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Using multiple case studies in ergonomics: an example of pointing device use☆

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Abstract

An aim of ergonomics is to design workplaces, systems, products, and tools, to accommodate human variability. Paradoxically however, conventional analytic techniques focus on average behaviour. This paper illustrates the importance of considering individual differences in movement kinematics through an examination of the wrist postures adopted during the use of two different pointing devices. An implication of these data is that the introduction of an alternate pointing device such as a trackball should be considered as an intervention, but that the intervention should be undertaken with care to ensure that the exposure to extreme wrist postures is reduced. The paper concludes by describing issues related to the use of such multiple case studies in ergonomics research.

Relevance to industry

As well as being of different sizes, people also differ in the way they use tools. The consequence is that the effect of an intervention may differ between individuals.

Keywords: Pointing devices; Individual differences; Research methods

1. Introduction

People are different. A fundamental principle of ergonomics is that injuries will be prevented and performance enhanced if workplaces, systems, products, and tools are designed to accommodate human variability. As well as differing in size and shape, people also differ considerably in the postures adopted, and patterns of movement used, to achieve any specific physical task. These differences may in part be related to anthropometric variation, but even people of similar shape and size interact with the environment in different ways.

One consequence of this variability is that conventional data analyses that focus on the effect of independent variables on average behaviour are not sufficient to gain a complete understanding of human behaviour. This paper provides an example of a situation in which understanding of the situation is increased by considering individual subject data within a multiple case study approach in addition to conventional nomothetic analysis. The paper then discusses some of the issues related to the

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use of such a method. The data used in this example were subsequently combined with additional data and a more comprehensive analysis is reported elsewhere (Burgess-Limerick et al., 1999).

2. An example: wrist posture during pointing device use

A consequence of the move from command line modes of human–computer interaction to icon-based and menu-driven modes of interaction has been increasing use of pointing devices, and particularly the computer mouse. It has been suggested (e.g., Fogleman and Brogmus, 1995) that the use of such devices may lead to musculoskeletal discomfort and injury as a consequence of prolonged exposure to postures involving extreme wrist extension and ulnar deviation. The aim of the research was to describe the postures adopted by six typical participants to use two different pointing devices to perform two standardised tasks.

3. Method

3.1. Participants

Six right-handed university students (3 male, 3 female, age 27–31 yr) participated in the experiment. All were familiar with the use of computer mouse, but had no previous experience with other pointing devices.

3.2. Procedures

Wrist extension and ulnar deviation were measured while participants completed two standardised tasks with each of two pointing devices. The positions of four infra-red emitting diodes (IREDs) placed on the participants' right hands and forearms were measured in three dimensions at 20 Hz via Optotrak (Northern Digital, CA).

Three IREDs were placed on a rigid flat plastic marker rig taped to the posterior surface of each participant's forearm. The marker rig was placed such that first IRED lay at the midpoint of a line joining radial and ulnar heads, and the second marker was positioned 90 mm from the first on the middle of the posterior surface of the forearm. The first IRED defined the origin of a local coordinate system embedded in the forearm. The second IRED defined the negative x-axis of this coordinate system that coincided with the longitudinal axis of the forearm. The third IRED on the marker frame defined the XY axis (co-ordinates -45, 12.5 mm) coincident with the posterior surface of the forearm. A fourth IRED was placed on the head of the third metacarpal. The Optotrak rigmaker and data analysis package software was used to compute the three-dimensional location of the fourth IRED (metacarpal III) in the local coordinate system of the forearm for each sample, and these coordinates were used to define the extension and ulnar deviation of the wrist.

Wrist posture was defined by expressing the three-dimensional location of metacarpal III in terms of the angular deviation from neutral in XY plane (coincident with forearm) and XZ planes (perpendicular to forearm). Neutral wrist posture (zero flexion/extension and radial/ulnar deviation) was defined as when the third metacarpal was parallel to the long axis of the forearm (Youm et al., 1978). Hence, the neutral posture occurred when the Y and Z coordinates of the Metacarpal III IRED were zero. Extension and ulnar deviation were defined as positive, and flexion and radial deviation as negative. Angular extension was calculated as the inverse sine of the Z coordinate of the Metacarpal III IRED divided by the absolute length of the position vector of the Metacarpal III IRED. Similarly, the angular deviation of the wrist in the ulnar direction was calculated as the inverse sine of the Y coordinate of the Metacarpal III IRED divided by the absolute length of the position vector of the Metacarpal III IRED (in this case the result was multiplied by negative 1 to obtain the desired sign convention).

Two standardised tasks were performed. Each task involved either repetitive horizontal or vertical movements of a cursor between 12 circular targets (8 mm diameter) drawn on alternate sides of the computer screen. Trials of the "vertical" task required continuous alternating up and down vertical cursor movements to targets at the top and bottom of the screen. Trials of the "horizontal" task required continuous alternating left and right horizontal cursor movements to each of 10 targets at the left and right screen edges. A click of the pointing device was required at each target to leave a black dot (3 mm diameter) within the area defined by the target. Instructions to the participants emphasised both accuracy and speed. Two devices were used to perform both tasks, a Mouse (Apple Desktop Bus Mouse II) and a Trackball (Kensington Turbo Mouse). The sensitivity (speed) of both devices was set to default values.

Three practice trials of each task were completed with each device. Blocks of six trials of each task were then performed, and data were collected from the first 10 s of the last three trials in each block.

3.3. Analysis

Wrist flexion/extension and radial/ulnar deviation data were recorded at 20 Hz for the first 10 s of three repetitions of each task for each pointing device. For each trial the maximum and minimum extensions and ulnar deviation were recorded, and the average extension and ulnar deviation of the wrist were calculated for each. Average values for horizontal and vertical trials were calculated for each participant, and the mean and standard deviation for horizontal and vertical trials were then calculated using participant average data. Data from both horizontal and vertical trials were combined to calculate Cohen's effect size (d) associated with different devices using the pooled standard deviation (Cohen, 1969; Thomas and Nelson, 1990). This effect size statistic describes the magnitude of the difference between the means of two groups as a proportion of the average standard deviation of the groups [(Mean 1 − Mean 2)/pooled SD]. By convention, effect sizes of 0.2SD units are termed small effects, 0.6 corresponds to a moderate effect, and 1.2 corresponds to a large effect (Hopkins, 1998).

Individual subject data were examined by constructing frequency distributions for extension and ulnar deviation using 5° bins for the 200 data points in each trial, summing these distributions across the three repetitions of each task, and expressing them as a percentage of trial duration. These data were interpreted in terms of data regarding the effect of wrist position on carpal tunnel pressure (Weiss et al., 1995; Werner et al., 1997).

4. Results

The average wrist posture adopted across horizontal and vertical trials performed with the mouse was 18.2° of extension from neutral (SD = 6°) and 11° of ulnar deviation (SD = 4°). The average wrist posture adopted to perform the same tasks using a trackball was 23.1° of extension (SD = 4°) and 5.7° of ulnar deviation (SD = 5°). The trackball involved a 4.9° increase in average wrist extension, and a 5.3° decrease in ulnar deviation. The effect size statistics for these comparisons were 0.98 and 1.2, respectively, which corresponds to effects which would be considered by statistical convention to be large. In physiological terms, however, a difference of 5° is the minimum which might be considered to be meaningful.

Fig. 1 describes maximum and average wrist posture data for each device and trial direction. The effects of increased wrist extension and decreased ulnar deviation with trackball use are consistent across trial directions. Horizontal trials involve greater maximum and average ulnar deviation, while the direction of cursor movement did not have a consistent effect on wrist extension. Considerable individual variability is evident in the magnitude of the error bars (standard deviations) included in this figure.

On the basis of this conventional analysis it might be concluded that the use of a mouse typically involves considerable exposure to extreme ulnar deviation (defined as postures involving ulnar deviation greater than 10°), and to extreme wrist extension (defined as postures involving wrist extension greater than 30°) to a much lesser extent. It also might be concluded that the trackball reduced exposure to postures involving extreme ulnar deviation, but that the benefit would be likely to be offset to some extent by an increase in exposure to postures involving extreme wrist extension.

These are appropriate conclusions (given appropriate caveats); however additional insight can be gained by examining data from individual participants. An examination of the frequency

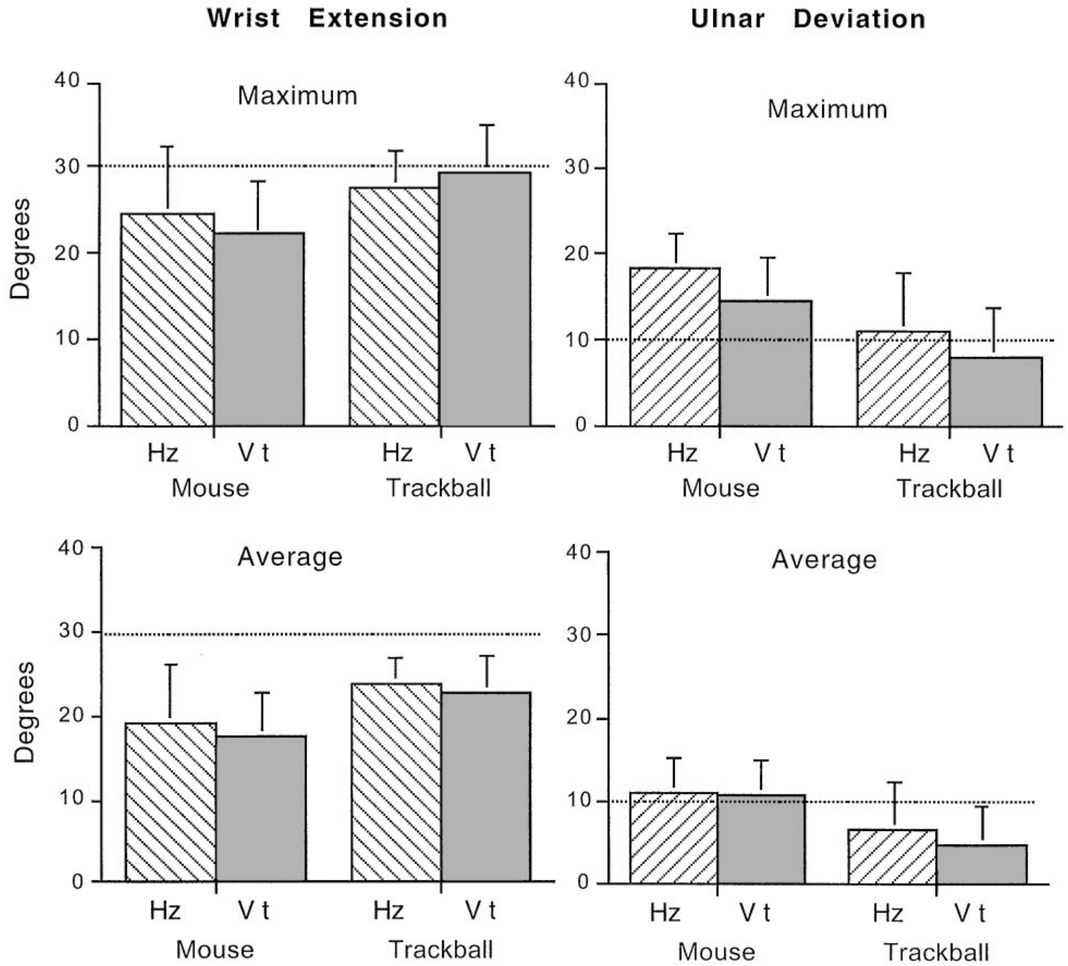

Fig. 1. Maximum and average wrist extension and ulnar deviation in horizontal (Hz) and vertical (Vt) trials performed with mouse and trackball. Error bars indicate between participant standard deviations. Dotted lines indicate extreme wrist extension (30°) and extreme ulnar deviation (10°).

distributions for each participant suggests that the six participants form three distinct groups. The data from all participants indicated that use of the mouse was associated with considerable exposure to wrist postures involving extreme ulnar deviation, although for some participants this was less evident during trials involving vertical cursor movements. For two of the six participants (see, for example, Fig. 2) the postures adopted to perform the same cursor movements were a dramatic improvement and eliminated exposure to extreme wrist postures (as defined above).

For another two participants (see Fig. 3) the postures adopted to perform the tasks with the trackball were an improvement (exposure to extreme ulnar deviation was reduced) but considerable exposure still remained. For the remaining two participants (see, for example, Fig. 4) the frequency of exposure to extreme ulnar deviation was only slightly reduced if at all, and the exposure to extreme wrist extension increased.

5. Discussion

One implication of these data is that the introduction of an alternate pointing device such as a trackball should be considered as an intervention for someone suffering wrist discomfort caused by the use of mouse, but such an intervention should be undertaken with care, and may need to be accompanied by close observation and

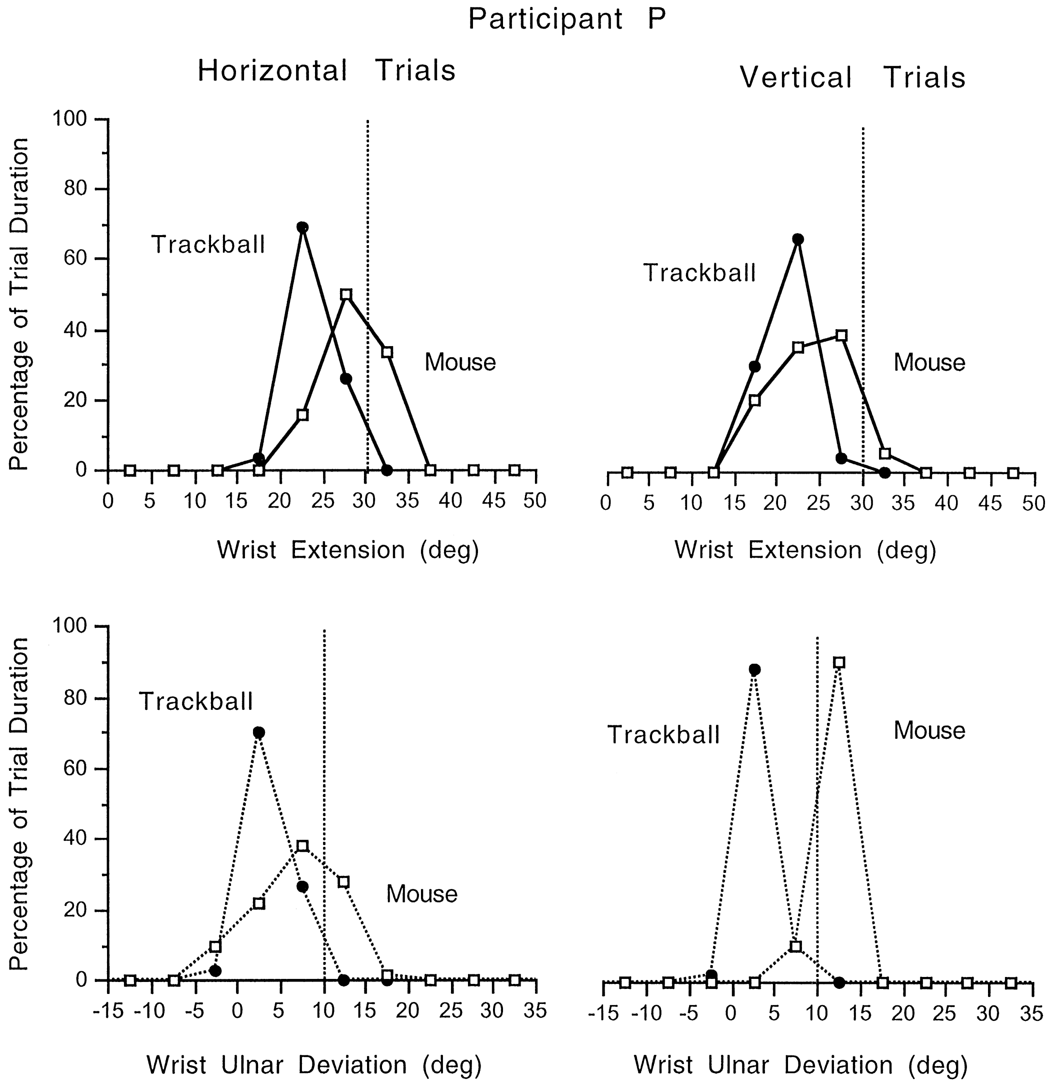

Fig. 2. Frequency distribution of wrist extension and ulnar deviation (average of three trials) for horizontal and vertical trials performed by participant P. The postures adopted by this participant were substantially improved by the trackball and exposure to extreme postures was eliminated.

training to ensure that the exposure to extreme wrist postures is not exacerbated rather than reduced.

These data raise a large number of potential lines of future investigation. For example, the reasons for the individual differences in postures adopted to manipulate the trackball remain unknown at this stage. One very important difference between the devices in this experiment is the differential experience the participants had with the devices. It may be that the variability is simply the consequence of the participants not being familiar with the trackball, and that given sufficient practice the variability would be reduced. Alternately, it may be that design of the trackball allows qualitatively different patterns of use to achieve the same outcome, and the differences observed would persist after practice. Other questions that deserve investigation include: Can the postures adopted be changed with training? What influence does the relationship between pointing device movement and cursor movement (the "speed" of the device) has on wrist postures? Does the type of software (CAD, Wordprocessing, Operating system) influence the postures adopted? What about the many other pointing devices available?

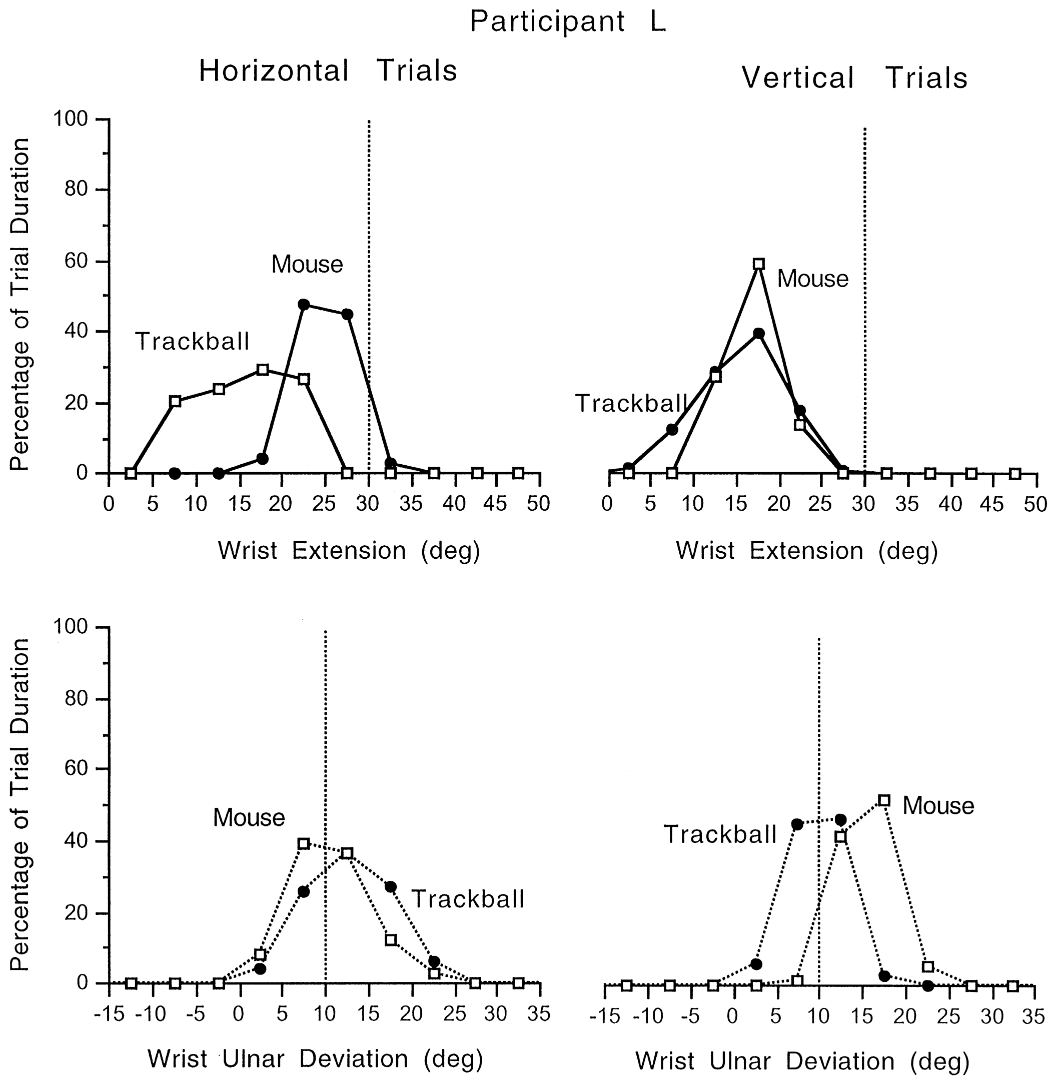

Fig. 3. Frequency distribution of wrist extension and ulnar deviation (average of three trials) for horizontal and vertical trials performed by participant L. The postures adopted by this participant were improved when using the trackball, but some exposure to extreme postures still remained.

The experiment described above demonstrates the potential of a multiple case study approach as a useful research method. This method is commonly used in product usability testing, where a small number of participants are observed using products, and where the products may be in various stages of design resolution. Individual behavioural patterns and responses to stimuli, incorporated in the product or present in the environment, are frequently the most valuable and illuminating feedback for designers. The boundary conditions for product use set by data describing human characteristics (such as anthropometric data) are frequently inadequate for predicting use. Allowing the possibility of using only loose conditions, actual usage, and the outer limits of "normal" usage in a selected population can be the most useful design input, since they usually extend well beyond what was postulated as "normal" by the designer or design team. The points made above concerning the care needed when specifying, for example, a trackball, are reflected in the care required when applying design modifications in user trials. Detailed analyses of video observation, sometimes together with protocol analysis, are required to establish

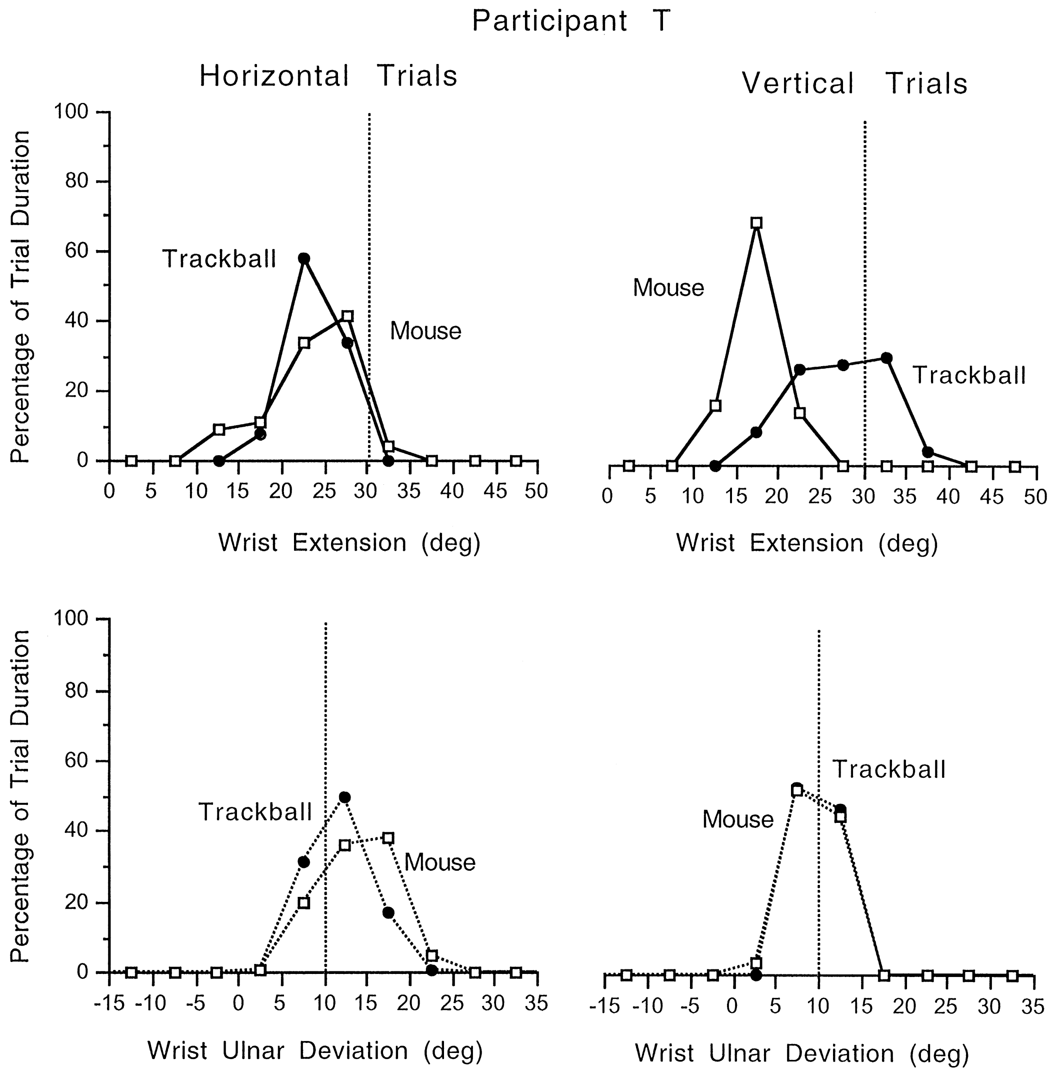

Fig. 4. Frequency distribution of wrist extension and ulnar deviation (average of three trials) for horizontal and vertical trials performed by participant T. Exposure to extreme ulnar deviation was slightly reduced in the horizontal trials when using the trackball, but exposure to extreme wrist extension was increased in the vertical trials.

underlying reasons for individual actions or behavioural patterns.

A number of issues require consideration in the planning and execution of multiple case research. The most important are the aims of the research, the selection of participants, and how such research may be evaluated.

5.1. Aims of research

Multiple case research is a particularly appropriate approach when the aim is to generate theory that is grounded in observation, rather than to confirm existing hypotheses. Multiple case research is a creative process, attempting to construct an increasingly complete understanding of a phenomenon of interest while knowing that, given human complexity, a complete understanding will never be possible. The outcomes are likely to include the framing of more questions (as in the example described above) and these questions have the advantage of being empirically driven.

There presently exists no entirely satisfactory predictive theory of product interaction. Observational research is presently the most promising way of refining or re-defining existing theories or generating new ones.

5.2. Selection of participants

The selection of participants for the research is a critical issue. In some cases the aims of the research may call for participants who are typical of users, or some group of users. In other cases it may be desirable to choose participants who are maximally different from one another with respect to some aspects of the phenomena. Any complete theory must explain the behaviour of all, not just the average. Consequently, the behaviour of individual outliers may be more illuminating for theory development than behaviour of average.

However, it might not be known in advance which participants are most likely to represent distinctive and informative vantage points. In this case, a strategy of drawing upon the researcher's developing understanding of the phenomenon to choose individuals is appropriate. For example, the choice can be directed by a reasonable assumption as in the case of product usability testing of complex electronic devices. Elderly populations may be expected to exhibit most difficulty with such products and this indeed proves to be true in practice. As understanding of the phenomenon develops, it informs the choice of additional participants.

Generalising from an individual case (or even several cases) proceeds through an analytic, rather than a statistical, inference process. The aim is not to achieve a random sample, but rather to choose typical or atypical participants as dictated by the needs of the research.

5.3. Evaluation

Research, and multiple case research in particular, should be evaluated by asking whether it is (a) convincing and (b) useful. Convincing research is research that is systematically conducted, and in which sufficient details of the data are provided to permit the reader to evaluate the interpretation of those data. This presents problems for some forms of observational research, in which, e.g. video observation requires extremely lengthy and detailed analysis before acceptable quantification can be presented. The raw data are not usually available for convenient scrutiny, and how is a reader to interpret, or even know about, an observed hesitancy of action that, in context, gave vital information to the researcher. Such problems must not be allowed to inhibit progress, but should condition the approaches to the presentation of data.

Useful research is research that creates new opportunities for action, or breaks boundaries in understanding (Gergen, in Misra, 1993). In this context, multiple case research is rich in both achievement and potential. It is only gradually being understood how relatively esoteric product/environment phenomena may change behaviour, or permit persistence with unsuccessful use strategies, or even precipitate unsafe behaviour. Almost every experiment reveals a new insight. As the experimental evidence begins to coalesce, an understanding of the physical, sensory, experiential, cognitive and environmental factors that constitute user/product interactions may approach the status of useful predictive theory.

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