Research Report

We Infer Rather Than Perceive the Moment We Decided to Act

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ABSTRACT—*A seminal experiment found that the reported time of a decision to perform a simple action was at least 300 ms after the onset of brain activity that normally preceded the action. In Experiment 1, we presented deceptive feedback (an auditory beep) 5 to 60 ms after the action to signify a movement time later than the actual movement. The reported time of decision moved forward in time linearly with the delay in feedback, and came* after *the muscular initiation of the response at all but the 5-ms delay. In Experiment 2, participants viewed their hand with and without a 120-ms video delay, and gave a time of decision 44 ms later with than without the delay. We conclude that participants' report of their decision time is largely inferred from the apparent time of response. The perception of a hypothetical brain event prior to the response could have, at most, a small influence.*

The question of free will has been debated since antiquity. The debate has traditionally been conducted only in theoretical or logical terms, but has recently been given empirical content by the research of Libet, Gleason, Wright, and Pearl (1983). They made the question of volition a neurophysiological one, and thus opened it to scientific investigation.

Kornhuber and Deecke (1965) found that a simple voluntary act such as pressing a key was preceded by an electroencephalographic (EEG) component known as the "readiness potential" (RP) that began 500 ms to about 1,000 ms before the action. Libet et al. (1983) asked participants to monitor a spot of light moving around a clock face and to report the location of the spot when the action was consciously initiated. The reported time, termed *W*, was approximately 200 ms before the response. This time of decision implies that neurological preparation for the action began about 300 to 800 ms before the person consciously made the decision to act. Conscious will would thus seem to be a latecomer in the process of choice, rather than the instigator of choice.

When a simple measurement challenges bedrock intuitions about free will, it is no surprise that it would be challenged. The rotating spot technique used by Libet et al. (1983) has been the principal target of methodological criticism. Banks and Pockett (2007) concluded that most possible errors in using the spot to note the time would be too small to make a meaningful difference in W, and other possible errors required assumptions difficult or impossible to test. Pockett and Miller (2007) experimentally tested and rejected seven possible factors that would significantly challenge the accuracy of the Libet clock method. In a review of the literature, Haggard (2005) concluded that Libet's clock "appears to offer one of the few viable methods for experimental studies of awareness of action" (p. 291).

Given that W is not largely the result of a combination of artifacts induced by the apparatus or experimental procedure (Banks & Pockett, 2007; Pockett & Miller, 2007), what does it mean? Researchers have reasonably searched for a cluster of neural events corresponding to W among those generating the RP (Eagleman, 2004; Haggard & Clark, 2003; Lau, Rogers, & Passingham, 2007; Passingham & Lau, 2006).

On the contrary, we propose that the reported W is not uniquely determined by any generator of the RP. Rather, W is the time participants select on the basis of available cues, chief among them being the apparent time of response. Eagleman (2004) suggested that the critical cue for judgment of intention is perception of the response, thus reversing the assumed causal relation between intention and action. Here, we report an explicit test of this hypothesis.

Our test used delayed-response feedback to create the illusion that the response was later than it actually was. If the perceived time of response is a primary factor in judging one's intention, a delay in the perceived time of the action would result in a delay in the reported time of W. If, on the contrary, W measures an event that occurred prior to the response, it would be constant no matter what false feedback was presented to influence the apparent time of response.

Experiment 1 provided auditory feedback delayed between 5 and 60 ms. Experiment 2 compared W for a video image of the

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responding hand delayed by 120 ms with W for direct viewing. Experiment 2 was conducted to make sure that the effect in Experiment 1 was not somehow specific to an auditory response signal.

EXPERIMENT 1

Method

Participants

Eight naive volunteers (4 females, 4 males; age range = 19–22 years), all Pomona College undergraduates, received either course credit or monetary compensation of $10.00 for their participation. Pomona College's Internal Review Board approved the project.

Apparatus and Procedure

The experiment followed a protocol adapted from Libet et al. (1983). Participants sat facing a computer screen 60 cm away. In each trial, a cursor on the computer screen moved in the clockwise direction around a clock face, completing two revolutions in 5.2 s. The clock was 90 mm in diameter with 60 evenly spaced tick marks numbered from 0 to 59. The clock was generated by a script provided by A. Widman (University of Leipzig) using the Matlab Psychophysics Toolbox Version 2 (Brainard, 1997) and delivered via a Dell Optiplex GX280 on a Dell Radeon X300 monitor with 60-Hz refresh rate.

Participants fixated the center of the clock and rested their right index finger on the response button, which was housed in a box with an opening large enough for the participant's hand to enter but not be visible. The response button was 20 mm in diameter and had a throw of 5 mm. The button had metal-film contacts that gave no tactile feedback when closed. Closure took place when the button was depressed 2.5 mm. The beep was generated after closure by the "Sysbeep" routine in the Psychophysics Toolbox. The participants were instructed to press a button spontaneously and suddenly during the second rotation of the cursor; they were asked not to plan the time of the button press. The participants could choose not to make a button press on any trial.

The computer registered the switch closure and emitted a 200-ms beep by a computer-generated random sequence at 5, 20, 40, or 60 ms after closure. When the cursor stopped at the end of the second revolution, the participants were asked to report the number marked by the cursor at the instant they made the decision to respond.

There were 40 trials at each delay, yielding a mean of 34.58 data trials per delay. Some trials did not yield data because participants chose not to respond, and other trials were lost because of equipment or recording errors.

The electromyographic signal (EMG) from the flexor carpi radialis and nearby muscles was picked up on the velar surface of the forearm by paste-on electrodes connected to an EMG amplifier (BioPac Systems, Goleta, CA). The onset of the EMG was measured at the first moment at which the EMG reached two thirds of its maximum.

The times of the clock presentation, EMG signal, and button press response, as well as the reported time of decision, were recorded and synchronized by Acknowledge software (BioPac Systems, Goleta, CA).

Results

Figure 1 plots W as a function of delay of feedback. W decreased at a rate of 0.77 ms for every millisecond of feedback delay. The effect was reliable, $F(3, 21) = 9.05$, $p < .001$, $p_{rep} = .99$. Despite the relatively small N, the power was .986. The reported Ws at delays of 5, 20, 40, and 60 ms were −122, −104, −95, and −77 ms, respectively, relative to time of response. The linear component of this effect had an $F(1, 7)$ value of 20.54, $p < .003$. The nonlinear component had an F value less than 1.0. When W was measured from the false feedback rather than the button press, it was nearly flat at −127, −124, −135, and −137 ms, respectively, for a mean of −131 ms, $F < 1.0$.

Discussion

If the report of W were perfectly locked to the feedback, the slope relating W to delay of feedback would have been −1.0. If W were based on brain events prior to the response, the function would have had a slope of 0.0. Kinesthetic cues could not have indicated the time of electrical closure, but the feeling of effort at the beginning of the press or the impact of the button at the bottom of its throw (for the participants who pressed it that far) would be at a relatively constant time relative to switch closure and result in a slope of 0.0. The slope of −0.77 in Figure 1,

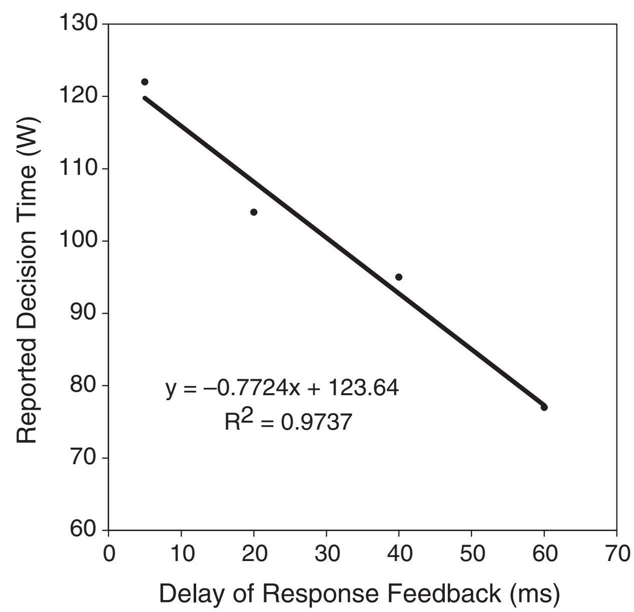

Fig. 1. Reported time of deciding to press a button (W) in Experiment 1, as a function of delay of response feedback after the button press. W is measured relative to the time of the button press. Larger values of W are earlier than smaller values.

TABLE 1

Electromyographic (EMG) Response and Relative Timing of the Reported Moment of Decision (W) for Each Beep Delay

Beep delay	EMG	W relative to EMG	W relative to beep	W relative to response
+5	−101	−21	−127	−122
+20	−107	+4	−124	−104
+40	−99	+4	−135	−95
+60	−98	+21	−137	−77

Note. All measures are in milliseconds. Positive values indicate occurrence after the reference point, and negative values indicate occurrence before the reference point. EMG refers to the earliest rise of the EMG potential associated with the action and was measured relative to the response.

though not reliably different from 1.0, $t(7) = 1.343$, $p = .22$, suggests that constant cues affected the perception of response time. However, the effect was not uniform across participants. For 5 of the participants, the mean slope was −1.1, but for the remaining 3, it was −0.23.

By a different account, the slope of −0.77 does not reflect integration of different cues at all. An adaptation effect over repeated trials, like that demonstrated by Stetson, Cui, Montague, and Eagleman (2006), would shorten the effective time between the response and the beep. For example, after many presentations, a delay of 60 ms might have the same effect as an unadapted 45 ms. The result would be a reduction in the slope with no need to assume perception of a preresponse brain event.

We also measured the EMG at the point of the first steep increase in the EMG record. The EMG preceded the switch closure by 101.5 ms, with little variability between delays (101, 107, 99, and 98 ms for the four delays, respectively). We found that the time chosen as W comes after the EMG at all but the 5-ms delay. These findings are summarized in Table 1.

The fact that W is roughly constant (−131 ms, ± 6 ms) when measured from the delayed feedback rather than from the response is evidence that W is largely based on the apparent time of response and not the motor response or a prior brain event. The fact that, at some feedback delays, the mean W comes after the EMG is registered renders doubtful the claim that W corresponds to brain events that trigger the response.

EXPERIMENT 2

Method

Participants

Twelve naive volunteers (6 females, 6 males; age range = 19–23 years), all Pomona College undergraduates, received either course credit or monetary compensation of $10.00 for their participation.

Apparatus and Procedure

A delayed video image was used to create deceptive information about the time of response. Participants either had their hand in full view (0-ms delay) or viewed it as a delayed video image (120-ms delay). As in Experiment 1, participants were asked to press a button during the second revolution of the clock, and to report the number on the clock face at the instant when the decision to respond was made. The conditions were counterbalanced; a mean of 55 responses out of 60 trials was recorded in both conditions.

The clock and response button were the same as in Experiment 1. In the delay condition, the button was placed within a frame covered by an opaque cloth. An iSight camera (Apple, Cupertino, CA) was mounted on the frame and imaged the hand and button. The video was displayed on an iMac computer and reflected by a 7-in. × 11.5-in. half-silvered glass pane through which the clock could be seen. Figure 2 shows the layout of the apparatus in the delay condition. For trials with no delay, the half-silvered mirror was removed and the response button put in its place, with the clock seen at approximately the same location behind the hand.

Results and Discussion

We found a reliable effect of delay of feedback in the expected direction. The shift in W was 44 ms, measured from the button press, from −131 ms with no delay to −87 ms with video delay, $t(11) = 3.84$, $p = .002$, one-tailed, $p_{rep} = .984$. The effect was less than the full 120 ms of the delay. We have also found in pilot work with auditory beeps that the effect of delayed feedback on W declines for delays longer than 100 ms. Stetson et al. (2006) also found a 44-ms shift when a postresponse cue was delayed by 100 ms and a decline in the shift for longer delays. It is possible that perceived time of actions may be affected by ancillary response cues only for short intervals, up to about 80 ms. Longer intervals may cause the cues to be perceived as separate events.

GENERAL DISCUSSION

We conclude that a large component, possibly the entire estimate, of W is retrospectively inferred from the response, or “postdicted” (Eagleman & Sejnowski, 2000). Although several articles have argued that W is not the result of retrospective interpretation, we have not found a direct test of retrospection of the sort we report here. Lau et al. (2007) found that W shifted when transcranial magnetic stimulation was applied regardless of whether the stimulation was concurrent with the action or 200 ms later. However, the effect at 200 ms was the same as at a delay of 0 ms, and seems not to be a result of shifting the apparent time of response.

One objection to our conclusions might be that the auditory feedback signal in Experiment 1 caused misperception of W because of intentional binding (Haggard & Clark, 2003). If binding occurred, the delayed feedback tone could have moved the perception of the button press forward in time, and then the estimate of W would have been derived from the button press rather than the tone. However, this effect would not change our

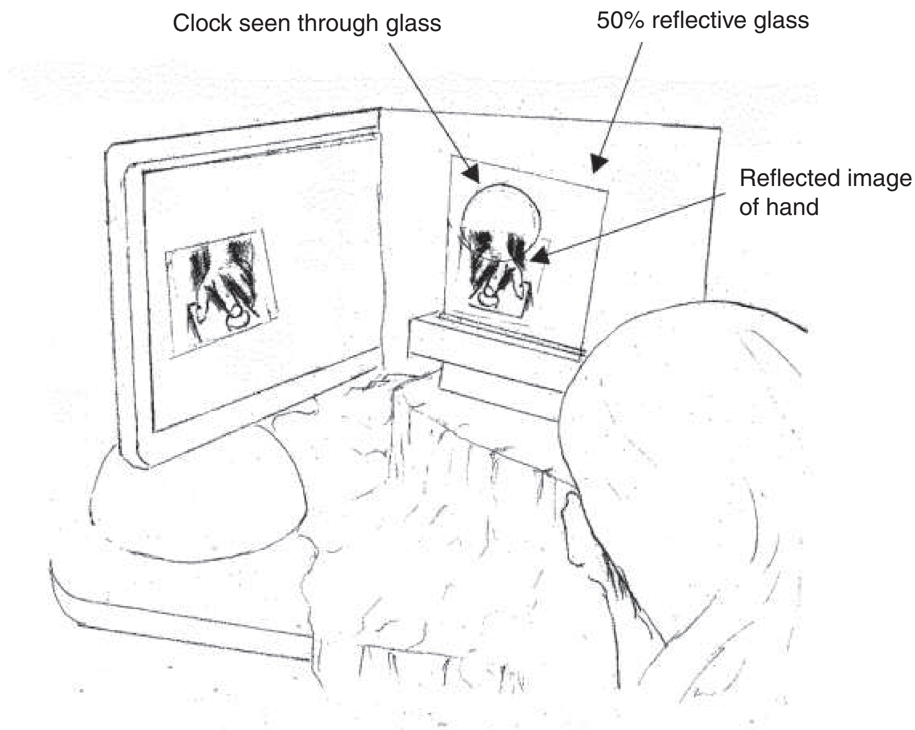

Fig. 2. Physical setup of Experiment 2. A barrier that prevented the participant from seeing the monitor on the left is not shown.

conclusions. Whatever influence such binding might have had, the report of W would still be inferred from events that must have taken place after the supposed moment of decision.

The effect of apparent shifts in the moment of response on W is consistent with the idea that conscious perception is a construction that lags action by approximately 100 ms. Ongoing perception would be a coherent, though possibly distorted, representation of the action. Eagleman and Sejnowski (2000, 2003; see also Edelman, 2003) summarize many perceptual phenomena that fall in this category. Here, W would be a reconstruction or postdiction incorporating the premise that conscious intention causes behavior immediately before action. See Choi and Scholl (2006) for parameters of ascribed causality where there was no causality.

If the delayed cues moved the perceived moment of W itself, the effect we found would not be retrospective interpretation but a volitional illusion. However, this possibility is not directly testable because there is no way to measure W other than by report. If W were independently discoverable, an illusory shift could be measured, as in the many cases when later stimuli alter temporal perception of earlier events. The lack of independent information establishing the moment corresponding to W makes the hypothesis untestable and without empirical meaning until it can be measured.

We do not take our findings to indicate that conscious intention has no role in behavior, but rather that the intuitive model of volition is overly simplistic—it assumes a causal model by which an intention is consciously generated and is the immediate cause of an action. Our results imply that the intuitive model has it backwards; generation of responses is largely unconscious, and we infer the moment of decision from the perceived moment of action (Eagleman, 2004).

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