Research Quarterly for Exercise and Sport

Vol. 79, No. 1, pp. 36–41

The End-State Comfort Effect in Young Children

Carola F. Adalbjornsson, Mark G. Fischman, and Mary E. Rudisill

The end-state comfort effect has been observed in recent studies of grip selection in adults. The present study investigated whether young children also exhibit sensitivity to end-state comfort. The task was to pick up an overturned cup from a table, turn the cup right side up, and pour water into it. Two age groups (N = 20 per group) were studied: preschool children (2–3 years old), and kindergarten students (5–6 years old). Each child performed three videotaped trials of the task. Only 11 of the 40 children exhibited the end-state comfort effect, and there were no differences between age groups. Results revealed the emergence of five different performance patterns, none of which were consistent with sensitivity to end-state comfort. The findings have implications for the advance planning of manual control in young children.

Key words: manual control in children, movement planning, object manipulation

Since the emergence of the field of movement control and learning around World War II, scientists have studied many different aspects of human movements (Schmidt & Lee, 2005). One focus of interest has been on response selection processes in simple and complex actions. For example, when people reach for an object, pick it up, and move it to another location, many movement options are available to complete the task. An important problem, therefore, is what constrains a person to select a particular movement, or combination of movements, from the many available options, or what Bernstein (1967) referred to as the *degrees of freedom* problem. One constraint on movement selection that has received considerable attention recently is the *end-state comfort effect* (Cohen & Rosenbaum, 2004; Fischman, 1997, 1998; Fischman, Stodden, & Lehman, 2003; Lam, McFee, Chua, & Weeks, 2006; Manoel & Moreira, 2005; Rosenbaum & Jorgensen, 1992; Rosenbaum et al., 1990; Rosenbaum, van Heugten, & Caldwell, 1996; Weigelt, Kunde, & Prinz, 2006). The effect illustrates the tendency to maximize comfortable hand and arm postures at the end of simple object manipulation tasks, such as picking up a tool or kitchen utensil or turning a dial on the radio, rather than at the beginning. To ensure comfortable ending postures, adults appear to be willing to adopt awkward initial postures. Rosenbaum, Vaughan, Barnes, and Jorgensen (1992) described how actors tend to evaluate how an arm positioning movement should be finished and plan initiating the movement to assure that the final position is the most comfortable one at the end of the task. This planning allows for maximum control over the fine positioning movements needed at the task's completion.

Studies of the end-state comfort effect have used various tasks, such as pronating/supinating a stick (Rosenbaum et al., 1996, Experiment 2), rotating a handle (Rosenbaum et al., 1992; Rosenbaum et al., 1996, Experiment 1), reaching for objects (Fischer, Rosenbaum, & Vaughan, 1997), bar transports with one or both hands (Cohen & Rosenbaum, 2004; Fischman, 1998; Fischman et al., 2003; Lam et al., 2006; Manoel & Moreira, 2005; Rosenbaum, Halloran, & Cohen, 2006; Rosenbaum & Jorgensen, 1992; Short & Cauraugh, 1997, 1999), and picking up an overturned glass and

Submitted: February 27, 2007
Accepted: September 6, 2007

Carola F. Adalbjornsson is with Actavis Group, Hafnarfirdi, Iceland. Mark G. Fischman and Mary E. Rudisill are with the Department of Kinesiology at Auburn University.

turning it right side up (Fischman, 1997). The present investigation studied the overturned glass task.

The planning constraint of end-state comfort is evidenced when adults reach for an overturned glass to turn it right side up. Initial contact with the glass is typically made with an awkward, pronated grip (thumb-down grip), followed by supination of the hand at the end of the movement, thus ensuring a comfortable thumb-up posture. Although it is possible to perform the task in the reverse sequence, doing so would place the hand in an awkward, uncomfortable ending posture and might make it more difficult to execute a subsequent task, such as filling the glass with water. Rosenbaum et al. (1990) found that adults' subjective ratings of awkwardness were over twice as high when they held a vertical bar with a thumb-down rather than a thumb-up posture. Fischman (1997) studied the overturned glass task with a relatively large sample of college students. In one condition (GLASS HELD), participants sat at a table and were instructed to turn over a drinking glass but not put it down. While holding the glass, with their other hand they picked up a measuring cup filled with water and poured it into the glass. In a second condition (GLASS DOWN), two drink coasters were placed on the table, one on each side of the overturned glass. Instructions were to turn over the glass, place it on either coaster, then pick up the measuring cup and pour the water into the glass. In the GLASS HELD condition, it clearly would be advantageous to pick up the glass with an awkward grip so that one could end the movement comfortably. However, in the GLASS DOWN condition, end-state comfort is theoretically not as important, because the participant can then reposition his or her hand to perform the pouring part of the task. Fischman (1997) found that 94% of the participants performed the task as described above, regardless of condition, and, thus, were sensitive to end-state comfort.

It is important to note that the end-state comfort effect can be used to study the advance planning of movements and how one may solve the degrees of freedom problem (e.g., Cohen & Rosenbaum, 2004; Rosenbaum, Halloran, & Cohen, 2006). While the bulk of research on the effect has used adult participants, there are a few studies involving children. Manoel and Moreira (2005) studied seven groups of children ranging in age from 2.5 to 6 years in approximate 0.5-year increments. The task was to use one hand to pick up a wooden bar resting horizontally on a cradle and insert one end of the bar into a hole in a box. Two precision conditions were manipulated. In a low-precision condition, the distal ends of the bar and the hole were cylindrical, making for an easy insertion irrespective of how the bar was grasped. However, in a high-precision condition, the ends of the bar and hole were semicylindrical, making for a more difficult insertion unless the children planned their initial grasp in advance. The children exhibited little evidence of end-state comfort in this study, regardless of the precision required. Rather, there were strong preferences to use the right hand and an overhand grip, which could be interpreted either as a preference for start-state comfort or as evidence for lack of planning ability in the age groups studied.

In two related investigations, McCarty, Clifton, and Collard (1999, 2001) found some support for advance hand-grip planning with infants and toddlers. McCarty et al. (1999) studied 9-, 14-, and 19-month-olds as they reached for a spoon loaded with food. The spoon was always presented horizontally at the child's midline, but the goal end (i.e., bowl) and the handle end were alternately presented to the child's left and right. In general, planning strategies differed across these developmental ages. The 9-month-olds tended to reach with their preferred hand in an overhand orientation. This strategy would sometimes produce an appropriate radial grip (holding the handle of the spoon with the thumb toward the bowl end), allowing the food to be successfully brought to the mouth. However, on half the trials an overhand orientation produced an inappropriate ulnar grip (holding the handle of the spoon with the thumb toward the opposite end of the bowl), resulting in the handle ending up in the mouth. By 19 months, the children were able to inhibit reaching with their preferred hand, coordinating with the spoon's orientation so that they reached with the handle-side hand in an overhand, radial grip. This way, they could smoothly and efficiently transport food to the mouth.

In a similar study (McCarty et al., 2001), children ages 9, 14, 19, and 24 months were observed as they used "tools" such as a spoon, hairbrush, toy hammer, and a magnet. In some conditions the children were instructed to use the tools in a self-directed manner, such as feeding oneself with the spoon or brushing one's hair. In other conditions the tool was directed toward an external goal, such as feeding another or brushing another's hair. Results showed that by 14 months, the children tended to use radial grips more often in the self-directed conditions than in the other-directed ones. It is important to note that the radial grip is the most efficient for completing these tasks, allowing the children to apply the tool without having to make an adjustment. The authors took these findings as evidence of advance planning when grasping tools with self-directed goals.

Taken together, previous research results are equivocal with respect to the degree of advance planning and sensitivity to end-state comfort exhibited by young children in simple object-manipulation tasks. In addition, we are aware of no studies that have used the overturned glass task with young children. Because this task has high ecological relevance and has produced straightforward end-state comfort findings with adult

participants (Fischman, 1997), we were interested in determining whether the movements are innate or learned as human beings develop. Therefore, the purpose of the present study was to test the generalizability of the end-state comfort effect, using the overturned glass task, in two younger populations (preschool children and kindergarten students). If the task is learned over developmental time, we would expect older children to exhibit greater sensitivity to end-state comfort, because they would likely have had more exposure to the task through play as well as more opportunities to observe and model adult performance. Alternatively, if the movements are innate, we should find no differences between the age groups as well as a preference to perform the task consistent with end-state comfort. Regardless of which hypothesis was supported, we also expected to see relatively high performance variability in both age groups.

Method

Participants and Setting

Forty children were tested, 20 in each of two age groups: preschool children (age range 2.25–3.67 years; 13 girls, 7 boys), and kindergarten students (age range 5.25–6.0 years; 11 girls, 9 boys). All procedures were approved by the university's Institutional Review Board for the Protection of Human Subjects. Parents provided informed consent, and the children gave their assent prior to participating in the study. Data on the preschool children were collected at the children's homes and in the company of one of their parents. These children were part of a large play group that met weekly at different homes. Data on the kindergarten students were collected at a local kindergarten school during the children's physical education period. The same experimenter collected all data.

Task, Equipment, and Procedure

The task was to pick up a plastic drinking cup that was sitting upside down on a table, turn the cup over, and pour water from a pitcher into it. The use of an awkward, thumb-down posture to grasp the cup was taken as evidence of sensitivity to end-state comfort (Fischman, 1997).

The same child-sized round plastic table (48 cm high, 44 cm diameter) and chair were used for both age groups. The chair seat height was 30 cm. The cup and water pitcher (Little Tikes®, Co., Hudson, OH) were also the same for both age groups (see Figure 1). As shown in the figure, the 7.5-cm high cup had six edges and was tapered such that the circumference at the top (open) end was approximately 19.6 cm, and approximately 14.8 cm at the bottom. These dimensions are much smaller than those of Fischman (1997) whose drinking glass was 12.3 cm high and tapered from a 27.5-cm circumference at the top to 17.3 cm at the bottom. We feel that the relative proportions of our cup are comparable to those of Fischman's (1997) glass. Our intention was to present the children with essentially the same task as adults performed, and we are confident that each child in our study was capable of manipulating the cup with one hand. Work by Kuhtz-Buschbeck, Stolze, Jöhnk, Boczek-Funcke, and Illert (1998) showed that children by the age of 5 years can reliably scale their grip aperture to the size of an object to be grasped. In addition, because the cup was upside down on the table, the children were more likely to contact it at a level that was easier, given their smaller hands. However, based on work by Newell and colleagues (Cesari & Newell, 2000; Newell & Cesari, 1998; Newell, McDonald, & Baillargeon, 1993; Newell, Scully, McDonald, & Baillargeon, 1989; Newell, Scully, Tenenbaum, & Hardiman, 1989), we acknowledge that the cup's size could potentially have an impact on performance.

The cup was placed upside-down on the table, 13 cm from the edge and directly in front of the midline, thereby allowing the children to use their preferred hand. The pitcher, approximately half filled with water, was placed directly behind the cup. The children entered the testing area, sat down at the table, and were instructed to use only one hand (child's preference) to turn the cup over and pour the water into it. Several children wanted to use both hands and were asked by the experimenter to sit on the other hand or place it in their lap. Performance was recorded on videotape so that the children's performance strategies could

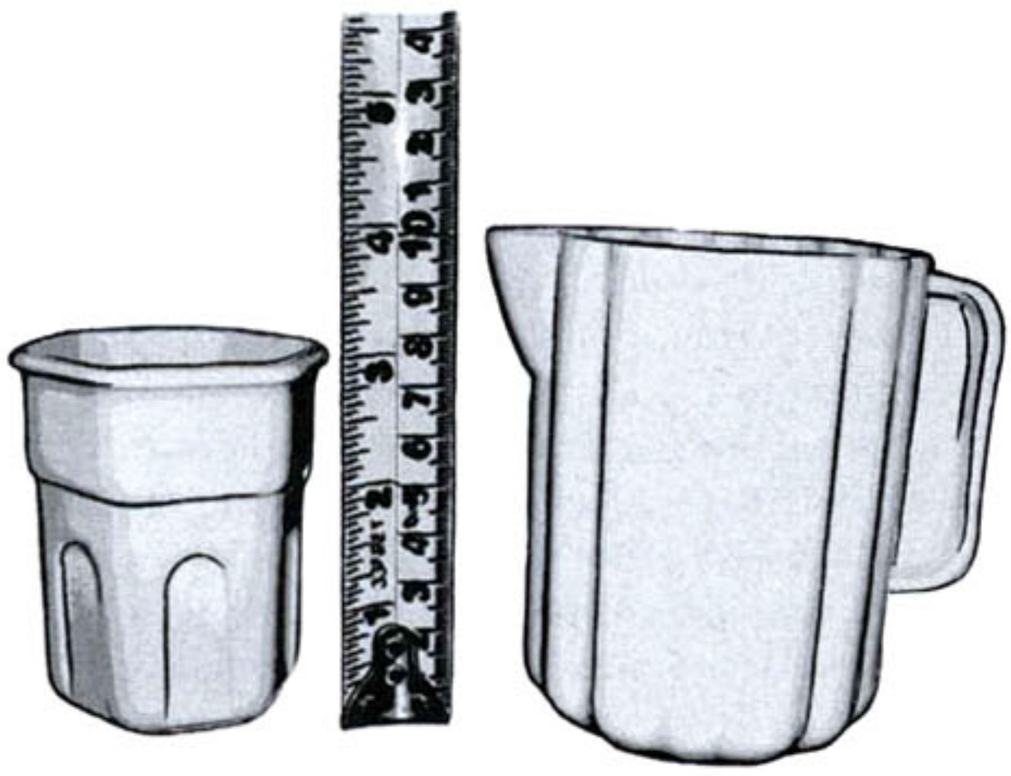

Figure 1. Scale drawing of the cup and pitcher used in the experiment.

be catalogued and described. A standard analog video camera was set up at a 45° angle from the frontal plane and approximately 1.5 m from the table. Following each trial, the experimenter refilled the pitcher and placed it and the cup in their starting positions in front of the child. Each child performed three trials, and the end-state comfort effect was considered present if the awkward initial grip appeared in at least two of the trials. We selected three trials mainly because of the children's brief attention span. For some, particularly the 2-year-olds, it was difficult to do the task three times before wanting to either drink the water from the cup or splash it on the table or floor. The experiment required approximately 10 min for each child.

Results and Discussion

Group Data

The main dependent variable of interest was the number of children who performed the task in a manner consistent with end-state comfort (i.e., with a thumb-down grip as the starting posture). Table 1 presents the data for the two age groups, separated by sex, across the three trials. It is fairly clear that the children showed little evidence of end-state comfort sensitivity. Out of the 40 children, only 11 used a thumb-down grip (4 preschool children, 7 kindergarten students); the other 29 used a variety of manipulations to perform the task, which also appear in the table and will be described in the next section. Interestingly, 11 children exhibited the end-state comfort effect on all three trials. Recall from the method section that we were willing to acknowledge the presence of end-state comfort sensitivity if the awkward initial grip appeared in at least two of these trials. Because there is typically high variability among children, it was important to have multiple trials to ensure a pattern of behavior. A chi-square analysis revealed the difference between the number of thumb-down grips and all others to be statistically significant, χ^2 (1) = 8.10, $p < .01$. In addition, there was no significant difference between the two age groups in using a thumb-down grip, χ^2 (1) = 1.13, $p > .05$.

Description of Other Manipulations

The vast majority of children performed the task in ways inconsistent with sensitivity to end-state comfort, and their performance bore little resemblance to the typical adult-like pattern. The children showed great variety in planning aspects of grip selection for this task. Five patterns occurred multiple times (see Table 1). We refer to these as (a) supination strategy, (b) start-state comfort strategy, (c) chest strategy, (d) table strategy, and (e) top-and-twist strategy. In the *supination strategy*, the children started by pointing their thumb upward and used supination to rotate their hand away from their body so that the thumb faced downward in an extremely twisted way. They then grabbed the cup and turned it over by rotating the hand backward. With the *start-state comfort* strategy, the children first grasped the upside down cup with a normal thumb-up grip. They then turned it over by supinating the hand (i.e., rotating the hand clockwise for a right-hander, or counter-clockwise for a left-hander), which produced an extremely uncomfortable ending posture. The *chest strategy* involved grabbing the cup with a comfortable thumb-up grip and then bringing it to the chest for support as they turned

Table 1. Number of children from each age group exhibiting the various strategies across trials

Strategy	Trial 1		Trial 2		Trial 3	
	Girls	Boys	Girls	Boys	Girls	Boys
Preschool children (13 girls, 7 boys)						
End-state comfort	3	1	3	1	3	1
Supination	0	2	0	0	0	2
Start-state comfort	0	1	2	2	2	2
Chest	1	0	1	0	0	0
Table	8	3	6	3	8	1
Top-and-twist	1	0	1	1	0	1
Kindergarten students (11 girls, 9 boys)						
End-state comfort	4	3	4	3	4	3
Supination	0	0	0	1	1	0
Start-state comfort	0	1	0	1	0	2
Chest	2	0	2	0	1	2
Table	4	5	3	3	4	2
Top-and-twist	1	0	2	1	1	0

it over. The *table strategy* required two steps; the children first grabbed the cup and laid it down on the table. They then regrasped the cup to turn it over. Finally, with the *top-and-twist strategy*, the children grasped the cup from the top and used their fingers to twist it in their hand to turn it over. Occasionally, these children would use their chest or the table for rolling the cup over. An interesting observation we noted is that most of the children were not consistent in their use of a particular strategy; rather, they would use one in one trial and switch to another for the next trial, which probably reflects their exploratory nature at these ages. Also, as can be seen in Table 1, the table strategy tended to occur more often than the others and was used consistently on all three trials by 4 preschool children and 2 kindergarten students. This strategy was also the only one that produced a difference between boys and girls in the preschool group, where the girls used this strategy considerably more than the boys. Other than this instance, task performance was similar between the sexes.

After turning the cup upright on the table, many children used both hands to reach for the pitcher of water to pull it closer. They also held the cup with the nonpreferred hand for support and used their preferred hand to pour the water. An interesting observation here relates to the use of both hands to reach for the pitcher. Research by Kuhtz-Buschbeck et al. (1998) showed that young children tend to use a bigger "safety margin" than adults when reaching for objects. The use of two hands would certainly allow for a greater safety margin to avoid spilling the water. Recall also that several of the children wanted to use both hands to turn the cup over but were not allowed to do so. It could be that these children may have exhibited a "nontraditional" strategy of end-state comfort, especially if their prior experience with a task like this was to use both hands.[1]

There were considerably fewer young children who appeared to be sensitive to end-state comfort for the same manual control task, when compared to previous studies (Fischman, 1997). Our findings are consistent with those of Manoel and Moreira (2005), who observed children of similar age to those in the present study, but used the task of inserting a wooden bar into a box. They found little evidence of sensitivity to end-state comfort or advance planning ability. On the other hand, our findings contrast somewhat with studies by McCarty et al. (1999, 2001) who showed that infants between the ages of 9 and 24 months begin to develop the skill to plan using a tool such as a spoon (also see Connolly & Dalgleish, 1989). Although these infants became more adept over developmental time at distinguishing the correct end of a spoon for grasping, their radial grip was certainly not close to the mature adult pattern for grasping and manipulating a spoon. McCarty et al. (1999) also identified strategic differences in spoon use across their 9–14-month-old infants that fit nicely with the different strategies we observed in the present study.

The varous grip selection aspects observed in most participants in this study reflects a complex interaction involving young children's exploratory nature, constraints imposed by physical characteristics, such as hand size, emerging coordination, spatial and perceptual awareness, and cognitive limitations for advance planning. These children use motor skills to explore their environment, and it may be through a trial-and-error process that they discover how to solve problems and reach the most efficient motor solutions, given their physical and cognitive capabilities. Furthermore, evidence from this study suggests the end-state-comfort effect is likely an acquired and learned motor phenomenon and not innate to humans.

Unlike previous studies of grip selection with adults (e.g., Fischman, 1998), no substantial differences between the sexes were noted in this study. This finding can likely be attributed to the fact that most of our participants had similar experience and exposure to the objects being manipulated. American children of both sexes play with these types of toys in sand boxes, the bathtub, and kitchen sets. However, previous studies of grip selection have not considered the amount of experience and exposure children have with similar manipulative tasks (e.g., Manoel & Moreira, 2005; McCarty et al., 1999, 2001). There are other tasks of manual control, one-hand catching for example, in which considerable sex differences have been found in young children (Fischman, Moore, & Steele, 1992) that are likely attributable, in part, to differences in exposure to ball sports such as baseball and softball.

In summary, we observed a relatively simple goal-directed behavior of turning over a cup and filling it with water, in children between 2 and 6 years of age. The goal was to determine whether these children exhibited the same sensitivity to end-state comfort as found in adults. Based on the results of our study, we can conclude that they do not. End-state comfort does not appear to be an innate characteristic of manual control but one that may emerge over developmental time. Whether instruction and modeling would lead to acquisition of the mature pattern for this task is a worthwhile subject for future research. It would also be interesting to determine if the few children who consistently exhibited the end-state comfort effect would show the effect if observed later, as on a delayed retention test. In addition, to the extent that sensitivity to end-state comfort can reveal information about the advance planning of manual control, further studies are necessary to establish at what age individuals acquire a consistent pattern of sensitivity to end-state comfort in this task as well as in others. This research is currently underway in our laboratory.

References

Bernstein, N. (1967). *The co-ordination and regulation of movements.* Oxford, England: Pergamon Press Ltd.

Cesari, P., & Newell, K. M. (2000). Body-scaled transitions in human grip configurations. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1657–1668.

Cohen, R. G., & Rosenbaum, D. A. (2004). Where grasps are made reveals how grasps are planned: Generation and recall of motor plans. *Experimental Brain Research, 157,* 486–495.

Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill in infancy. *Developmental Psychology, 25,* 894–912.

Fischer, M. H., Rosenbaum, D. A., & Vaughan, J. (1997). Speed and sequential effects in reaching. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 404–428.

Fischman, M. G. (1997). End-state comfort in object manipulation [Abstract]. *Research Quarterly for Exercise and Sport, 68*(Suppl.), A-60.

Fischman, M.G. (1998). Constraints on grip-selection: Minimizing awkwardness. *Perceptual and Motor Skills, 86,* 328–330.

Fischman, M. G., Moore, J. B., & Steele, K. H. (1992). Children's one-hand catching as a function of age, gender, and ball location. *Research Quarterly for Exercise and Sport, 63,* 349–355.

Fischman, M. G., Stodden, D. F., & Lehman, D. M. (2003). The end-state comfort effect in bimanual grip selection. *Research Quarterly for Exercise and Sport, 74,* 17–24.

Kuhtz-Buschbeck, J. P., Stolze, H., Jöhnk, K., Boczek-Funcke, A., & Illert, M. (1998). Development of prehension movements in children: A kinematic study. *Experimental Brain Research, 122,* 424–432.

Lam, M., McFee, K., Chua, R., & Weeks, D. J. (2006). Macroscopic aspects of gross motor control: A test of the end-state comfort effect. *Research Quarterly for Exercise and Sport, 77,* 396–400.

Manoel, E. J., & Moreira, C. R. P. (2005). Planning manipulative hand movements: Do young children show the end-state comfort effect? *Journal of Human Movement Studies, 49,* 93–114.

McCarty, M. E., Clifton, R. K., & Collard, R. R. (1999). Problem solving in infancy: The emergence of an action plan. *Developmental Psychology, 35,* 1091–1101.

McCarty, M. E., Clifton, R. K., & Collard, R. R. (2001). The beginnings of tool use by infants and toddlers. *Infancy, 2,* 233–256.

Newell, K. M., & Cesari, P. (1998). Body scale and the development of hand form and function in prehension. In K. J. Connolly (Ed.), *The psychobiology of the hand* (pp. 162–176). London: Mac Keith Press.

Newell, K. M., McDonald, P. V., & Baillargeon, R. (1993). Body scale and infant grip configurations. *Developmental Psychobiology, 26,* 195–205.

Newell, K. M., Scully, D. M., McDonald, P. V., & Baillargeon, R. (1989). Task constraints and infant grip configurations. *Developmental Psychobiology, 22,* 817–831.

Newell, K. M., Scully, D. M., Tenenbaum, F., & Hardiman, S. (1989). Body scale and the development of prehension. *Developmental Psychobiology, 22,* 1–13.

Rosenbaum, D. A., Halloran, E. S., & Cohen, R. G. (2006). Grasping movement plans. *Psychonomic Bulletin & Review, 13,* 918–922.

Rosenbaum, D. A., & Jorgensen, M. J. (1992). Planning macroscopic aspects of manual control. *Human Movement Science, 11,* 61–69.

Rosenbaum, D. A., Marchak, F., Barnes, H. J., Vaughan, J., Slotta, J. D., & Jorgensen, M. J. (1990). Constraints for action selection: Overhand versus underhand grips. In M. Jeannerod (Ed.), *Attention and performance XIII—Motor representation and control* (pp. 321–342). Hillsdale, NJ: Erlbaum.

Rosenbaum, D. A., van Heugten, C. M., & Caldwell, G. E. (1996). From cognition to biomechanics and back: The end-state comfort effect and the middle-is-faster effect. *Acta Psychologica, 94,* 59–85.

Rosenbaum, D. A., Vaughan, J., Barnes, H. J., & Jorgensen, M. J. (1992). Time course of movement planning: Selection of hand grips for object manipulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1058–1073.

Schmidt, R. A., & Lee, T. D. (2005). *Motor control and learning* (4th ed.). Champaign, IL: Human Kinetics.

Short, M. W., & Cauraugh, J. H. (1997). Planning macroscopic aspects of manual control: End-state comfort and point-of-change effects. *Acta Psychologica, 96,* 133–147.

Short, M. W., & Cauraugh, J. H. (1999). Precision hypothesis and the end-state comfort effect. *Acta Psychologica, 100,* 243–252.

Weigelt, M., Kunde, W., & Prinz, W. (2006). End-state comfort in bimanual object manipulation. *Experimental Psychology, 53,* 143–148.

Note

1. We thank an anonymous reviewer for suggesting this interpretation.

Authors' Notes

Portions of this study were presented at the 2001 conference of the North American Society for the Psychology of Sport and Physical Activity, St. Louis, MO.
At the time of this study, the first author was with the Department of Kinesiology at Auburn University. We thank Nancy Getchell and two anonymous reviewers for helpful comments on the initial draft of the manuscript. Please address all correspondence concerning this article to Mark G. Fischman, Department of Kinesiology, Auburn University, Auburn, AL 36849-5323.

E-mail: fischmg@auburn.edu.