the distance to be covered, the second the next quarter, and the next the next eighth, and so on. This explanation emphasizes feedback control in rapid movements with limitation in movement speed being defined by the number of corrections the subject must make to acquire the target. Using this argument, Keele (1968) has shown that Fitts' Law can be derived mathematically.

Findings from research examining movement patterns are equivocal, showing that movement corrections may (Annett, Golby & Kay, 1958; Brown & Slater-Hammel, 1949) or may not (Langolf, Chaffin & Foulke. 1976) take place in aiming responses.

The Crossman - Goodeve theory has, however, come in for much criticism on a number of counts. Logically it can be seen that correcting for errors in response selection would take at least one reaction time to perform since a new temporal-spatial pattern of movement needs to be intitated. This would take between 120 and 200 msecs. Schmidt, Zelaznick, Hawkins, Frank and Quinn (1979), suggest that such corrections may, in fact, take longer than one reaction time.

The Crossman-Goodeve theory assumes a correction every 200 msecs. with the first coming 200 msecs. after the initiation of the movement. Schmidt et al. (1979) suggest that if the first correction appears 200 msecs. after initiation of the movement, and the reaction time for the correction is 200 msecs., then the error must have been detected prior to or at the moment movement was initiated.

> "Logically it would seem that some initial portion of the movement must be carried out before the system could detect that the movement was in error." (Schmidt et al., 1979, p.5.)

By this arguement it would appear that the first correction could not occur 200 msecs. after the error was detected and the actual time of correction would, perhaps, be nearer 300 msecs. after the movement was initiated.

Furthermore, the Crossman-Goodeve (1963) model holds that corrections are required in a movement. Langolf (1973) has noted, however, that microscopic movements show little evidence of corrections, perhaps because they are programmed correctly from the start. Schmidt et al. (1979), regard the neccesity for corrections in a movement, and the failure to account for movements requiring no corrections, as a conceptual weakness of the model.

Another interesting objection arises from the work of Hick (1952) examining choice reaction time tasks. The suggested time for a single correction of 200 msecs. assumes a simple reaction time where the number of possible errors which can occur in the movement is reduced to one. This is obviously not the case, as the number of possible errors greatly exceeds one and the situation is, therefore, one of choice reaction time. Therefore the suggested time for correction of 200 msec would seem to underestimate the time required for a correction.

The Psychological Refractory Period.

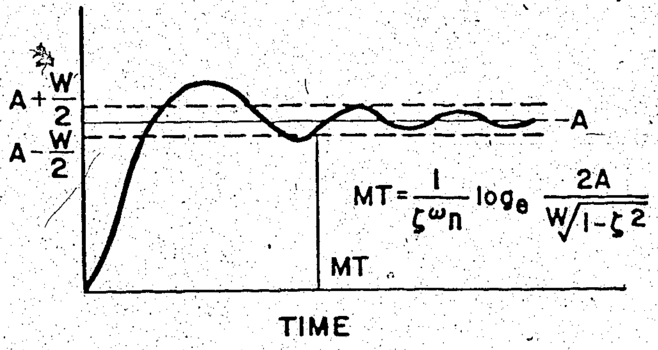
The psychological refractory period (PRP), the delay in responding to a stimulus while another is being processed, was first reported by Welford (1952). In accounting for the phenomenon Welford proposed that:

1. All input and output streams are controlled by a common processor, and
2. The processor acts sequentially on current inputs, rather than simultaneously.

With regard to the Crossman-Goodeve theory, it would appear unlikely, in the light of PRP, that responses to two closely following feedback stimuli could occur within the suggested 200 msecs., since processing of the second stimulus could not occur until a response to the first had been made. Even assuming the parallel processing model of McCleod (1977), which would allow processing of the second feedback stimulus along with the first, a decrement in response to the first stimulus would be noted. In neither case could processing and response be completed within 200 msec.

Systems Models

Langolf et al (1976) present the Crossman-Goodeve theory as representing a first order system response. A second order underdamped system is also shown to settle according to Fitts' law, (see figure below), and it was proposed that further linear control systems models have outputs obeying Fitts' law.



Representation of second order underdamped system from Langolf et al (1976, p. 115).

An examination of a wide range of amplitudes using the Fitts' reciprocal tapping task was made in order to confirm the applicability of control systems models to Fitts' law. Under large amplitudes it was found that:-

> "...linear control models are untenable explanations of Fitts' law. The human trajectories are obviously non-linear. For all linear models discussed, decreasing the terminal tolerance W simply has the effect of adding more settling time to the same basic movement trajectory. However.... changing the tolerance has the effect of completely altering the human's movement trajectory. In particular the Crossman-Goodeve and Keele constant time, constant accuracy discrete corrections models specified that the movement shouldon the average achieve a given deviation from target center (P A) after each discrete correction n at time nt. Thus the discrete corrections model must generally show the same rate of progress toward target center regardless of terminal tolerance W. Therefore, if a discrete correction mechanism is present (but masked by inertia), then in order to produce the varied trajectories of figure 12, the time per correction (t) and/or relative accuracy (P) must change as a function of tolerance demands (W). The real explanation of Fitts' law in terms of method of human control must be more complex and non-linear."

Langolf et al. (1976) found that larger amplitude movements did not show evidence of break points indicating a discrete correction process. Decreasing the tolerance, W, merely had the effect of progressively decreasing the velocity of the movement in approaching the target.

Based on experimental evidence that the hand slows down as it approaches a target (Peters & Wenborne, 1936; Taylor, 1947; Edwards, 1965) Howarth, Beggs and Bawden (1971) proposed an intermittent feedback theory for the control of aiming movements. Howarth and Beggs (1970) proposed the existance of a visually mediated intermittent correction mechanism since removal of visual feedback when the hand is close to the target has little effect on terminal accuracy. This was only the case if there was less than one corrective reaction time between removal of feedback and the hand reaching the target. The theory proposed that the error on target was related to the velocity of the hand during the terminal phases of the movements being made at different speeds. Howarth et al. (1971) provide evidence to support this theory for slow movements. Beggs and Howarth (1972) provide further evidence to support the theory that the error on target is proportional to the distance away at which the last correction was applied.

This theory, however, falls prey to the same criticism as the Crossman-Goodeve theory of movement control in that it can not account for movements which are completed within one corrective reaction time.

Alternative Theories

Motor Output Variability

The previously reviewed theory was based on the subject's ability to process feedback information and to make corrections based on this information. Schmidt, Zelaznick and Frank (1978) suggest that researchers have consistently disregarded the possibility that the output of the human muscular system is contaminated by "noise" (within subject variability) and that this variability is related to the parameters of the movement, i.e., amplitude and speed. According to Schmidt et al. (1978) central to both theories is the notion of the motor program, which can be described as a set of prestructured motor commands, which, when executed, will complete a movement without involving peripheral feedback. Schmidt et al (1979), proposing the theory of motor output variability, suggested that if movements can be structured in advance, then errors contained in the program, or in the recruitment of motor units involved in its execution, cannot be corrected until the program has been completed.

Evidence is cited by Schmidt et al (1979), from the areas of neurosciences (Brooks, 1974) and motor behaviour (Pew, 1974; Schmidt, 1975, 1976) to support the notion that movement control, especially in rapid movements, is carried out via the motor program. Shapiro (1977) even suggests that motor programs may control movements of duration as long as 1300 msecs.

The basic premise of the theory of output variability is that the variability in horizontal distance travelled (effective target width, W_e) in an aiming movement is proportional to the within subject variability of the velocity after the end of acceleration. Since the velocity of a movement is proportional to the magnitude of the accelerative impulse, the variability in velocity is, consequently, proportional to variability in impulse force and the variability in time over which the impulse is acting. As a result the theory proposes that the effective target width, W_e, is proportional to the variability in impulse force and impulse duration.

Schmidt et al. (1979) derived the following proportionalities:-

1. Effective target width and amplitude are proportional.
2. Impulse variability and movement time are inversely proportional such that σ Impulse $1/MT^2$

3. Citing Michon (1967) who demonstrated that the longer an interval of time to be metered, the larger the variability in metering, Schmidt et al proposed a relationship between impulse duration and movement time. Further, assuming a constant force amplitude, that Impulse $\propto$ MT.

4. Combining (2) and (3) Schmidt et al. propose that:

Impulse $\propto 1/MT$

5. Combining (4) and (1) gives the basic statement of the model:- $W_e \propto 1/MT$

> "The clear implication of this model is that as one asks the subject to move farther or faster, the subject does so with greater noise in his force- and time-production mechanisms, resulting in greater error in reaching the aimed for target." (Schmidt et al., 1979, p.194)

Schmidt et al propose that this notion of speed accuracy trade-off fits well with Fitts' equation, since it suggests that as the subject attempts to move faster he/she will make more errors.

> "Thus the present theory sees the limitation in the subject's movement time as an indirect result of his inability to be accurate because of variability in the force production and time-production mechanisms; this is quite different from the Crossman-Goodeve (note 1) model, which suggests that the limitation in movement time is the number of corrections the subject must make in arriving at the end point." (p. 195)

This is the Impulse Timing view of motor control.

Feedback in Motor Programming

Before presenting experimental evidence accumulated by Schmidt et al to support the motor output variability theory; it is intended to review the feedback versus motor programming controversy.

Klapp (1975) suggests that, in a choice reaction time experiment, the signal to respond informs the subject which of a set of possible responses is to be made. During the reaction time interval several processes may occur, of which interpretation of the signal, and programming or preparation of a response are two. Henry et al., (1960) and Klapp (1974), have suggested that when the number of alternative responses is kept constant, then increases in reaction time as a function of response parameters may be interpreted as reflecting changes in the time required to generate the response program.

Klapp (1975), argues that, in the Fitts' and Peterson (1964) paradigm, if reaction time reflects response programming, then choice reaction time should increase as the precision required is increased by reducing the size of the target. However, Ells (1973) demonstrated that this was not the case. Klapp (1975) goes on to say:

> "Although movement time, measured from the moment the stylus leaves the rest position until target contact occurs, depended on both target size and movement length, reaction time was independent of these parameters. This negative result may mean that the response is under feedback control rather than programmed in advance."
> (p. 147)

It was stated earlier that research findings concerning the question of corrections were equivocal. Klapp (1975) proposes that in long, accurately terminated movements, the whole movement may not be programmed in advance, accounting for the independence between reaction time and parameters of the movement. Short movements, which may not display corrections (Langolf et al, 1976), could be programmed in advance. If this were the case then more complex responses would require longer programming, leading to the observation of increased reaction time as required precision for short movements increases.

In a single aiming movement, Klapp (1975) demonstrated that the relationship between amplitude and the $\log_2$ of target width appeared to be linear for long movements but not for short movements. This, for short movements, represented a departure from Fitts' Law. This departure, according to Klapp (1975) suggests that: "....short movements are programmed ahead of time and executed ballistically. On the other hand, Fitts Law should and does hold for long movements which are under feedback control according to the present analysis." (p. 150). This analysis would seem to parallel that suggested by Schmidt et al (1978, 1979) in the theory of motor output variability. Further, Klapp (1975), demonstrated a linear relationship between reaction time and target width for short movements, such that reaction time increased as target width decreased indicating a longer processing time for more precise movements.

Klapp (1975) contended that long movements were under feedback control while short movements were programmed in advance. In a second experiment, in which visual feedback was disrupted by turning out illumination, it was found that long movements were totally disrupted, while for short movements reasonable accuracy was maintained.

Schmidt and M^cGown (1980) regard the controversy concerning the locus of movement control as one of the most persistent in the field of motor behaviour. Peripheralists posit that movement is controlled by some combination of feedback from the responding limbs, the visual and auditory systems and the vestibular systems. This position takes two basic forms:

1. A stimulus response chaining hypothesis, James (1980), which suggests that successive responses are elicited by successive cues in the environment. Entire skills can be executed in response to a starting stimulus, in the absence of other external stimuli, since each succeeding response is elicited by the pattern of internal stimuli from the preceding response (Greenwald, 1970).
2. Adams' (1971) closed-loop hypothesis which proposes that feedback is compared to some stored referent which represents correct performance. Errors are determined as deviations from the referent and corrections are issued on this basis.

Centralist theory, conversely, as developed by Henry (1960) and Fitts (1964), emphasizes a central process that is not dependent upon sensory monitoring. Keele (1968) states that a motor program can be viewed as:

> "...a set of muscle commands that are structured before a movement sequence begins and that allows the entire sequence to be carried out uninfluenced by peripheral feedback." (p. 387)

The central control hypothesis proposes, therefore, that skilled movements are organized and initiated by some central control process. Knowledge of movement does not depend on the monitoring of afferent input.

One argument against stimulus-response chaining theory involves the rate of processing of feedback information. Lashley (1951) suggested that this processing was too slow to account for rapid sequences of movements such as finger movements in piano playing. Keele (1968) and Glencross (1975) report the time taken to react to kinesthetic information is in excess of 100 msecs , while Keele and Posner (1968) increase this time to between 190 and 260 msecs for visual feedback information. Furthermore, in the complex skill situation, which usually involves perceptual [illegible] response uncertainty, Glencross (1977) suggests the shortest interval of intermittent functioning is at least 300 msecs.

Pew (1966), in a task which involved the repositioning of a constantly moving visual target by alternately pressing response keys, demonstrated a change in strategy from feedback dependent pattern early in practice to control by motor program. Early responses were made only after delays in which feedback information about the effectiveness of response was assessed. Later in practice, however, subjects responded rapidly, indicating less dependency on continuous monitoring of sensory feedback and instead, the control of response sequences rather than single units

Speech, a complex, serially organized skill, shows evidence of central control. Lenneberg (1967) states:

> "Thus we gather that the rate at which individual muscular events occur (throughout the speech apparatus) is of an order of magnitude several hundred events every second. It is evident that the activation of so many muscles in such a short time span cannot depend upon volition alone. There must be some automations - whole trains of events that are programmed and run off automatically." (p. 92).

Support of this theory and evidence of 'tone units' in speech is given by Boomer (1965) and Laver (1970).

The most persuasive evidence in favour of central processing comes from the studies of deafferentation in which kinesthetic feedback is prevented in animals by surgically cutting dorsal roots which supply afferent feedback to the central nervous system. Keele and Summers (1975) suggest that if skill can proceed without kinesthesis then stimulus-response chaining, which depends on kinesthetic feedback, cannot explain the sequencing of the skill.

The most impressive experiments of this nature involved the the elimination of sensory feedback in the rhesus monkey. Taub and Berman (1968) repeated the experiments of Mott and Sherrington (1895) by surgically severing the dorsal roots supplying afferent input from one of a monkey's front legs. This procedure, therefore, eliminated sensory feedback without affecting efferent input to the muscles. Mott and Sherrington (1895) observed that the monkey failed to use the deafferented limb, which lent support to the stimulus-response chaining theory of movement control. However, Taub and Berman (1968), after restraining the normal limb, demonstrated that the monkey could, in fact, use the deafferented limb.

Furthermore, when both limbs were deafferented:

> "...the animals were able to use the limbs rhythmically and in excellent coordination with the hind limbs during slow and even moderately fast ambulation." (p. 177)

Taub and Berman (1973) have further shown that monkeys deafferented and visually blocked soon after birth learn to walk, suggesting that sequencing of movements in walking is not dependent on ~~normal~~ feedback.

Criticism of the Taub and Berman technique centers around the question of total elimination of sensory feedback. Taub and Berman showed that no cortical responses occured when nerve ends in a deafferented limb were stimulated. However, Bossom (1974), suggested that some afferent fibers may enter the spinal cord through the ventral root and, therefore, escape severing in dorsal root cutting. Some reservation must, therefore, exist with regard to these results.

More significantly, perhaps, is the emphasis Taub and Berman placed on the ability of the deafferented monkeys to perform gross movements. Bossom (1974) reported that these movements were produced without elegance, suggesting that gross movements can be performed in the absence of sensory feedback but fine motor skills such as manipulative skills, can not.

Ischemic nerve block techniques have been employed in studies of human movement in an attempt to block afferent sensory information. Of importance in this technique is the differential effect on sensory and motor systems. Loss of sensory information occurs much sooner than loss of muscular power (Magladery, McDougal & Stoll, 1950). Laszlo (1966, 1967, 1968) in a number of studies has shown gross impairment of performance as a result of ischemic blockage. However, Glencross and Oldfield (1975) raise objections to the ischemic nerve block technique by demonstrating gross motor impairment due to the cuff and also the presence of some sensory information arising distal to the cuff. Glencross (1977) states that:

> "Consequently, the motor deficit observed following ischemic nerve block is not solely the result of blocked kinesthetic sensation, and thus its relevance to the issue of central versus peripheral control of movement cannot be directly assessed." (p. 21)

Evidence has been presented, therefore, which would suggest some combined or integrated use of central and feedback processes in the organization and performance of movements.

Philips, Powell and Wiesendanger (1971) demonstrated that positional information from the eyes arises from the receptors in the extraocular muscles. Skavenski (1975) demonstrated that feedback control is important in control of eye movement, concluding that: " these inflow signals are accessible to the occulomotor system for the control of eye position." (p. 225). Also, Provins (1957) demonstrated that blocking sensory information by anaesthetizing the metacarpal-phalangeal joint, resulted in impairment in reproducing pressure by flexion.

Further support for the theory comes from the study of effects of delayed and augmented feedback. Smith (1962) in a review, presents evidence of jerky, uncoordinated movements as the result of delayed visual feedback. Glencross (1975) reports that augmented feedback, when closely related to the task, enhances performance.

This treatment has seen feedback control and motor programming as mutually exclusive modes of control. However, each theory is seen to be deficient to some extent and the possibility that some integrated control mechanism must exist as the means of coordinating skilled movement. Glencross (1975) suggests: "...that for a central control process (e.g. a motor program) to be fully effective, it must be integrated with peripheral sensory information at some stage." (p. 25).

This possibility will be discussed later in the chapter.

Evidence For The Theory Of Motor Output Variability

Schmidt et al.(1978, 1979) conducted a number of experiments in an attempt to confirm the relationships stated earlier in this chapter. Since these are the basis of the theory of motor output variability, a review of these experiments is felt to be in order.

The most important relationships proposed were that variability in force produced was proportional to the force produced, and that the within subject variability in impulse duration is proportional to the impulse duration. These variabilities in force and time could be introduced into the system in two distinct ways.

Either, they could be caused by the subject changing the goal of the response from trial to trial, variability thereby being due to changes in what was programmed. Or, the subject may repeat the same program over and over and variability is introduced as noise downstream from the program, causing different outputs for different trials. In testing the proposed proportionalities, Schmidt et al. (1978, 1979) attempted to have the subject repeat the same movement every trial, thus eliminating the possibility of variability due to choosing different responses.

Variability in Force

Using a fixed lever and attached strain gauge subjects exerted force in order to shoot a dot across an oscilloscope screen to a target. This was done in time with a metronome set at one response per 800 msecs. Force required was varied and a strong linear relationship between the within subject variability in force and the amount of force produced was observed over a wide range of forces. Also, a strong linear relationship between impulse duration and movement time was apparent and this relationship appeared to be a proportional one.

Amplitude

If the amplitude of a movement were doubled, however, the movement time remains constant, Schmidt et al argue that the velocity at the end of acceleration must be twice as large. Impulse for acceleration can only be doubled by increasing force, and variability of force is proportional to the amount of force produced. Since variability in the impulse is proportional to the effective target width then it follows that:

$$W_e \propto \text{Amplitude}$$

Movement Time

Assuming no variability in the duration of an impulse, halving the movement time for a fixed amplitude movement requires the impulse to increase four fold. Extrapolating from this it can be seen that variability in the impulse will be inversely proportional to the square of the movement time (MT):

$$\text{Impulse} \propto 1/MT^2$$

Since, however, variability in length of impulse is proportional to impulse duration and therefore movement time, then the variability in the impulse is proportional to the movement time:

$$\text{Impulse} \propto MT$$

Combining these effects it can be seen that the impulse variability is proportional to 1/MT and hence:

$$W_e \propto 1/MT$$

Amplitude and Movement Time

Since W_e is directly proportional to amplitude and inversely proportional to movement time, then:

$$W_e \propto A/MT$$

This is the basic statement of the Schmidt et al (1978, 1979) model, which relates the three variables of movement time, amplitude and movement accuracy in a single expression.

The Single Aiming Paradigm

Schmidt et al (1979) conducted a number of experiments using a single aiming paradigm. The technique involved manipulating amplitude and the movement time allowed and measuring the resultant effective target width. For long movement times (up to 500 msecs) the relationship: $W_e \propto A/MT$ did not hold, however Schmidt et al cite Keele and Posner (1968) who found that visually based corrections are possible with aiming responses as short as 260 msecs. For short duration movements (less than 200 msecs), however, a strong linear relationship between A and MT was found, lending strong support to the model. However, the relationship was not proportional, a finding partly attributed to error in measurement and also noise in the motor system not related to the task being performed.

The Locus of Variability

Schmidt et al (1979) approach the question of variability by assessing the variability added during the various processes contributing to movement. For example, variability may be added as a result of selecting an inappropriate program. However, in a single aiming movement this variability is small since there is little uncertainty about what to do in aiming at the target. Another source of variability is seen as noise, which is added downstream from parameter selection. Burke and Edgerton (1975) suggest, in physiological terms, that noise might exist in terms of how the neuronal information to the motor neuron pool in the spinal cord becomes translated into the activation of a certain number of motor units, which ultimately determines the amount of force produced.

Based on the findings of Kelso, Southard and Goodman (1979a, 1979b), which demonstrated that simultaneous left and right hand aiming responses had similar kinematic properties, Schmidt et al (1979) examined a two handed paradigm in an attempt to isolate the invariant features of the motor program. For example Kelso et al (1979a, 1979b) found that subjects could move the hands simultaneously different heights or distances, suggesting that these features were not invariant. However, they could not move the hands with different movement times, suggesting that this was common to the two hands, and an invariant feature of the movment determined by the motor program. Logically, Schmidt et al (1979) argue that:

> "Whatever these common paramameters might be, variability in their selection will be evident in the behaviour of both hands."

Using a two handed aiming task Schmidt (1979) reports that for movement time 69% of the variability in movement times was due to program or common parameter selection and only 31% associated with subsequent factors, (based on between hands correlations). For spatial measures of accuracy, however, only 1% of the variability could be associated with program selection. Schmidt concludes that:

> "Very little of the variability in the spatial aspects of a single aiming response is associated with variability in program selection; rather; the variability appears to be caused by variability in the particular parameter selection or in motor unit recruitment. Locating the exact source of this latter variability could have important implications in understanding motor behaviour." (p.433)

Schmidt et al (1979) extend the theory of impulse variability and programmed motor control to apply to motor responses other than hitting a target. In a rapid timing rask Schmidt reports that the variable error for timing is essentially unrelated to the amplitude of the movement and directly related to the movement duration, (except for very small movement velocities). These results are also supported by Newell et al (1979).

In the reciprocal tapping task Schmidt reports correlations ranging from .67 to .84 for individual subjects between effective target width and impulse force.

> "This result provided some support for the idea that the impulse variability is a major determiner of W_e in the reciprocal-movement task." (p.440)

Schmidt et al (1979) go on to report that;

> "We have shown that the variability in movement endpoints (W_e) is linearly and directly related to the movement amplitude, independent of the movement time and independent of the mass to be moved." (p.446)

However, with movement times in excess of 200 msecs. Schmidt et al suggest that their model does not account very well for the effects of amplitude and movement time, which are accommodated well by Fitts' Law. Subsequently it is suggested that Fitts' Law, which is deriveable from the principles of feedback (Crossman and Goodeve, 1963; Keele, 1968) might account for slower responses while the Schmidt et al (1979) theory of motor output variability is more effective for movements of less than 200 msecs. However, Schmidt contends that the Fitts' Law may hold when the subject is attending to the movement. With movements not requiring the subjects attention it is possible that Schmidt's theory may hold even for slower moves.

> "We prefer to argue that when subjects make a programmed movement in everyday settings, they do in fact determine the distance and movement time in advance, with the movement accuracy being the result of these choices." (p.448)

Schmidt et al (1980) propose that the human operator is able to switch between controlled modes of action and actions based on motor programming on the basis of available processing capacity, and the attention demands of a particular situation. Schmidt suggests that subjects adopt feedback control when no other actions are present or the actions require little attention, since the 'cost' of allocating attention is no problem. However, when attentional demands are high, Schmidt suggests subjects abandon the costly feedback-based mode of control in favour of a pre-programmed mode.

The evidence presented by Schmidt et al (1978, 1979) could be interpreted as supporting a model of behaviour in which, for rapid movements, the subject executes motor programs and variability around the target is due to 'noise' in the motor system. For longer duration movements feedback control is adopted, and noise in the system can, therefore, be corrected for, resulting in less variability around the target. Schmidt's model, therefore, proposes a trade-off between accuracy and attentional demand of a task.

This theory is logically appealing but it does not account for one area of experimental evidence. When ballistic aiming movements are performed, i.e. less than 200 msecs. in duration, there is insufficient time for feedback loops to operate for ongoing control purposes. The movements, however are still performed smoothly, and with precision (Glencross, 1973, 1974). When feedback is blocked or distorted, the fine grading of movement and its temporal precision are lost, e.g. Bossom (1974). It would appear, therefore, that in order for a central control process (a motor program) to be executed efficiently it must be integrated in some way with peripheral sensory information. Schmidt et al (1980) propose a switching mechanism based on attentional demand, which does not call for the completely integrated system that is apparently in operation.

To this end Glencross (1977) proposed a two stage integrated model. The first stage, or executive control system, is feedback dependent and is based on an analysis of th input and the relation of the signal to the response. The second stage consists of a motor program which once initiated will run its full course without intervention.

This theory can also account for attentional demand, since the executive system can combine predictable sequences of action and form larger units of action. In ballistic movements it is proposed that the single channel mechanism can operate directly through the motor program, that is to say, no time is spent in routine analysis by the executive system.

This proposition is well stated by Adams (1976):

> "This is a compromise hypothesis which seems very difficult to test. It is insufficient to show that either the motor program or feedback are governing agents for movement (the issue which is at the center of our scientific eye at the moment). Rather it must be shown that both the motor program and feedback are operating and also, the circumstances of their interaction must be demonstrated." (p. 99)

Other Theories of The Locus of Variability

Evidence From Neurophysiology

Bizzi, Polit and Morasso (1976) conducted research aimed at understanding some of the mechanisms whereby the central nervous system terminates a given phase in a motor sequence and maintains a newly acquired position. Using normal, intact monkeys and deafferented monkeys, Bizzi et.al. (1976) investigated the extent to which the termination of a centrally initiated head movement (coordinated eye-head response to the unexpected appearance of a stimulus in the animal's visual field), and the subsequent maintenance of posture, depended on the proprioceptive afferent input generated during the movement itself or, instead, the central programming of the movement.

Using vestibulectomized but otherwise intact monkeys, load disturbances were applied unexpectedly at the beginning and throughout centrally initiated head movements. The aim was to provoke a proprioceptive response in all types of neck receptors and to observe the outcome of this stimulation on the final head position. In a second set of experiments the afferent input was interrupted by cutting servical and thoracic dorsal roots and observing how the absence of proprioceptive feedback affected final head position.

Results indicated that final head position was determined by a central pattern of neural impulses which was programmed and was not reset by afferent proprioceptive impulses generated during the movement. Furthermore, Bizzi et al. (1976) provided evidence to support the theory that final position is an equilibrium point dependent on the firing rate and recruitment of motor neurons, the length tension properties of the muscles involved and the passive elastic properties of external loads.

This work cast doubt on the role of proprioceptive feedback in the control of movement endpoints and also re-emphasized the role of length tesion properties of the opposing muscle groups in determining the position of the limb in which torques in the two directions about the joint are equal. This idea was first posited by Crossman and Goodeve (1963) and termed the "mass-spring" view of motor control. It was later studied independently by Asatryan and Fel'dman (1965) and Fel'dman (1966a, 1966b).

Further work by Bizzi et al. (1978) has demonstrated that corrective responses to unexpected loading of muscles during a movement are only in small part due to reflexive activity. It would appear that the majority of corrective action is due to the mechanical properties of the muscle itself.

> "..showed that during the first 200msecs., the contribution of the neural component relative to the applied disturbance ranged from 10 to 30% of full compensation in deafferented animals and that a significant proportion (from 20 to 40%) of the total compensation was due to the intrinsic mechanical properties of the musculature." (Bizzi et al. 1978 p. 553)

Possibly the most important work conducted by Bizzi and Polit (1979) examined the processes controling arm movements. Bizzi et al. examined normal, intact monkeys and monkeys with bilateral dorsal rhizotomy, (C2 - T3) performing forearm positioning tasks. In both cases the pointing tasks were performed without sight of the arm. During the experiments the arms were unexpectedly displaced prior to initiation of the movements. The intact monkeys were able to move accurately to the target. Similarly, this procedure yielded qualitatively the same results in deafferented monkeys. Bizzi et al (1979) suggest that these results can be explained by postulating that the motor program specifies, through the selection of a set of length tension properties in agonist and antagonist muscles, an equilibrium point between these two sets of muscles that correctly positions the arm in relation to the visual target.

The position is qualified by the suggestion that this process must be accompanied by a mechanism controlling arm velocity. Also, the mechanism by which the described process is intitated is still unknown. Bizzi et al (1979) state that:

> "The postulated independence of the processes controlling velocity, indicates that a number of parallel processes underlie arm movement, and that motor control may be thought to be organised in a modular fashion." (p.193)

Results also demonstrated that displacing the arm from the body caused the responses of deafferented monkeys to become inaccurate, while the intact monkeys quickly compensated for the new relative position of the arm to the body. According to Bizzi et al:

> "The dramatic inability of the deafferented monkey to execute accurate pointing responses in an unusual postural setting or when a constant bias load was applied underscores the great importance of afferent feedback in updating and adjusting the execution of learned motor patterns when posture is changed." (p.193)

This evidence presented is, as Schmidt (1980) comments: "particularly damaging for an impulse timing view of motor programming, at least for this kind of movement." (p.151).

Evidence which tentatively supports the proposition of parallel processes in the control of movement is given by Falkenberg and Newell (1980). They report that reaction time, (the time between a start signal and the beginning of a movement) has been generally accepted as a measure of the processing demands of movement initiation. Kerr (1978) and Klapp (1976, 1978) suggested that variations in reaction time due to manipulation of various response parameters indicated the degree to which the parameter was a feature in response programming.

The only response parameter consistently seen to affect reaction time, as reported earlier, has been movement time (Kerr, 1978; Klapp et al, 1974). However, Falkenberg and Newell (1980) suggest that initiation time differences attributed to movement time could equally have been explained by variations in average velocity. They cite the work of Klapp and Erwin (1976) in which, as average velocity of movement increased, initiation time decreased in a systematic fashion. Newell et al (1979) demonstrated further, that different movement time amplitude combinations, which generate the same mean velocities, had similar initiation times. Falkenberg and Newell state that:

> "It seems, therefore, that average velocity rather than movement time may be the key kinematic parameter determining response initiation time." (p.761)

Falkenberg and Newell (1980) demonstrated, using self-timed movements, simple response techniques, and choice response techniques, that initiation time decreased as average velocity of movement increased.

Conclusions from this research should be treated with caution however, since, as demonstrated by Schmidt et al (1978), initiation time covaried with velocity and also impulse force. According to Falkenberg and Newell (1980):

> "Indeed it seems entirely reasonable that the system is programmed around the force-time or impulse requirements of the response, which are dictated by the mass of the system being moved, together with the kinematic demands particularly average velocity, of the criterion response. In other words, kinematic requirements may be mere concomitants or determiners of programming rather than features of the program." (p.767)

Although the theory that control and coordination of movement may be partly based on the viscous and elastic properties of the muscle joint system, has only recently been recognized, it was proposed as early as 1947 by Bernstein (reported in Bernstein, 1967). Bernstein suggested that when muscles acting at a joint are constrained to act as a unit, the linkage is describeable as a class of vibrating system whose physical and behavioural characteristics are qualitatively similar to a mass-spring. Asatryan and Feldman (1965) and Feldman (1966) demonstrated that when subjects were required to hold a constant angle at the elbow joint against a resistance, changes in the load resulted in changes in joint angle that were predictable as the behaviour of a non-linear spring.

Kelso and Holt (1980) suggest that this mass-spring account of limb localization reduces many of the problems confronting theorists in movement control.

> "Perhaps its major characteristic for our purpose is that it is intrinsically self equilibrating: once set in motion the spring will always come to the same resting length for any particular load value. Neither an increase in the initial deflection of the spring from its resting length nor temporary perturbations will prevent the achievement of the equilibrium point...." (p.409)

One concern of theorists has been to explain how the brain accommodates variability in the context within which movements occur; labelled by Turvey et al (1978) as "context-conditional variability." Simply, this refers to the lack of an invariant relationship between centrally generated signals and movement autocues, what Schmidt (1978,

1979) would call motor-output variability. Since the mass-spring disregards initial conditions and is impervious to perturbations of movement trajectory, it goes some way to alleviating this problem.

Aslo of concern is how end point might be achieved through a variety of movement trajectories and diverse kinematic details such as velocity and amplitude. According to Kelso and Holt (1980) it is not the kinematic details but the underlying dynamic parameters of mass, stiffness and viscosity that are important in the regulation of movement. Specification of these dynamic parameters determines kinematic details and variability in these parameters will effect the equilibrium process only in terms of the observed kinematics but not in achievement of equilibrium position.

Kelso and Holt (1980) have attempted to determine whether any of the observed kinematic characteristics that occur in localization violate the mass-spring model. One prediction is that production of terminal location will be superior to production of amplitude since terminal location is specified by a motor program as an equilibrium point. However, amplitude production requires programming of new equilibrium points as the initial conditions vary. Kelso and Holt (1980) demonstrated that reproduction of location is hardly affected by changes in initial starting point, whereas amplitude reproduction reflects a bias to reproduce location.

> "....the data are consonant with the equifinality characteristic of a mass-spring system. That is, despite changes in initial conditions (displacement of a limb to a new starting position) a mass-spring system will always reach an invariant final position or equilibrium as determined by its parameters."

Further, Kelso and Holt demonstrated that accuracy of movements was not affected by perturbations which again supports the mass-spring view.

Cooke and Eastman (1977) and Evarts and Granit (1976) have proposed fast acting feedback loops, acting in a closed loop manner, to account for these findings. However, Kelso and Holt (1980), using a wrist-cuff technique, demonstrated that performance in a localization task showed no significant difference between perturbed and non-perturbed trials, even in the absence of sensory feedback.

While the mass-spring theory of limb localization appears to account for many observed phenomena in movement, the applicability of this engineering analogy to the human muscular system is open to some dispute. Houk (1976) demonstrated that when loaded, skeletal muscle fails to demonstrate the same characteristic elastic properties of springs as suggested by Bizzi et al (1976, 1978); Polit and Bizzi (1979); Kelso and Holt (1980) and by earlier worker (Bernstein, 1947; Crossman and Goodeve, 1963). In fact, Houk (1976) demonstrated that the spring analogy to muscle breaks down if the muscle is stretched by only 1% of its original length. Houk goes on to propose that the important property of muscle in the control of limb localization is the property of 'stiffness' which is the function of length and tension.

This theory is well supported by evidence from neuromuscular physiology which has demonstrated the presence of fast acting feedback loops which may be responsible for adjusting stiffness of the muscle throughout movement (Garnett & Stephens, 1980;

Buller, Garnett & Stephens, 1980). Furthermore, many deafferentation studies demonstrate loss of fine motor coordination of deafferented limbs while gross accuracy is maintained. This observation led Glencross (1977) to propose a two tier model of movement control which is paralleled by the current theories of alpha-gamma coactivation as the means of movement control.

Clearly, therefore, while the 'mass-spring' has attracted a great deal of attention from psychologists, its enthusiastic reception must be tempered by a regard for the evidence from neuromuscular physiologists and engineers.

Summary and Conclusions

This chapter has presented a number of conceptual approaches to the theories of movement control. The early work of Fitts' (1954) emphasized an information processing approach to movement control. The theory stated that if repetitive movements of average amplitude are speeded up then each movement can provide less information and, therefore, variability in the movement or its duration will increase. Accounting for this theory, Crossman and Goodeve (1963) proposed a system of control based on the continual monitoring of feedback. The most contradictory evidence to this point of view comes from study of deafferentation in which decrements in performance were not noted in the absence of sensory feedback.

Schmidt et al (1978, 1979) in examining the locus of variability in movement, proposed an impulse timing representation of movement control. Such a theory suggested that variability in movement endpoint was due to variability in force production and time production mechanisms. However, while Fitts' law is seen to hold for longer amplitude, slow movements, Schmidts law accomodates only short duration, ballistic type movements.

The existence of two, independent methods of movement control would appear excessively complicated. Most recent studies, especially those concerned with deafferentation have favoured a method of movement control which takes advantage of the passive elastic properties of the agonist and antagonist muscles. The mass-spring theory proposes that final limb position is an equilibrium point based on the firing rate and recruitment of motor units, the length tension properties of the muscles involved and the passive elastic properties of the loaded muscles. This theory was first proposed by Crossman and Goodeve (1963) and has recently been supported by the work of Bizzi et al. (1974, 1978); Polit and Bizzi (1979) and Kelso and Holt (1980). Such a theory accomodates the observations that final endpoints can be achieved by a number of varying trajectories, velocities and forces. This view of movement control and the evidence to support it, are particularly damning for the impulse timing view of control. Impulse timing hypothesises that if the mass of a limb is increased then the time production mechanism will meter out the same length of time and since the force is maintained then the limb will fall short of the target. However, this situation is not observed as increasing the mass of the limb (Polit & Bizzi, 1979) does not prevent acquisition of the target. This supports the mass-spring view of control.

Although the mass-spring theory of movement control is regarded, even by Schmidt and McGown (1980) as damaging to the motor output variability theory, one or two questions still remain. Polit and Bizzi (1979) have proposed that although the mass-spring theory accounts for correct positioning of limbs, it must be accompanied by a mechanism which controls limb velocity. It is proposed that these mechanisms underlying limb movement are independent but act in parallel.

Reaction time is generally accepted as a measure of processing demands and variations in reaction time due to manipulation of response parameters indicate the degree to which a parameter is a feature in response programming. The only response parameter consistently seen to affect reaction time has been movement time (Klapp et al , 1974; Kerr, 1978). However, Falkenberg and Newell (1980) have shown that these variations in reaction time could equally be attributed to variations in average velocity. As a result, the possibility still remains that the system is programmed around the force-time or impulse requirements of the response, since Schmidt et al (1978) demonstrated that reaction time varied not only with velocity but also with impulse force.

It could be that the theory of Schmidt et al although not speaking directly to this point, account for the proposed parallel process governing velocity described by Polit and Bizzi (1979).

APPENDIX B

Figure A shows the rate of change of velocity with time as represented in digital values per second. This data was obtained from the accelerometer during one trial from one subject performing a 40 cm. movement. Digital values have been adjusted by subtracting 200 from each value in order to reduce the length of the Y axis. 312 digital values, therefore, represents zero acceleration. Values below 312 represent acceleration, while those above 312 represent decceleration. Due to noise in the system and the extreme sensitivity of the accelerometer, a small fluctuation around the zero value is present even when the accelerometer is at rest.

Time has been partitioned into four units:

1. Represents time from the presentation of the signal to move to the initiation of the response by the subject. This is, therefore, a measure of reaction time.

2. Represents the time during the movemnet in which the limb undergoes acceleration. This is the time of acceleration. The area under the curve bounded by the two lines of 2 represents the accelerative impulse.

3. Represents the time during the movement in which the limb undergoes dec~~c~~eleration. This is the time of dec~~c~~eleration. The area under the curve bounded by the two lines of 3 represents the dec~~c~~elerative impulse.

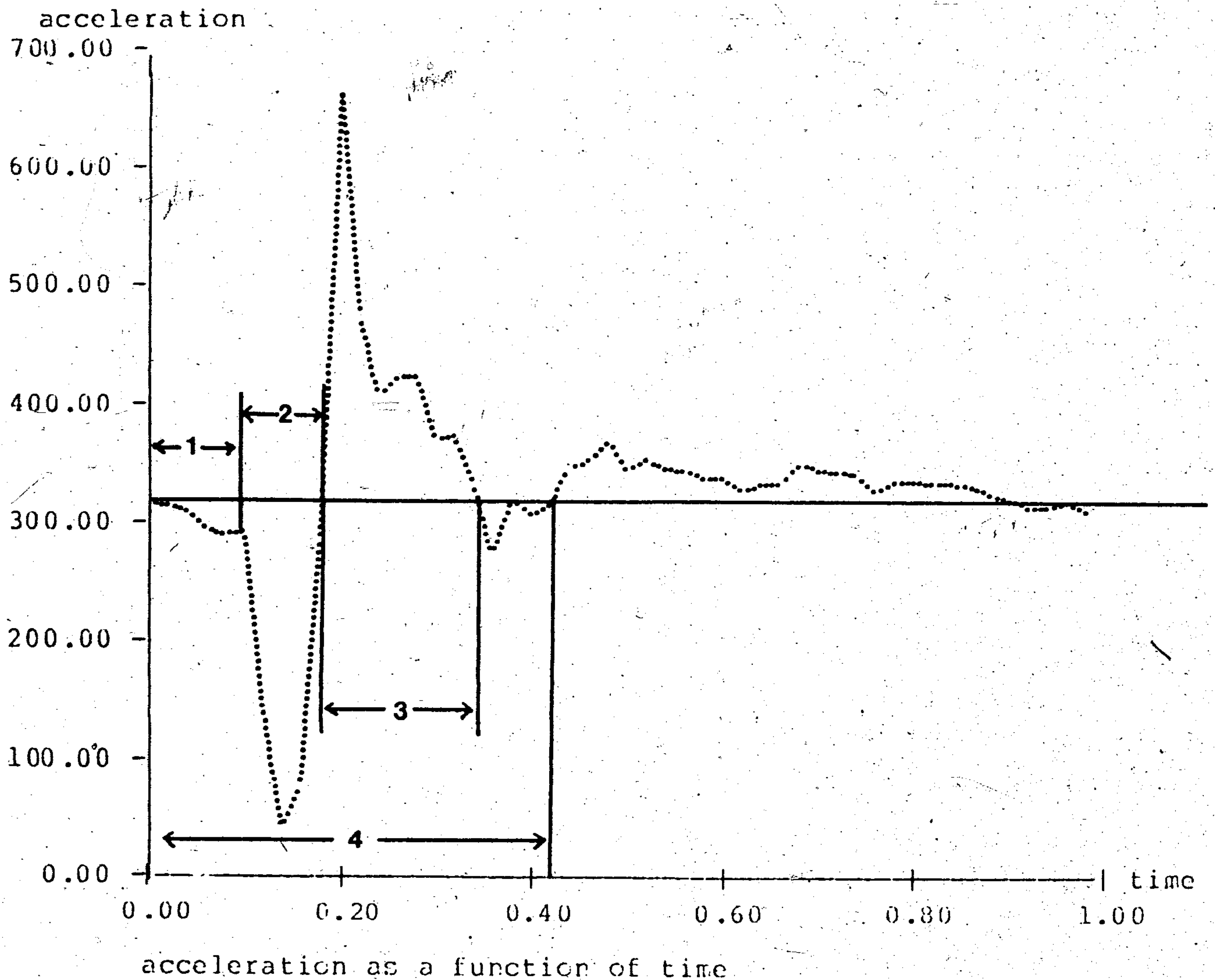


Figure A

Digitally coded analog data from accelerometer for one trial for a single subject performing a 40 cm. movement.

4. Represents the time from the presentation of the signal to move to the completion of the response by the subject. This is a measure of the total movement time.

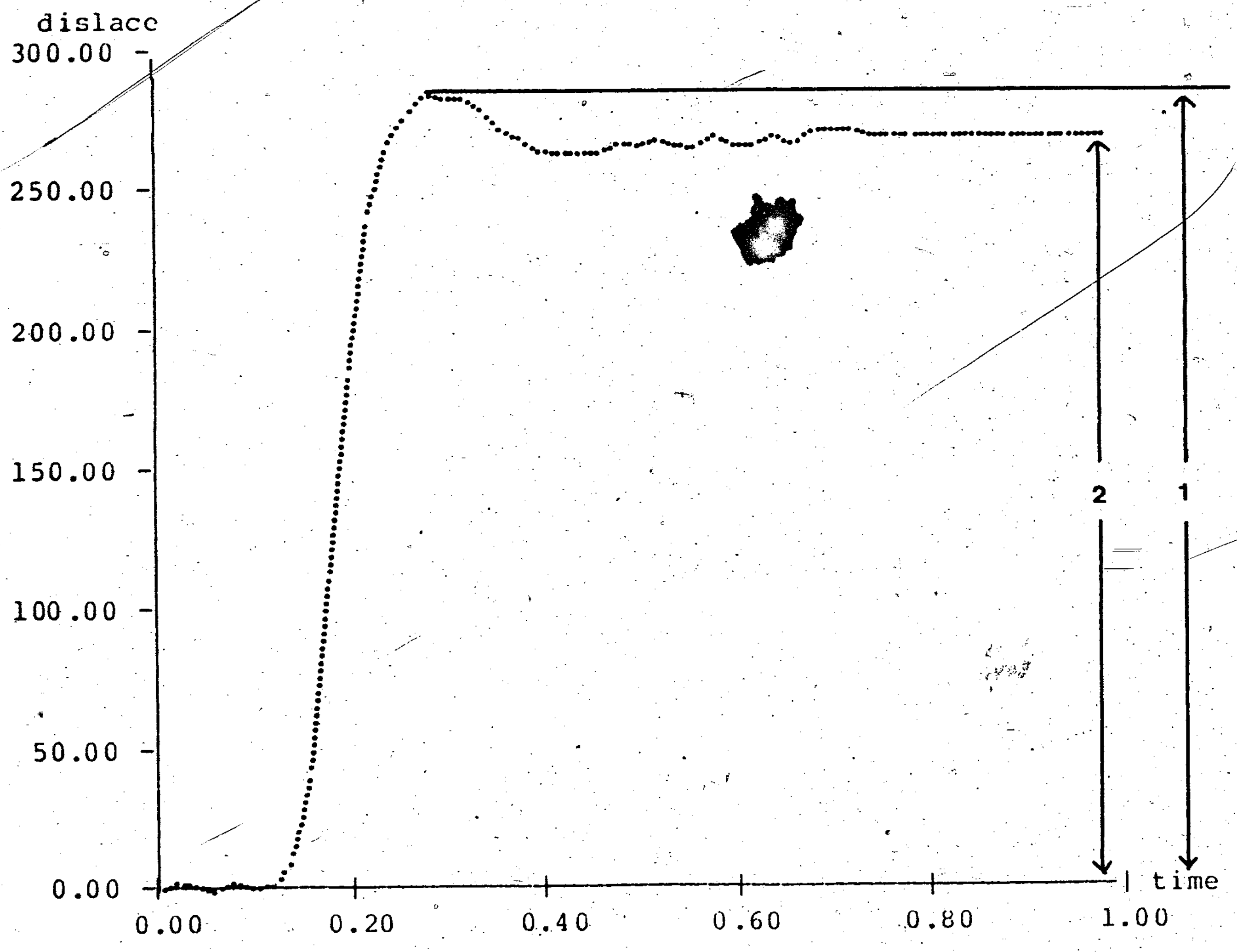
The computer was programmed to calculate the variables listed for each trial completed under each amplitude of movement. Results were printed in tabular form.

Figure B shows the displacement as measured in digital values over time for a single trial by one subject performing a 40 cm. movement. The data has been partitioned into two units:

1. Represents the distance in digital values that the subject moved prior to the initiation of a correction.

2. Represents the distance moved in digital values following a correction.

The computer was programmed to calculate these distances for each trial performed for each amplitude of movement.



displacement as a function of time

Figure B

Shows displacement in digital values for a subject performing a single trial of amplitude 40 cm.

APPENDIX C

C

Table

Analysis of Variance

Experiment 1 Variable: Reaction Time

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	1	2011376.0	22.00*
AMPLITUDE (A)	2	43368.000	3.00
GP X A	2	33416.000	2.31
TRIALS (T)	19	3238.7368	1.25
GP X T	19	2654.3157	1.02
A X T	38	2013.4736	0.92
GP X A X T	38	2086.3157	0.95
SUBJECTS (S)	19	192474.00	
GP X S	18	91424.000	
GP X A X S	36	14474.219	
GP X T X S	342	2600.5140	
GP X A X T X S	684	2185.1460	

Table

Analysis of Variance

Experiment 1 Variable: Time of Acceleration

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	14005.500	5.94*
AMPLITUDE (A)	2	47720.000	46.05*
GP X A	4	717.25000	0.69
TRIALS (T)	19	265.31367	0.97
GP X T	38	197.63158	0.72
A X T	38	288.52612	1.08
GP X A X T	76	215.77631	0.81
SUBJECTS (S)	29	3161.2700	
GP X S	27	2358.0000	
GP X A X S	54	1036.3500	
GP X T X S	513	274.27000	
GP X A X T X S	1026	265.93000	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Time of Deceleration

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	93208.000	4.84*
AMPLITUDE (A)	2	110776.00	8.21*
GP X A	4	2459.9990	0.18
TRIALS (T)	19	2189.4736	0.34
GP X T	38	8003.7891	1.23
A X T	38	5663.5781	0.91
GP X A X T	76	5367.5781	0.86
SUBJECTS (S)	29	24354.650	
GP X S	27	19253.333	
GP X A X S	54	13494.219	
GP X T X S	513	6492.2200	
GP X A X T X S	1026	6206.7900	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Distance Moved Prior to Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	6728.0000	0.93
AMPLITUDE (A)	2	4341160.0	1479.9*
GP X A	4	536.00000	0.18
TRIALS (T)	19	946.52612	1.25
GP X T	38	693.05249	0.91
A X T	38	906.10522	1.15
GP [illegible] A X T	76	950.10522	0.11
SUBJECTS (S)	29	7163.5860	
GP X S	27	7195.8500	
GP X A X S	54	2933.3300	
GP X T X S	513	758.20600	
GP X A X T X S	1026	787.94500	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Distance Moved Following Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	1512.0000	0.55
AMPLITUDE (A)	2	4813840.0	7110.1 *
GP X A	4	980.00000	1.45
TRIALS (T)	19	103.57893	0.53
GP X T	38	98.526306	0.50
A X T	38	234.10526	1.19
GP X A X T	76	261.69000	1.33
SUBJECTS (S)	29	2680.2700	
GP X S	27	2766.8100	
GP X A X S	54	677.03000	
GP X T X S	513	197.17700	
GP X A X T X S	1026	196.19000	

* $p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Accelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	724.836×10^6	7.74*
AMPLITUDE (A)	2	187.800×10^7	60.32*
GP X A	4	31401984.0	1.01
TRIALS (T)	19	5200008.00	1.19
GP X T	38	4566069.00	1.03
A X T	38	5357244.00	1.21
GP X A X T	76	5167481.00	1.16
SUBJECTS (S)	29	2743766.00	
GP X S	27	93658832.0	
GP X A X S	54	31187696.0	
GP X T X S	513	4436630.00	
GP X A X T X S	1026	4444391.00	

$*p < .05$

Table

Analysis of Variance

Experiment 1 Variable: Decelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	886.01×10^6	1.72
AMPLITUDE (A)	2	428.84×10^7	31.22*
GP X A	4	29163520.0	0.21
TRIALS (T)	19	30156896.0	0.56
GP X T	38	42531136.0	0.79
A X T	38	41296288.0	0.84
GP X A X T	76	37907392.0	0.77
SUBJECTS (S)	29	1621202.40	
GP X S	27	514799620.0	
GP X A X S	54	137342820.0	
GP X T X S	513	53545584.00	
GP X A X T X S	1026	49029536.00	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Duration of Accelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	138.630	5.83*
AMPLITUDE (A)	2	59.1750	2.248
GP X A	4	15.4830	0.58
SUBJECTS (S)	29	31.6900	
GP X S	27	23.7690	
GP X A X S	54	26.3220	

*$p < .05$

Table

Analysis of Variance

Experiment 1 Variable: S.D. Duration of Decelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	11292.75	4.902*
AMPLITUDE (A)	2	107.7500	0.062
GP X A	4	710.0780	0.407
SUBJECTS (S)	29	2923.580	
GP X S	27	2303.630	
GP X A X S	54	1745.890	

*$p < .05$

Table

Analysis of Variance

Experiment 1   Variable: S.D. Accelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	1021717.00	2.036
AMPLITUDE (A)	2	2821120.00	9.482*
GP X A	4	38400.0000	0.128
SUBJECTS (S)	29		
GP X S	27	501826.130	
GP X A X S	54	299633.750	

Table

Analysis of Variance

Experiment 1 Variable: S.D. Decelerative Impulse

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2		1.369
AMPLITUDE (A)	2		4.981*
GP X A	4		0.491
SUBJECTS (S)	29		
GP X S	27		
GP X A X S	54		

Table

Analysis of Variance

Experiment 1 Variable: S.D. Distance Moved Prior to Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	9.24800	0.122
AMPLITUDE (A)	2	1607.19	26.532*
GP X A	4	57.3400	0.947
SUBJECTS (S)	29	70.9400	
GP X S	27	75.5130	
GP X A X S	54	60.5740	

Table

Analysis of Variance

Experiment 1 Variable: S.D. Distance Moved Following Correction

SOURCE	DF	MS	F
TREATMENT GROUP (GP)	2	2.1780	0.233
AMPLITUDE (A)	2	220.41	20.926*
GP X A	4	5.8180	0.552
SUBJECTS (S)	29	8.8490	
GP X S	27	9.3440	
GP X A X S	54	10.533	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Reaction Time

SOURCE	DF	MS	F
AMPLITUDE (A)	2	14521.9	2.10
PERIPHERAL TARGET WIDTH (PTW)	2	13550.5	1.129
SUBJECTS (S)	4	93988.2	
A X PTW	4	13082.1	1.816
A X S	8	6914.04	
PTW X S	8	11993.9	
A X PTW X S	16	7201.81	

Table

Analysis of Variance

Experiment 2 Variable: Duration of Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	1844.796	18.915*
PERIPHERAL TARGET WIDTH (PTW)	2	291.4450	5.985*
SUBJECTS (S)	4	26.44100	
A X PTW	4	113.6640	1.344
A X S	8	97.52900	
PTW X S	8	48.69100	
A X PTW X S	16	84.57200	

*p < .05

Table

Analysis of Variance

Experiment 2 Variable: Duration of Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	7946.670	7.029*
PERIPHERAL TARGET WIDTH (PTW)	2	224.8090	1.137
SUBJECTS (S)	4	1603.608	
A X PTW	4	1233.877	2.820
A X S	8	1130.548	
PTW X S	8	197.7250	
A X PTW X S	16	437.4260	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Movement Time

SOURCE	DF	MS	F
AMPLITUDE (A)	2	41595.73	5.213*
PERIPHERAL TARGET WIDTH (PTW)	2	18749.68	1.232
SUBJECTS (S)	4	136598.0	
A X PTW	4	12177.49	0.578
A X S	8	7976.488	
PTW X S	8	15216.74	
A X PTW X S	16	6069.438	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	57522718.0	45.92*
PERIPHERAL TARGET WIDTH (PTW)	2	2520564.00	2.789
SUBJECTS (S)	4	19618000.0	
A X PTW	4	989102.000	1.481
A X S	8	1252668.00	
PTW X S	8	903544.000	
A X PTW X S	16	667482.000	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	145684050	6.864*
PERIPHERAL TARGET WIDTH (PTW)	2	15866323.0	1.746
SUBJECTS (S)	4	120411130	
A X PTW	4	35478570.0	3.252*
A X S	8	21223240.0	
PTW X S	8	9089092.00	
A X PTW X S	16	10909311.0	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Distance Moved Prior to Correction

SOURCE	DF	MS	F
AMPLITUDE (A)	2	98916.92	159.290*
PERIPHERAL TARGET WIDTH (PTW)	2	946.8380	3.102*
SUBJECTS (S)	4	1386.915	
A X PTW	4	441.2110	2.928
A X S	8	620.9810	
PTW X S	8	305.1380	
A X PTW X S	16	150.652	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: Distance Moved Following Correction

SOURCE	DF	MS	F
AMPLITUDE (A)	2	109572.1	239.430*
PERIPHERAL TARGET WIDTH (PTW)	2	506.621	1.813
SUBJECTS (S)	4	284.961	
A X PTW	4	151.057	2.403
A X S	8	457.626	
PTW X S	8	279.433	
A X PTW X S	16	62.8200	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Distance Moved Prior to Correction

SOURCE	DF	MS	F
AMPLITUDE (A)	2	1979.77	11.96*
PERIPHERAL TARGET WIDTH (PTW)	2	40.6350	5.05*
SUBJECTS (S)	4	228.753	
A X PTW	4	234.735	2.44
A X S	8	165.431	
PTW X S	8	8.04800	
A X PTW X S	16	96.2300	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Duration of Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	748.480	1.276
PERIPHERAL TARGET WIDTH (PTW)	2	715.765	2.375
SUBJECTS (S)	4	112.673	
A X PTW	4	698.384	2.039
A X S	8	586.551	
PTW X S	8	301.388	
A X PTW X S	16	342.348	

Table

Analysis of Variance

Experiment 2 Variable: S.D. Duration of Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	8042.14	5.539*
PERIPHERAL TARGET WIDTH (PTW)	2	617.765	1.746
SUBJECTS (S)	4	3767.49	
A X PTW	4	2853.16	2.215
A X S	8	1451.84	
PTW X S	8	353.744	
A X PTW X S	16	1288.28	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Accelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	2844753.0	4.68*
PERIPHERAL TARGET WIDTH (PTW)	2	721466.00	3.47
SUBJECTS (S)	4	62335.000	
A X PTW	4	527763.0	1.87
A X S	8	607734.0	
PTW X S	8	208001.0	
A X PTW X S	16	281419.0	

*$p < .05$

Table

Analysis of Variance

Experiment 2 Variable: S.D. Decelerative Impulse

SOURCE	DF	MS	F
AMPLITUDE (A)	2	11460300.0	6.53*
PERIPHERAL TARGET WIDTH (PTW)	2	8303421.00	1.16
SUBJECTS (S)	4	67239232.0	
A X PTW	4	40652767.0	2.24
A X S	8	17561313.0	
PTW X S	8	7163444.00	
A X PTW X S	16	18118271.0	

*$p < .05$

APPENDIX D

Raw Data from Experiments One and Two

The data for experiment one is organized in the following manner:-

Column	1	Treatment Condition
Columns	2-3	Amplitude of Movement
Columns	4-5	Subject Number
Columns	6-7	Trial Number
Columns	9-11	Reaction Time
Columns	13-15	Duration of Accelerative Impulse
Columns	17-19	Duration of Decelerative Impulse
Columns	21-23	Movement Time
Columns	25-27	Distance Moved Without Correction
Columns	29-31	Distance Moved Following Correction
Columns	33-37	Accelerative Impulse
Columns	39-43	Decelerative Impulse

For Experiment Two data will be found in the same columns. Columns 1-6 are as follows:-

Column	1	Subject Number
Columns	2-3	Amplitude of Movement
Column	4	Peripheral Target Width
Columns	5-6	Trial Number

EXPERIMENT 1

```
1100101 070 046 086 230 071 068 04010 07773
1100102 070 034 086 210 068 063 02268 07272
1100103 072 070 078 266 085 069 04254 06926
1100104 098 060 062 248 068 068 04994 04463
1100105 072 036 104 234 072 068 02278 09275
1100106 092 048 056 266 057 057 03082 04857
1100107 070 058 084 244 086 075 04838 06665
1100108 070 044 080 244 096 079 05455 09169
1100109 070 050 086 250 083 074 04962 06569
1100110 094 066 044 224 078 082 05839 03697
1100111 076 062 102 260 065 066 05843 09380
1100112 138 064 118 340 091 080 05742 10120
1100113 070 046 148 284 076 076 04167 15032
1100114 070 054 060 204 070 070 04207 06677
1100115 244 048 084 412 080 072 02380 06442
1100116 070 050 082 230 087 081 05542 07477
1100117 134 060 078 390 083 055 04836 08735
1100118 070 036 054 180 065 062 02595 06623
1100119 070 044 076 234 082 069 03869 07900
1100120 270 040 240 570 071 072 05868 22003
1200101 070 072 092 254 129 131 06642 08062
1200102 218 084 034 356 116 130 07882 03069
1200103 088 030 088 226 118 122 01267 08988
1200104 204 074 058 386 137 139 09184 05110
1200105 074 048 382 540 129 130 05095 39693
1200106 230 074 060 418 136 134 08978 06395
1200107 070 064 176 336 131 124 08714 23153
1200108 078 068 034 220 098 126 05390 01517
1200109 228 054 062 404 131 142 03248 05249
1200110 076 046 078 234 108 106 05138 08484
1200111 086 074 148 356 123 127 07367 15026
1200112 134 082 040 276 113 119 05445 01995
1200113 070 062 160 332 137 129 08945 18283
1200114 076 060 172 338 113 116 09048 30150
1200115 094 060 030 462 114 122 07570 02279
1200116 070 048 340 478 127 130 09102 58376
1200117 072 058 178 328 139 139 07448 18630
1200118 142 070 394 630 124 127 06955 55677
1200119 114 064 058 394 139 127 08820 08630
1200120 106 062 236 428 122 118 06268 28967
1400101 072 050 130 298 265 253 07301 14205
1400102 100 082 152 370 277 269 09632 17725
1400103 230 074 138 462 257 254 09937 16087
1400104 092 078 104 294 267 268 12194 13310
1400105 070 062 056 208 246 255 09196 10751
1400106 070 056 160 320 259 254 08206 16002
1400107 070 068 144 318 282 266 09830 15922
1400108 104 076 178 378 272 265 10672 18497
1400109 082 080 124 266 280 288 10974 11579
1400110 094 082 096 282 274 271 11483 14994
1400111 070 072 056 236 290 287 11762 12082
1400112 226 072 072 442 237 247 11283 11331
1400113 070 030 186 306 237 235 02070 21827
1400114 070 070 080 240 291 289 12552 15647
1400115 078 074 082 264 273 273 11416 13788
1400116 094 084 074 234 251 254 12045 13321
1400117 102 078 154 366 248 238 12399 18278
1400118 070 066 104 260 279 280 11181 12654
1400119 094 088 062 264 243 256 09494 09485
1400120 070 050 188 328 238 231 05667 22478
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1100201 070 058 352 352 065 065 08330 17350
1100202 070 068 056 294 105 059 06959 10282
1100203 078 036 086 378 091 055 04089 10934
1100204 070 058 084 298 106 054 06368 12610
1100205 070 052 032 492 116 072 06373 11484
1100206 144 062 132 398 067 063 07133 19988
1100207 070 062 076 244 092 072 05440 09768
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3402115	060	030	414	148	208	05171	00212
3402116	060	088	636	229	205	02587	10668
3402117	048	116	594	224	202	03187	12228
3402118	080	114	608	262	231	07749	14311
3402119	082	090	684	253	238	07202	12152
3402120	036	036	438	187	215	01894	03707

3102201	056	030	342	069	072	02919	01831
3102202	054	032	372	071	080	04617	01392
3102203	062	030	360	072	082	05515	00164
3102204	054	066	444	086	070	03136	05312
3102205	050	036	352	067	074	02319	01375
3102206	032	124	438	074	068	01647	07810
3102207	050	102	436	070	064	02083	06894
3102208	066	030	374	068	078	03682	00913
3102209	030	030	430	057	070	00789	02472
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3102211	054	052	360	078	077	03679	03668
3102212	064	036	514	060	069	03394	00394
3102213	056	050	758	079	076	03923	01368
3102214	060	056	756	068	065	03997	03559
3102215	052	084	438	078	073	03553	04554
3102216	032	044	354	065	079	01058	02576
3102217	050	032	366	056	067	01780	01057
3102218	050	082	396	073	055	01886	04258
3102219	048	032	384	065	079	01556	02742
3102220	048	084	456	084	063	02859	05714
3202201	066	128	444	150	137	06264	11899
3202202	030	040	166	103	125	01231	03530
3202203	120	094	716	152	138	06233	07040
3202204	046	106	446	126	117	01459	08438
3202205	058	030	376	110	143	06409	01184
3202206	042	128	606	155	145	02919	08416
3202207	044	178	662	122	124	02790	17119
3202208	048	142	470	131	122	03900	14016
3202209	048	086	494	138	139	02003	08198
3202210	056	156	592	121	120	01839	11965
3202211	048	044	448	120	136	02763	04020
3202212	056	070	418	144	142	04759	06327
3202213	052	076	482	146	141	04371	07136
3202214	058	110	450	130	116	05206	11817
3202215	120	032	810	123	138	06298	01128
3202216	060	040	386	110	131	04595	02660
3202217	040	038	390	115	142	04504	01660
3202218	058	162	728	121	118	06193	21800
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3402202	060	168	524	261	258	06124	11052
3402203	080	082	416	259	261	08522	09108
3402204	088	092	484	266	265	08687	11171
3402205	090	074	464	253	257	07914	08644
3402206	062	080	444	276	274	08595	12061
3402207	068	032	566	185	237	07408	02421
3402208	068	072	468	278	274	08433	10262
3402209	068	082	556	259	253	07618	09713
3402210	050	050	614	245	242	05652	10498
3402211	066	070	496	250	255	06570	09136
3402212	082	042	406	236	252	09575	04249
3402213	086	284	676	245	247	06958	18001
3402214	064	084	546	286	284	10427	12251
3402215	062	084	474	249	245	06995	08416
3402216	078	034	418	188	238	10173	04873
3402217	066	078	830	275	244	08614	07267
3402218	074	050	468	213	237	05575	04999
3402219	066	066	672	248	248	07995	04518
3402220	068	084	426	246	244	06267	10461

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3102305	032	064	346	050	046	00778	04324
3102306	058	048	322	084	084	05226	01919
3102307	088	048	272	069	066	04857	04111
3102308	050	090	342	063	054	01566	10742
3102309	074	056	252	080	080	07009	02113
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3102311	034	056	256	075	074	01727	05944
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3102313	048	088	392	053	041	02145	03949
3102314	086	046	308	071	072	05770	00988
3102315	032	106	334	085	065	01007	17065
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3102317	054	080	358	059	046	03447	07678
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3202302	052	054	296	143	155	04194	03279
3202303	086	042	302	128	147	06237	01258
3202304	058	048	338	142	148	04148	03149
3202305	052	072	386	157	152	03311	06969
3202306	072	044	352	128	128	05036	03176
3202307	078	042	314	143	146	06463	03080
3202308	076	060	310	148	148	04230	05088
3202309	064	050	516	158	138	05947	04608
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3202312	072	052	406	158	158	08607	03298
3202313	076	068	398	159	152	05336	03123
3202314	034	046	450	119	119	00855	02207
3202315	058	368	690	131	136	06018	35977
3202316	088	034	434	139	139	16278	01161
3202317	056	042	364	147	147	08345	03374
3202318	062	052	680	127	129	05070	04046
3202319	072	052	406	158	158	08600	03498
3202320	090	140	401	126	128	08491	03476
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3402304	040	146	452	257	257	03865	29006
3402305	048	140	346	272	266	04438	12215
3402306	066	036	244	184	234	07176	00745
3402307	064	098	370	287	281	11741	10971
3402308	058	116	268	250	243	07441	15038
3402309	094	116	502	277	240	16446	12377
3402310	078	102	304	262	262	08794	11762
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3402312	088	148	414	261	248	08758	24215
3402313	030	066	352	242	280	02115	12962
3402314	030	142	332	262	262	03999	20977
3402315	032	184	370	258	253	02255	27207
3402316	054	124	432	262	245	07126	18635
3402317	076	142	460	258	245	13549	23303
3402318	088	068	366	285	285	17905	05818
3402319	084	098	370	261	261	10134	15718
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3102405	086	092	348	106	080	07769	11560
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3102407	086	086	392	109	076	07745	11657
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3202402	088	092	308	131	133	04200	02405
3202403	146	046	292	113	130	06770	01249
3202404	044	104	424	149	132	05006	10359
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3202407	034	160	286	145	146	02510	09176
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3202418	064	332	668	133	131	06661	35984
3202419	072	128	354	161	152	05474	16513
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3402414	070	082	442	281	267	10040	06895
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3402417	060	076	400	305	259	09167	17643
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3202501	096	146	366	118	117	10796	24720
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3202503	044	032	264	102	118	04452	01528
3202504	060	096	446	142	131	05673	07541
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3202507	066	062	294	119	127	06676	01940
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3202513	074	052	312	104	115	04743	03055
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3402516	080	086	460	254	251	10737	09762
3402517	104	074	470	262	253	13885	11904
3402518	100	064	460	259	259	11881	09651
3402519	080	110	548	255	234	08204	15520
3402520	080	032	424	185	222	09113	04504

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3102603	048	030	178	067	076	03177	00495
3102604	048	078	326	083	074	02522	05290
3102605	090	066	372	096	067	09620	09023
3102606	048	030	284	073	085	02900	01659
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3102620	066	046	664	093	080	07806	02782
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3202603	074	036	232	093	112	02560	01690
3202604	074	030	232	118	145	06615	00685
3202605	094	048	306	116	128	08780	00676
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3202617	072	074	650	139	135	05366	03256
3202618	064	068	582	133	141	06379	06137
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3202620	064	036	236	103	117	05730	02843
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3402602	106	360	998	233	251	15125	78091
3402603	076	060	310	243	243	10298	06045
3402604	074	128	408	259	257	09281	13326
3402605	068	106	396	259	259	07599	12286
3402606	098	052	300	247	282	12532	04107
3402607	086	068	340	243	243	14460	07786
3402608	064	116	522	278	246	10752	11542
3402609	092	076	390	259	259	11323	10776
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3402617	084	134	460	256	243	10944	16507
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3202702	070	080	662	135	135	04653	04099
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3202705	050	124	362	149	138	03815	13201
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3202715	076	072	696	158	126	11252	04192
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3202717	060	062	586	126	126	06870	04150
3202718	050	254	962	125	119	03365	08392
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3402707	082	082	662	266	253	12507	10112
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3402716	080	040	340	192	221	07489	02980
3402717	076	142	484	253	242	07345	14208
3402718	078	094	440	250	247	10945	11166
3402719	072	144	480	233	232	08257	13842
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3102803	070	048	646	081	066	07037	02808
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3102806	068	042	712	093	065	08757	02240
3102807	060	066	860	090	066	02940	06200
3102808	030	056	352	057	055	00409	01793
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3202802	144	076	976	116	127	07756	01738
3202803	094	108	368	117	118	03644	03074
3202804	078	092	760	127	131	04360	05496
3202805	084	034	272	085	110	05523	00491
3202806	102	112	428	128	125	02312	06368
3202807	034	206	410	118	115	00963	10929
3202808	050	136	276	131	126	03606	12460
3202809	062	038	328	095	124	02572	01409
3202810	084	070	260	111	124	03965	03052
3202811	062	038	212	076	112	02633	00534
3202812	070	040	338	113	125	03522	00519
3202813	098	040	434	134	134	09123	01958
3202814	052	052	222	091	113	01577	03235
3202815	064	136	400	131	118	04215	10765
3202816	064	120	372	139	132	02560	11227
3202817	084	038	242	108	124	04126	00892
3202818	050	134	924	139	130	01765	12179
3202819	058	048	238	099	118	02649	02448
3202820	068	098	514	126	125	03886	09641
3402801	112	064	334	223	247	09412	01690
3402802	104	032	300	208	232	10451	01280
3402803	108	116	390	247	247	08569	05717
3402804	062	046	254	196	234	05298	01628
3402805	062	030	238	163	210	04355	00282
3402806	084	074	330	252	261	06242	04728
3402807	078	030	424	184	224	05263	02360
3402808	088	034	414	216	246	09869	01795
3402809	070	156	620	262	243	06552	13217
3402810	094	128	436	271	267	07075	09973
3402811	104	076	404	241	241	09556	05307
3402812	082	030	348	185	219	06203	01702
3402813	134	056	404	230	243	11144	04142
3402814	090	030	362	202	240	06408	01347
3402815	116	090	392	260	262	09204	06360
3402816	096	070	356	249	259	09986	04998
3402817	092	070	408	256	256	11137	05156
3402818	094	124	574	265	255	07253	09592
3402819	074	038	334	204	244	06618	01835
3402820	090	100	406	264	262	09929	05073

3102901	060	072	520	068	049	04798	11781
3102902	076	096	484	058	049	08041	17132
3102903	068	098	446	065	046	04412	23905
3102904	060	088	556	097	056	05588	07599
3102905	062	098	550	068	050	06630	16129
3102906	050	070	546	089	061	02999	09399
3102907	060	070	538	073	057	05606	09858
3102908	064	096	420	061	049	02937	15257
3102909	064	084	496	069	046	02534	06976
3102910	060	080	482	073	043	04537	10392
3102911	036	038	330	072	089	02339	00845
3102912	062	056	524	082	045	04738	08186
3102913	050	080	468	068	041	02628	10388
3102914	052	074	496	076	045	03984	07828
3102915	068	046	540	095	063	06081	09116
3102916	072	072	508	084	058	07124	09361
3102917	060	122	514	059	053	06198	19069
3102918	060	074	614	071	054	04877	08103
3102919	070	056	582	095	067	03606	15227
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3202901	080	080	668	175	118	09480	14881
3202902	074	076	604	176	136	11183	09330
3202903	068	070	532	140	116	07103	11508
3202904	056	090	572	153	105	05864	13197
3202905	056	108	526	152	113	04985	19883
3202906	062	094	536	156	130	05542	13593
3202907	068	050	560	167	111	07283	10645
3202908	096	040	456	163	143	10398	08952
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3202910	064	078	432	159	145	04550	10330
3202911	066	074	534	178	105	06225	11650
3202912	064	094	460	149	108	05916	16923
3202913	060	096	494	139	110	08208	14947
3202914	058	094	492	149	101	06395	15086
3202915	030	126	630	144	116	06723	22910
3202916	060	100	550	157	133	08041	17330
3202917	064	100	544	138	101	05846	16124
3202918	058	100	440	144	109	05375	18526
3202919	080	076	570	174	124	09627	09985
3202920	030	128	520	145	110	04972	15795
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3402902	084	098	690	277	244	10635	15030
3402903	078	112	614	248	222	10052	15319
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3402905	070	106	620	267	232	06908	18417
3402906	062	142	614	248	222	05254	20144
3402907	078	096	632	271	215	08457	15150
3402908	080	100	732	249	217	08787	15579
3402909	074	100	578	282	235	07798	13964
3402910	076	102	552	263	228	08355	17053
3402911	092	096	622	278	226	08947	13729
3402912	078	146	606	253	240	05284	21329
3402913	078	098	642	252	219	09500	12835
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3402915	068	132	588	250	219	07372	20689
3402916	068	112	652	248	225	05532	18167
3402917	086	104	718	267	240	07206	15195
3402918	064	090	652	284	237	07144	11439
3402919	106	042	868	293	235	16082	05128
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3103002	066	070	734	102	063	08116	05131
3103003	050	106	770	079	068	02855	10544
3103004	068	076	546	088	063	06351	05920
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3103006	064	080	778	084	063	02995	09724
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3103011	042	090	576	077	068	02020	07697
3103012	064	080	688	083	061	01980	11362
3103013	070	070	556	092	069	05450	06372
3103014	056	046	732	091	063	04173	03570
3103015	070	118	576	075	062	02686	10123
3103016	058	046	640	088	063	05770	03144
3103017	058	086	526	087	078	03055	10061
3103018	056	068	996	086	061	04360	05414
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3203002	062	038	364	114	139	07077	01379
3203003	036	034	294	113	135	03386	01764
3203004	054	128	468	140	130	02483	12402
3203005	050	106	384	147	135	04124	13748
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3203010	062	102	436	148	127	04465	10559
3203011	040	082	902	151	148	03387	07207
3203012	054	066	528	156	131	04974	07239
3203013	052	104	530	153	136	04588	11806
3203014	054	082	530	151	118	04589	12123
3203015	052	106	514	154	123	04686	13212
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3203017	056	074	936	143	125	05071	08425
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3403001	082	030	362	198	242	07369	02220
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3403007	136	130	562	269	261	06367	15043
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3403009	078	144	606	263	256	03987	17969
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3403011	076	042	342	243	264	07896	05683
3403012	074	104	376	264	259	05990	15455
3403013	088	098	578	271	256	10938	10148
3403014	084	096	846	256	246	06725	11208
3403015	082	150	528	265	251	07342	13667
3403016	080	092	458	254	255	07464	10123
3403017	062	117	880	259	241	05793	13544
3403018	064	128	456	254	249	04583	14942
3403019	060	116	680	264	244	06706	10497
3403020	060	116	680	264	244	06706	10497

EXPERIMENT 2

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110103	292	056	072	476	101	063	03960	11274
110104	338	046	088	494	079	064	02945	11231
110105	408	068	066	602	088	059	06033	06051
110106	432	066	064	742	101	057	05714	06737
110107	504	[illegible]	078	824	098	061	07043	08607
110108	448	066	060	624	108	078	06442	10584
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110110	388	056	098	566	078	064	05732	14376
110111	438	052	090	610	096	077	03805	08198
110112	392	082	088	596	102	082	06974	10008
110113	426	064	090	604	079	069	03369	06692
110114	440	068	116	644	086	081	06307	16167
110115	528	064	350	942	060	060	05226	42810
110116	518	062	074	704	108	073	05191	08696
110117	564	056	098	744	085	070	02737	10727
110118	436	032	030	522	023	068	02407	03279
110119	484	030	030	564	027	064	01297	03120
110120	542	068	064	722	092	055	03662	09701
110201	488	052	078	642	074	058	04057	09567
110202	530	056	064	862	084	067	07046	03802
110203	438	058	100	616	068	061	02767	10952
110204	464	[illegible]	096	686	086	071	07646	10813
110205	586	076	068	778	099	072	08170	04570
110206	512	070	066	876	090	058	06096	05862
110207	490	058	078	778	081	050	04721	06923
110208	642	060	060	820	085	058	04538	06194
110209	600	074	066	784	086	061	08240	04264
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110211	656	034	102	812	073	060	00981	08545
110212	726	074	086	906	086	073	05733	07122
110213	604	066	050	786	079	053	07350	04199
110214	528	066	070	684	092	087	06736	06253
110215	584	054	080	740	071	062	02982	08590
110216	804	070	066	982	098	083	05554	05446
110217	762	060	098	940	094	081	03756	08960
110218	492	070	066	678	098	071	06377	05713
110219	634	068	084	920	107	053	08483	07202
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110401	168	070	072	356	101	070	05214	06788
110402	310	062	062	856	100	064	05036	05149
110403	386	052	130	594	077	063	01939	12500
110404	222	060	148	450	081	072	05883	14754
110405	270	058	104	454	087	072	03283	09663
110406	324	084	322	750	072	072	09966	50299
110407	250	050	110	432	069	057	02307	13191
110408	254	068	066	440	112	079	06671	05967
110409	286	086	050	528	090	059	08367	04420
110410	390	062	084	586	096	072	06357	05048
110411	252	066	138	476	060	061	04675	14084
110412	314	064	066	464	109	100	05408	05289
110413	206	076	100	410	081	068	06478	11320
110414	312	062	078	508	085	058	02013	07966
110415	304	040	032	396	060	087	01698	03220
110416	338	068	068	532	076	053	03722	05634
110417	296	060	090	466	092	076	02207	11326
110418	332	068	086	518	120	090	06024	09938
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110420	254	036	030	340	048	068	02300	03180

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140102	536	090	130	778	250	246	10861	18046
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140104	384	076	080	999	263	215	12096	12177
140105	532	076	108	742	258	255	08878	14619
140106	524	086	086	716	270	264	08985	11937
140107	542	096	074	740	274	274	13292	10757
140108	456	068	112	658	260	260	09213	12417
140109	536	076	094	798	277	253	10761	11691
140110	552	094	112	778	272	263	09743	18089
140111	544	084	096	758	259	254	09175	14460
140112	674	068	130	904	272	240	09234	16564
140113	428	090	096	718	273	252	11489	12966
140114	426	076	032	554	182	230	09714	01172
140115	480	084	290	884	255	255	12705	47778
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140117	524	082	044	670	215	242	11509	03152
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140119	294	086	090	500	261	263	10552	13442
140120	452	082	102	780	259	245	08827	16299
140201	296	086	424	996	245	243	11555	37670
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140203	318	074	030	442	190	256	08970	01645
140204	270	076	[illegible]	[illegible]	265	252	08380	16949
140205	216	062	[illegible]	[illegible]	237	271	06988	05048
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140209	302	078	250	650	246	249	08471	45248
140210	346	092	082	996	295	249	14460	09791
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140212	276	090	484	872	247	247	10874	51502
140213	216	088	046	728	263	241	10159	05883
140214	156	088	122	396	292	267	13949	22941
140215	344	084	030	478	200	250	13194	03496
140216	306	082	078	486	297	295	14124	13036
140217	262	090	090	516	290	277	11636	10480
140218	192	104	030	346	268	244	13821	02010
140219	224	088	030	362	205	244	07782	03523
140220	258	084	122	490	281	270	09031	17932
140401	382	084	104	946	309	244	08975	17559
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140403	288	076	146	530	243	233	09482	32802
140404	302	080	140	542	282	272	09553	28028
140405	390	084	042	536	208	242	08096	04221
140406	208	088	120	416	263	263	09056	13530
140407	270	082	130	526	282	260	08844	16166
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140414	298	076	140	580	254	236	09347	27928
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210104	078	034	112	244	073	073	01993	03989
210105	206	058	096	420	085	064	03078	04544
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210116	180	052	104	366	074	061	02727	07564
210117	184	068	078	382	085	064	03185	04578
210118	314	030	092	482	063	056	00690	06531
210119	102	054	046	222	066	072	03034	02034
210120	218	032	070	320	044	059	00894	03387
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210202	312	320	030	682	060	082	08213	02286
210203	070	154	036	280	070	078	05270	01408
210204	224	054	030	328	052	069	01987	01601
210205	218	030	046	314	053	051	00111	01678
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210208	176	056	036	288	062	068	03526	00637
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210402	108	078	032	238	051	064	01227	00196
210403	094	110	094	318	086	065	05781	05435
210404	226	138	122	818	072	052	04391	03026
210405	128	130	244	438	055	049	00210	08879
210406	112	068	034	234	073	085	03688	00871
210407	128	120	060	328	058	066	03181	01021
210408	156	030	064	270	032	059	00260	00300
210409	070	082	250	500	049	049	01983	14040
210410	112	104	052	288	059	068	02145	01340
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210413	128	090	036	274	047	056	02578	00909
210414	096	036	064	216	032	042	00152	02780
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210416	094	030	150	294	052	060	00513	07218
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210418	226	138	122	818	072	052	04391	03026
210419	115	059	040	245	063	065	03221	01897
210420	156	060	065	290	062	064	01260	01230

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a

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240106	550	078	180	844	244	234	03250	13777
240107	210	104	136	526	235	237	03759	05569
240108	366	098	104	570	226	224	04707	08213
240109	100	038	058	216	143	187	03704	00584
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240114	096	094	208	418	229	232	02728	11775
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240119	220	072	036	348	144	185	04361	01091
240120	246	080	046	392	152	196	05250	00522
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240203	078	080	346	594	233	232	02121	17646
240204	070	064	204	412	251	251	05429	20349
240205	074	118	170	472	265	250	10061	11636
240206	070	094	036	220	181	211	06429	05752
240207	086	076	030	212	158	192	06408	02555
240208	128	030	032	210	136	177	00246	02092
240209	150	034	052	256	150	171	01574	02850
240210	108	030	592	750	196	184	00392	22426
240211	084	090	118	418	255	246	04934	09232
240212	114	054	030	218	162	191	02713	01293
240213	078	058	278	430	202	208	03572	17347
240214	072	076	052	220	164	196	01555	00874
240215	132	054	030	236	152	178	01383	00426
240216	086	036	084	226	203	208	00898	10093
240217	078	080	346	594	233	232	02121	17646
240218	090	084	224	452	251	240	05263	18632
240219	096	066	108	306	240	235	06258	12036
240220	128	088	128	458	256	242	05698	10022
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240404	316	086	098	520	287	272	06146	19624
240405	356	090	106	592	297	248	09436	16319
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240415	346	068	152	682	262	214	05323	16037
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240417	400	090	446	936	247	247	07592	85466
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310407	090	034	110	266	069	056	01249	07608
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310417	100	114	044	278	053	062	04990	01505
310418	110	046	092	332	073	051	01769	05194
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320210	274	080	048	494	147	123	06792	06044
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340118	072	048	304	424	242	242	05646	37112
340119	092	048	044	204	142	188	04913	06999
340120	098	100	162	538	263	241	12568	15632
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340203	232	104	118	490	269	246	10264	14612
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340206	290	042	052	404	155	204	03612	01307
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410114	256	060	050	396	058	066	02145	01368
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