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Precision hypothesis and the end-state comfort effect

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Abstract

Recently, motor control research has emphasized the planning of macroscopic aspects of control. In object manipulation studies, when participants complete a movement in a comfortable posture, an end-state comfort effect is attained. One explanation for this effect is the precision hypothesis, which states that precision increases when participants are in a comfortable position. This research directly tests the precision hypothesis in two experiments. In Experiment 1, participants picked up a dowel and touched a large or small target on a wall. For the second experiment, the same procedure was followed using a pinpoint target. The probability analyses of the first experiment indicated that the end-state comfort effect was magnified in the small target condition and that the point-of-change effect (Short and Cauraugh, 1997) appeared only when end-state comfort was magnified. Error analyses in Experiment 2 showed that participants were more accurate when in a more comfortable position. The present findings indicate that the precision hypothesis plays a significant role in the end-state comfort effect. © 1999 Elsevier Science B.V. All rights reserved.

1. Precision hypothesis and the end-state comfort effect

Every movement situation has a multitude of solutions, and one is usually chosen quickly and consistently for each task. The near limitless number of postures the body can assume is due to the degrees of freedom of the joints (Bernstein, 1967).

One way of solving a movement problem is to identify interactions or dependencies within the motor system that effectively limit or ‘‘freeze’’ these degrees of freedom by dynamical constraints or by the training of the neuromuscular system

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through practice. These constraints imply that there are fewer effective degrees of freedom than one would expect based on just counting the body's mechanical possibilities (Kugler et al., 1980).

Another way of solving a movement problem is by looking at the biomechanical constraints or mechanical properties. Since the limits of movement in the joints and the use of the elastic properties of muscles as well as gravity, often govern which movements are possible, the amount of planning is reduced considerably (Bizzi and Mussa-Ivaldi, 1989).

A third way of looking at the question of how movements are planned is using a cost-analysis strategy. Based on movement selection criteria such as the spatial and temporal demands of the task, choices are made that reduce the cost to the motor system. One such recent theory of planning movements is the knowledge model (Rosenbaum et al., 1993, 1995).

1.1. Knowledge model

This model is a posture-based system and claims that (a) movements are selected from the stored posture representations (b) these representations are activated based on their fit to task demands, and (c) that the output of the system is based on the pooling of these activations. Evidence suggests that people recall limb positions better than limb movements and that psychophysical ratings of posture comfort are better than for movement comfort (Rosenbaum et al., 1993). This implies that the comfort of a posture in the terminal position of a movement would be a better gauge of the movement than the comfort of the movement itself. The posture adopted in reaching for a target depends on the size and spatial location of the targets to which a stylus or arm (hand) is moved (Sidaway et al., 1995; Short et al., 1996). This suggests that one should plan the posture for the final target (end-state comfort) to optimize the posture with respect to the starting position (Rosenbaum et al., 1995).

1.2. Selection criteria of movement planning

Research on the planning of macroscopic features of manual control has uncovered several interrelated phenomena that can be considered selection criteria such as the (a) end-state comfort effect; the focus of this paper (Rosenbaum et al., 1990), (b) sequential effect (Rosenbaum and Jorgensen, 1992), (c) point-of-change effect (Short and Cauraugh, 1997), and (d) middle-is-faster effect (Rosenbaum et al., 1996).

1.2.1. End-state comfort effect

The end-state comfort effect dictates that the response chosen by a participant for executing the initial part of a movement will be one that ensures a comfortable position at the end of the movement. This effect was tested by Rosenbaum et al. (1990) with a grip preference task and all participants used the selection criteria of end-state comfort to choose their initial posture. Rosenbaum and Jorgensen (1992) further tested the end-state comfort effect in more complex tasks by using a different grip preference task involving height as well as a handle rotation task (Rosenbaum et al., 1996). It has also been found recently that when end-state comfort in controlled for, the comfort of the initial position may determine grip selection (Fischman, 1997).

1.2.2. Sequential effect

Another finding was that when the task was to place the right end of a dowel against targets arranged from the top to the bottom one trial at a time in consecutive order, the participants kept using the overhand grip for the targets in the middle. However, if the task was to place the right end against the targets numbered from the bottom to the top, the participants used the underhand grip when they placed the bar to the targets in the middle. This occurrence was named the sequential effect by Rosenbaum and Jorgensen (1992) although it seems synonymous with the hysteresis region found by Kelso et al. (1994).

1.2.3. Point-of-change effect

When the order of targets was randomized and participant height is controlled for, a distinct point-of-change effect was observed (Short and Cauraugh, 1997). People appeared to change their final posture during a reaching movement at the point of the shoulder. This was interpreted as a direct result of the end-state comfort effect in that comfort causes participants to change their initial grip on a manipulandum depending on the most comfortable end position. These results were supported by awkwardness ratings; that is, determining and ranking body deviations from neutral postures (Genaidy and Karwowski, 1993) and demonstrated some of the biomechanical limitations that govern comfortable end states.

1.2.4. Middle-is-faster effect

When studying the precision hypothesis of the end-state comfort effect, Rosenbaum et al. (1996) found that participants' movements were quicker in the middle of the range of motion than at the extremes. In a handle rotation task they found that movements ending with the thumb in the most extreme positions took longer than any other movements. Later experiments confirmed that subjects could indeed move their forearm more quickly in the middle of the range of motion than at the extremes.

2. End-state comfort effect explanations

Several explanations for the end-state comfort effect have been postulated such as the Working Backwards Hypothesis and the Fatigue Hypothesis (Rosenbaum et al., 1990) as well as Minimizing Time in Awkward Postures and Exploiting Potential Energy (Houk and Rymer, 1981; Rosenbaum and Jorgensen, 1992).

The most recent and most promising explanation of the end-state comfort effect is the precision hypothesis (Rosenbaum et al., 1993). This explanation predicts that executing positioning movement at or near the middle of the range of motion is easier than at or near the extremes. In essence, precision increases while in a comfortable posture and movements can be made more quickly within that range of comfort (Rosenbaum et al., 1996).

In experiments using bar transport tasks, precise control is needed to touch a dowel correctly to a target that is only slightly larger than the dowel's diameter. Rosenbaum et al. (1996) confirmed the prediction that the end-state comfort effect would be small or even absent when precision was not a main requirement, and that movements can be made more quickly within a comfortable range of motion known as the middle-is-faster effect. The results confirmed the hypothesis that participants determined that by completing these tasks with the arm and hand in comfortable positions, precise task completion would be ensured. The general prediction was that the likelihood of seeing the end-state comfort effect should be inversely related to the precision required for task completion (Rosenbaum et al., 1993).

Rosenbaum et al. (1996), p. 65, stated that "These observations do not constitute direct tests of the precision hypothesis, however: they are only retrospective accounts of task features that are compatible with the hypothesis". Although these results offer support for the precision hypothesis, there still has not been any direct evidence to show that people are more accurate when in a comfortable position.

3. Present experiments

Given that there is no direct evidence supporting the precision hypothesis for movement planning, the present experiments were undertaken for two reasons. The first reason was to search for direct evidence by examining the end-state comfort effect with and without precision requirements. The second purpose was to quantify movement accuracy when in comfortable and uncomfortable positions by using Hancock et al. (1995) two-dimensional error analysis methods.

We hypothesized that the two present experiments would support the existence of a distinct point-of-change effect (Short and Cauraugh, 1997) as the effect should be magnified when there is a greater need for end-state comfort. An influential point-of-change effect is predicted to occur in a task with greater accuracy constraints (as in the small target condition of Experiment 1 described below). We also predicted that participants would be more inclined to use the most comfortable end position when the accuracy constraints are higher (as in the small target condition of Experiment 1 and the error analysis of Experiment 2). If these predictions were true, they would present convincing support favoring the precision hypothesis as an explanation for the end-state comfort effect.

4. Experiment 1

4.1. Method

Participants: Thirty-five right-hand dominant students at the University of Florida (16 females and 19 males; *M* age = 20.4 years) volunteered to participate.

They received no compensation for their participation and none were familiar with the experiment or the concepts being tested.

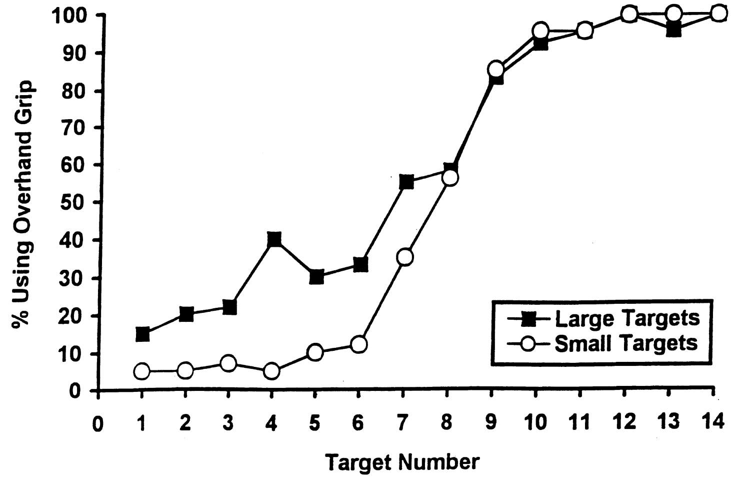
Apparatus: The transport task used a wooden dowel 32 cm long, 2 cm in diameter, and weighed approximately 45 g. The left end was painted black and the right end was painted white, and it rested in a cradle 1.2 m high at an angle of 135° to the target. Two sets of 14 targets were used for this experiment. One set for the 2 cm diameter circles (small targets) and one set for the 8 cm diameter circles (large targets). For both sets of targets, the diameter circles were placed on a length of white paper 15 cm vertically apart. The targets were numbered from #1 to #14 with #1 being near the floor and #14 being the highest. Before starting, the specific target paper was adjusted on the wall so that the #9 target was even (vertically level) with each participant's shoulder. This avoided possible confounds due to varying heights of the participants. A diagram of the apparatus is displayed in Short and Cauraugh, (1997), p. 138.

Procedure: Participants read and signed an informed consent before starting the experiment. Participants read a detailed set instructions on what was required of them during the task and they received further specific verbal instructions related to the proper execution of the task. All participants performed the task with their right-hand while gripping the dowel firmly in the middle. They were instructed to take their time and use either grip (overhand or underhand) on each trial. Participants performed in two conditions: (a) move the left or right end of the bar to a large target 8 cm in diameter and (b) move the left or right end of the bar to a small target 2 cm in diameter. Each trial consisted of the participant taking the dowel from the cradle and touching it to a random selected target specified by the experimenter and then returning the dowel to the cradle. Three seconds of rest were given between trials while the experimenter recorded the grip used on the previous trial.

4.2. Results and discussion

As expected, the point-of-change effect found by Short and Cauraugh (1997) was replicated in the small target condition (high accuracy demand) but not the large target condition (low accuracy demand). This indicated that when the end-state comfort is magnified as in the small target condition a distinct point-of-change effect occurs. The difference between targets #7 and #8 were chosen to be analyzed because according to Short and Cauraugh (1997), this is where the point-of-change is predicted to occur. This point shows where it is more awkward to maintain the same grip, especially when there are accuracy constraints. Significant differences were found between the #7 and #8 target for the left end X^2 (3, $N = 35) = 9.06$, $p < 0.05$ and the right end X^2 (3, $N = 35) = 9.29$, $p < 0.05$ (see Fig. 1, panel A).

Fig. 1 (panel B) also shows that participants tended to choose the more comfortable end-state when there was an increased need for precision. The number of participants using the more comfortable grip determined by awkwardness ratings and the point-of-change effect (Short and Cauraugh, 1997) were analyzed using a chi-square. The analysis revealed that the end-state comfort effect was magnified



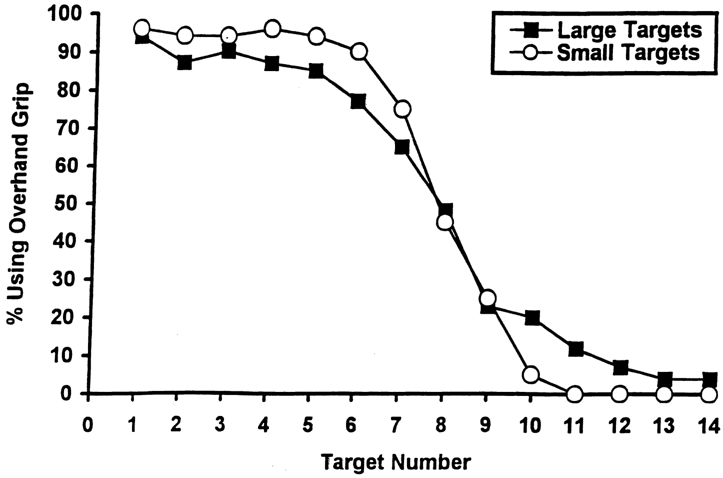


Fig. 1. Probability of using an overhand grip; (Panel A, top): black (left) end of dowel. (Panel B, bottom): white (right) end of dowel.

significantly for both the left (black) X^2 (13, $N = 35$) $= 22.51$, $p < 0.05$ and the right (white) end X^2 (13, $N = 35$) $= 30.97$, $p < 0.005$ in the small condition.

At the point of change (between #7 and #8), participants were much more likely to change their grip in the small target condition than in the large one. To meet the precision demands of the small condition, participants changed their grip. In the large condition, the switch was not made until late because precision was not a factor until the task became more awkward and a change was necessary. It can also be observed in panels A and B that participants were less likely to use the grip prescribed by the end state comfort hypothesis throughout the entire experiment and is especially evident in panel B. This is evident by the results for the large condition being further away from the extremes (0% and 100% use of overhand grip) at each target.

This experiment offered evidence for the point-of-change effect in planning movement as well as provided support for the precision hypothesis by showing that participants chose to be in a more comfortable position when the accuracy demands were greater. Results from this experiment also support Rosenbaum et al.'s prediction (Rosenbaum et al., 1993) that the likelihood of seeing the end-state comfort effect is inversely related to the precision required for task completion.

5. Experiment 2

5.1. Method

Participants: Twenty right-hand dominant students (13 females and 7 males; M age = 20.8 years) volunteered to participate. They received no compensation for their participation and none were familiar with the experiment or the concepts being tested. All volunteers signed an informed consent before participating.

Procedure: The same apparatus used in Experiment 1 was used with two exceptions. First, the dowel had a hole drilled in the left end and a marker was inserted in the hole with approximately 2 cm of the marker extending from the end of the dowel. Second, each of the 14 targets was centered on a x, y coordinate system with a unit increase of 2.5 mm per axis (10). The target and axes were fully visible at all times by the participants during the task and participants touched only the left end of the dowel to each target (movement goal was to touch the center position of an interior x and y axis) in random order using an underhand grip and overhand grip. The exact location (i.e., x and y coordinates) of the mark on the target was recorded by the experimenter.

5.2. Results and discussion

Participants were asked to touch each target using an underhand and an overhand grip despite perceived comfort. Awkwardness ratings findings showed that when using the left end for targets #8 and higher (in number and in height), it was more comfortable to use an underhand grip and for targets #7 and below (in number and in height), it was more comfortable using an overhand grip. Using Hancock et al.'s (Hancock et al., 1995) two-dimensional error measure procedure, mean radial errors for each target in both underhand and overhand grips were calculated for comfortable and uncomfortable end states (see Fig. 2).

T tests were performed to compare accuracy between comfortable and uncomfortable end states for both overhand ($t(19) = 11.08$ $p < 0.001$) and underhand ($t(19) = 6.64$ $p < 0.001$). This analysis indicated that participants were significantly more accurate when in a comfortable position. Thus, these accuracy findings provide strong direct support for the precision hypothesis as an explanation of the end-state comfort effect.

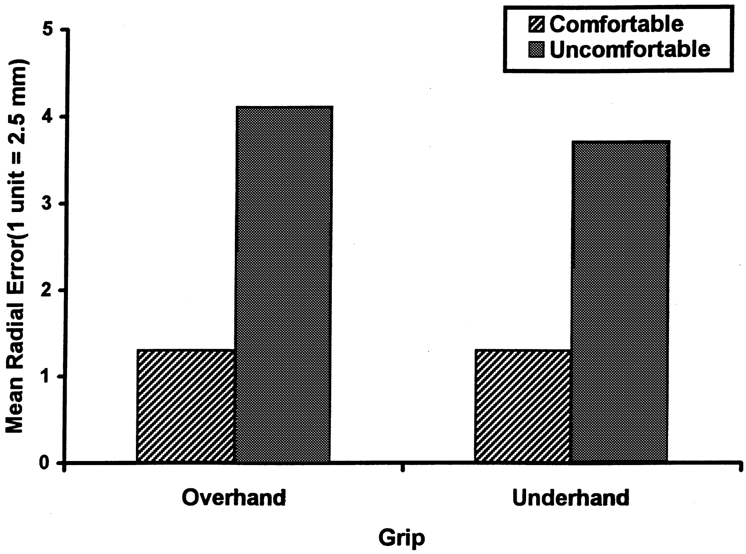


Fig. 2. Precision error (mean radial error) comparison: comfortable vs. uncomfortable.

6. General discussion

The results from these two experiments support Short and Cauraugh's (Short and Cauraugh, 1997) point-of-change effect and the precision hypothesis regarding the origin of the end-state comfort effect. The point-of-change effect was supported by the large differences found between the #7 and #8 targets where a large shift was found between an overhand and underhand grip in the small target condition of Experiment 1. Apparently, as demands for end-state comfort are increased via more awkward tasks (Short and Cauraugh, 1997) or greater accuracy demands (present study), a distinct point-of-change effect occurs.

Additional evidence in favor of the precision hypothesis was found in Experiment 1. The results showed that participants selected more comfortable end states when the accuracy demands were greater. Further precision hypothesis evidence was identified in Experiment 2. The direct two-dimensional spatial error measurement findings revealed greater accuracy when participants performed movements in more comfortable positions. These phenomena appear to dictate the way we solve movement problems and offer us a greater understanding of the way people function in everyday situations. Moreover, the results from these experiments imply that ensuring a comfortable final posture allows faster and more accurate movement executions.

Overall, the evidence from both experiments supported a prediction of the knowledge model concerning being able to predict the effects of starting postures on selected target postures. Specifically, stored target postures (end states) for the low or high targets appeared to dictate the how participants performed the transport tasks.

In other words, whether or not a starting arm posture was comfortable did not adversely affect performance accuracy across these two experiments.

An alternative view to the knowledge model interpretation is a direct perception perspective. Direct perception involves affordances (i.e., possibilities for action) of objects and events in the environment (Summers, in 1998). These affordances reflect the interaction of energy patterns between specific capabilities of the organism and specific properties of the object(s) in the environment (Summers, in 1998). Applying direct perception concepts to our target aiming task (i.e., touching one end of a dowel to one of a set of vertically aligned targets) involves detecting the energy patterns required to specify affordances. Determining possibilities for action could be accomplished by actively exploring the perceptual-motor workspace (Summers, in 1998). If participants were executing their movements based on affordances, then stored representations were not required. Further research is needed to determine if affordances are functioning in the identified perceptual-motor workspace.

Additional investigations should examine the role of the point-of-change effect (Short and Cauraugh, 1997), the middle-is-faster effect (Rosenbaum et al., 1996), the precision hypothesis (Rosenbaum et al., 1993, 1996), and the present findings in planning and executing instrumental daily activities. Indeed, determining if these effects are present outside the laboratory and to what extent they shape our movement plans while executing daily activities are future research goals.

7. Further reading

Readers may also find these references of interest: Rosenbaum et al., 1992; Viviani, 1993; Fisher et al., 1997.

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