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RESEARCH NOTE

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Semantics affect the planning but not control of grasping

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Abstract The semantic meaning of a word label printed on an object can have significant effects on the kinematics of reaching and grasping movements directed towards that object. Here, we examined how the semantics of word labels might differentially affect the planning and control stages of grasping. Subjects were presented with objects on which were printed either the word "LARGE" or "SMALL." When the grip aperture in the two conditions was compared, an effect of the words was found early in the reach, but this effect declined continuously as the hand approached the target. This continuously decreasing effect is consistent with a planning/control model of action, in which cognitive and perceptual variables affect how actions are planned but not how they are monitored and controlled on-line. The functional and neurological bases of semantic effects on planning and control are discussed.

Keywords Language · Planning · Control · Action · Grasping

Introduction

The interaction between language and motor systems has been extensively examined and evaluated (Kimura 1979; Klatzky et al. 1987; Jeannerod 1997; Rizzolatti and Arbib 1998). For example, word meanings can interfere with the process of responding to colors when the words and colors are incongruent (Stroop 1935). In the present study, we used a kinematic analysis of a grasping movement to investigate the effects of word meanings on the planning and on-line control of a reaching and grasping movement. The motivation for this investigation came partly from recent work by Gentilucci and his colleagues (Gentilucci and Gangitano 1998; Gentilucci et al. 2000) that showed that words printed on objects affected the kinematic characteristics of actions directed towards those objects.

Gentilucci and Gangitano (1998) observed that peak acceleration and peak velocity of a reaching and grasping movement were greater for objects on which the word "LUNGO" ("long") had been printed than for objects on which was printed the word "CORTO" ("short"). This was consistent with what had been found for objects that were actually greater or shorter distances from the hand (Jeannerod 1988). However, it was also noted by Gentilucci and Gangitano (1998) that the words had an opposite effect on the peak deceleration of the reach. That is, whereas the initial portion of the reach seemed to be consistent with a semantic effect on planning, the latter portions seemed to reflect an on-line correction of this effect.

The apparent on-line correction of semantic effects over the course of a reaching movement bears a striking resemblance to the on-line correction of the effects of visual illusions on actions. In several studies (Glover and Dixon 2001a, 2001b, 2001c, 2002), illusions have been shown to have large effects early in a movement trajectory but decreasing effects thereafter. We have argued that these effects reflect the use of separate visual representations in the planning and control of action, with planning being highly susceptible to illusions and control being relatively immune.

More generally, we hold that the representation used in planning integrates a broad array of visual and cognitive information with memories of past experience in selecting an appropriate action plan. (A computational model based on similar assumptions was proposed by Rosenbaum et al. 1995.) The representation used in on-line control, on the other hand, is aimed solely at minimizing the spatial error of the movement, and is thus focused on the spatial characteristics of the target (e.g., size, shape, orientation),

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independent of top-down perceptual and cognitive influences.

According to this planning/control model, a semantic effect on action should be evident early in the movement, reflecting a cognitive influence on planning processes. However, this semantic effect should decline as the movement progresses, reflecting the relative immunity of on-line control to such influences. Here, we examined the predictions of the planning/control model by analyzing the effects of the words "LARGE" and "SMALL" throughout the course of a grasping movement. Gentilucci et al. (2000) examined the Italian equivalent of the same word pair, and found effects both early and late in the movement (i.e., in the maximum velocity of grip aperture and in the maximum grip aperture, respectively). However, it was not obvious from their data whether this effect declined over time as did the effects of the words used by Gentilucci and Gangitano (1998). Thus, the present study used a continuous measure of the labels' effects on grip aperture. This continuous measure allowed us to more readily compare the effects of the words throughout the course of the movement.

Materials and methods

Subjects

Six University of Alberta undergraduates participated in the experiment in return for course credit. All six reported having normal or corrected to normal vision, and each was strongly right-handed as measured by a modified version of the Edinburgh Inventory (Oldfield 1971). All participants were naive as to the exact purpose of the study. All gave their informed consent prior to testing.

Apparatus

Subjects sat on an adjustable chair at a 100×60-cm table and viewed the table through a 20×80-cm two-way mirror positioned approximately 10 cm from the participant's eyes. The subject's vision above and around the table top was restricted by the testing apparatus, but subjects were able to see the table surface, including their reaching hand and arm, throughout each individual trial. The experimenter manipulated the ability of subjects to see through the mirror by switching on or off the table lighting.

The table surface was covered with black construction paper to minimize reflections. The target object was laid in front of the subject on either the left side or right side of the table. The target was a prism with three rectangular sides and two triangular ends. Due to the triangular shape of the object the front surface was always sloped 60° away from the subject from the base to the peak. The shape of the object allowed the labeled side to be presented perpendicularly to the subjects' line of sight, in order to facilitate their reading the words. The sides of the blocks were 2 cm in height and either 5, 6, or 7 cm in length. The ends of the blocks were all 2-cm equilateral triangles. On one side of each object was printed either the word "LARGE" or the word "SMALL" in capital letters in black ink. The words were centered on the blocks, and the size of the words was 4.0×1.5 cm in all conditions. A 1×5-cm starting bar was secured to the table parallel with the subject's frontal plane. The near edge of the target block was placed at a distance of 20 cm from the starting bar, at one of two symmetrical positions at an angle of 22.5° to the left or right of the center of the starting position. The target block was oriented 45° clockwise from the end nearest to the subject; this made it easy for subjects to comfortably grasp the target while still allowing them to see the printed words. The distance between the center of the starting bar and the subject's midsection was approximately 20 cm.

The table surface was monitored with an overhead infrared video camera that fed information into an IScan tracking system. This system (originally developed for monitoring eye movements) was configured to record the position of an infrared light source at 60 Hz. The position of the ired in a 1500 (forward) × 2000 (lateral) grid was recorded by computer for later analysis. In the present application, we needed to measure both the position of both the thumb and forefinger in order to determine grip aperture. To this end, we devised a system in which two ireds were alternately lit in synch. with the video camera scan; using this approach, we could determine the position of each ired every other video frame. The distance between the ireds was determined for each measurement by interpolating between the positions of the other ired on the previous and following frames. The accuracy of this tracking system was measured using a method adapted from Haggard and Wing (1990). This involved fixing the ireds to either end of a 12-cm bar and moving the bar forward and sideways across the workspace from various starting positions. The standard deviation of the calculated distance between the ireds was less than 1.2 mm in both the forward and horizontal planes.

Experimental procedure

Subjects used their right hand for the duration of the experiment. Each subject wore one ired on the index finger (near the base of the nail on the left side, palm facing down) and another on the thumb (near the base of the nail on the right side, palm facing down) of the right hand.

Subjects were required to begin each trial by pinching the starting bar between their thumb and fingers. After the table lighting was switched on and the target display became visible, there was a 300-ms pause before a tone signaled the subjects to reach. The pause ensured that subjects had sufficient time to read the written word on each target block. The task was to reach out and pick up the target by its ends using the thumb and forefinger. Subjects were instructed always to place their thumb on the left side of the target from their perspective. The instructions to the subjects emphasized accuracy as the first priority, followed by speed. Subjects were instructed to ignore the words printed on the objects.

The task consisted of 6 practice and 60 experimental trials. The experimental trials consisted of five repetitions of each object size (5, 6, or 7 cm), printed word ("LARGE" vs "SMALL"), and side of the midline (left vs right) combination, presented randomly.

Data analysis

The dependent variable was the grip aperture (i.e., distance between the thumb and forefinger) throughout the reach. Data were analyzed by first passing the position recordings through a custom filter designed to exclude artifacts based on acceleration and velocity criteria. Data points were excluded if acceleration exceeded 10.0 m/s^2 or if the velocity exceeded 1.5 m/s. Missing observations were then estimated by interpolation. The criterion velocity for the onset and offset of the movement was set at 0.025 m/s. The thumb was used to determine the onset and offset criteria, as this tends to be the more stable digit during reaching (Wing and Fraser 1983; Wing et al. 1986). Trials were excluded if the reaction time was less than 50 ms or greater than 800 ms, or if the movement time was less than 250 ms or greater than 1,000 ms. A total of 7.5% of the trials were excluded from the final analysis.

For each movement, the magnitude of the grip aperture was computed at 21 temporally equal intervals from onset to offset, inclusive, so that each interval corresponded to 5% of the movement. These time-normalized data were averaged for each subject by word and size. An index of the semantic effect was constructed as follows at each interval. First, the raw semantic effect was calculated as the difference in grip aperture between the "LARGE" and "SMALL" word conditions. Second, the effect of target size was calculated by finding the difference between the grip aperture with the 7-cm target and 5-cm target, and dividing this difference in grip aperture by the 2-cm difference in actual size. This yielded the proportion of the actual size of the target that was reflected in the grip aperture and can be described as the slope relating actual size to grip aperture. Finally, the scaled semantic effect was calculated by dividing the raw semantic effect by this size-aperture slope.

A scaling procedure of this general sort is needed so as to obtain an unbiased measure of effects on movement parameters over time. This is because the range and sensitivity of those parameters change over the course of the movement (cf. Franz et al. 2000; Glover and Dixon 2001a, 2002). For example, large variations in object size produce relatively little change in grip aperture early in the reach, but roughly equivalent variations in grip aperture at the end of the reach (Glover and Dixon 2002; Jeannerod 1984). As such, the effect of a cognitive variable is best described as the change in object size that would be required to achieve a similar effect at that particular point in time.

In order to assess the statistical evidence for the changes in the scaled semantic effects over time, we analyzed the results at each quarter of the duration of the movement. Two issues were of most importance: First, was there an effect of the semantic manipulation on grip aperture? That is, was the scaled semantic effect generally greater than zero? Second, did this effect change over time? We hypothesized that the scaled semantic effect should be large at the outset of the reach and smaller near the end. The evidence relevant to these questions was assessed by comparing the fits of simple linear models to the results. The relative quality of the two fits in each comparison was evaluated by computing the maximum likelihood ratio. This represents the likelihood of the data based on one model divided by the likelihood of the data based on the other. This statistic provides a simple, easily interpreted measure of the quality of the fits, with large values (e.g., greater than 10) indicating clear evidence in favor of one model over the other. Likelihood ratios of this sort are also closely related to the statistics used in null hypothesis significance testing, and the null hypothesis would generally be rejected when the likelihood ratio is 10 or greater (Dixon 1998; Dixon and O'Reilly 1999). A likelihood ratio of 10 would be classified as "moderate" evidence using the criteria of Goodman and Royall (1988).

Results

Figure 1, left, shows the effect of the size of the targets on the grip aperture over time. Consistent with past studies (e.g., Glover and Dixon 2002; Jakobson and Goodale 1991; Jeannerod 1984), grip aperture increased gradually to the point of maximum grip aperture at roughly two-thirds of the duration of the reach, then decreased again during the final approach to the target.

Figure 1, right, shows the slope of the effect of object size on grip aperture over time. This shows that the same difference in object size resulted in a relatively small difference in grip aperture early in the reach, but that the effect of object size generally increased as the hand approached the target. This increase in slope over time is typical for reaching and grasping movements (Glover and Dixon 2002; Jeannerod 1984).

Figure 2 shows the raw (left) and scaled (right) effects of the words on grip aperture. To assess whether the scaled effects were generally greater than zero, we first compared a null model that assumed that the effects were identically zero to one that included a constant effect of

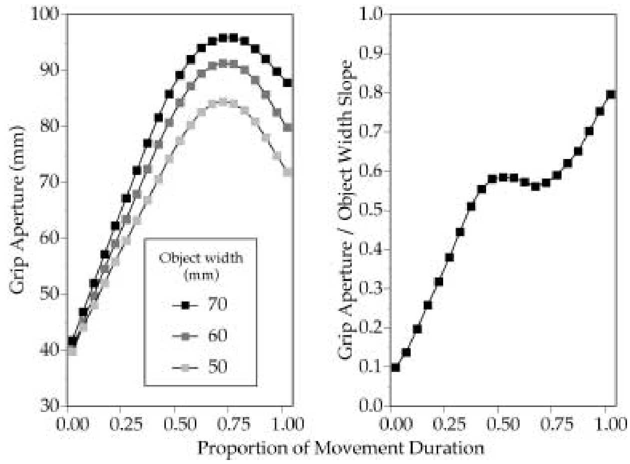

Fig. 1 The effect of object size on grip aperture over time (*left panel*) and the slope of the relationship between grip aperture and object size (*right panel*). For both panels, the *x-axis* represents normalized time. For the *left panel*, the *y-axis* represents grip aperture. For the *right panel*, the *y-axis* represents the slope relating grip aperture to object size

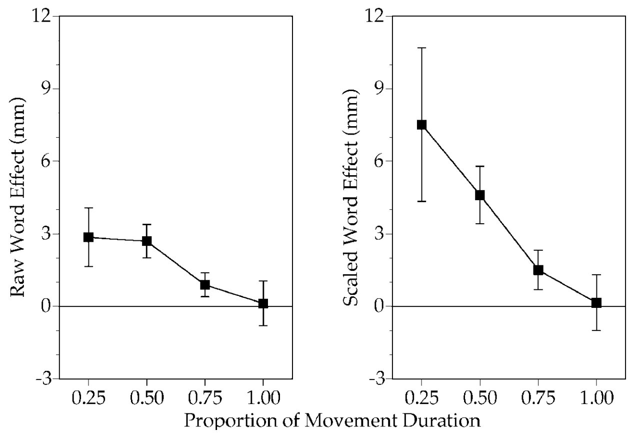

Fig. 2 The raw (*left panel*) and scaled (*right panel*) effects of the printed words on grip aperture over time for each quartile of the movement. For both panels, the *x-axis* represents normalized time. The *y-axis* represents the raw (*left panel*) and scaled (*right panel*) effects of the words on grip aperture. The scaled effect was obtained by dividing the raw effect by the slope at the corresponding point in normalized time

words. The latter model fit considerably better and the comparison led to a large likelihood ratio, λ>100. In other words, the data were more than 100 times as likely on the assumption that the printed words had an effect on the grip aperture than on the assumption that the words had no effect. To assess whether the effect of words varied over time, we compared the model with a constant effect of words to a model in which the semantic effect varied over time. The comparison again yielded a large likelihood ratio, λ>100, indicating clear evidence for a time-varying effect.

It might be argued that grip aperture at the end of the reach is constrained to be close to the actual size of the target block and consequently could not show a semantic effect in principle. However, even when we excluded this point and performed an analysis on the change over the first three points independent of the constant term, there was still clear evidence that the semantic effect decreased over time, λ=59.8. In sum, the data provided strong evidence for an effect of the words on scaled grip aperture that diminished over the course of the movement.

Discussion

The results of the present study demonstrated that a semantic effect was present during the early stages of a reaching and grasping movement and decreased over the course of the movement. These data extend the results found using visual illusions, in which the early portions of the movements were much more affected by the illusion than the latter portions (Glover and Dixon 2001a, 2001b, 2001c, 2002). These data also provide further support for the planning/control model (Glover 2002a, 2002b; Glover and Dixon 2001a, 2001b, 2001c, 2002), in which cognitive and perceptual variables are said to have large effects on how actions are planned, but little or no effect on how they are monitored and corrected on-line.

A functional account of the semantic effects observed here may be related to the typical correlation between verbal labels and object characteristics in everyday experience. In the present case, objects labeled “LARGE” might have encouraged the expectation of an object that was in fact larger than an object of a similar class labeled “SMALL.” During on-line control, however, this crude analysis may have been fine-tuned by more accurate information regarding the veridical spatial characteristics of the target, and the semantic effect on planning would have been corrected in flight.

Neurologically, the semantic effect may be related to the proximity of language and motor planning centers in the left hemisphere (Geschwind 1972; Kimura 1979; Rizzolatti and Arbib 1998). One candidate region where planning and language processes seem to overlap is in and around Broca’s area. This hypothesis is supported by the data from a number of positron emission tomography (PET) studies that show increased activation in Broca’s area correlated with both word reading (Petersen et al. 1988; Price et al. 1994) and motor preparation (Deiber et al. 1991, 1996). A second candidate for the overlap of language and motor-planning centers is the left inferior parietal lobe (IPL). This region has been implicated in both motor preparation (Decety et al. 1992; Krams et al. 1998; Rizzolatti and Arbib 1998; Rushworth et al. 2001) and Wernicke’s aphasia (Damasio and Damasio 1989).

The immunity of on-line control systems to the semantic effect on planning may be due in part to the use of a visual representation distal to and presumably independent of language processing centers. In line with this, we have posited that a control representation is localized (bilaterally) to the superior parietal lobe (SPL) (Glover 2002a; Glover and Dixon 2001c), based on PET studies that have shown activation in this region during action execution (Grafton et al. 1992; Krams et al. 1998), and on the reported deficits in the on-line guidance of action that follow damage to the SPL (Jeannerod et al. 1994; Perenin and Vighetto 1983, 1988; see also Pisella et al. 2000). Disruption of this region by transcranial magnetic stimulation impairs the ability to make on-line corrections (Desmurget et al. 1999).

In the present study, semantics affected the planning of a grasping movement, but these effects were continuously corrected as the hand approached the target. These observations provide further support for the planning/control model of action (Glover 2002a, 2002b; Glover and Dixon 2001a, 2001b, 2001c, 2002), in which the two stages of action operate using separate visual representations. A planning representation, hypothesized to be centered in the left IPL, integrates a vast array of visual and cognitive information with memories of past experience into an action plan. A control representation, hypothesized to be centered in the SPL, monitors and guides the action based on visual information that is largely independent of cognitive and perceptual influences.

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