Insight into Goal-Directed Movement Strategies

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ABSTRACT
The current paper proposes a novel method of analyzing goal-directed movements by dividing them into distinct movement intervals. We demonstrate how the description of the first and second most prominent movement intervals in terms of duration and length can provide insight into the applied movement strategies under different conditions. This method, although demonstrated for goal-directed movements, has the potential to be generalized to other types of movements, such as steering movements.

Author Keywords
Computer input devices, movement analysis, pointing tasks

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation, (e.g. HCI)]: User interfaces - input devices and strategies.

General Terms
Performance, Measurement

INTRODUCTION
The personal computer (PC), be it a desktop, laptop or tablet computer, is used by millions of people on a daily basis. Therefore, it is important that the interaction with a PC is well tailored to the users' needs. Currently, most people interact with the PC via a direct manipulation interface, also called WIMP (Window, Icon, Menu, Pointing device) interface. This form of a Graphical User Interface (GUI) allows people with limited computer skills to use computer software by directly manipulating windows, graphical icons and menus.

The most common way to interact with WIMP interfaces is to point at and subsequently select graphical items. Also dragging items from one place to another (e.g. from window to window) is a frequently used interaction technique. These fairly simple goal-directed tasks have been applied in many studies that aim at systematically evaluating computer pointing devices, such as the mouse, stylus, trackball, touchpad or joystick [1, 4] and interaction techniques such as pointing, selecting and dragging [5, 6].

This paper focuses on the evaluation of mouse performance in a goal-directed selection task. The main contribution of this paper is in proposing a novel analysis method that provides insight into the applied movement strategies. These insights can be used in the design of new input devices and interaction techniques, e.g. by evaluating different settings and deciding upon the most appropriate ones (those that best agree with the desired movement strategy).

MOVEMENT EVALUATION
Studies evaluating input devices and interaction techniques often focus on characteristics of the overall movement, like movement time and error rate [1, 6]. The interaction movements are also frequently described by Fitts' Law [2], which states that the time to move to a target is logarithmically related to the ratio of the target distance over the target width. Although overall measures and Fitts' Law can establish that there is a difference between input devices or interaction techniques, it does not try to understand the underlying reasons for these differences.

Therefore, we argued in a previous study that interaction movements should be analyzed in more detail to get accurate insights into strengths and weaknesses of input devices and interaction techniques [7]. We proposed a method that divides movements into five meaningful phases: latency, initiation, ballistic, correction and verification phase. Together with a selection of measures describing the movement phases' characteristics, the analysis method proved to provide insights that could not be obtained from the analysis of the overall movement.

The proposed movement analysis method [7] was tailored to assess the quality of rapid aimed movements. A key feature of these interaction movements is that they consist of a ballistic phase, programmed to reach the target, and often a correction phase during which unintended errors are corrected based on sensory feedback [9]. However, not all computer interaction movements are rapidly aimed, e.g. steering through menu structures and drawing and tracing in graphics tools. Also when interacting in a challenging environment, such as virtual reality, the lack of training results in movements that do not necessarily reflect rapid aimed movements. This means that the movement analysis method needs to be adjusted so it can also be applied to movements with no distinct ballistic and correction phase.

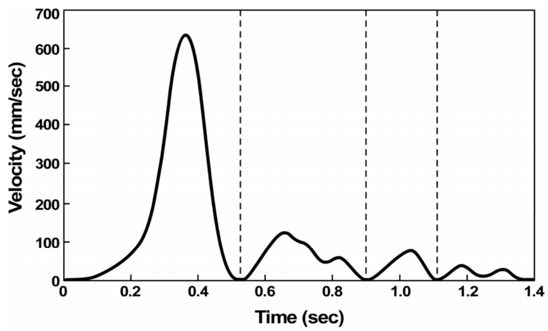

Figure 1. An example of a velocity profile containing 4 separate movement intervals.

MOVEMENT INTERVALS

When looking at the time-velocity profiles of goal-directed movements it can be observed that trials often contain several movement intervals separated from each other by pauses (see Figure 1). This observation is also supported by other studies, e.g. Hwang et al. [3] showed that movement trajectories of both motion impaired and able-bodied users contain pauses (i.e. multiple movement intervals). The number of movements required to reach the target can already indicate differences between movement conditions: an increase in the number of movement intervals necessary to reach the target indicates a decrease in the amount of control users have when carrying out the task.

However, the number of movement intervals does not provide information about the characteristics of the separate movements, i.e. whether different movement strategies were applied. As can be seen from the time-velocity profile in Figure 1 the characteristics of these separate movement intervals can be quite different. The first movement interval shows a clear bell-shaped velocity profile. The second movement interval is less regular and shows the occurrence of corrections, also called submovements [3, 7].

According to Plamondon and Alimi [8] bell-shaped velocity profiles are key features of well-practiced rapid aimed movements. These movements are ballistic in nature, which means that no sensory feedback is used to control the trajectory. They formulated a kinematic model for the execution of rapid aimed movements, also known as the delta-lognormal or $\Delta\Lambda$ law. In our opinion, the degree to which a movement velocity profile resembles this model might indicate the degree of trust people have when carrying out the movement.

Furthermore, Plamondon and Alimi consider controlling the velocity of the movement as the key strategy for carrying out rapid aimed movements [8]. They described a rapid-aimed movement as "a motor task producing a certain spatial output within relatively stringent time limits". In other words, the distance towards a target and the desired movement duration are used as input to the motor program to produce a movement with a certain velocity and accuracy. As a result, we think that the relationship between the movement intervals' path length and duration is able to demonstrate whether different movement strategies were applied within a goal-directed task or even between different movement conditions. This notion is further explored in the remainder of this paper.

EXPERIMENT

Method

To investigate rapid aimed movements an experiment was designed with a goal-directed selection task.

Task. A multi-directional selection task (similar to the task used in [7]) was applied in which 16 "target" circles were arranged in a circle (∅ 180 mm) around a central "home" circle. The home circle had a diameter of 4mm and the targets had diameters of 3, 6 and 13mm. At the beginning of a new trial, one target was presented together with the home circle. The data collection started when the home-circle was selected and continued until the target was correctly selected. Selection occurred by means of a button-click.

Participants. Eight university employees, two males and six females, voluntarily participated in the study. Their age ranged from 23 to 33 years (M = 30.3 years). They all indicated to be right-handed and regular computer users (i.e. more than 5 hours/day).

Design. The experimental design followed a 2x2x3 within-subjects model with instruction (fast/accurate), hand (preferred/non-preferred) and target size (3/6/13) as independent variables.

Procedure. The selection task was presented on a 19-inch TFT screen, with a resolution of 1280x1024 pixels. A Dell optical computer mouse was used as input device.

The experiment consisted of four sessions. In the first and second session the participants were asked to select the targets as fast as they could while using their preferred hand and non-preferred hand, respectively. During the third and fourth session participants were asked to move accurately instead of fast. These variables were introduced to ensure that different movement behavior occurred. Each session consisted of 48 trials (16 positions x 3 target sizes). A practice session with 9 trials (3 positions x 3 target sizes) preceded each actual experimental session, so that subjects could adjust to a change in condition or instruction.

Parsing method. A Gaussian time filter with a standard deviation of 25 ms is used to filter the noisy position data as a function of time [7]. After filtering the data, the overall movement is divided into movement intervals by identifying the pauses between them. A pause is defined as an interval in which the speed of the pointer remains below 0.02 times the movement's peak speed, where the pointer speed is determined along the movement path.

Results

Figure 2A-D show the relationship between relative path length (ratio between length of traveled path and distance to target at beginning of movement interval) and movement duration of the two largest (in length) movement intervals

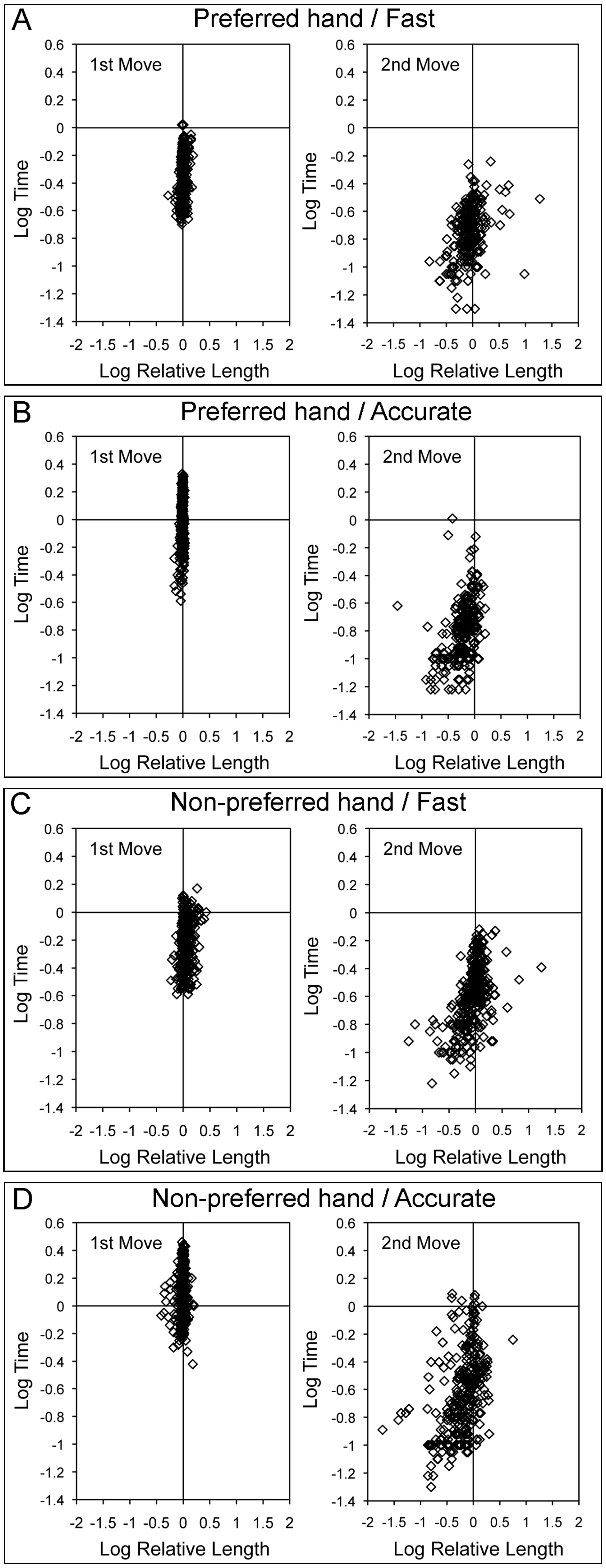

Figure 2. Log relative length and log duration of the two largest movement intervals for 4 different movement conditions

for the four movement conditions. This figure clearly shows that there is a difference in the relationship between relative path length and movement duration for the two separate movement intervals: the first (largest) movement interval hardly shows any dependency between the relative path length and the movement duration, whereas the second (largest) movement interval shows a positive correlation (ranging from r=.42 to r=.54). The independency of the path length and movement duration during the first movement interval indicates the execution a movement program intended to get into the neighborhood of the target.

When looking at the first movement interval, using the non-preferred hand results in a larger variation in relative path length than when using the preferred hand, $F(755, 767)=4.96$, $p<.01$. Because the accuracy of the first movement interval is much lower when using the non-preferred hand, larger movements are required during the second movement interval. As a result the movement carried out with the non-preferred hand have a less pronounced ballistic and correction phase strategy. On the other hand, the instruction to move as accurately as possible results in a larger variation of the largest movement interval's duration than the instruction to move as fast as possible, $F(763,759)=1.21$, $p<.01$. In order to be able to move accurately people chose the strategy of moving slower. As a result, fewer additional movements are required after the first movement interval.

We created Figure 3 to illustrate the differences in behavior during the second movement interval. The correlation between log path length and log movement duration during this second movement interval is approximately linear (ranging from r=0.80 to r=.92), which indicates that subjects adopt an approximately constant trade-off between movement duration and path length. This trade-off can be modeled by a power-law relationship $D=a.L^b$, where D denotes duration and L denotes length. The regression lines in Figure 3 have a steeper slope (higher value for the power b) when users moved accurately instead of fast.

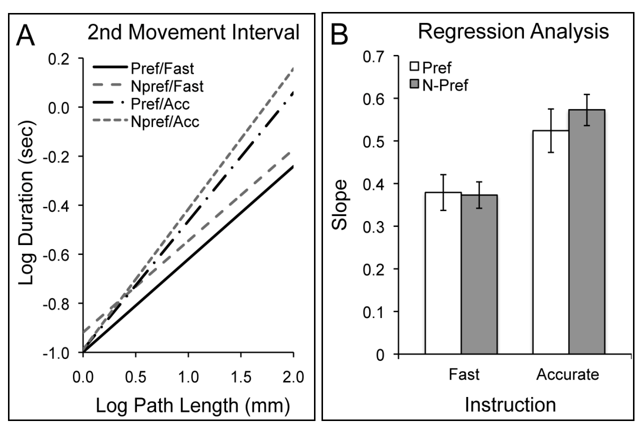

Figure 3. A) Relationship between log path length and log duration of 2nd movement interval; B) Slopes (b) of linear regression analysis with 95% confidence intervals

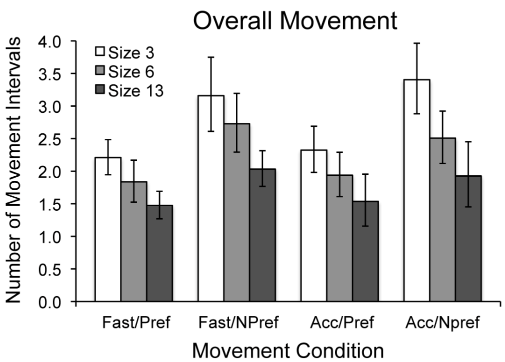

Figure 4. Number of movement intervals for the 4 movement conditions as a function of target size with 95% confidence intervals.

An interesting finding was that target size did not have a clear effect on the relationship between path length and duration of the first and second most prominent movements. This of course raises the issue how the effect of target size can be visualized. Because target size determines the amount of control required to position the cursor in the target area, it can be expected that the number of movements is a more appropriate way to illustrate the effect of target size. Figure 4 illustrates that the smaller the targets are the more movement intervals are required to get to the target area, $F(2,14)=109.93$, $p<.01$.

The number of submovements is a possible way of illustrating the level of confidence that people have when carrying out the movement: movements that are ballistic in nature do not contain a lot of corrections. The repeated measures analysis with target size (3mm/6mm/9mm), hand (preferred/non-preferred) and instruction (fast/accurate) as independent variables showed that the most prominent movement contains more submovements when people were instructed to move accurately instead of fast, $F(1,7)=40.02$, $p<.01$. In other words, people move with less confidence when they have to approach the target more accurately.

DISCUSSION

The movement analysis method proposed in this paper focuses on the characteristics of distinct movement intervals. This approach of analyzing interaction movement does not require a definition of a ballistic phase and a correction phase. As a result this method can also be applied when interaction movements do not reflect rapid aimed movements, such as steering movements.

The visualization of the relationship between path length and duration of the separate movement intervals, together with the analysis of the number of movement intervals and the number of corrections, provided insight into the effect of instruction, hand of use and target size. As a result, different movement strategies could be distinguished. The information about the movement strategies can be used to support people in their computer interactions. For example, slower movements with more online corrections (submovements) signal that a task is performed that requires more steering. In these cases, users can potentially benefit from an automation technique that enables them to move faster while maintaining accuracy (e.g. a technique that predicts the path based on previous positions and introduces resistance to deviating from this predicted path).

In this paper, we mainly focused on the identification of movement strategies in different movement conditions. However, different strategies might also be applied to the distinct movement intervals. For example, it appears from Figure 2 that the second movement interval is typically too short (i.e. skewed distribution). The characteristics of distinct movement intervals should be investigated in more detail. In addition, we used the number of submovements as an indirect means of assessing how close the movement interval approaches the ballistic movement described by the kinematic model of Plamondon and Alimi [8]. This measure showed that when users are required to move fast fewer corrections are made. The low number of submovements is an indication that, in contrast to accurate movements, fast movements can be fitted by the $\Delta\Lambda$ law. Future work will focus on the question how well the different movement intervals can be fitted by the kinematic model.

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