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Unconscious cerebral initiative and the role of conscious will in voluntary action

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Abstract: Voluntary acts are preceded by electrophysiological "readiness potentials" (RPs). With spontaneous acts involving no preplanning, the main negative RP shift begins at about -550 ms. Such RPs were used to indicate the minimum onset times for the cerebral activity that precedes a fully endogenous voluntary act. The time of conscious intention to act was obtained from the subject's recall of the spatial clock position of a revolving spot at the time of his initial awareness of intending or wanting to move (W). W occurred at about -200 ms. Control experiments, in which a skin stimulus was timed (S), helped evaluate each subject's error in reporting the clock times for awareness of any perceived event.

For spontaneous voluntary acts, RP onset preceded the uncorrected Ws by about 350 ms and the Ws corrected for S by about 400 ms. The direction of this difference was consistent and significant throughout, regardless of which of several measures of RP onset or W were used. It was concluded that cerebral initiation of a spontaneous voluntary act begins unconsciously. However, it was found that the final decision to act could still be consciously controlled during the 150 ms or so remaining after the specific conscious intention appears. Subjects can in fact "veto" motor performance during a 100-200-ms period before a prearranged time to act.

The role of conscious will would be not to initiate a specific voluntary act but rather to select and control volitional outcome. It is proposed that conscious will can function in a permissive fashion, either to permit or to prevent the motor implementation of the intention to act that arises unconsciously. Alternatively, there may be the need for a conscious activation or triggering, without which the final motor output would not follow the unconscious cerebral initiating and preparatory processes.

Keywords: conscious volition; event-related chronometry; free will; mental timing; motor organization; readiness potentials; unconscious processes; voluntary action

One of the mysteries in the mind—brain relationship is expressed in the question: How does a voluntary act arise in relation to the cerebral processes that mediate it? The discovery of the "readiness potential" (RP) opened up possibilities for experimentally addressing a crucial feature of this question. The RP is a scalp-recorded slow negative shift in electrical potential generated by the brain and beginning up to a second or more before a self-paced, apparently voluntary motor act (Deecke, Grozinger & Kornhuber 1976; Gilden, Vaughan & Costa 1966; Kornhuber & Deecke 1965). The long time interval (averaging about 800 ms) by which RP onset preceded a self-paced act raises the crucial question whether the conscious awareness of the voluntary urge to act likewise appears so far in advance. If a conscious intention or decision to act actually initiates a voluntary event, then the subjective experience of this intention should precede or at least coincide with the onset of the specific cerebral processes that mediate the act.

This issue has recently been subjected to experimental tests and analyses, which I shall review briefly (Libet, Gleason, Wright & Pearl 1983; Libet, Wright & Gleason 1982; 1983). The experimental findings led us to the conclusion that voluntary acts can be initiated by unconscious cerebral processes before conscious intention appears but that conscious control over the actual motor performance of the acts remains possible. I shall discuss these conclusions and their implications for concepts of "the unconscious" and of conscious voluntary action. I propose the thesis that conscious volitional control may operate not to initiate the volitional process but to select and control it, either by permitting or triggering the final motor outcome of the unconsciously initiated process or by vetoing the progression to actual motor activation. (The reader is referred to our original cited research papers for the full details of the experimental techniques and observations together with their evaluation, etc.)

1. Definitions of voluntary action and will

Since the meanings assigned to the terms "voluntary action" and "will" can be quite complicated and are often related to one's philosophical biases, I shall attempt to clarify their usage here. In this experimental investigation and its analysis an act is regarded as voluntary and a function of the subject's will when (a) it arises endogenously, not in direct response to an external stimulus or cue; (b) there are no externally imposed restrictions or compulsions that directly or immediately control subjects' initiation and performance of the act; and (c) most important, subjects *feel* introspectively that they are

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performing the act on their own initiative and that they *are free* to start or not to start the act as they wish. The significance of point (c) is sharply illustrated in the case of stimulating the motor cortex (precentral gyrus) in awake human subjects. As described by Penfield (1958) and noted by others, under these conditions each subject regarded the motor action resulting from cortical stimulation as something done *to* him by some external force; every subject felt that, in contrast to his normal voluntary activities, "he," as a self-conscious entity, had not initiated or controlled the cortically stimulated act.

The technical requirements of experiments do impose limits on the kinds of voluntary choices and settings available to the subject. The nature of the acts must be prescribed by the experimenter. In the studies to be discussed here the acts were to consist uniformly of a quick flexion of the fingers or wrist of the right hand; this yielded a sharply rising electromyogram (EMG) in the appropriate muscle to serve as a trigger for O-reference time. The subjects were free, however, to choose to perform this act at any time the desire, urge, decision, and will should arise in them. (They were also free *not* to act out any given urge or initial decision to act; and each subject indeed reported frequent instances of such aborted intentions.) The freedom of the subject to act at the time of his choosing actually provides the crucial element in this study. The objective was in fact to compare the time of onset of the conscious intention to act and the time of onset of associated cerebral processes. The specific choice of what act to perform was not material to the question being asked.

Volitional processes may operate at various levels of organization and timing relative to the voluntary act. These may include consciously deliberating alternative choices as to what to do and when, whether or not to act, whether or not to comply with external orders or instructions to act, and so on. If any of these processes are to result in the motor performance of a voluntary act, they must somehow work their way into a "final common motor activation pathway" in the brain. Without an overt motor performance any volitional deliberation, choosing, or planning may be interesting for its mental or psychological content, but it does not constitute *voluntary action*. It is specifically this overt performance of the act that was experimentally studied by us.

In the present experimental paradigm subjects agree to comply with a variety of instructions from the experimenter. One of these is an expectation that the subject is to perform the prescribed motor act at some time after the start of each trial; another is that he should pay close introspective attention to the instant of the onset of the urge, desire, or decision to perform each such act and to the correlated spatial position of a revolving spot on a clock face (indicating "clock time"). The subject is also instructed to allow each such act to arise "spontaneously," without deliberately planning or paying attention to the "prospect" of acting in advance. The subjects did indeed report that the inclination for each act appeared spontaneously ("out of nowhere"), that they were consciously aware of their urge or decision to act before each act, that they felt in conscious control of whether or not to act, and that they felt no external or psychological pressures that affected the time when they decided to act (Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983).

Thus, in spite of the experimental requirements, the basic conditions set out above for a voluntary act were met. Conditions for the subject's decision as to when to act were designated to represent those one could associate with a conscious, endogenously willed motor action, So that one could study the cerebral processes involved in such an act without confusing them with deliberative or preparatory features that do not necessarily result in action.

Finally, one should note that the voluntary action studied was defined operationally, including appropriate and reliable reports of introspective experiences. The definition is not committed to or dependent upon any specific philosophical view of the mind-brain relationship. However, some implications that are relevant to mind-brain theories will be drawn from the findings.

2. Cerebral processes precede conscious intention

Two experimental issues have to be resolved in order to obtain a relevant answer to the questions about the relative timing of conscious intentions and cerebral processes in the performance of voluntary acts: (1) Is the RP a valid indicator of cerebral processes that mediate voluntary acts? (2) How can one meaningfully measure the onset of the conscious intention, urge, or will to perform a specific voluntary motor act?

2.1. RPs in voluntary acts

Self-paced acts were used in the discovery of RPs (Gilden et al. 1966; Kornhuber & Deecke 1965) and in subsequent RP studies (e.g., Deecke et al. 1976; Shibasaki, Burrett, Halliday & Halliday 1980; Vaughan, Costa & Ritter 1968). Such acts have features that may compromise the exercise of free volition or confuse its interpretation: (a) Recording an RP requires averaging many events. When these self-paced acts are repeated in a continuous series, with irregular intervening intervals of 3-6 sec as selected by the subject, they become boring and may come to be performed in a stereotyped and almost automatic way, with no assurance that conscious control could be exercised in each trial, (b) Since subjects were asked to act within an allotted time interval, they may be under pressure consciously or unconsciously to plan to act within the time limit; that is, the subject's voluntary choice of when to act may be compromised by an external requirement, (c) Subjects are required not to blink until just after each act. The need to blink may impel the subject to act, thus serving as an external controlling factor.

In a study of what we termed "self-initiated" acts, these external forces were minimized or eliminated (Libet et al. 1982). Each trial in an averaging series of 40 trials was initiated as a separate independent event after a flexible delay determined by each subject's own readiness to proceed; there was no limit on the time in which subjects were to act; they were given the option to blink if necessary. For each trial, subjects were asked to perform a simple quick flexion of the wrist or fingers at any time they felt the "urge" or desire to do so; timing was to be entirely "ad lib," that is, spontaneous and fully endoge-

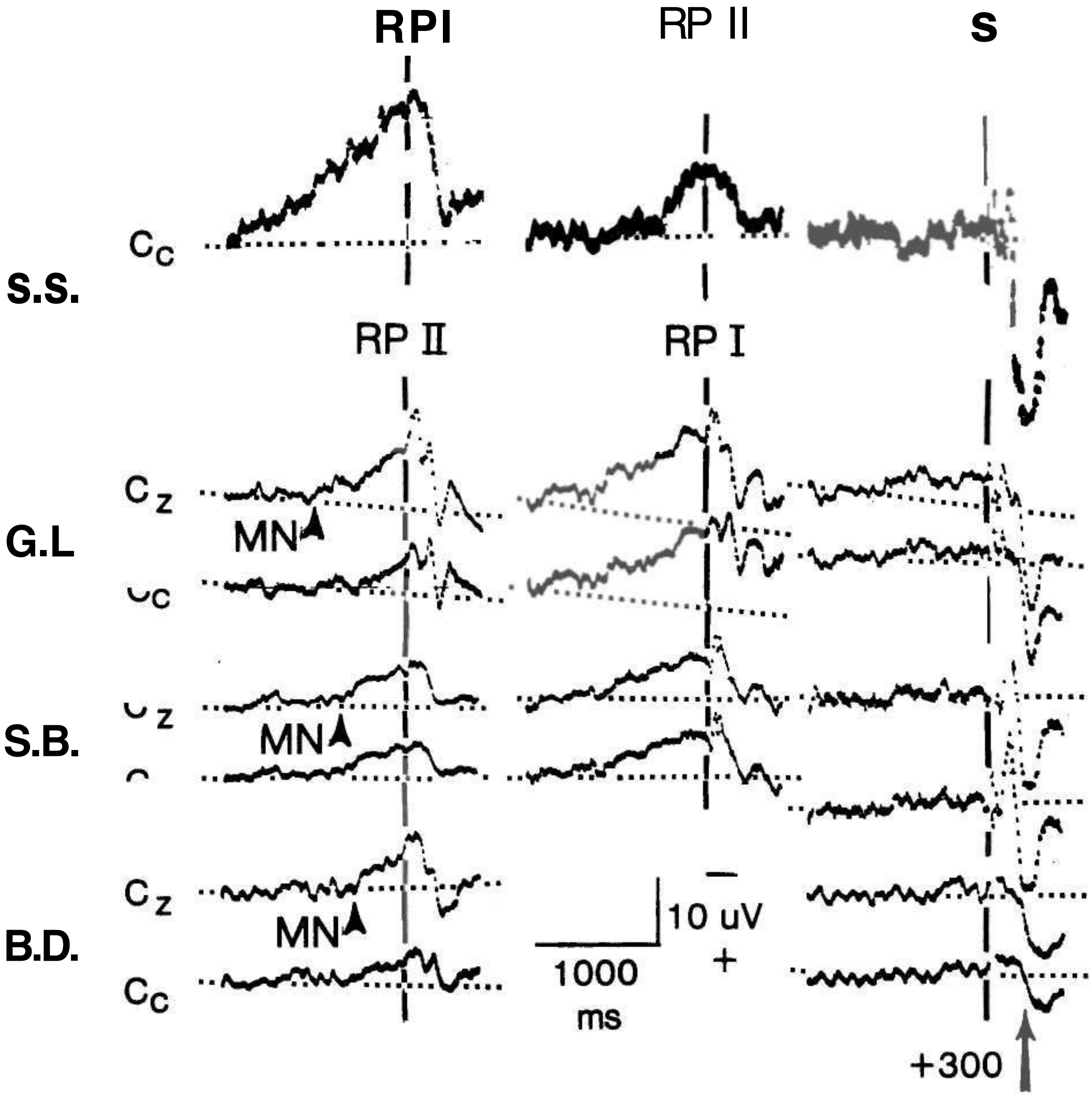

Figure 1. Readiness potentials (RP) preceding self-initiated voluntary acts. Each horizontal row is the computer-averaged potential for 40 trials, recorded by a DC system with an active electrode on the scalp, either at the midline-vertex (Cz) or on the left side (contralateral to the performing right hand) approximately over the motor/premotor cortical area that controls the hand (Cc).

When every self-initiated quick flexion of the right hand (fingers or wrist) in the series of 40 trials was (reported as having been) subjectively experienced to originate spontaneously and with no preplanning by the subject, RPs labeled type II were found in association. (Arrowheads labeled MN indicate onset of the "main negative" phase of the vertex recorded type II RPs in this figure; see Libet et al. 1982. Onsets were also measured for 90% of the total area of RP; see Table IB). When an awareness of a general intention or preplanning to act some time within the next second or so was reported to have occurred before some of the 40 acts in the series, type I RPs were recorded (Libet et al. 1982). In the last column, labeled S, a near-threshold skin stimulus was applied in each of the 40 trials at a randomized time unknown to the subject, with no motor act performed; the subject was asked to recall and report the time when he became aware of each stimulus in the same way he reported the time of awareness of wanting to move in the case of self-initiated motor acts.

The solid vertical line through each column represents 0 time, at which the electromyogram (EMG) of the activated muscle begins in the case of RP series, or at which the stimulus was actually delivered in the case of S series. The dashed horizontal line represents the DC baseline drift.

For subject S.S., the first RP (type I) was recorded before the instruction "to let the urge come-on its own, spontaneously" was introduced; the second RP (type II) was obtained after giving this instruction in the same session as the first. For subjects G.L., S.B., and B.D., this instruction was given at the start of all sessions. Nevertheless, each of these subjects reported some experiences of loose preplanning in some of the 40-trial series; those series exhibited type I RPs rather than type II. Note that a slow negative shift in scalp potential that precedes EMGs of self-initiated acts (RP) does not precede the skin stimulus in S series. However, evoked potentials following the stimulus are seen regularly to exhibit a large positive component with a peak close to +300 ms (arrow indicates this time); this P300 event-related potential had been shown by others to be associated with decisions about uncertain events (in this case, the time of the randomly delivered stimulus), and it also indicates that the subject is attending well to the experimental conditions. (Modified from Libet et al. 1982.)

nous. (For full technical details see Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983.) Subjects reported that they were aware of the urge or intention to move before every act in the series; that is, the acts were not automatic or involuntary "tics." The absence of any larger meaning in this act appears to exclude external psychological or other factors as controlling agents. Acts of this kind may thus be taken as paradigmatic examples of unrestricted volition, at least in regard to choosing when to act. The basic initiating process for these simpler volitional acts may be the same as that for the actual motor expression of other, more complex forms of voluntary action, since the latter are manifested behaviorally only when final decisions to move have been made.

These self-initiated, endogenous acts were indeed found to be preceded by RPs (Libet et al. 1982). When all 40 self-initiated acts in an averaging series were performed with this spontaneous ad lib timing, with no reports of specific preplanning to act, the recordable averaged RP generally had an onset for its main negative rise at about 550 (±150) ms before the motor act began; these were called "type II" RPs (see Figure 1). (As is customary, the beginning of the muscle activity is signaled by the onset of the electromyogram, EMG, recorded at an appropriate muscle. This provides the "0-time" trigger for averaging the preceding scalp potential at the vertex and for other timing features.)

In some trials, subjects did report experiencing some general preplanning or preparation to act in the near future a few seconds before the act, despite the encouragement to be completely spontaneous. These occurrences were reported during the "debriefing" conducted at the end of each series of 40 trials. In those series that included even a small number of such reported experiences, a ramplike RP with onset at about —1050 ms (±175) was typically recorded (the "type I" RPs, Figure 1); these RPs were called type I because they resembled those RPs previously described for self-paced acts (e.g., Deecke et al. 1976). However, subjects all insisted that the more specific urge or intention to perform the actual movement was still experienced just before each act in a type I series, just as in the type II series; and they clearly distinguished this urge or intention from any advance feelings of preplanning to move within the next few seconds. In other experiments that required deliberate preplanning by instructing the subject to act at a preset time, there appeared a large ramplike RP that resembled the type I RP of our self-initiated acts. We concluded, therefore, that the RP component that starts at about —550 ms, the one that predominates in type II RPs recorded when all acts in a 40-trial series are spontaneous, is the one uniquely associated with an exclusively endogenous volitional process. The latter process is distinguished from a looser preintentionality or general preparation-to-act-soon that is not necessarily endogenous (Libet et al. 1982).

2.2. *Timing the conscious intention to act*

It presented a difficult challenge to devise the operational criteria for determining the time at which the subjects become aware of wanting or deciding to act. One begins with the premise that this subjective event is only accessible introspectively to the subject himself; some kind of report of this by the subject is therefore a requirement (Libet 1966; 1973; 1981b). Conscious subjective experience, in this case an awareness of the endogenous urge or intention to move, is a primary phenomenon; it cannot be defined in an a priori way by recourse to any externally observable physical event, including any behavioral action not directly representative of the subject's introspective report (Beloff 1962; Creutzfeldt & Rager 1978; Eccles 1980; Libet 1965; 1966; 1981a; 1981b; Nagel 1979: Popper & Eccles 1977; Thorpe 1974). The report, whether a verbal one or some other motor indication (e.g., pressing an answer key), *cannot* be an immediate one made as soon as the conscious experience has occurred: (a) Cerebral preparations for the motor action of reporting might introduce some confusing RPs of their own. (b) There could be a substantial delay for neurally organizing and achieving the motor actions required to make the report, (c) When a premium is put on the speediness of a response, as in measuring reaction time to a stimulus, there is no assurance that the motor response directly indicates when an actual subjective experience has occurred. The fast response to a stimulus can represent an unconscious mental process; but when the subject becomes consciously aware of the stimulus some hundreds of ms later (Libet 1965; 1966; 1973), the experience can be subjectively referred backward in time to an early neural signal (Libet 1981a; 1982; Libet, Wright, Feinstein & Pearl 1979).

For present purposes the experience of the time of the first awareness of wanting to move ("W") was related by the subject to his observation of the "clock position" of a spot of light revolving in a circle on the face of a cathode ray oscilloscope (CRO); the subject subsequently recalled and reported this position of the spot. (For technical details see Libet, Gleason, Wright & Pearl 1983.) Thus, the timing of this experience was converted to a reportable, visually related spatial image, analogous to reading and later recalling the clock time for any experience. This indicator of the time of first awareness of the intention to move could then be compared to (a) the actual time of the voluntary motor act, as indicated by the EMG recorded from the appropriate muscle, and (b) the time of appearance of the simultaneously recorded RP that is generated by the brain in advance of each act. For all self-initiated acts studied, the actual mean Ws for each series of 40 acts averaged about —200 ms (Table 1); that is, subjects reported becoming consciously aware of the urge to move 200 ms before the activation of the muscle (EMG) (Libet, Gleason, Wright & Pearl 1983).

2.3. *Difference between RP onset and reported time of conscious intention, W*

The RP onset time was found to be consistently in advance of W, the time of initial awareness of wanting to move (Table 1). For all of the series in which all 40 acts were experienced as fully spontaneous and unplanned, the average RP onset of (type II, described above) was about —535 ms relative to the initiation of muscle action (as indicated by the EMG). Reported times of conscious intention to act (W) in these same series with type II RPs averaged about —190 ms. The average onset of these RPs therefore *precedes* average W by about 345 ms. (For the significance of the even larger discrepancy in series ex-

Table 1. *Average times (ms) of reported awareness and recorded readiness potentials (RP)for all experimental series on 5 subjects, in 6 or more separate sessions for each subject. Each series consisted of 40 trials in which subjects reported only W or M or S times in that entire series. (Modified from Libet, Gleason, Wright ir Pearl 1983.)*

A. Reported awareness times (ms) relative to recorded muscle activation (EMG).

	W[a]		(W-S)[b]		M[c]		(M-S)	
Subject	n[d]	X				X	n	X
S.B.	8	-125	5	-123	4	-59	4	-19
GL.	8	-282	5	-136	4	-202	4	-60
B.D.	7	-152	4	-249	4	+51	4	-32
S.S.	7	-246	4	-145	4	-118	4	-7
CM.	8	-227	4	-165	4	-103	4	-20
Grand averages	38	-207	22	-160	20	-86	20	-28

B. reported time of conscious intention (W) related to recorded RP onset, separated for type I and II (see text).

Type of RP, for W series	Reported awareness times		Onset of RP (in W series)		(Onset RP) *minus* (W) using onset of:		(Onset RP) *minus* (W-S), using onset		
	n	W	**RPmn**	**RP 90%**	**RPmn**	**RP90%**	n	**RPmn**	**RP 90%**
II	20	-192	-535	-527	-343	-333	14	-366	-323
I	12	-233	-1025	-784	-825	-522	6	-950	-585

[a] W = time of first awareness of wanting to move (see text). [b]*S* was based on reported time of awareness of the sensation elicited by a near-threshold electrical stimulus pulse to the hand, delivered at a randomly irregular time in each trial. The attentive and other conditions (subject's observing and recalling "clock time" for each S) closely paralleled those for the W and M series, except that the event was an externally induced sensory one instead of a self-initiated motor one. The difference (S) between reported and actual stimulus times may be regarded as a measure of the subject's error or "bias" when observing and reporting under the experimental conditions employed (see text and Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983). Almost all subjects exhibited a negative net bias for S (except for B.D.). For (W-S) values, the S bias exhibited by each subject is subtracted from the W values available in the same sessions. [C]M was time reported for subjects' awareness that they were actually moving, instead of wanting to move as for W. The consistently negative though smaller values for M suggest that it reflects the time of initiation of the final motor cortical output, i.e., the endogenous "command to move" (McCloskey et al. 1983), rather than the awareness of proprioceptive sensory impulses evoked after onset of the movement (see text). [d]n = number of series, each of 40 trials. Each average or X value for n series is the mean of the mean Ws (or mean Ms), each of which was determined for each series of 40 trials (see Libet, Gleason, Wright & Pearl 1983). [e] Onsets of RP, relative to EMG (electromyogram indicating that the activation of the muscle has started), are given for both the "main negative shift" (MN), as estimated by eye, and for the time at which the last 90% of the total area under the RP tracing begins.

hibiting type I RPs, those recorded when some acts were preplanned, see Libet, Gleason, Wright & Pearl 1983.)

This riming relationship, with the "physical" (cerebral process) preceding the "mental" (conscious intention), held not just for average values of all series but for each individual series of 40 self-initiated acts in which RP and W were recorded simultaneously. Although RPs of 40 events were averaged to produce the recorded RP, statistical and mathematical evaluation of the experimental data strongly supported the view that each individual RP precedes each conscious urge (see Libet, Gleason, Wright & Pearl 1983). The timing relationship also held regardless of which of the available parameters was used either to measure the onset of the RP (for the onset of its main negative component or for 90% of its area), or for W (using either the "actual" or the "order" mode of recall of the clock position of the revolving spot at the time of conscious intention; see section 2.4.3). Confidence in the significance of the difference between RP onset and W is further raised by the feet that it was almost invariably large in all the individual series when compared to the standard error of the mean value for W in each respective series. In addition, the individual W time reported for each act in a series of 40 trials was almost never negative to (timed in advance of) the onset of the averaged RP recorded for that series. In view of the foregoing considerations (and additional methodological checks listed in Libet, Gleason, Wright & Pearl 1983), the substantial interval by which RP onset precedes W appears sufficiently reliable. Questions about the validity and meaning of the values must still be considered.

2.4. Validity of criteria for the time of a conscious intention to act

Because subjective experiences are not directly accessible to an external observer, it may be logically impossible for the external observer to determine directly any feature of the experience (Creutzfeld & Rager 1978; Libet et al. 1979; Nagel 1979). This restriction applies also to the actual time of a subjective experience (Harnad, unpublished; Libet et al. 1979). We do not normally apply the criterion of logical impossibility to the validity of introspective reports by the people around us in everyday life although we do attempt to evaluate the accuracy of these reports. I do not know of any serious believer in Berkeleyan solipsism, even though that position may be logically unassailable. (On the other hand, the descriptions even of externally observable physical events cannot be regarded as having an absolute validity; they have been appropriately viewed as mental representations or constructs elicited by or developed from the available sensory experiences, e.g., Margenau 1984.)

One is always faced, then, with the unacceptable alternative of not attempting to study a primary phenomenological aspect of our human existence in relation to brain function because of the logical impossibility of direct verification by an external observer. Or one can attempt to evaluate the accuracy of the introspective report and gain confidence in its validity by applying indirect controls, tests and converging operations. In the present study we rely on the subject's ability to associate his introspective awareness (of the urge or decision to move) with the (later reported) position of a visually observed revolving spot, the "clock time." The crucial experimental question thus becomes: Is there any convincing way of estimating what might be the discrepancy between actual and reported times (for the subject's introspective experience of the urge to move)? The several independent types of control evidence discussed below provide confidence that the accuracy of the reported clock times is sufficient for present purposes (i.e., for determining the significance of the difference between RP onset and time of conscious intention).

2.4.1. Comparisons of simultaneous events. Our method requires that the subject observe simultaneously, for later report, the conscious urge or intention to move and a visual experience of "clock position" for the revolving spot on the CRO. Subjective timing comparisons of simultaneous but disparate events are known to be subject to potential errors (see Boring 1957; Efron 1973; Sternberg & Knoll 1973). However, we introduced a control series in each experimental session to help measure such an error. For this, a skin stimulus was delivered at an irregular, randomized time after the start of each trial and the subject reported the time of his awareness of that stimulus. All procedures were otherwise the same as in series of self-initiated acts (except that awareness of the stimulus replaced awareness of the urge to move). The actual time of the stimulus in the control series was later known to the investigator, and the discrepancy between the subject's reported riming and the actual stimulus time could be objectively determined. To the extent that simultaneous observation of visual clock time and awareness of skin sensation shares similar processes and difficulties with simultaneous observation of clock time and awareness of urge to move, one may regard any measured "error" in reports of stimulus time as an estimate of the potential error in reports of W (time of awareness of wanting to move). Skin sensations were commonly reported to occur somewhat in advance of (negative to) the actual delivery time, reminiscent of the prior entry effect (e.g., Allan; 1978; Boring 1957). However, the amount of the error found in the stimulus series did not qualitatively alter the difference between onset of RP and W; in fact, it generally enlarged the difference (Table 1).

2.4.2. Judging onset time of an endogenous mental event. It might be proposed that subjects do not judge the onset of an endogenous mental event such as conscious intention the same way they judge the onset of an experience induced externally by a skin stimulus. In relation to such a suggestion we note:

a. Each subject was instructed to "watch for" and report the earliest appearance of the awareness in question, and subjects did not raise any difficulties about doing this.

b. The onset time even of an intracerebrally generated event of some complexity, although admittedly induced by an applied stimulus, can be reported with no significant delays. In earlier work (Libet et al. 1979), onset time of a vaguely perceived near-threshold sensation elicited by a stimulus to a cerebral somatosensory structure (medial lemniscus) was judged subjectively to differ by only a few tens of ms from the sharper sensation elicited by a skin stimulus. In addition, both the medial lemniscus and the sensory cortex required repetition of stimulus pulses (at 20 per sec) for at least 200 ms, to elicit any subjective sensory experience at all in those experiments. Yet the subjects could consistendy report a different onset time for each; they reported that the medial lemniscus-induced sensation began with no significant delay relative to the sensation elicited by a single pulse stimulus to the skin, whereas onset of the cortical sensation was delayed by the amount of the required stimulus duration (Libet et al. 1979).

c. For two different though related endogenous mental events related to the same voluntary act, the subjects consistently reported different onset times with an appropriate direction of difference. Under the identical experimental conditions for studying the self-initiated acts, the subjects were asked to report the clock time for their awareness of actually moving (M) instead of for awareness of wanting to move (W). M values were, unexpectedly, negative to EMG-0 time and slightly but consistently negative to reported times for awareness of skin stimulus (S) in which no movement was involved (see Table LA).

Because M times were slightly before actual movement, this suggested that M may reflect awareness associated with the immediate initiation of cerebral motor outflow (Libet, Gleason, Wright & Pearl 1983). This would be in accord with the findings by McCloskey, Colebatch, Potter & Burke (1983) that subjective timing of one's own "command to move" preceded the EMG by up to 100 ms; a sensation of having already moved, elicited by input from peripheral sensory sources, was found to be separately reportable with an appropriately delayed time. M thus appears to be an endogenous mental event, different from but related to W. Nevertheless, the subjects did not confuse their reports of onset times for M with those of W; reports of W times (for awareness of wanting to move) were consistendy negative to (in advance of) M times (for awareness of actually committing the movement), by about 120 ms on the average.

2.4.3. Modes of reporting. One way to test and improve confidence in the validity of the reported timings lies in using different and independent but converging modes of observing and reporting. Two quite different modes were used for reporting the "clock positions" of the CRO spot at the time of awareness: (a) absolute readings and (b) order relative to final stopping positions of the CRO spot, varied randomly (see Libet, Gleason, Wright & Pearl 1983). Yet both modes produced values for W that were essentially indistinguishable. (When reporting in the "order" mode, subjects had to recall the position of the moving spot [at the time of initial awareness of the urge to act] only with respect to a final resting position of the spot that was varied randomly in different trials. Subjects needed to make judgments about whether the CRO spot came to rest at a clock position that was "earlier" or "later" than the recalled position of the revolving spot when they were aware of the urge; they did not have to specify an absolute clock position of the moving spot associated with W [Libet, Gleason, Wright & Pearl 1983]. See also McCloskey et al. [1983] for an analogous order method for timing judgments.)

2.4.4. Nonrecallable initial awareness of conscious intention?It might be argued that a nonrecallable phase of a conscious urge exists, so that the reported time would apply only to a later, recallable phase of awareness. However, one should note that to report W time, the subject need recall only the clock position of the revolving spot at the time he first becomes aware of the urge or intention to move and not necessarily the initial awareness itself. In any case, there is no evidence for a nonrecallable initial awareness. But, like some other conceivable hypothetical uncertainties in timing an endogenous mental event, such a hypothesis cannot be excluded since it is presently not experimentally testable.

2.5. *RP as indicator of cerebral initiation*

For the experimental question about the initiation of a voluntary act, one must also consider whether the onset of recorded RP is a valid indicator of the time when cerebral processes begin to produce the act. The precise role of the cerebral activity represented by the RP in the initiation of the voluntary process is yet to be determined. It appears likely that the component of the RP associated with volitional preparation to act is generated in the supplementary motor area, a portion of the cerebral cortex located on the mesial surface of each hemisphere facing the midline (Deecke & Kornhuber 1978; Eccles 1982a; Libet et al. 1982). RPs associated with spontaneous self-initiated acts (type II) are indeed distinctly maximal at the vertex of the head (Libet et al. 1982), a scalp site that is above and adjacent to the supplementary motor areas. It has been proposed that the initial neuronal events in all voluntary movements arise in the supplementary motor areas (Eccles 1982). However, for present purposes it is not necessary that the full role of the supplementary motor area of the RP processes be established. It is only necessary to accept the RP as a valid *indicator* of *minimum* onset times for cerebral processes that initiate the voluntary act, even if these processes should be initiated elsewhere in the brain.

It might be proposed that the RP does not indicate directly or indirecdy the specific initiation of the voluntary act. Rather, the RP might represent preprogramming processes that develop periodically without signifying a volitional function. The actual initiation of a given voluntary act would then depend on conscious activation or triggering of one of these preparatory sequences so as to generate an actual motor discharge. Such a proposal would seem to be an ad hoc speculation not supported by the experimental evidence, (a) The proposal would predict that endogenous RPs appear repeatedly without any associated subjective awareness developing and with no actual voluntary movements occurring. This has not been experimentally demonstrated and would seem to be untestable with present techniques. The RP that precedes an individual voluntary act is not clearly discernible from the background rhythmic activity; averaging of the pre-EMG periods (1.4 sec) for 40 acts gave us a usable though still noisy RP shift at the vertex. However, one should note that individual spontaneous negative and positive slow potential (SP) shifts have been successfully recorded during 5-sec periods preceding a choice reaction test and found to be related to proficiency of performance (Born, Whipple & Stamm 1982)[5]. These interesting spontaneous SPs were apparendy maximal at frontal rather than vertex sites and they were either negative or positive in polarity; they presumably reflect processes different from those of the negative RP that is maximal.at the vertex and obtained in a different mental context, (b) The recorded RPs in self-initiated acts do not exhibit any special electrophysiological event that might signal introduction of an activating process at the reported time of about -200 msec for the conscious urge (Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983). (For RPs in self-paced acts see also Deecke et al. 1976; Shibasaki et al. 1980.) (c) The available evidence suggests that an RP precedes every voluntary act as well as the conscious awareness of the urge to perform each act (Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983). Consequently, the proposal against RP initiation of the act would at best result in a two-stage mediation; "preparatory" cerebral processes would still unconsciously initiate the volitional sequence but consummation of the actual motor action would depend on a conscious control function. This sort of role for the conscious function is compatible with the thesis being advocated in this paper.

Is it possible that the subject's introspective observation of his conscious intention for each act would itself introduce a cerebral process that affects the recorded RP (a question raised by an anonymous editorial reviewer)? In a small number of experiments RPs were recorded for series of 40 self-initiated movements in which no reports of awareness time were requested from or made by the subjects. The RPs of these "no-report" series were similar in form and onset times to RPs of the "report" series (Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983). Furthermore, reporting the time of awareness of a sensory stimulus delivered at a randomly irregular time ("S" series) required the same kind of attention and introspection by the subjects as did the reporting in self-initiated acts; yet there were no significant pre-event potentials at all in association with the stimulation experiments (e.g., Figure 1; Libet et al. 1982; Libet, Wright & Gleason 1983). One may conclude that the "introspective process" did not affect the RPs in any manner significant to the conclusions in the study, and that if there were any electrophysiological correlates of introspective observation or of the attentive state required for it, they are not manifested in the scalp recordings of RPs at the vertex.

3. Unconscious initiation of voluntary acts

Onsets of RPs regularly begin at least several hundred ms before reported times for awareness of any intention to act in the case of acts performed ad lib. It would appear, therefore, that some neuronal activity associated with the eventual performance of the act has started well before any (recallable) conscious initiation or intervention is possible. This leads to the conclusion that cerebral initiation even of a spontaneous voluntary act of the land studied here can and usually does begin *unconsciously*. (The term "unconscious" refers here simply to all processes that are not expressed as a conscious experience; this may include and does not distinguish among preconscious, subconscious, or other possible nonreportable unconscious processes.) Put another way, the brain "decides" to initiate or, at least, to prepare to initiate the act before there is any reportable subjective awareness that such a decision has taken place.

It might be argued that unconscious initiation applies to the kind of spontaneous but perhaps impulsive voluntary act studied here, but not to acts involving slower conscious deliberation of choices of action. The possible role of unconscious cerebral activities in conscious deliberation is itself a difficult and open question. In any case, after a deliberate course of action has been consciously selected, the specific voluntary execution of that action, i.e., the cerebral activation and implementation of the actual motor deed, may well be related to that for the ad lib kind of act we have studied. Even when a more loosely defined conscious preplanning has appeared a few seconds before a self-initiated act, the usual specific conscious intention to perform the act was consistently reported as having been experienced separately just prior to each act by all subjects (Libet et al. 1982; Libet, Gleason, Wright & Pearl 1983). This leads me to propose that the performance of every conscious voluntary act is preceded by special unconscious cerebral processes that begin about 500 ms or so before the act.

3.1. Cerebral basis of unconscious mental functions

A role for "the unconscious" in modifying and controlling volitional decisions and actions was advocated long ago (e.g., Freud 1955; Whyte 1960). This role was inferred from analyses of strong but indirect psychological evidence. The present experimental findings provide direct evidence that unconscious processes can and do initiate voluntary action and point to a definable cerebral basis for this unconscious function.

In addition, these findings are in accord with a previous general hypothesis that dealt with the question of how the subjective conscious experience of each individual is related to his cerebral processes and what distinguishes this from unconscious processes. That hypothesis proposed that some substantial time period of appropriate cerebral activity lasting hundreds of ms may be required for eliciting many forms of specific conscious experiences (Libet 1965). The hypothesis developed out of experimental findings that cortical activities must persist for up to 500 ms or more before "neuronal adequacy" for a conscious sensory experience is achieved (Libet 1966; 1973; 1981a; 1982; Libet et al. 1979). This led to the further inference, supported by evidence, that those cerebral activities which did not persist sufficiently long would remain at unconscious levels. The present evidence suggests that a similar substantial period of cerebral activity may also be required to achieve "neuronal adequacy" for an experience of conscious intention or desire to perform a voluntary act. The experience of the conscious intention to act would, in these terms, arise as a secondary outcome of the prior unconscious initiating process; nevertheless, it could still have a role either in completing the initiating process ("conscious trigger") or in blocking its progression ("veto").

4. The conscious function in voluntary action

If the brain can initiate a voluntary act before the appearance of conscious intention, that is, if the initiation of the specific performance of the act is by unconscious processes, is there any role for the conscious function? It is of course possible to believe that active conscious intervention to affect or control a cerebral outcome does not exist and that the subjective experience of conscious control is an illusion (e.g., Harnad 1982). However, such a belief is not required even by a monist, determinist theory, as seen in Sperry's (1980) formulation of an emergent consciousness that can interact with and affect neuronal activity; and the theoretical physicist Margenau (1984) has claimed that conscious intervention in brain function can occur without any expenditure of energy or violation of the known physical laws. In any case, the potentialities for conscious control may be considered at a phenomenological level; that is, we can for the present discuss operational possibilities for conscious control at a level which does not require a commitment to any specific philosophical alternatives for mind-brain interaction, whether these be determinism versus free will or epiphenomenalism versus mental intervention.

I propose that conscious control can be exerted before the final motor outflow to select or control volitional outcome. The volitional process, initiated unconsciously, can either be consciously permitted to proceed to consummation in the motor act or be consciously "vetoed." In a veto, the later phase of cerebral motor processing would be blocked, so that actual activation of the motoneurons to the muscles would not occur. Such a role is feasible since conscious intention is reported to appear about 150 to 200 ms before the beginning of muscle activation (signaled by the EMG), even though it occurs several hundred ms later than the cerebral initiating processes. The late cerebral processes thought to lead more directly to descending discharge in the pyramidal cells may be reflected in the so-called final motor potential (MP) component near the end of the RP shortly before the muscle activation. An MP that is generated in the premotor/motor cortex contralateral to the activated hand begins about 50 ms (Deecke et al. 1976) or perhaps as little as 10 ms (Shibasaki et al. 1980) before the muscle EMG. There would remain a net period of about 100 to 200 ms in which conscious control could block the onset of the MP. A "premotion positivity" (PMP) may also develop about 90 ms (Deecke et al. 1976) or about 50 ms (Shibasaki et al. 1980) before the EMG. The significance of this component is. still unclear. But even if the PMP is

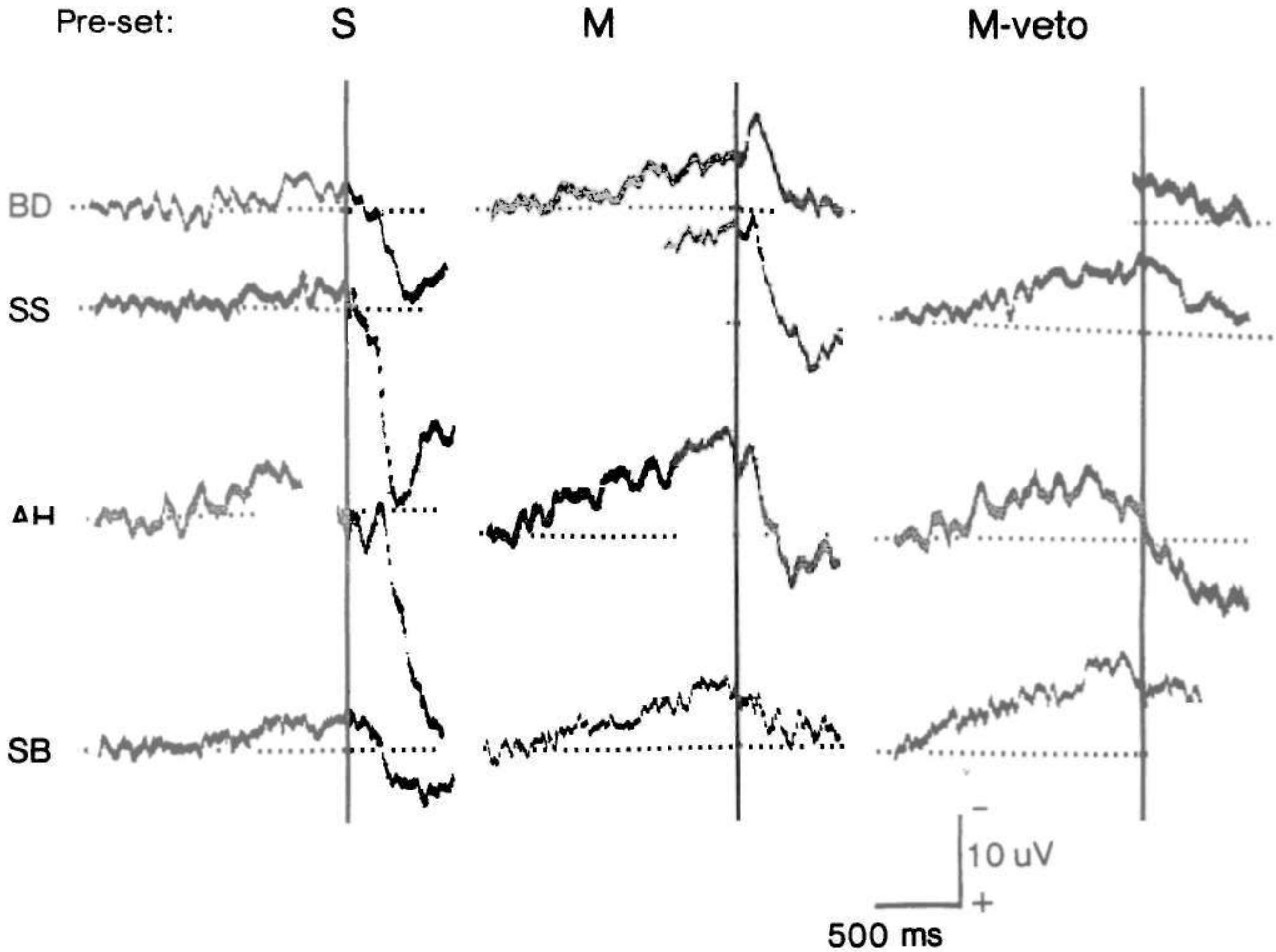

Figure 2. Pre-event vertex potentials when preparation to act is "vetoed." In column "M" (motor), the time for the subject to perform each of the 40 acts was preset (prearranged), so that preplanning was regularly expected of the subject. The recorded slow negative shift in potential preceding 0 (EMG) time resembles the type I RP found for those self-initiated acts for which endogenous preplanning was reported (Libet et al. 1982); it also resembles the RP of "self-paced" acts (e.g., Deecke et al. 1976). In the column "M-veto," subjects were instructed (a) to adopt the same mental sets as in the M series (preparing to move at the designated preset time) but (b) "to veto" this intention when the revolving CRO spot arrived within about "2.5 to 5 sec" of clock dial (actually about 100 to 200 ms) before the preset time. The absence of any observable motor activation was confirmed by monitoring the EMG at sufficiendy high gain. The computer trigger for preset 0 times in the absence of an EMG was supplied by an operator in another room. In spite of the absence of actual muscle activations, a ramplike prepotential like that in the M series was regularly exhibited, representing the developing intention and preparation to move; note, however, that these M-veto RPs tended (for 3 of the subjects shown) to terminate their negative rise within some 150 to 250 ms before 0 time, at about the presumed time for reversing the intention to act. (For the fourth subject, S.B., the preset M potential in 3 other experiments was larger and rose with a steady ramp form until at least 50 to 100 ms before 0 time, unlike the M recorded in the session shown here; see Libet et al. 1982.) In column "S," a skin stimulus delivered at similar preset times replaced the preparation to act. Pre-event potentials were absent or relatively insignificant in the S series, in spite of attention and anticipation for each event being similar to those in M and M-veto series, in that the subject had to watch for and report those events in which the stimulus was omitted at the preset time. (Modified from Libet, Wright & Gleason 1983.)

assumed to reflect cortical motor activation just preceding the efferent discharge (Deecke et al. 1976) there would still remain about 60 to 100 ms after the "corrected" time of conscious intention, or 110 to 150 ms after the uncorrected time, in which conscious control could affect the PMP process.

4.1. *Evidence for "veto" control*

The evidence for conscious veto is of two kinds: (a) Subjects in our study of RPs and conscious timings reported that during some of the trials a recallable conscious urge to act appeared but was "aborted" or somehow suppressed before any actual movement occurred; in such cases the subject simply waited for another urge to appear, which, when consummated, constituted the actual event whose RP was recorded (Libet et al. 1982). However, there is presently no technique available for recording and analyzing any RPs that may be associated with such spontaneous, irregularly appearing conscious urges to act that do not lead to an actual motor event, (b) In series of acts to be performed at prearranged times, subjects were instructed in advance to veto the developing intention/preparation to act and to do this about 100 to 200 ms before the prearranged clock time at which they were otherwise supposed to act. In these series a ramplike pre-event potential was still recorded during >1 sec before the preset time (Figure 2, "M-veto"), even though no actual muscle activation occurred (Libet, Wright & Gleason 1983). This resembles the RP of self-initiated acts when preplanning is present (Libet et al. 1982, type I RP). The form of the "veto" RP differed (in most but not all cases) from those "preset" RPs that were followed by actual movements; the main negative potential tended to alter in direction (flattening or reversing) at about 150-250 ms before the preset time (Libet, Wright & Gleason 1983). This difference suggests that the conscious veto interfered with the final development of RP processes leading to action. (Whether the above-mentioned MP or PMP components of RP are specifically eliminated by such a conscious veto remains to be analyzed.) In any case, the preparatory cerebral processes associated with an RP can and do develop even when intended motor action is vetoed at approximately the time that conscious intention would normally appear before a voluntary act.

The veto findings suggest that preparatory cerebral processes can be blocked consciously just prior to their consummation in actual motor outflow. As an alternative study, we might have randomly presented an external signal at which the subject would veto the prearranged or preset act. (External signaling to veto an act after a given *self-initiated* RP has begun is not technically feasible, since the individual RPs are not sufficiently discernible from the background EEG activity.) However, an externally signaled veto would not be an endogenous conscious process; as a quick reaction to a sensory signal it could even be generated unconsciously. It would of course be even more desirable to study the uninstructed veto of a spontaneous, self-initiated act, but, as mentioned, this is not presently possible technically because an objective trigger time for averaging RPs would not be available.

4.2. *Conscious "trigger" versus "veto"*

An alternative mode of conscious control might lie in a requirement that a conscious "trigger" finally impel the unconsciously initiated cerebral processes to achieve the actual motor act. Conscious control would then have an active role in completing or consummating the volitional process; the absence of a positive conscious trigger would mean no actual motor act occurs. If one grants the availability of the veto process, then an active trigger role becomes a redundant and unnecessary means of achieving conscious control. On the other hand, it is conceivable that both modes of control, active trigger and veto blockage, are available. Whether by active positive triggering or by vetoing the completion of the volitional process, the conscious function may be thought of as selecting from among the possible acts developed by the unconscious initiating processes.

Would the appearance of a conscious trigger or veto also require its own period of prior neuronal activity, as is postulated for the development of the conscious urge or intention to act and for a conscious sensory experience? Such a requirement would imply that conscious control of the volitional outcome, whether by veto or by an activating trigger, is itself initiated unconsciously. For *control* of the volitional process to be exerted as a *conscious initiative,* it would indeed seem necessary to postulate that conscious control functions can appear without prior initiation by unconscious cerebral processes, in a context in which conscious awareness of intention to act has already developed. Such a postulate can be in accord either with a monist view, in which a conscious control function could be an ongoing feature of an already emergent conscious awareness (Margenau 1984; Sperry 1980), or with a dualist interactionist view (Popper & Eccles 1977).

5. Free will and individual responsibility

This is not the place to debate the issue of free will versus determinism in connection with an apparently endogenous voluntary action that one experiences subjectively as freely willed and self-controllable (see Eccles 1980; Hook 1960; Nagel 1979; Popper & Eccles 1977). However, it is important to emphasize that the present experimental findings and analysis do not exclude the potential for "philosophically real" individual responsibility and free will. Although the volitional process may be initiated by unconscious cerebral activities, conscious control of the actual motor performance of voluntary acts definitely remains possible. The findings should therefore be taken not as being antagonistic to free will but rather as affecting the view of how free will might operate. Processes associated with individual responsibility and free will would "operate" not to initiate a voluntary act but to select and control volitional outcomes. (Voluntary action and responsibility operating behaviorally within a deterministic view would, of course, be subject to analogous restrictions.)

Some may view responsibility and free will as operative only when voluntary acts follow slower conscious deliberation of alternative choices of action. But, as already noted above, any volitional choice does not become a voluntary action until the person moves. In the present study, the subjects reported that the same conscious urge or decision to move that they experienced just before each voluntary act was present and that it was similar whether or not any additional experience of general preplanning had already been going on. Indeed, the reported times for awareness of wanting to move were essentially the same for fully spontaneous acts and those with some preplanning (Libet, Gleason, Wright & Pearl 1983). One might therefore speculate that the actual motor execution even of a deliberately preselected voluntary act may well involve processes similar to those for the spontaneously voluntary acts studied by us. The urge or intention actually to perform the voluntary act would then still be initiated unconsciously, regardless of the preceding kinds of deliberative processes.

The concept of conscious veto or blockade of the motor performance of specific intentions to act is in general accord with certain religious and humanistic views of ethical behavior and individual responsibility. "Self-control" of the acting out of one's intentions is commonly advocated; in the present terms this would operate by conscious selection or control of whether the unconsciously initiated final volitional process will be implemented in action. Many ethical strictures, such as most of the Ten Commandments, are injunctions not to act in certain ways. On the other hand, if the final intention to act arises unconsciously, the mere appearance of an intention could not consciously be prevented, even though its consummation in a motor act could be controlled consciously. It would not be surprising, therefore, if religious and philosophical systems were to create insurmountable moral and psychological difficulties whenthey castigate individuals for simply having a mental intention or impulse to do something unacceptable, even when this is not acted out (e.g., Kaufinann 1961).

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Problems with the psychophysics of intention

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Several methodological and conceptual problems come to mind after a reading of Libet's article. For one, the timing of all consciously apprehended events under investigation was measured relative to the "clock position" of a dot revolving in a circle. Similar timing methods plagued by several problems have been used for over 100 years. Using a revolving dial, Wundt (1904) noted that the perceived time of a sensory event relative to the simultaneously visually perceived position of the rotating dial depended crucially on the angular rate of the dial's rotation and the other sense being stimulated. Libet's work is based on a single angular dot velocity; hence, despite acceptance of his particular implementation of the procedure by refereed journals, there is a very strong possibility that his measures are idiosyncratic.

Moreover, the timing of S, the awareness of a tactile stimulus, does not serve as a clear control that allows one to regard any timing "error" here as an indication of the potential error found in timing W, the awareness of the intent to act. First, judgments of intermodal sensory simultaneity depend on the particular senses investigated and the stimuli used/ Besides the prior entry effect noted by Libet, intrinsic latency and processing rate differences among senses as well as latency differences introduced extrinsically by use of a near-threshold tactile stimulus relative to a clearly suprathreshold visual dot stimulus (Libet, Gleason, Wright & Pearl 1983) render use of any one estimate of timing error arbitrary and suspect. Second, attending to W may not be equivalent to attending to S, as Libet assumes. Indeed, one can voluntarily allocate attention to endogenously produced cognitive/mental processes as well as to mental processes produced exogenously by sensory stimuli. However, in the latter case a compulsory, stimulus-evoked allocation of attention is typically also engaged, as illustrated by Remington's (1980) and Jonides's 1981) studies of attention to brief suprathreshold visual stimuli. Insofar as Libet's near-threshold tactile stimuli were above threshold, their presentation would also evoke such an obligatory or nonvoluntary attention.

Even if one were to pass over these pertinent methodological problems, several concerns of a more conceptual nature need addressing. First, in what sense can the voluntary acts as operationally defined by Libet be paradigmatic of volitional action generally, particularly when he draws certain weighty religio-ethical implications from his findings? As Libet admits, his experimentally reduced acts of finger/wrist flexion occur in the absence of any larger meaning. Hence they are as limited in application to our understanding of volitional action as use of nonsense syllables is to our understanding of memory. By what rules do we proceed from these experimental findings to human volitional action (or memory) occurring inextricably within a rich, varied, and meaningful context? William James (1950) held that a *strictly* voluntary act must be guided throughout its whole course not only by volition but also by idea and perception. Moreover, he observed that consciousness, besides being primarily a selective, intentional process, is more or less intense depending on action's being more or less significant and hesitant (nonhabitual), that is, where indecision is present to a greater or lesser degree. Consequendy, one might at least require that subjects choose freely among several actions, each of which carries some practical consequence (cost and benefit) rather than merely choosing to act or not in some stereotyped and inconsequential way.

To counter the requirement that a stricdy voluntary act be characterized by slow conscious deliberation and existential alternatives of action, Libet notes that no volitional choice becomes voluntary action until the person moves. The implication is that Libet's paradigmatic acts tap this final, effective conscious intent, which invariably appears approximately 350 ms after an RP is generated but 200 ms before one actually moves. It should be noted that the actions investigated by Libet have been performed (by myself and several of my colleagues) without awareness of intent to act. By requiring subjects to attend to awareness of intent, Libet may have imposed intention artificially and in a way that is not comparable with more