
Cortical Movement Preparation and Conscious Decisions:
Averaging Artifacts and Timing Biases

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The main goal of our article (Trevena & Miller, 2002a) was to elucidate the smearing artifact that arises in event-related potential (ERP) research and the consequences of this artifact for studies examining the relative timing of brain activity and conscious awareness. We believe that our article substantiates four main conclusions, and we consider the implications of various points raised by the commentators with respect to each of these conclusions. (1) A smearing artifact can make the onset of an ERP component appear much earlier in average ERP than it actually occurs, on average, in individual trials. For example, smearing makes the readiness potential (RP) and lateralized readiness potential (LRP) appear to start earlier than they actually do. Thus, smearing could potentially explain the finding that these types of brain activity appear to precede conscious decisions to move (e.g., Libet, Gleason, Wright, & Pearl, 1983). That is, conscious decisions might always precede RP and LRP onset in individual trials, even if the onsets of these smeared components of brain activity start before the average time of the conscious decision. A proper interpretation of Libet et al.’s (1983) effect thus requires consideration of the effects of smearing. (2) One plausible way to correct for the smearing artifact is to compare the onsets of RP and LRP against the earliest times at which conscious decisions to move are made. If these onsets precede even the earliest conscious decisions, then the smearing artifact is not wholly responsible for their early onsets. (3) After using this correction in the paradigm of Libet et al. (1983), the onset of RP precedes conscious decisions by too large an amount to be explained solely by the smearing artifact. On the other hand, RP onset also precedes conscious decisions and motor responses by such a long time that it is unlikely to represent subconscious motor preparation for the spontaneous response. It could instead represent a general preparation to “do something in the not-too-distant future,” an intention that the participant must consciously hold given the instructions of the experimenter. (4) After using this same correction, the onset of the LRP does not precede conscious decisions. Thus, the conscious decision may always precede LRP onset.
Conclusions 1 and 2

Except for Libet (2002), no one has taken issue with these conclusions. We are gratified that these essentially methodological points seem to have been acceptable to almost all. Libet’s comment that to compare the onset of RPs and LRPs with the earliest decisions is to “dismiss the significance” of later decision times may suggest that he has chosen to misunderstand our argument. As indicated in our original Fig. 1, our point is that there may be no later decision times at all. Libet also suggests that the hypothesis of smearing is purely speculative and that there is no actual evidence that it takes place. To the contrary, we would cite the well-known differences between waveforms in fast versus slow trials (e.g., Haggard & Eimer, 1999; Miller & Low, 2001) as strong evidence that smearing is essentially always present in motor-related ERPs.

Even if there is general agreement about the possible effects of smearing on the measurement of RP and LRP onsets, there is still plenty of debate about the proper way to measure the time at which conscious decisions occur, as is discussed further below. Whatever method is used to time these decisions, though, it seems clear that the phenomenon of smearing must be taken into account in comparing decision time with RP and LRP onsets.

Conclusions 3 and 4

Given that we wished to illustrate the potential smearing artifact, we had to adopt some procedure to assess the timing of conscious decisions. Although we acknowledge that there are many criticisms of the procedure used by Libet et al. (1983), we nonetheless adopted that procedure partly because there is as yet no consensus on a better procedure and partly to ensure maximum comparability of our results to those of previous investigators (e.g., Keller & Heckhausen, 1990; Libet et al., 1983).

Several commentators, however, seem to have rejected our third and fourth conclusions because they depend on our use of Libet et al.’s (1983) potentially biased procedure to measure the times of conscious decisions. We think this was too harsh. Examining the major potential sources of bias one by one, it appears to us that the third conclusion is not seriously threatened by any of them. The fourth conclusion is weakened by one potential source of bias (which would cause decisions to appear earlier than they actually are), but it is actually strengthened by several others (which would cause decisions to appear later than they really are).

One suggested source of bias is that the clock-based measure makes decisions appear earlier than they actually are due to a time lag between participants’ internal representation of the position of the spot and the actual position of the spot on the clock (cf. Gomes, 2002; Klein, 2002; Pockett, 2002; van de Grind, 2002). To the extent that this bias operates, then, the true times of the conscious decision are somewhat later than those reported by the participants. Such a bias would have essentially no effect on our third conclusion because it would tend to increase rather than diminish the time by which RP preceded conscious decisions in our experiments. On the other hand, as Klein commented, it could reverse our fourth conclusion, because a 100-ms later shift in decision times would make LRP onset clearly before even the earliest decisions (cf. Trevena & Miller, 2002a, Figs. 3 and 4). We see this potential
source of bias as the most important threat to any of our conclusions—specifically the fourth one.

Another suggested source of bias arises out of the results of lag-flash experiments. These results suggest that the true times of conscious decisions may be somewhat earlier than those reported by the participants. Although this source of bias works in the direction necessary to undermine our third conclusion, it is clearly too small to present much of a problem. Estimates of the flash-lag bias range from about 80 to 100 ms, but we found the RP to start as much as 1.5 s before the earliest of the conscious decisions, so no correction for flash-lag bias could reverse the ordering of the RPs and the conscious decisions. And this source of bias merely strengthens the fourth conclusion, as noted by van de Grind (2002), because if the true conscious decisions are even earlier than our measurements indicated them to be then they precede LRP onset by an even greater amount.

Joordens et al. (2002) identified two further sources of potential bias in participants’ reports of their decision times: (a) a memory bias due to a representational momentum effect and (b) a decision bias due to a higher proportion of “after” than “before” trials. The memory bias would have been present in all experiments using the clock-based measurement of decision times, but the decision bias may have been specific to the particular psychophysical tracking procedure that we used to adjust the location of the test spot on the clock face. Overall, they concluded that the true decision times were approximately 70 ms earlier than those reported by the participants. Note that this suggested bias is in the same direction as the flash-lag bias, and it is of approximately the same magnitude as well. Thus, like the flash-lag effect, this source of bias does not seriously challenge our third conclusion and actually reinforces our fourth one.

Although the potential biases suggested by Joordens et al. (2002) do not seriously compromise our third conclusion and actually strengthen our fourth conclusion, we comment further on several of the points that they raised. First, consider the suggestion that there was decision bias. We are not sure what aspect of our description of methods led to the impression that there were more “after” than “before” trials, but in fact these two types of trials were almost equally common (47%/53% “before”/“after” responses in Experiment 1 and 48%/52% in Experiment 2). Because we interleaved two adaptive sequences with targets of 25% “after” responses and 75% “after” responses, with equal numbers of trials allocated to each sequence, the expected number of trials of each type is exactly 50%, except for possible distortions introduced by inappropriate experimenter guesses as to the correct starting points. Interestingly, Joordens et al. used a fixed set of test spot locations chosen in advance rather than a set adjusted adaptively, and the fixed set they chose yielded 77% “after” responses (Joordens, 2002, personal communication). Thus, it seems quite possible that the decision bias discussed by Joordens et al. was present in their task to a much greater extent than in ours.

The issue of representational momentum is more difficult to deal with conclusively. It is possible that participants located the decision later than it actually occurred due to the fact that the reference display was moving, but we suspect this was not a major factor. Libet et al. (1983) used the same moving clock task to measure the subjective times of occurrence of mild electrical shocks, and they found that the mean reported
time of the shocks was approximately 50 ms earlier than the shocks had actually been presented. We have replicated this finding using tones rather than shocks (Trevena & Miller, 2002b). If the representational momentum effect were large, one would expect all timing judgments to be too late with this clock task, but clearly they are not. We note too that Joordens et al. (2002) did not attempt to provide any specific evidence for an effect of representational momentum within their experiment.

A closer look at the procedure used by Joordens et al. (2002) suggests that, although they did not discuss it as such, they may have identified a third possible source of bias in the clock task that has not been considered elsewhere. Participants in their task watched a moving clock display, as usual. When this display changed color, participants were required first to respond as quickly as possible with a key press and then to make the timing judgment about when the clock had changed color. Thus, their participants performed both a simple reaction time (RT) task and a temporal-order judgment task using the same stimulus (i.e., change of clock’s color). In contrast, in our experiments (Trevena & Miller, 2002b) and those of Libet et al. (1983), participants only had to judge the time of stimulus occurrence, not to make any simple RT responses.

It is debatable whether the simple RT task should or should not be embedded in the timing task to provide the most appropriate control condition for comparison with the judgments of decisions to move in the standard task of Libet et al. (1983). On at least one story about what happens in the standard task, though, we think that the simple RT task should be embedded, as Joordens et al. (2002) have done but others have not. Specifically, imagine that a participant in the standard task generates a spontaneous movement by monitoring for some random internal timing signal to be generated. When this signal is detected, the participant must both note its position in time and make a motor response to it. On this story, the standard task involves both a simple RT and the storage of a temporal reference point, and therefore so should the control task, as implemented for the first time by Joordens et al.

Further research is needed to see whether this aspect of the control task is important, and we wish that Joordens et al. (2002) had included a time-judgment-only control condition analogous to that used by Libet et al. (1983). It is easy to imagine, however, that the activity of generating a simple RT to a stimulus causes it to be localized later in time. Perhaps, for example, the motor response itself serves as another temporal anchor toward which the perception of another event is drawn by some sort of temporal averaging process. In that case, the event would naturally be judged to occur later (i.e., closer to the subsequent motor response), creating another source of bias by which the true decision times would be earlier than those reported by the participants. This potential source of bias would also likely be too small to overturn our third conclusion, and it would again further reinforce our fourth one.

Dualism and Brain Waves

In his commentary, Gomes (2002) suggests that our article seems intended to rescue a Cartesian dualist position. That was never our intent. Indeed, we accept completely that the mind is simply one expression or manifestation of brain activity. Furthermore, we believe that it would be impossible for anything mental to precede
and cause all of the brain activity with which it is associated. In that respect, we have never doubted Libet et al.’s (1983) overall conclusion that some aspects of brain activity precede and directly give rise to even a “spontaneous” conscious decision to move, and we would therefore have no quarrel with the claim that there must be some unconscious causal precursors to the conscious decision. Nevertheless, we believe that the RP and the LRP arise too early and too late, respectively, to be appropriate indices of the brain activity associated with those precursors. Despite our agreement with the overall conclusion, though, we believe that this is not just a quibble, because researchers interested in studying the neural underpinnings of consciousness really do need to know which measures of brain activity seem most relevant.

If the RP does arise before the conscious decision to move, then what does it measure? In our haste to explain why we thought it does not index the unconscious brain precursors of movement, we perhaps gave insufficient attention to the question of what it actually does measure, alluding admittedly somewhat vaguely to “general preparatory” or “anticipatory” processes. Joordens et al. (2002) suggested that our interpretation “does still leave the mystery of why readiness potentials are occurring prior to the time when participants claimed to have initiated their movement,” and Gomes (2002) wondered why these general preparatory processes should not be seen as exactly the unconscious neural precursors of the decision to move that we said they were not. Fortunately, Gomes’s (2002) distinction among three types of intentions is ideally suited to clarifying our position about the role of RP. He suggests that the spontaneous movement task of Libet et al. (1983) involves (a) a prior intention to do something in the future, (b) an intention to act immediately that can still be aborted, and (c) an intention to act immediately that is irrevocable. We suggest that the RP reflects the first of these, which may be entirely conscious as Gomes notes. Certainly, participants in these tasks are quite aware of the requirement to make movements sometimes while the clock is being displayed, at least in most trials, in order to satisfy the experimenter’s instructions (cf. Durgin & Sternberg, 2002). Common sense tells us that they are furthermore aware of the passage of time within the trial, and as time passes they must feel an increasing pressure to do something sooner rather than later in order to produce their spontaneous movement before the trial ends. We suggest that the development of the RP across the trial reflects exactly this increasing pressure that they must do something soon rather than continuing to do nothing, and we see no reason to suppose that there is anything unconscious about it. This does not mean that participants are preplanning the movements in any sense. They may be waiting on a signal from some random neural time-point generator, and yet increasingly anticipate or prepare for that neural signal over the course of the trial based on the increased likelihood or at least desirability that the awaited signal will or should arrive soon.

REFERENCES


Joordens, S., van Duijn, M., & Spalek, T. M. (2002). When timing the mind one should also mind the timing: Biases in the measurement of voluntary actions. Consciousness & Cognition, 11, 231–240.


