The temporal trajectories of discrete manual movements, aimed at a visual target

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The temporal trajectories of discrete manual movements, aimed at a visual target
a literature studie

R. van der Made

Summary

This report is an account of a literature study, investigating the temporal trajectories of discrete movements, aimed at a visual target. The main objective of this study was to find out which factors influence the subjects' performance in a pointing task and how they affect the movement characteristics.

When a person moves a limb from a certain position to a target object, speed and accuracy are two important constraints that can affect the performance. It has been shown that fast movements can be made only at the expense of reduced spatial accuracy; conversely, accurate movements can be made only at the expense of reduced speed. Fitts' law describes this trade-off fairly good, but tells us nothing about the temporal movement trajectory.

The movement of a hand towards a target of some sort may (after an acceleration phase and a deceleration phase) terminate exactly at the aimed-for target, but usually does not. The trajectory will therefore contain corrective movements to remove residual error. Irrespective whether the error signal is fed back externally (by visual feedback), internally (by kinaesthetic feedback) or both, it takes some time to translate this error signal to an adaptation of the actual movement. The corrective movements are therefore visible as discrete submovements in the movement trajectory.

There are numerous factors that cause variability in the movement patterns. One of them is neuromotor noise, which can never be controlled. I found in the literature that there are also several factors (influencing the temporal trajectories) that can be controlled in an experimental design. The most important ones are :

Index of difficulty : both the length of a movement and the required endpoint accuracy can influence the movement characteristics.

Uncertainty about the target location : especially the initial force produced by a subject to accelerate his hand in a pointing task will depend on the expectation of the subject about the target location. If there is uncertainty about the target location some time before the movement is started, this may have its effect on the temporal trajectory.

Instructional set : whether the subject is told to move quickly or accurately will have a considerable influence on his movement.

Level of practice : the general shape of the trajectory will change and the variability will decrease when subjects are given more practice on a certain pointing task.

Magnitude of impact force : if the goal of a movement is to strike the target with a particular magnitude of impact, this will especially have its influence on the deceleration of the moving limb.

Coming to an understanding of movement control has been an important issue in many of the articles I found in this literature study. I think the most complete, interesting and up to date model is the stochastic optimized-submovement model as presented by Meyer, Abrams, Kornblum, Wright and Smith in [Mey88](1).

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(1) When such a code is used in this report, this refers to the book or article mentioned in chapter 6.

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1 Introduction

In the research project 'Trackball with Contextual Motor Feedback' the question arose : *Can we predict the user's goal in an early stadium of his pointing movement with the trackball ?* If the answer to this question would be : 'Yes, we can, very accurately.' , the application field of the trackball with tactile feedback increases substantially. The motor feedback can then be used very effectively to facilitate that pointing movement.
Answering the question mentioned above is the main concern of my research project, that I call 'Target Prediction by Movement Interpretation'.

It is generally agreed nowadays that people do not always behave exactly as formal logic, probability theory, or decision theory would prescribe. This unpredictable part of human behaviour also has its consequences for the study of human motor performance. Furthermore there are numerous factors that influence movement control in different, mainly unidentified, ways. Comprehending the factors that influence the production of rapid aimed manual movements is a necessity to succeed in predicting the endpoint of such a movement.

When a person moves a limb from a certain position to a target object, speed and accuracy are two important constraints that can affect the performance. It has been shown (e.g., [Fit64]) that fast movements can be made only at the expense of reduced spatial accuracy; conversely, accurate movements can be made only at the expense of reduced speed. Many models have attempted to identify the control processes underlying this speed-accuracy trade-off. Explanations in terms of the availability of visual feedback (e.g., [Cro63]), the variability of the muscular system (e.g. [Sch78]), as well as a model in which both visual control and muscular variability are responsible for aiming accuracy [Mey88] have been presented.
The most useful information about the control process used in the production of aiming responses has been acquired by examining the movement patterns produced in the completion of those responses. Therefore an overview is presented in this report of the literature examining the trajectories of a discrete manual movement, aimed at a visual target.

After showing what the trajectory of an aimed movement generally looks like (chapter 2), in chapter 3 the factors that influence the characteristics of that trajectory are described. These factors are found to be important in many different articles. They each have their own influence on the trajectory and by these means on the subjects' performance in the pointing task. In chapter 4 some models of movement control in man are given as developed and presented over the last 50 years based on the knowledge at that time. The discussion in chapter 5 is meant to hand a guideline for setting up pointing movement experiments properly, by answering the question:
When we want to investigate the exact influence of one factor on the movement characteristics in a pointing task, how can we make sure that the influence of other factors is minimized ?

2 The general temporal trajectory of aimed movements

2.1 Different phases⁽¹⁾

A considerable number of experiments has been done, trying to discriminate different phases in the movement of a hand towards a target of some sort.

[Woo1899] distinguished an acceleration phase, a central phase of uniform velocity and a deceleration phase in movements of this type. [Tay47] and [Tay48] found that there was no period of constant velocity in approach movements and that the relative size of acceleration and deceleration phases depended on terminal accuracy: accurate movements tended to have longer deceleration phases, while movements of an approximate extent only have symmetrical patterns. [Vin48] confirmed the two phase nature of accurate movements in tracking tasks, with the deceleration phase of longer duration. [Ann58] considered the approach as occurring in two distinct parts, a fast gross movement to the target area, followed by a slow terminal phase. [Mur60] showed that approaches to targets were of a complex nature, with changes in velocity during the main acceleration and deceleration phases. They suggested this was tremor. They found acceleration to occupy about one third of the movement time. [Cro63] also found irregularity in approach curves. They suggested that this was evidence for corrective responses.

These workers used many sorts of task, including line drawing, aiming, step-tracking, joystick control, wrist rotation, and repetitive tapping. The results can thus be considered fairly general for approach movements.

2.2 Corrective movements

[Bro49] found that the primary phase of a discrete movement may terminate exactly at the aimed-for target, but usually does not. It was found later that reasonably large quick movements have an average error of about 5% of their size.⁽²⁾ Very small quick movements even are a good deal less accurate. It is therefore conceivable that the movement trajectory will contain corrective movements to remove residual error.

Irrespective whether the error signal is fed back externally (by visual feedback), internally (by kinaesthetic feedback) or both, it takes some time to translate this error signal to an adaptation of the actual movement. The corrective movements are therefore visible as discrete submovements in the movement trajectory. Several experiments (e.g. [Car80]) provided evidence that a number of types of aiming responses are indeed characterized by discrete corrections. Some of these experiments revealed that more than one discrete correction often occurs in high index of difficulty conditions.

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(1) This section has mainly been taken from the introduction of [Beg72].

(2) Taken from [Pou74]

2.3 Displacement, velocity, acceleration and/or jerk

In examining the movement patterns produced in the completion of aiming responses, besides the displacement plot both the velocity and acceleration plot are often used. The time derivative of the acceleration (jerk) has also been analyzed a few times.

In figure 2.1 tracings of selected sample records have been reproduced to illustrate certain of the fairly typical characteristics as found in [Bro49]. In the concerning experiment, the subjects were required to move a slide piece with their hand from one marker to another upon the sounding of a buzzer.

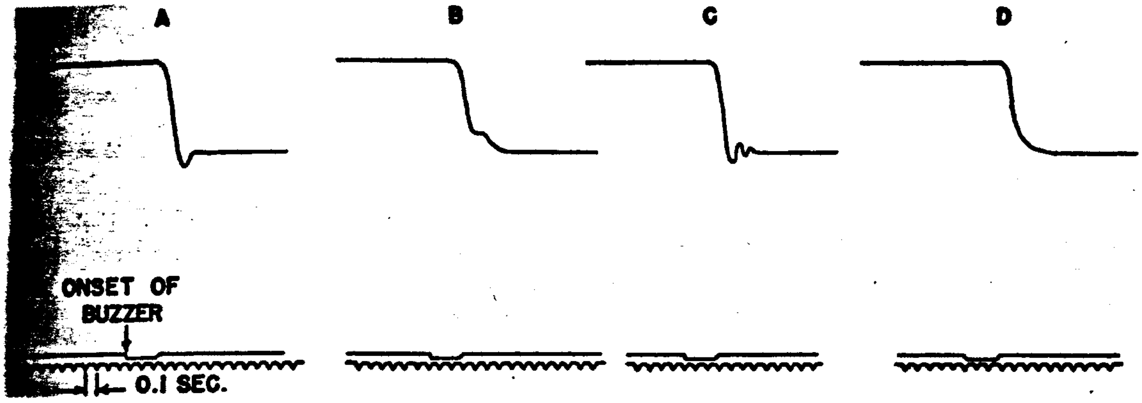

Figure 2.1 : Tracings of selected records of discrete movements

The trajectory shown in A, where the limb ended beyond the terminal line after the initial movement, often occurred in the higher-speed movements. In B the initial movement fell short of the mark. In C the terminal adjustment resembles a damped oscillation. In the movement curve of D, which was seldom observed except in the records of very slow-moving subjects, the primary movement phase blends smoothly into a relatively long phase during which the limb gradually decelerates until the correct position is reached.

In [Tay48] the subjects were required to move back the displaced target to a stationary hairline by means of a joystick. In figure 2.2 the smoothed representations of the typical movement patterns are shown. A is the position plot. The response to the target displacement takes place from a to g. No overshoot or undershoot is shown in the diagram, though both over- and undershoots are frequently encountered. B is the velocity plot, C is the acceleration plot and D is the jerk plot. The d in D need not to be at the lowest point on the function.

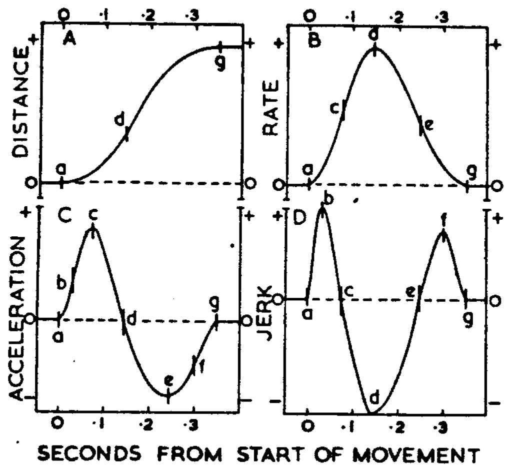

Figure 2.2 : Smoothed representations of the typical movement patterns

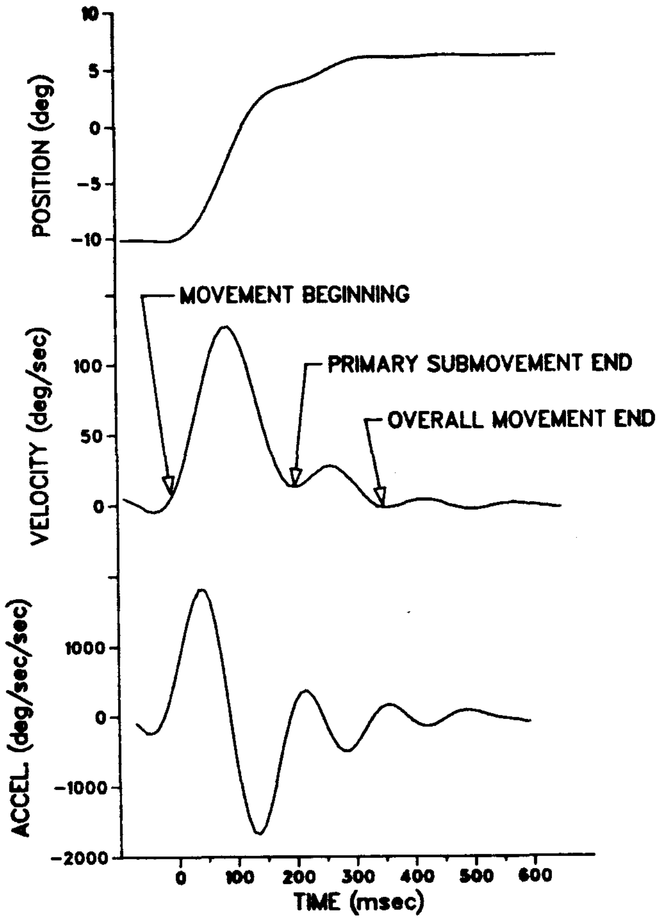

Figure 2.3 : Example of position, velocity, and acceleration records from a movement to a target.

In figure 2.3 the records of a representative movement in an experiment described in [Mey88] are plotted. The subjects were required to move a cursor on a screen by making a rotation with their wrist. At the onset of an auditory response signal, the subject had to move the cursor quickly and accurately from the home position to the target position, defined by two vertical lines.

In the position plot a secondary submovement is visible, by which the error at the end of the primary submovement is corrected. Since the position plot shows undershoot, the corrective movement has the same orientation as the primary submovement in the velocity- and acceleration plot.

In this chapter the temporal trajectory of aimed movements has been described without considering the causes of the variability. A number of factors that influence the trajectories will be discussed in chapter 3.

3 Factors that influence the trajectories

There are numerous factors that cause variability in the movement patterns. One of them is neuromotor noise, which can't even be controlled by the process that generates the aimed movement in man, so it will definitely be impossible to control this in any experimental set-up. I found in the literature that there are also several factors (influencing the temporal trajectories) that can be controlled in an experimental design. In this chapter the most important ones will be discussed.

3.1 Index of difficulty: distance and width of the target

Fitts (see [Fit64]) defined the index of difficulty (ID) of a pointing task to a target of width W at distance D as:

$$ID = \log_2(\frac{2D}{W}) \qquad (3.1)$$

For the mean movement time (MT) required for such a task he obtained the relation

$$MT = a+b.\log_2(\frac{2D}{W}) = a+b.ID \qquad (3.2)$$

where a and b are constants. This relation, known as Fitts' law, is still one of the few precise laws describing motor performance. Adjustments to Fitts' law have been suggested, but in general the law tends to hold in a variety of experimental situations.

Although movement time can be predicted fairly good in a certain task with Fitts' law, it tells us nothing about the temporal movement trajectory:
- How does it's shape change when we vary D or W ?
- Does it's general shape change when we change D and W, keeping ID constant ?

[Bro49] found that increases in length of the movement are accompanied by significant increases in:
(a) the duration of the primary movement
(b) the speed of movement
(c) the variability of both time and speed scores.
[Car80] suggested that both the initial aiming response and the discrete corrective response(s) may be produced with higher velocities than a similar condition with a smaller target.
[Mar90] found that the time from peak deceleration to impact increased as target size decreased. This supported their earlier work ([Mac87]) where they showed in a pointing task that arm trajectories changed their shape (due to changes in the deceleration portion of the trajectory) when targets of different size were used. Other work has also shown that in pointing tasks when target size is decreased, subjects spend a greater proportion of time in the deceleration phase ([Car80], [Lan76], [Soe84] and [Tay48]).

3.2 Uncertainty about the target location

In 3.1 we saw that the temporal trajectory of a movement is influenced by the length of the movement and the width of the aimed for target. It is therefor conceivable that the initial force produced by a subject to accelerate his hand in a pointing task depends on the expectation of the subject about the target location (and size). If there is uncertainty about the target location some time before the movement is started, this may have its effect on the temporal trajectory. I didn't find any literature that studied this phenomenon explicitly. What I did find was that [Sea48], where subjects were required to make movements of which the sizes were varied within a series, noticed that subjects reacted 0.02 sec. more quickly to steps of intermediate size. They concluded from this result that the subject prepares itself for a movement of average size.

[Geo81] studied the spatial and temporal characteristics of arm movements in three rhesus monkeys, i.a. under conditions of spatial uncertainty. They found that this spatial uncertainty concerning the location of the target caused a significant increase in handpath variability, while reaction times and peak velocities were not affected.

3.3 Instructional set

Only a few studies have explored how the subject's objective in making a movement affects the coordinated sequence of eye and limb movements that unfolds as the subject points to a target. In [Fis89] the characteristics of the targets and the environment remained constant while the demands for speed and accuracy were varied across blocks of trials by changing the instructions to the subject. The speed and accuracy demands of the task were varied by requiring the subjects to point to the target "as quickly as you can", "as accurately as you can" or both "quickly and accurately". The time to initiate the hand movement was reduced only in the speed condition. While the duration of the acceleration phase remained constant in real time, the duration of the deceleration phase was increased with increased demands for accuracy.

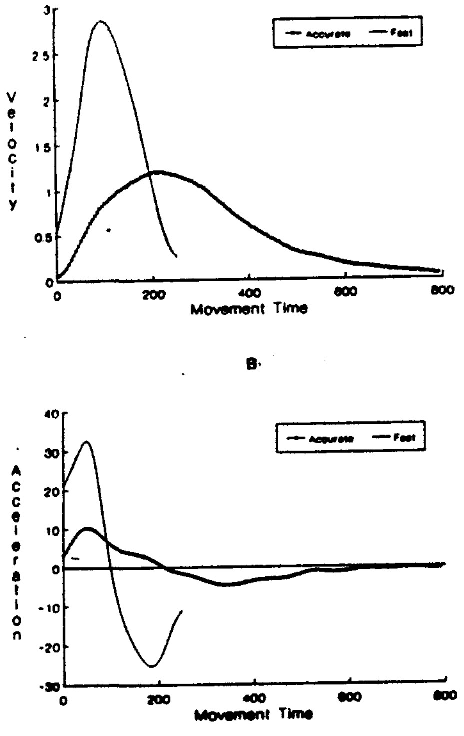

Figure 3.1 : Typical velocity (m/s) and acceleration (m/s^2) by movement time functions from [Ell91]

In [Ell91] the influence of instructional set on the kinematics of a simple target-aiming movement was examined (among other things). They found that instructional set (fast / accurate) had a large impact on the velocity and acceleration patterns of the movements (see figure 3.1).

3.4 Level of practice

It very often occurs that subjects show a considerable learning effect in the performance of a certain task. [Beg72] showed that this effect can also be seen in the approach trajectories of hands towards targets in tracking and aiming tasks. They used a (initially) naive subject and gave her extended practice on a paced aiming movement. The subject successively hit the base-plate and target coincident with metronome ticks. Figure 3.2 shows how the smoothed temporal trajectory of her movements changed in four successive days (a, b, c and d). The graphical presentation differs from the other figures: here the relationship of *distance to impact* and *time to impact* is plotted.

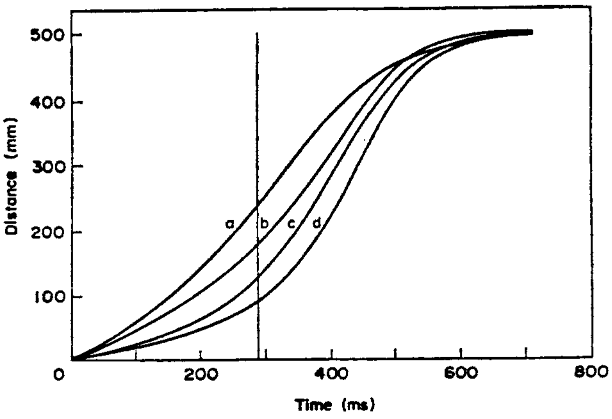

Figure 3.2 : The smoothed relationship of distance to impact (d) and time to impact (t) for four levels of practice at 85 ticks per min.

[Geo81] studied the spatial and temporal characteristics of arm movements in three rhesus monkeys during 40 days. The results of this study indicate that the process that generates the aimed movement becomes less variable with practice.

3.5 Magnitude of impact force

Often, the goal of a movement is to strike the target with a particular magnitude of impact. Models of speed-accuracy trade-off, however, have neglected to account for the contribution of these impact forces in the control of accurate movements. The aim of [Tea91] was to examine the modifications in the control strategy as a function of the amount of impact force a subject is allowed to use in decelerating his or her limb. The experiment suggests that the impact with a target is an important contributor to the deceleration of the moving limb and a critical determinant of movement organization. For example the duration of the acceleration phase was slightly longer than the duration of the deceleration phase when a small impact magnitude was imposed, whereas the acceleration phase was more than 4 times longer when a large impact was imposed.
In certain pointing tasks (e.g. computer use via a pointing device) most of the movements will end at the target with both velocity and acceleration at zero.

4 Models of movement control in man

In this chapter I want to pay some attention to the modelling of movement control in man. Coming to an understanding of movement control has been an important issue in many of the articles referred to in this report.

[Tay48] found that at least the early phases of acceleration are completed in less time than it would take to perceive and to react selectively to a visual stimulus, what must mean that this part of the response is not guided continuously by information obtained through vision. They stated that it is doubtful if this effect can be accounted for by proprioception or 'muscle feedback'. Though it is conceivable that the reaction time to proprioceptive cues may be shorter than that to visual stimuli, it would have to be infinitely small to permit kinaesthetic control of the continuous variation in applied force found in their study. They suggested that the program of making quick corrections works as follows: The subject perceives an error, selects a certain force program which is judged on the basis of past experience to best approximate the required force pattern and then starts the mechanism operating. The perception and program selection require one reaction time. Once started, the force program runs and the continuously varying force pattern which includes stopping forces as well as starting forces appear in proper sequence. At any rate their findings suggest that movement control is, at least in part, an intermittent rather than a continuous process.

[Cro63] found that Fitts' law can be explained by postulating either continuous velocity control or intermittently sampled proportional control of limb position. They rejected the first of these two models because it fails to account for 'ripple' observed particularly in wrist-rotation trajectories. The second model gives an (for them) acceptable account of this phenomenon. This model assumed that movement to a target is comprised of a series of discrete submovements of constant duration and relative accuracy. Each submovement supposedly has a well-defined beginning and end, takes a constant time increment to complete, and travels a constant proportion of the remaining distance to the centre of the target. The model thus claims that the initial movement covers most of the distance to the target in a time that is independent of both target distance and width. They pointed out that the position error might be signalled visually or kinaesthetically. [Kee68] presented an elaborated version of this model under which he assumed that visual feedback provides the main information for making the necessary corrections.

Although this deterministic iterative-corrections model provides a neat quantitative account of Fitts' law, it cannot deal with several other observed characteristics of rapid aimed movements :

» Under certain circumstances indeed primary submovement durations are found to be independent of target distance and width, but under more typical circumstances, investigators (e.g. [Lan76]) have observed marked effects of both distance and width on the duration of primary submovements. As the distance of the target increases or the target width decreases, primary submovement durations usually increase. This contradicts the deterministic iterative-corrections model.

- » Another obvious problem for this model concerns the inherent spatial variability of submovement endpoints. The model assumes that each submovement always travels a constant proportion of the remaining distance to the centre of the target. In many of the articles referred to in this report it was found that this assumption is clearly wrong. It is found that the endpoints of primary submovements as well as those of subsequent higher order corrective submovements show a considerable variability and even overshoot the target quite often.
- » Because of its failure to deal with submovement endpoint variability, the model also has trouble explaining the observed relative frequencies of secondary submovements. For any ratio of target distance to width, the model predicts that secondary submovements should always or never occur, depending on the value of D/W and the assumed constant proportion of distance travelled by the primary submovements. This prediction is violated by the finding that secondary submovements occur probabilistically with relative frequencies whose magnitudes increase gradually from zero to one as a function of D/W (e.g. [Car80]).

The stochastic optimized-submovement model as proposed in [Mey88] tries to explain these and other results from the literature on human motor performance. According to this model, an aimed movement towards a specified target region involves a primary submovement and an optional secondary corrective submovement. The submovements are assumed to be programmed such that they minimize average total movement time while maintaining a high frequency of target hits. The programming process achieves this minimization by optimally adjusting the average magnitudes and durations of noisy neuromotor force pulses used to generate the submovements. A key feature of the model is that it represents the movement-production process as an ideal compromise between the durations of primary and secondary submovements. The form of the compromise depends on assumptions about neuromotor noise and the spatial variability of submovement endpoints.

I don't want to describe this very interesting model extensively in this report. For the exact basic assumptions and quantitative predictions, I refer the interested reader to the article of Meyer, Abrams, Kornblum, Wright and Smith ([Mey88]).

5 Discussion

5.1 Interpretation of the findings

The findings of the research presented in the many articles that are available on the subject 'discrete manual movements, aimed at a visual target', which are partly reviewed in this report, should be regarded as the results for that specific experimental set-up. Different kind of movements in various tasks with different equipment are analyzed in those articles. Simply adopting the general conclusions of the past research without validating it by checking the data of your own experiments is therefore not recommendable. This does not mean that nothing can be learned from the literature. The generality of some movement characteristics is the very reason for their suitability as guidelines for setting up an experiment and formulating the hypothesis.

The main general finding is that the movement of a hand towards a target of some sort consists of one or more submovements in all of which an acceleration phase and a deceleration phase can be distinguished.

5.2 Attention points for experiments

The five factors mentioned in chapter 3 are important factors to take into account when setting up an experiment in which a pointing task is involved. They each have their own influence on the trajectory and by these means on the subjects' performance in the pointing task. In a certain research it has to be decided which of these factors are to be investigated and then the experiments have to be designed carefully. It is recommendable to vary only one factor at a time, keeping the others as constant as possible. When analysing the results all possible ways of measuring the influence of all factors should be used to make sure that the experimental circumstances matched the intentions.

For example :

You want to investigate the effect of varying the index of difficulty on the peak acceleration in a pointing task. You use only one target per session, you tell the subjects to move both quickly and accurately and give them extended practice on the task before running the experimental trials. When analysing the results of your experiment, you cannot simply let the index of difficulty account for all the differences between two sessions of the same subject. You'll first have to make sure that the other factors did not effect the results significantly. In this case the trend in the variability of successive subsets of the sessions can be used to make sure that the level of practice of the subject was indeed fairly constant during the experimental trials. You can also check whether the velocity and acceleration at the end of the movement were zero for all trials. Using only one target per session probably avoided the uncertainty about the target location and size. You still can't be sure that there isn't a significant difference between different subjects concerning their tactics : different subjects can interpret the instructional set (move both quickly and accurately) differently.

5.3 Prediction of predictability

Whether the endpoint of a discrete pointing movement can be predicted fairly accurately is dependent on several currently unknown features in pointing movements. In my opinion the most important question is : which part of the movement is affected most by neuromotor noise ?

If the first selected motor program would be the right one in the absence of neuromotor noise and the neuromotor noise hardly affects the acceleration phase, then the intended endpoint should be predictable from that part of the movement.

6 References

[Ann58] Annett, J., Golby, C.W. and Kay, H. (1958).
The measurement of elements in an assembly task - the information output of the human motor system.
Quarterly Journal of Experimental Psychology, **10** : 1-11.

[Beg72] Beggs, W.D.A. and Howarth, C.I. (1972).
The movement of the hand towards a target.
Quarterly Journal of Experimental Psychology, **24** : 448-453.

[Bro49] Brown, J.S. and Slater-Hammel, A.T. (1949).
Discrete movements in the horizontal plane as a function of their length and direction.
Journal of Experimental Psychology, **39** : 84-95.

[Car80] Carlton, L.G. (1980).
Movement control characteristics of aiming responses.
Ergonomics, **23** : 1019-1032.

[Cro63] Crossman, E.R.F.W. and Goodeve, P.J. (1963).
Feedback control of hand movement and Fitts' Law.
Paper presented at the meeting of the Experimental Psychology Society, Oxford, July 1963.
Published in: Quarterly Journal of Experimental Psychology,
1983, **35A** : 251-278.

[Ell91] Elliott, D., Carson, R.G., Goodman, D. and Chua, R. (1991).
Discrete vs. continuous control of manual aiming.
Human Movement Science, **10** : 393-418.

[Fis89] Fisk, J.D. and Goodale, M.A. (1989).
The effects of instructions to subjects on the programming of visually directed reaching movements.
Journal of Motor Behavior, **21** : 5-19.

[Fit64] Fitts, P.M. and Peterson, J.R. (1964).
Information capacity of discrete motor responses.
Journal of Experimental Psychology, **67** : 103-112.

[Geo81] Georgopoulos, A.P., Kalaska, J.F. and Massey, J.T. (1981).
Spatial trajectories and reaction times of aimed movements: effects of practice, uncertainty, and change in target location.
Journal of Neurophysiology, **46** : 725-743.

[Kee68] Keele, S.W. (1968).
Movement control in skilled motor performance.
Psychological Bulletin, **70** : 387-403.

[Lan76] Langolf, G.D., Chaffin, D.B. and Foulke, J.A. (1976).
An investigation of Fitts' law using a wide range of movement amplitudes.
Journal of Motor Behavior, **8** : 113-128.

[Mac87] MacKenzie, C.L., Marteniuk, R.G., Dugas, C., Liske, D. and Eickmeier, B. (1987).
Three-dimensional movement trajectories in Fitts' task: Implications for control.
Quarterly Journal of Experimental Psychology, **39A** : 629-647.

[Mar90] Marteniuk, R.G., Leavitt, J.L., MacKenzie, C.L. and Athenes, S. (1990).
Functional relationships between grasp and transport components in a prehension task.
Human Movement Science, **9** : 149-176.

[Mey88] Meyer, D.W., Abrams, R.A., Kornblum, S., Wright, C.E. and Smith, J.E.K. (1988).
Optimality in human motor performance: Ideal control of rapid aimed movements.
Psychological Review, **95** : 340-370.

[Mur60] Murrell, K.F.H. and Entwisle, D.G. (1960).
Age difference in movement pattern.
Nature, **185** : 948.

[Pou74] Poulton, E.C. (1974).
Tracking Skill and Manual Control. Chapter 5 : Tracks with single steps.
New York : Academic Press.

[Sch78] Schmidt, R.A., Zelaznik, H.N. and Frank, J.S. (1978).
'Sources of inaccuracy in rapid movement'.
In: Stelmach, G.E. (Ed.), Information processing in motor control and learning. New York: Academic Press. pp. 183-203.

[Sea48] Searle, L.V. and Taylor, F.V. (1948).
Studies of tracking behavior, I. Rate and time characteristics of simple corrective movements.
Journal of Experimental Psychology, **38** : 615-631.

[Soe84] Soechting, J.F. (1984).
Effect of target size on spatial and temporal characteristics of a pointing movement in man.
Experimental Brain Research, **54** : 121-132.

[Tay47] Taylor, F.V. (1947).
A study of the acceleration pattern of manual corrective responses.
American Psychologist, **2** : 340.

[Tay48] Taylor, F.V. and Birmingham, H.P. (1948).
Studies of tracking behavior, II. The acceleration pattern of quick manual corrective responses.
Journal of Experimental Psychology, **38** : 783-795.

[Tea91] Teasdale, N. and Schmidt, R.A. (1991).
Deceleration requirements and the control of pointing movements.
Journal of Motor Behavior, **23** : 131-138.

[Vin48] Vince, M.A. (1948).
Corrective movements in a pursuit task.
Quarterly Journal of Experimental Psychology, **1** : 85-106.

[Woo1899] Woodworth, R.S. (1899).
The accuracy of voluntary movement.
Psychological Review Monograph Supplement, **3** : (2, Whole No.13).