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Judgments of moving and intending to move in a timed-response task

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Summary. Subjects performed a timed-response task in which they attempted to synchronize a rapid flexion of the index finger of their preferred hand with the last of a train of four regularly spaced acoustic clicks. The task was used to stabilize the execution time of a simple voluntary response in order to facilitate psychophysical judgments about the subjects' perception of having responded and of having intended to respond. In the first experiment, male subjects (*N* = 6) adjusted the appearance time of a reference stimulus (a brief percutaneous pulse to the responding finger) until it appeared to be simultaneous with their perception of having made the response. All subjects adjusted the reference stimulus to appear after response onset during the latter half of the force impulse. This finding suggests that the perception of having responded is based on peripheral feedback from the response. In the second experiment, male subjects (*N* = 6) performed the same motor task, but adjusted the time of the reference stimulus so that it appeared to be simultaneous with their intention to respond. Two subjects were not able to do the task successfully; the remaining four subjects adjusted the reference stimulus to appear from 101 to 145 ms before response onset. This finding suggests that the intention to respond is perceptually separable from the response itself and occurs at a measurable time before response onset.

Introduction

Neurophysiologists and psychologists studying voluntary movement have found it convenient to talk of a motor command that is generated in the central nervous system and that results ultimately in the excitation of motoneurons and the contraction of muscle fibres (e. g., Gandevia, 1987). Gandevia and Rothwell (1987) have outlined the long history of the controversy of whether centrally generated motor outflow is available to subjective awareness, and summarized recent evidence which suggests that the motor command has distinct perceptual consequences.

A reliable temporal relationship between the motor command (as a perceived intention to move) and the initiation of the act itself would give credibility to the idea that a distinct motor command precedes movement. However, the more basic question of the timing of the perception of movement in relation to the initiation of the movement itself is currently in dispute. Two independent studies of subjects' awareness of their intention to execute a simple voluntary movement are relevant (Libet, Gleason, Wright, & Pearl, 1983; McCloskey, Colebatch, Potter, & Burke, 1983). In these studies, subjects judged the relative time of occurrence of an external reference stimulus with criterion events associated with the movement. First, they judged the time of the reference stimulus in relation to their perception of having made a simple rapid movement to estimate when movement is perceived relative to the appearance of the movement itself. Second, they judged the time of the reference stimulus in relation to their perception of intending to make the movement to estimate when the intention to move is perceived relative to the appearance of the movement itself.

In one experiment, Libet et al. (1983) asked subjects to note the "clock position" of a revolving spot on a visual display that corresponded to a simple rapid movement or to the perceived intention to make the movement; in another experiment the revolving spot stopped at different times and the subjects judged whether the spot stopped before, after, or at the same time as the criterion event, the perceived movement or the perceived intention to move. The subjects made the movement ad libitum within a specified period. McCloskey et al. (1983) asked subjects in one series of observations to judge the temporal order of an external reference stimulus (a brief percutaneous electrical stimulus to the ankle) and their perception of having made a simple rapid movement; in another series of observations, the subjects judged the temporal order of the reference stimulus and their perceived intention to make the movement. McCloskey et al.'s subjects also made the movement ad libitum within a specified period.

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Both studies reported that judgments of the intention to move preceded judgments of movement itself, suggesting that the subjects were able to differentiate their intention to move (i. e., their perception of the motor command) from the movement. However, the two reports disagreed on the temporal relationship of the perceived movement and the movement itself. Libet et al. (1983) reported that the perception of movement generally preceded the onset of electromyographic (EMG) activity associated with movement and argued that the perception of movement could not therefore be based on proprioceptive input associated with the movement. McCloskey et al. (1983) reported that the perception of movement generally followed the onset of EMG activity, a finding consistent with the perception of movement being based on proprioceptive input. More precise psychophysical estimates of the temporal location of the perception of movement would resolve the disagreement. The forced-choice methods used by both Libet et al. (1983) and McCloskey et al. (1983) were inefficient because, with little experimental control over the temporal relationship of the reference stimulus and the movement, many observations were made when the reference stimulus clearly preceded or clearly followed the movement, and relatively few observations were made around the critical point of perceived simultaneity of the reference stimulus and the movement.

Experiment 1

More efficient psychophysical estimates can be made by stabilization of the temporal location of the response. The present experiment used the timed-response task developed by Hening, Favilla, and Ghez (1988) for this purpose. In this task, subjects are required to execute a simple response synchronously with the last in a series of four regularly spaced acoustic stimuli. The task is easily mastered, and has the advantage of relatively little trial-to-trial variability in the timing of response excecution. We used this task to restrict the variability in the time of execution of an abrupt finger flexion and required subjects to adjust the presentation time of a percutaneous reference stimulus to the responding finger until it was perceptually synchronous with their perception of having made the response. The Method of Adjustment was chosen because even the relatively small trial-to-trial variation in response timing with the timed-response task makes constant-stimulus methods inefficient.

Method

Subjects. Six right-handed males ranging in age from 21 to 46 years (median = 21 years) were tested.

Apparatus and procedure. The subjects were isolated in a sound-attenuated room sitting with their preferred hand resting on a flat surface with the index finger on a 25-mm disk machined from an aluminum bar. A trial was self-initiated by a footswitch closure; following a 1,000-ms delay, a train of four clicks with a regular stimulus onset asynchrony of 500 ms was presented over headphones. The subject's motor task was to make an abrupt voluntary flexion of his index finger at the same time as the fourth click in the train. The subject's perceptual task was to adjust the temporal location of a reference stimulus (a 1-ms percutaneous electrical pulse delivered to the responding finger) from trial to trial until it appeared to be simultaneous with the perception of having executed the response on a particular trial. Stimulus generation, timing, and data acquisition were done with a microcomputer.

The reference stimulus was generated by a Grass SD9 stimulator coupled in series with a Grass CCU-1 constant current unit and delivered through 7-mm-diameter stainless-steel electrodes taped lightly to the dorsum of the second and third phalanges of the responding finger. The threshold intensity for detection of the reference stimulus was first determined by an ascending Method of Limits; an intensity of three to four times the threshold value, which was painless and clearly perceptible, was used in the experimental trials. The acoustic clicks were obtained by the delivery of a 1-ms square-wave pulse to headphones worn by the subject. The voltage of the square wave was set to produce a clearly perceptible click. The response was detected by a strain gauge on the response key, which generated a voltage proportional to the force applied to the key. The voltage output of the strain gauge was amplified, fed into a 12-bit analog-to-digital converter, and sampled at 1 KHz for 300 ms, starting at response onset. The point of force onset was indicated by a pulse output and recorded as the onset time of the response.

A trial began with the reference stimulus presented so that it appeared clearly to precede or clearly to follow the perceived movement. The subject then adjusted a rotary knob to vary the presentation time of the reference stimulus in relation to the third click on the next trial; clockwise rotation of the knob increased the delay of the reference stimulus after the third click and anticlockwise rotation of the knob reduced the delay of the reference stimulus after the third click. The position of the knob (and hence the reference-stimulus delay) was not indicated by any feature on the knob itself. Subjects continued to adjust the delay of the reference stimulus on successive trials until satisfied that it appeared to be simultaneous with the perception of having moved on a particular trial. The subjects signaled the perception of simultaneity by pressing a separate response button. After a synchronous trial a green or red light-emitting diode was illuminated briefly to signal the subject to reset the reference-stimulus adjustment knob either fully clockwise or fully anticlockwise before the next trial. The direction in which the reference stimulus was reset was selected randomly. The session continued until 20 judgments of synchrony were made. Only sessions in which the correlation between the reference-stimulus delays and response delays on synchrony trials was greater than .35 were accepted. This criterion was applied so that only sessions in which subjects were adjusting the reference stimulus in relation to a response-related cue were accepted. Of the completed sessions 25% were rejected for this reason. Each subject completed 5 acceptable sessions for a total of 100 synchronous trials.

On non-synchronous trials the delay of response onset in milliseconds from the third click was saved; on synchronous trials, the delays of response onset and of the reference stimulus in milliseconds from the third click were saved. The digitized values that described the force-time profile of the response were saved on each synchronous trial. The duration of the force impulse, the period during which force was increased, was later measured to the nearest millisecond. The force-time profiles were kept as a more detailed description of the temporal structure of the response.

Results and discussion

The force-time profiles of the responses recorded on synchrony trials showed little within-subjects variation. There were, however, characteristic differences between subjects in the duration of the force impulse. These durations ranged from 70 to 112 ms in the different subjects, with a mean of 92 ms.

Mean response-onset delays from the third click on non-synchrony trials were less than 500 ms for all subjects, showing that on average the subjects initiated their response before the fourth click. The response delays ranged from 304 to 445 ms after the third click, with a mean of 380 ms. The timing of response execution did not differ on synchrony and non-synchrony trials. The mean response delays on synchrony trials ranged from 316 to 437 ms after the third click, with a mean of 379 ms. On average, the subjects made 4.8 ($SE_M = 0.7$) observations to reach a synchrony judgment.

The results from each of the six subjects are summarized in Table 1. The correlation coefficients between the reference-stimulus delay and the response delay on synchronous trials ranged from .53 to .85. The correlation of these variables shows that the subjects were adjusting the reference stimulus in relation to some response-related cue, and were not adjusting it in relation to some external stimulus (such as the fourth click) or setting the adjustment knob to a particular position. The delays of the reference stimulus in relation to response onset were obtained by subtracting the response delay on each synchrony trial (measured from the third click) from the corresponding reference-stimulus delay (also measured from the third click). The mean of the resulting reference-stimulus delays were all positive (with a range of 40 to 101 ms), showing that on average the subjects adjusted the reference stimulus to appear after response onset. The reference stimulus was set to appear before response onset on only 1.5% of all synchrony trials.

All subjects on average set the reference stimulus to appear within the duration of the force impulse. The delay of the reference stimulus from response onset on each synchrony trial was expressed as a ratio of the duration of the force impulse on that trial. The means of these ratios for each subject ranged from .47 to .99, showing that the reference stimulus was adjusted to appear from about the midpoint to the end of the force impulse. The small standard errors of the mean ratios show a high within-subjects consistency in the position within the force impulse to which the reference stimulus was adjusted.

The results agree with those reported by McCloskey et al. (1983) and disagree with those reported by Libet et al. (1983). The perception of movement in the conditions studied here follows the onset of the movement and presumably depends upon proprioceptive or cutaneous feedback from the movement itself. There is no need to suppose (as did Libet et al.) that the perception of movement depends upon awareness of the efferent outflow for the movement.

Table 1. Correlation coefficients (r) for the association of reference-stimulus delays and response delays from the third click, mean reference-stimulus delays from response onset (ms), and means of the ratios of the reference-stimulus delays from response onset and the durations of the corresponding force impulse in Experiment 1. Standard errors of the means are in parentheses

	Correlation coefficient (r)	Mean reference-stimulus delay (ms)	Mean ratio
SD	.53	40 (2.5)	.47 (.03)
SS	.83	58 (2.8)	.51 (.02)
JQ	.58	52 (3.0)	.75 (.04)
FG	.65	75 (2.5)	.79 (.03)
RL	.85	101 (4.3)	.96 (.05)
OC	.70	73 (4.2)	.99 (.06)

Experiment 2

The procedures used in Experiment 1 were successful in that reliable estimates of the time of perception of having made a simple voluntary response in relation to the appearance of the response were obtained. The same procedures were followed in this experiment with subjects asked to adjust the reference stimulus to a different perceptual event, the perception of the intention to execute the response.

Method

Subjects. Six right-handed males ranging in age from 21 to 46 years (median = 21 years) were tested. Three of the subjects had been tested in Experiment 1.

Apparatus and procedure. Subjects performed the timed-response task in the same conditions as Experiment 1. Only the sensory task differed: in this experiment the subjects were asked to adjust the temporal position of the reference stimulus from trial to trial until it appeared to be simultaneous with their awareness of intending to make the response. No other instructions were given.

The requirement of a substantial correlation between reference-stimulus delays and response delays on the 20 synchrony trials of a session used in Experiment 1 was not applied. This requirement was too restrictive and led to the rejection of sessions in which only a narrow range of response delays was produced, and hence an attenuated correlation. In this experiment, no sessions were excluded because of a low correlation of reference-stimulus delays and response delays.

Results and discussion

The response-onset delays from the third click on non-synchrony trials ranged from 341 to 627 ms with a mean of 464 ms; on synchrony trials, the response delays ranged from 224 to 560 ms with a mean of 384 ms. The within-subjects variability of the response delays was greater than in Experiment 1: the means of the standard deviations of the response delays for Experiments 1 and 2 respectively were 55 and 328 ms for the non-synchrony trials and 43 and 92 ms for the synchrony trials. This increased variability is probably a consequence of the greater difficulty of adjusting the reference stimulus to apparent simultaneity with the intention to respond than to the response itself. The more difficult sensory task would have interfered with the concurrent motor task of synchronizing the response with the fourth click. The greater difficulty of the sensory task was also evident in an increase of the mean number of adjustments required for synchrony to 6.2 ($SE_M = 1.0$).

Table 2 gives the correlations of the response delays from the third click with the corresponding reference-stimulus delays from the third click on synchrony trials and the mean delays of the reference stimulus in relation to response onset. The correlation coefficients were high ($.75 \leq r \leq .96$) for five subjects, but low for one (LV; $r = .32$), indicating that this subject's reference-stimulus adjustments at synchrony were not linked strongly to a response-related event. Of the five subjects with an acceptably high correlation, four adjusted the reference stimulus to appear before response onset. The remaining subject (RL) adjusted the reference stimulus to appear on average 25 ms after response onset; this subject showed a much larger difference between response delays on synchrony

Table 2. Correlation coefficients (*r*) for the association of reference-stimulus delays and response delays from the third click and mean reference-stimulus delays from response onset (ms) in Experiment 2. Standard errors of the means are in parentheses

	Correlation coefficient (*r*)	Mean reference-stimulus delay (ms)
SS	.87	–101 (3.8)
FG	.77	–130 (4.2)
OQ	.75	–140 (11.0)
RF	.96	–145 (3.5)
RL	.80	25 (7.7)
LV	.32	36 (6.5)

and non-synchrony trials (403 ms) than the others, whose mean absolute difference was 24 ms. This observation suggests that RL, who had an absolute difference of 12 ms between response delays on synchrony and non-synchrony trials in Experiment 1, was not able to perform the concurrent sensory and motor tasks accurately in this experiment. The results of the remaining four subjects are consistent with each other, with the reference stimulus adjusted to appear from 101 to 145 ms before response onset in order to appear simultaneous with the intention to respond. Two of these four subjects had served in Experiment 1 and were aware of the research issue and two were tested for the first time in Experiment 2 and were not aware of the research issue.

The concentration of intention estimates from four of the subjects at about 130 ms before response onset implies that some event that occurred at about this time was perceived by the different subjects as their intention to respond. Two electrophysiological events that precede voluntary movements, the pre-motion positivity (the offset of the readiness potential) and the motor potential (a negativity over MI contralateral to the responding body part) occur respectively about 90 ms and 30 ms before EMG activation (Deecke, 1987). Allowing for central transmission of the reference stimulus (the first cortically generated component of the somatosensory evoked potential has a latency of about 22 ms; e.g., Mauguiere, Desmedt, & Courjon, 1983) and for the time by which EMG precedes response onset (recordings from two subjects showed activity in the first dorsal interosseus and the flexor digitorum superficialis led response onset by 25 to 60 ms), either of these electrophysiological signs might indicate response-related neural activity which is perceived as the intention to move.

Although these findings are consistent with the subjects having adjusted the reference stimulus to appear coincident with their perception of intending to respond, it is possible that the subjects instead adjusted the reference stimulus to appear at some brief interval before the response. Assuming that the interval between the motor command and the response is more or less constant, the correlations observed between the reference-stimulus delays and the response delays do not exclude this possibility. The issue could be resolved experimentally by manipulation of the interval from the generation of the motor command to the execution of the response; one way in which this might be done is to require responses that have different peripheral transmission times, say a voluntary eyeblink and a voluntary foot movement. If the subjects synchronized the reference stimulus with the motor command, they would set it to a time before response onset that included the different peripheral transmission times required; if they merely set the reference stimulus to appear before the response, the interval by which the reference stimulus preceded the response would not vary with transmission time.

Exact temporal location of the motor command, however, should be treated with some scepticism. The ability of the four subjects in Experiment 2 to adjust the reference stimulus reliably to a time before response onset that was synchronous with their perceived intention to move does not imply that the motor command is a brief impulsive event that can be localized exactly in time. Instead, the motor command may be a progressive specification of response parameters that takes place over a substantial time (e.lg., Georgopoulos, 1991). Furthermore, it is likely that different subjects would adopt different psychophysical detection criteria for the intention to respond (Marks, 1983), making an exact psychophysical determination uncertain.

Given these cautions, two conclusions can be drawn from the present experiments. First, subjects consistently judged the time of making a simple voluntary response to be after the initiation of the movement, suggesting that the judgment was based on feedback from the execution of the response. Second, a majority of subjects consistently judged their intention to make a simple voluntary movement to occur before initiation of the movement, suggesting that the judgment was based on some perceptible feature of the motor outflow for the response. This latter conclusion strengthens the argument that at least some part of the motor command is available to conscious awareness, and encourages the conjecture of Gandevia and Rothwell (1987) that conscious monitoring of motor commands may enable control of fine manipulative behavior without subsequent afferent feedback.

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