

# **The Inner Sense of Free Will:**

## **Conscious Intention and Neural Substrates**

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by

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# **1. INTRODUCTION**

## 1.1. Philosophical Position on Free Will

One of the oldest and perennial debates is whether we humans have *free will*. The free will issue arises when we are self-consciousness about the relationship between the world and our choice (Kane, 2011); how our choice and action alter the world accordingly and/or how the world influences our choice and action in ways of which we are unaware. It includes issues about the nature of human freedom, rational deliberation, compulsion and self-control, human agency and moral responsibility, criminal liability, the relation of mind to body, freedom in theology, questions about foreknowledge, the nature of rationality and law of nature. The term 'free will' thus covers for several different notions.

The prevalence of philosophical positions on free will has been dominated by a doctrine of determinism that appears to threaten free will. If any event (including our choice or our action) is inevitably the result of antecedent physical causes according to the laws of nature, then the origin or source of such an event is not up to us, but beyond our control. By contrast, if making a choice from alternative possibilities is up to us and not pre-determined, then we are capable of influencing the world in various ways. The so-called 'free-will issue' or 'the problem of free will' deals with this philosophical debate.

### 1.1.1. The problem of free will

There is a general subjective experience and belief that alternative choices could have been made in the same past conditions. Therefore, our common sense says that we can make decisions that are up to our own desires and goals, which are unconstrained by certain factors. However, this is not how we conceptualize scientifically changes occurring in the world. According to the natural laws of physics, every event is caused by preceding events and there is one actual causal chain of events. Everything that happens could have a sufficient causal explanation for being as it is. *Determinism* is a position claiming that every event including our behaviors is a consequence of the prior conditions, and thus, there is only one unique future that is not up to our 'will' (van Inwagen, 1983). Since we are part of nature and our behaviors are also events, we might not be an exception of these laws.

If we have free will, one could argue, it entails that our behaviors are ultimately unpredictable. In some respect, this view parallels the position of *indeterminism*, which rejects determinism in favor of the view that every event is not a cause of prior events rather it occurs as a result of chance. To that view, humans are a particular first cause of their own actions and could be free agents (Myers, 2008). However, the position of human behaviors as the results

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of purely chance events also reflects that those behaviors are totally random and out of one's desire or control. Freely behaving does not mean doing things that have no one's desire or no control. Therefore, it seems that free will is neither compatible with deterministic position nor with indeterministic position.

Within this debate a crucial issue is whether a deterministic position is compatible with free will. If not, this position is called *incompatibilism*, which states that if deterministic explanation for human behaviors is true, then it would be inconsistent with the existence of free will (van Inwagen, 1983). Therefore, whether determinism is true becomes a major concern. In contrast, *compatibilism* is a position claiming that the deterministic view is compatible with the existence of free will (Watson, 1982a). Determinism does not rule out the existence of free will. Here it becomes a major concern how free will and determinism could coexist. As a consequence, debates about free will in the modern era have been dominated by two questions, "Is determinism true?" and "Is free will compatible with determinism?" (Kane, 2011).

If determinism is compatible with the existence of free will, it seemingly answers the free will question by keeping the causal closure of the physical world intact. However, compatibilism has been criticized because of this association with determinism. What is really 'free' in such a free will if our behavior is entirely determined by preceding events? This account would not seem to allow for any further questions about human behavior as far as *freedom* is concerned, (Watson, 1982b). The freedom to do something is defined as one's 'power' or 'ability' to do what one wants to do in absence of any constraints or impediments (Kane, 2011). For instance, physical constraints, mental impairments, lack of opportunity, and coercion, which affect our ability to act and prevents us from doing what we want to do, result in a lack of freedom.

A position affirming the existence of free will and also claiming that free will is incompatible with determinism is the view of *libertarianism* (which thus entails the existence of free will and incompatibilism). Accordingly, libertarians have to prove that compatibilism as well as determinism are false. In addition, the denial of these two positions requires answering a third question. If determinism is false and free will is not compatible with determinism, indeterminism does not seem to be compatible with free will either, because if an action occurs by chance or is arbitrary, it is by definition not under control of a free will. Therefore, how free will can be reconciled with the position of indeterminism (the so-called 'intelligibility question'; Kane, 2011) needs also to be addressed by libertarians.

### 1.1.2. Moral responsibility

The notion that our behaviors are depending on our own ‘will’, i.e. that we could have alternative possibilities, is a necessary condition for moral responsibility. And there is strong position to consider that determinism would preclude the presence of alternative possibilities (e.g., van Inwagen, 1983). If our behavior is a necessity of one causal chain of events, there were no other choices that we could have done. Therefore, it has appeared that moral responsibility is incompatible with determinism.

Since the question of moral responsibility is intimately connected with the free will issue, also here the two positions of incompatibilism and compatibilism are of importance (Nahmias et al., 2005; Nichols & Knobe, 2007). Incompatibilists maintain that we are not morally responsible if determinism is true, i.e., determinism is not compatible with moral responsibility for the same reason discussed above. By contrast, compatibilists maintain that we are morally responsible even if determinism is true (Watson, 1982a). If we have the freedom in the above defined sense that is a power or ability to do what we want to do in the absence of certain constraints or impediments, it is reasonable to think that we could have done otherwise. Thus, it has appeared that from the view of compatibilism does not undermine moral responsibility.

The discussion of this topic, however, was fundamentally altered when H. Frankfurt (1969) and P. F. Strawson (1962) published their seminal works, which are the most widely discussed theories of free will and moral responsibility in the past fifty years (Kane, 2011). The existence of free will requires alternative possibilities in the sense of ‘could have done otherwise’, which is a prerequisite of moral responsibility. However, Frankfurt (1969) argued by providing thought experiments (a hypothetical control machine manipulates a person’s choice by blocking alternative possibilities, in ways of which s/he is unaware) that “*a person may well be morally responsible for what he has done even though he could not have done otherwise*” (Frankfurt, 1969, p. 829-830). There might be a circumstance that makes it impossible for a person to avoid doing something, and thus, s/he could not have done what s/he otherwise really wanted to do. Under this condition, one could argue, the person will not be morally responsible because s/he could not have done otherwise. But, what if the person did what s/he really wanted to do even though s/he could not have done otherwise. In a ‘Frankfurt-type example’, a hypothetical control machine (a controller) continues to monitor a person if s/he is to show any inclination to choose ‘B’. The controller would then intervene to assure that s/he actually chooses ‘A’, in ways of which the person is unaware. If s/he is to

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show any inclination to choose 'A', the controller does nothing and continues to monitor. In this case, s/he can make choice of 'A', and thus, s/he can be morally responsible for the choice of 'A'. However, s/he could not have done otherwise except choosing 'A' because the controller blocks choosing 'B', indicating no alternative possibilities. In Frankfurt's view, thus, moral responsibility does not require alternative possibilities and being morally responsible is possible without libertarian free will.

A counter argument to the position of 'Frankfurt-type example' has been presented by contemporary philosophers e.g., R. Kane, D. Widerker, C. Gient, and K. Wyma (for an overview see Fischer, 2011). The claim begins with conceptual analysis relating to the 'logic' of the free will problem, presupposing the truth of either indeterminism or determinism. In an indeterministic world, the choice is undetermined up to the moment when it occurs. Therefore, the controller cannot know in advance what s/he will choose, either 'A' or 'B'. In this case, s/he is the first cause of the choice and s/he had alternative choices because the choice was undetermined. Thus the 'Frankfurt-type example' would not work in an indeterministic world. By contrast, in a deterministic world, the choice is determined so that the controller must act *in advance* to block choosing 'B' and bring it to 'A'. In this case, s/he will not have alternative possibilities at all, and thus, s/he is not morally responsible for the choice, but the controller will be. These two cases questioned the 'Frankfurt-type example' by showing that moral responsibility and alternative possibilities go together. Instead Wyma (1997) argued that a certain kind of 'leeway' is required for moral responsibility: "*A person is morally responsible for something she has done, A, only if she has failed to do something she could have done, B, such that doing B would have rendered her morally nonresponsible for A.*" (p. 59).

Strawson (1962) viewed the free will and moral responsibility from the requirement of holding personal relationships. *Reactive attitudes* such as gratitude, resentment, forgiveness, love, and hurt feelings are constitutive of moral responsibility; to regard oneself or another as responsible is to react in these kinds of ways. These attitudes could be of expressions adopting the personal attitude toward someone; how much we actually mind others, how much it matters to ourselves, and how the behaviors of some others reflect attitudes toward us. In Strawson's view, lack of freedom or moral responsibility cannot be assessed as a result of accepting deterministic explanations, but only when a person is viewed as 'incapacitated in some or all respect for ordinary personal relationships'. Strawson believes that because in most cases we have strong and practical reasons for maintaining these relationships (e.g.,



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social benefits), assessing others and ourselves in terms of reactive attitudes does not depend on the truth or falsity of determinism.

The strategy that Strawson pursues is an important aspect, which suggests that personal conceptions of free will and responsibility cannot be understood independently of a moral sense. A moral sense may modify personal attitudes related to social benefits. Reasons for choice or action might derive from one's conception of a good way to live that is mediating a distinction between desire and valuing (Watson, 1982b). That is to say, Strawson's approach depends less on a conceptual analysis of the problem of free will, but more on a descriptive psychology of human moral sentiments (Russell, 2011).

### **1.2. Free Will in Psychology**

While the discussion of free will in philosophy has a longstanding tradition the issue was neglected until recently in the field of psychology. While philosophy deals with the logical and moral problems which arise when one either assumes that free will exists or not, psychology is more concerned with the personal experience of humans regarding the free will issue. This includes questions such as how we experience free will, why we believe that we have free will and what are the influences, and processes underlying volition (Baumeister, 2008b).

Nevertheless psychology as an empirical science draws on causal concepts. Here, Baer et al. (2008, p. 4) remark that "*a psychology that doesn't accept causes of behavior or the possibility of prediction is no psychology at all*". From this perspective a deterministic view should be at least a working hypothesis for the field of psychology, and thus, also a psychology of free will be based on the assumption that behavior can be explained by discernable causes. Many studies in psychology, thus, have examined and demonstrated the role of free will in our daily lives.

#### **1.2.1. Belief in free will**

Our common sense says that we have a free will. In a study by Pronin and Kugler (2010), it was furthermore found out that people perceive their own lives as more guided by free will than others' lives. Participants completed questionnaires that contained questions regarding the degree of prior unpredictability of personal action, multiple possible paths in a person's future, and regarding one's personal desire or intentions in guiding one's actions for both themselves and their peers. Individuals viewed their past and future behaviors as less

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predictable because they perceived their behavior as driven by their own desires and intentions. On the other hand they perceive others' behavior as driven by their personality, certain circumstances, and situations. Although, such view of free will is not necessarily held for every person, increasing empirical evidences suggest that having belief in free will plays a crucial part in our daily lives.

In order to assess the role of belief in free will this belief can be experimentally manipulated, e.g. by reading an essay written by a well-known scientist who explains convincingly that free will is an illusion. This approach was used in a study by Vohs and Schooler (2008). Participants who read such an essay were more willing to cheat in a computer-based math task than controls who read another chapter from the same essay without any references to free will. That is, after participants were told that their actions were predetermined and therefore not under their control, they cheated more. Subsequent work using similar procedures showed that inducing people to disbelieve in free will led to an increase in aggression and also in a reduction in willingness to help others (Baumeister et al., 2009).

But the belief in free will does not only affect moral decisions, it has also affects working performance. Stillman et al. (2010) found that a personal philosophy of believing that one has free will contributed to a positive attitude and more effective performance in the workplace, suggesting that a belief in free will results in benefits itself. Fortunately, people generally have the sense of having free will (Nahmias et al., 2005), and therefore human society most likely benefit from a believe in free will. Baumeister (2008b) contends that having such a belief might motivate people to control their automatic and impulsive behaviors in favor of cooperation and pro-social forms.

It should be noted, though, that there is also an advantage in a disbelief in free will (Shariff et al., 2014). In this study it could be shown that participants who were discouraged regarding a belief in free had a reduced tendency of retribution for criminal punishment (lab-based manipulation that participants were acting as hypothetical jurors and recommended the length of a prison sentence for an offender who beat a man to death). This study suggested that through just reading popular neuroscience articles and learning about the brain shifted people's philosophical view from a belief in free will toward a mechanistic view of human behavior. One possible explanation of this result is that we are more lenient towards certain behavior if we believe that the action was determined by neurological and chemical processes (a mechanistic view of human behavior), but more strict if we believe that the action was driven by conscious psychological processes (Nichols S., 2011).

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Although all of this empirical evidence do not shed light on the debate on whether or not we actually have free will, it provides some insights into how free will, at least the consequence of believing in free will, might work in our daily lives. It can be concluded that a belief in free will seems to have some functional consequences with respect to social behavior. This is also reflected within many aspects of our cultural practices which are based on the existence of free will, such as our legal system. So even if science should one day prove definitely that humans have no free will, as many neuroscientists already claim today, the collective assumption of having free choices seems to be a necessary condition for our present society.

### 1.2.2. Experience of will

Being aware of one's 'will' is a major component of the free will experience. We usually think about doing something and then do it. Before an actual movement we apparently experience our willing to move in advance. This account provides us with the sense that our conscious will causes what we do. However, there is strong evidence suggesting that many aspects of action occur in the absence of awareness (e.g., Johansson et al., 2005; Lind et al., 2014). For instance, an experiment manipulated the outcome of a subject's decision (one of two choices) and then they were asked to explain their decision (Johansson et al., 2005). Interestingly, without noticing the experimental manipulation, i.e., the mismatches between their intention to choose and its actual outcome, participants provided introspectively derived explanations for a decision they did not make. This finding suggests that we rather infer our experience of will retrospectively from the apparent outcome, which we believe it was caused by our 'command'. It therefore seems to confirm the case of "telling more than we can know" (Nisbett & Wilson, 1977).

For two decades, studies on *awareness of action* have been focused mainly on two aspects. The *predictive* position on the one hand, is a view that the awareness of action is generated by processes that are related to the prediction of the future state (Blakemore et al., 2002). One may be aware of an action if that action is predicted by an internal forward model, which has two types of predictions. The forward model predicts both the actual outcome of the motor command (e.g., Miall et al., 1993) and the consequences of that action (e.g., Gentsch & Schütz-Bosbach, 2011; Hughes et al., 2013). These predictions may underlie the ability to distinguish between self- and externally-generated actions, and also to achieve better motor control by comparing the desired outcome with the actual outcome in a feedback process (for a review see Blakemore & Frith, 2003).

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On the other hand there is the *retrospective inference* position. Daniel Wegner proposed that the experience of conscious will might be merely an apparent mental causation. Such an apparent causation appears if it fits three criteria, which he claims to draw from the philosophy of David Hume (1711-1776). Hume suggested that the feeling of will is a perception arising from the constant conjunction of events. The three criteria are *priority* - a conscious thought should appear before an action, *consistency* - the conscious thought should be consistent with the action and *exclusivity* - the conscious thought should be the only one that causes the action (Wegner & Wheatley, 1999). Thus, according to Wegner the experience of causing an action is inferred retrospectively from the match of outcome with the earlier mental state. Several studies have examined and demonstrated the influence of these three principles of apparent mental causation (Wegner, 2008; see below).

*Priority* effects have been examined in a study of vicarious agency by Wegner et al. (2004). Participants were led to visually experience the arm movement of another person as if the arm were their own. An introduction was provided for the participants before the actual movement to elicit consistent prior thought for the movement that they would perceive visually. Participants experienced enhanced control over the arm movements of another person when an instruction was provided in advance of the movements, as compared to the conditions without instruction or with the instruction given only after the movements had occurred.

Another principle of apparent mental causation is *consistency* between thoughts and events. This has been assessed in a study by Pronin et al. (2006). Thinking about an outcome before it occurs led participants to experience “I made it”, even if such causation seems magical. For example, participants performed a voodoo curse (sticking pins in a doll) to stress a potential victim into a headache, who later feigned a headache. Experience of will in the sense of “I made the victim sick” was significantly increased when participants disliked the potential victim. In cases where the participants perceived the victim as neutral or likable they rather disbelieved that their curse had caused the headache. Obviously the consistency between this kind of negative thought (dislike) about a potential victim before the curse was made in connection with the outcome had strengthened the experience of will.

The third criterion is that one’s thought should be the only one that precedes and causes the outcome of that thought. If someone else is doing the same action that we thought to do, our experience of conscious will is different. This is called the *exclusivity* effect of the experience of will. In a study (Wegener & Sparrow, 2007), participants tapped alphabet letters in order, which were irregularly distributed on a screen. At a same time, an experimenter sitting on the

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other side of the screen tapped the same alphabet in order either in advance or behind of the participant's current letter. This paradigm enabled to manipulate the participant so that he thought that he/she was tapping an alphabet letter into regarding either as the only one source of that tapping (an experimenter pointed behind of the participant's action) or as one of several sources of that tapping (an experimenter pointed in advance of the participant's action). They found that subjective report on experience of will was reduced if an experimenter pointed to the same alphabet letter in advance of the participant's current letter. By contrast, the experience of will was increased when the experimenter pointed at the letter behind the participant's current letter.

Wegner's conscious will theory (which does not fit our experience) implies that consciousness plays no crucial role in action planning as well as that it also implies that moral responsibility does not exist. It is not surprising that the apparent mental causation theory has been criticized by several philosophers (e.g., Double, 2004; Mele, 2011). Nahmias (2002) argued that although 'the illusion of conscious will' theory provides successful empirical facts, it has not shown that conscious will does not play a crucial causal role in planning and forming intentions. He also noted that Wegner's conscious will is focused on proximal intention, which is just occurring before an action. It does not explain our deliberations and planning, which are often playing together as an essential role in conscious experience of will.

### **1.2.3. Psychology of volition**

The philosophical term 'will' is in psychology referred to as 'volition'. Thereby volition is conceptualized as the cognitive process of making a decision leading to action. This process is seen as intentional and purposeful. From this perspective volition is driven endogenously rather than determined by immediate external events. Therefore, human behavior could be considered as a voluntary action whenever there is a relevant inner process, which is preceding the actual action (a prerequisite condition for both predictive and retrospective inference models for the experience of will as shown above). However, a coherent psychology of volition is still nascent (Miller & Atencio, 2008); perhaps not only because of the historic debate regarding to the problem of free will but also because of growing evidence contradicting our common sense (e.g., Wegner's conscious illusion theory).

What is thought to be an *intentional action* might be a start of understanding volitional action that is self-generated. Malle and Knobe (1997) studied the conditions under which, according

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to the folk concept, a behavior is seen to be intentional, i.e. what intention is and how such an intention leads the generation of intentional action. Participants completed a questionnaire asking for definitions of ‘intentional’ (i.e., “when you say that somebody performed an action intentionally, what does this mean? Please explain”). It revealed that for an action to be intentional five main components are required: a person must have (a) a desire for an outcome, (b) beliefs about an action that will lead to that outcome, (c) a wish to perform the action, (d) the skills to perform the action and (e) the awareness of fulfilling the intention while performing the action. According to people’s folk concept, the direct cause of an intentional action is the mental state of intention (a desire and a belief must be present), but for an action to be seen as *performed* intentionally the quality of the action (skill and awareness) have to be present as well (Malle, 2010). Malle suggests that if one of these components appears to be absent, we are reluctant to call a given behavior as intentional. Instead, we might label such a behavior as unintentional or accidental as ‘cause explanations’, which is referring to more mechanical causal factors such as traits, other’s behaviors or physical events.

Miller and Atencio (2008) suggest volitional action as a constitution of two components; an intention (conscious deliberation to do) and an enactment of that intention (characterization of the subsequent action stage). An autonomic behavior, e.g. reflexes to prevent injury, is a goal-directed behavior (enactment), but without an intention it is not necessarily volitional. On the other hand, an intended outcome is not sufficient for volition if it occurs without ‘thinking’ of this outcome. Volition, thus, is tied to conscious deliberation, intentional process and self-control of the subsequent outcome, which is driven endogenously rather than determined by immediate external events. They further proposed the term *volitionality of behavior*, to characterize the extent to which a behavior is subject to willful control. Some behaviors have a higher volitionality that is hard to restrain, and some people have greater degree of volitional control in contrast to those who show more impulsivity.

Recently, Schüür and Haggard (2011) proposed three different types of self-generated actions. The first type defines self-generated action as *operant* action, which is not triggered by immediate external cue, but by previous internal events (‘endogenous processes’) such as memory traces, experience of previous actions or behavioral goals. The second type defines self-generated action based on free choice (*undetermined* actions) from the present moment. While operant action emphasis the importance of previous internal cues, undetermined action depends on the action that is caused by ‘me’ immediately, and thus, the actions should involve novel and spontaneous aspects. According to the third type, self-generated action is the

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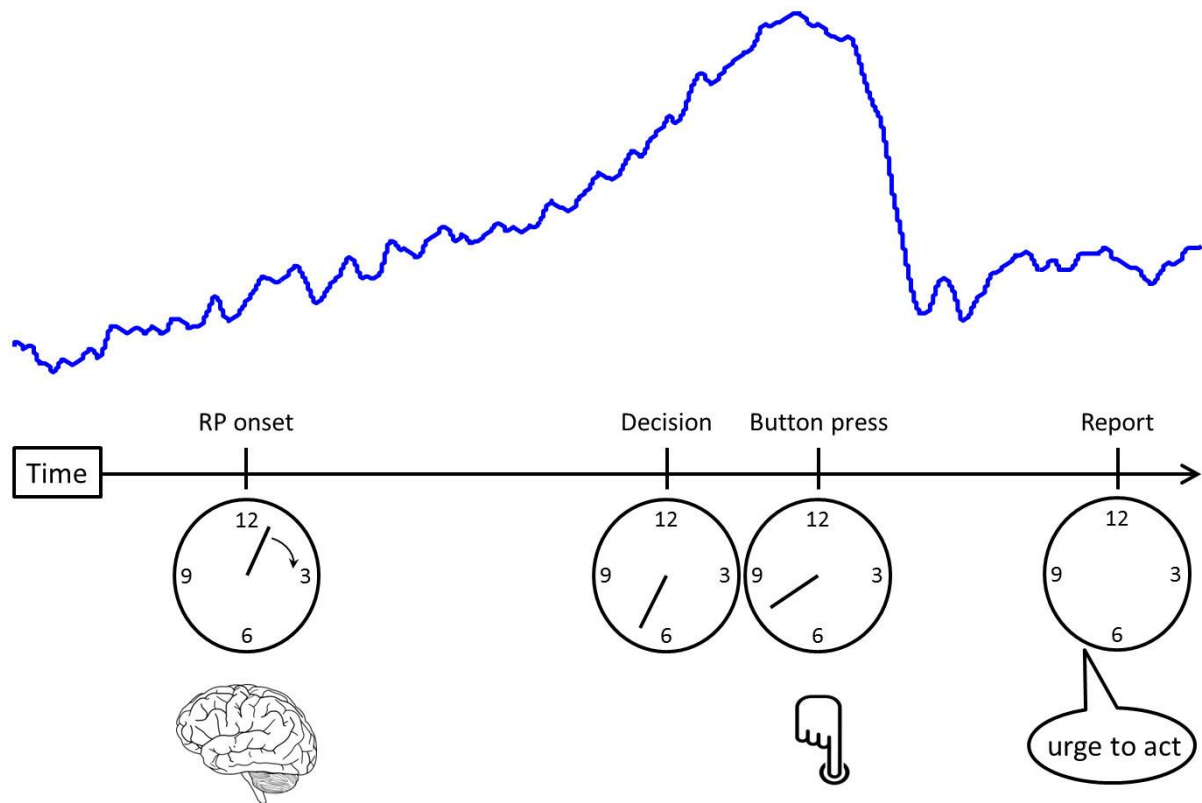
consequence of the integration of different types of inputs. This type of action does not rely on a specific origin or source; rather it relies on a cognitive process that is integrating larger numbers of qualitatively different types of inputs. Complexity and integration of inputs are features of how an action is generated. This integrative account does not require direct causations; instead the personal past contributes to how an action is generated.

On the other hand, Baumeister (2008a) proposed different perspective on action initiation by asking: how exactly does a thought cause the body to start to move? All organisms from the simplest to the most complex would never reach a state of being 'at rest'. Our biology is already happening all the time, and thus, choice (or action initiation) might not need a certain thought (or behavior) to start. Instead he contends that "*the role of free will would be to alter the flow of behavior*" (Baumeister, 2008a, p. 69). Seen in this way, a function of volition would be to suspend or interrupt one set of causal processes to move, or choosing among various options for the coming course of action. Thus, some degree of conscious and effortful thought would produce action initiations by altering earlier response tendencies.

There is growing evidence that human behavior is largely affected by hereditary and environmental factors such as evolutionary, genetic and social influences (for an overview see Myers, 2008 and Baumeister, 2008a). For instance, a recent cultural psychology study has found that those who have grown rice are much less individualistic than those from a wheat culture (Talhelm et al., 2014). In other words, history of farming culture may influence the formation of individual behavioral dispositions. Thus, such wider cultural influences might also contribute to individual volition.

### **1.3. Free Will in Neuroscience**

The philosophical and psychological debates on free will made a sharp neuro-scientific turn when Benjamin Libet and his colleagues published their now famous study on voluntary movement (Libet, et al., 1983a). In 1965, Kornhuber and Deecke discovered a slow negative shift in the electroencephalography (EEG) recording that is preceding a voluntary action, the readiness potential (RP, also known as the Bereitschaftspotential). They recorded EEG while the subjects made repeating self-paced movements. After segmentation of the EEG recordings aligned to the movement onset, they could find the RP by averaging the EEG segments. Following this discovery, Libet's experiment (Libet et al. 1983a) has incited hot debates concerning the question of free will (Haggard, 2008).



**Figure 1-3-1.** A schematic results of the Libet experiment. The RP (the blue line) starts rising much earlier than the ‘Button press’, notably it even precedes the ‘Decision’ time to act.

### 1.3.1. The Libet experiment

In the Libet experiment, participants were asked to spontaneously flex their finger (or button press) in a moment of their own choice, whenever they felt an intention, desire, or urge to do so. Simultaneously, participants watched a small analogue clock on a screen, which has a clock-hand rotating clock-wise with a period of 2.5 s. After the finger movement they were asked to indicate the time of appearance of their ‘intention’, ‘urge’, or ‘decision’ to act by reporting the position of the clock-hand. At the same time brain activity on the scalp was recorded with EEG. Since the EEG signal has a very small signal-to-noise ratio with other brain activity, it can be only seen by averaging the recordings of several identical trials. This experimental setup allowed comparing temporal events; i.e. the conscious awareness of intention time, the onset of the finger movement, and the brain activity. It turned out that conscious awareness of intention occurs about 200 ms *before* the actual finger movement, but about 300 ms *after* the onset of the RP (see **Figure 1-3-1**). Based on the occurrence times of the events, it is claimed that a ‘decision’ to move might have already been initiated by the brain before the conscious experience of the decision to act. Thus, it seems that conscious decisions cannot cause the onset of the RP. This finding led to the assertion that behavior is



not under conscious control because consciousness comes too late. This stands in contrast to our experience that generally provides us with the sense of having free will.

### 1.3.2. Free won't (veto)

Because Libet's finding implies that the decision to move is determined by the brain rather than by one's own 'will', it has raised a number of controversial issues (e.g., Libet, 1985; Klemm, 2010; Walter, 2011; Radder & Meynen, 2012). Regarding the definition of 'intention' used in the task, one can doubt whether the RP is an adequate marker of movement decisions, and methodological problems, such as the effects of watching the clock-hand rotation and reporting the intention time, are issues of this debate.

Nevertheless, Libet has rather contended, "*Although the volitional process may be initiated by unconscious cerebral activities, conscious control of the actual motor performance of voluntary acts definitely remains possible*" (Libet, 1985, p. 538). That is, an emerging intention to act that had been prepared by the brain and that is ready for execution can be consciously inhibited (free won't, veto mechanism). The decision making process still precedes by about 200 ms the start of a voluntary action (the latency between decision and button press in **Figure 1-3-1**), and this time period might be enough for conscious inhibition processes.

Bass and Haggard (2008; see also Haggard, 2008) outline a model of human volition which consists of several discrete steps. In this model the so-called 'whether decision', whether or not to perform an action, is split in an early motivational component and a late final check which would allow to cancel an action which was already been on the brink of execution (veto, inhibition). Despite the importance of internal inhibition in cognitive control, this process is not well studied due to the difficulty that it has no behavioral output. Thus it is difficult to determine whether an action does not occur because of an internal or external inhibition or whether there was never any intention to act at all (Filevich et al., 2012).

Recent studies, however, suggested that a conscious free decision to inhibit an action may also depend on preceding brain states. A cue stimulus prompted participants to decide whether to press a button immediately or with delay (Filevich et al., 2013). They found that a reduced event-related potential (ERP) amplitude preceding the cue stimulus lead to delayed button press, while a higher ERP amplitude was associated with rapid button presses. In addition, another recent study suggests that the decision to inhibit may be a consequence of the ongoing brain states (Misirlisoy & Haggard, 2013). Omitting a particular action within a

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repetitive manual motor sequence, which is based on endogenous voluntary choice, was prefigured by reduced RP for the immediately preceding action in the sequence.

In sum, withholding or canceling (veto) 'action' plans can be predicted through monitoring neural activity long before conscious decision processes. Therefore, this seems to demonstrate that conscious experience of free will and free won't are both merely byproducts of neural processing, supporting the position of a deterministic view.

### **1.3.3. State of neuroscience research**

The Libet task was replicated by many researchers in different laboratories confirming that conscious intention emerges approximately two seconds after the onset of pre-conscious brain activity (e.g., Haggard & Eimer, 1999; Rigoni et al., 2011; Sirigu et al., 2004). A recent study of the Libet experiment with intracranial single neuron recording adds to those findings by revealing with more precise methodology and in greater spatial detail (Fried et al., 2011). This study fills important gaps of previous EEG recordings in humans that lacked spatial precision, but keeps fine temporal precision intact. Additionally, fMRI studies suggested that the earliest predictive information of the brain was encoded up to seven seconds before it enters conscious awareness of a decision (Soon et al., 2008, 2013). Participants were asked to press either the left or right button when they became aware of the urge to do so. In agreement with Libet's finding, the fMRI data showed specific brain activity in the frontal cortex area that predicted which button subjects would press (left or right) up to seven seconds before the movement with the average prediction accuracy of about 60 %. But there is also a methodological critique arguing that when asked to generate a random sequence, people typically alternate between binary responses with a probability of about 0.6. This response pattern appears to be the same as Soon's findings (Lages et al., 2013). All these neuronal findings seem to suggest that human behavior is controlled by neurobiology, and that belief in free will is an illusion.

In support of this view, studies with patients during brain surgery have shown that electrical stimulation of the brain (in the supplementary motor area, SMA) produced an irrepressible desire to move which is beyond patient's will (Fried et al., 1991). An increasing stimulation intensity in the same area generated movement executions that remained completely unaware for the patient (Desmurget et al., 2009). Interestingly, it was also possible to provide a stimulation resulting in the patient having experiences in the opposite direction. Stimulation of the parietal lobe generated the impression of a conscious movement that has been

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accomplished, although in fact no actual movement was observed. Therefore, modulating brain signals via electrical stimulation can produce not only a desire or intention to move, but also the experience of an illusory movement (illusory subjective experience).

However, several recent findings have challenged the view that human behavior is controlled by neurobiology and thus believing in free will is an illusion. The brain signals (the RP) preceding conscious awareness of intention to move was found to be not dependent on the decision to move. Trevena and Miller (2010) conducted a study in which a tone sound prompted participants to decide whether to move or not. They found no evidence for a stronger RP before a decision to move than before a decision not to move. In addition, the lack of causal relationship between the onset of the RP and the time of conscious awareness of intention to move suggested that the RP reflects processes independent of will (Haggard & Eimer, 1999; Schlegel et al., 2013). It was also argued that the RP might not necessarily reflect decision-related neural processes but rather an epiphenomenon of cognitive processes for performing the Libet task (Miller et al., 2011).

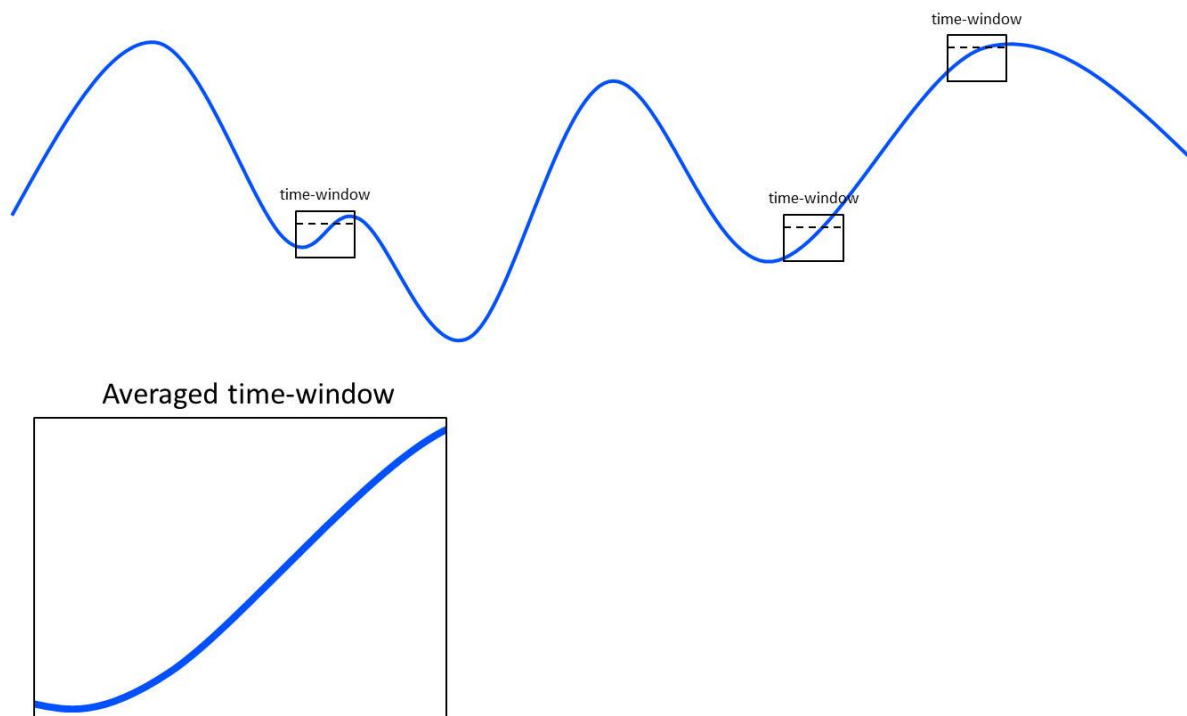
In fact, there are several methodological debates concerning the Libet task. Since participants in the Libet task were instructed to perform a movement whenever an urge to act appeared, it is unclear whether self-initiated movements were purely 'voluntary' acts or simple reactions to an internal stimulus (Bennett & Hacker, 2003). In the latter case, it might be argued that pre-conscious brain activity may reflect the general fluctuations of internal non-specific preparation instead of a decision process to move. Here we encounter the problem that subjects participating in the Libet task have already agreed to perform as they are told. Thus, it is often said that the only free decision within this experimental framework is the decision to participate. Whatever then follows has to be seen with respect to the specific context in which the experiment is conducted. This argument is often referred to as 'rules of the game' (Klemm, 2010) since the Libet task sets a set of rules which are primarily accepted by the participants.

In 2012 a study by Schurger and his colleagues provided a strong argument that the RP is not entirely a preparatory signal but it might be an expression of spontaneous neural fluctuations. The fluctuating time series average produced by their model (a stochastic accumulator for neural activity) was well fitted to the RP. According to this model, a movement is triggered if the fluctuation is sufficient to cross a threshold, and that the shape of the climbing RP only appears to build up steadily by averaging the fluctuations through backward-tracking. In other words, a similar RP-like negativity can be observed if neural fluctuations, which cross the

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threshold during a constant negative phase, are averaged (see **Figure 1-3-2**). This means that the RP, at least the early part, might be an averaging artifact of spontaneous neural fluctuations rather than reflecting a preparatory brain process to move. In the literature, the RP can be divided into two components based on the scalp distribution and the slope of negative potential (Shibasaki & Hallet, 2006). The early RP starts about 2 sec before a voluntary movement and consists of a prolonged and increasing negativity. This activity is localized in the bilateral pre-SMA. In contrast, the late RP has a steeper slope seen in the contralateral premotor cortex starting around -0.5 sec before movement onset.

Another criticism is that the results of the Libet task are highly dependent upon the accuracy of the participants' subjective reports, i.e., self-reported timing of one's conscious intention to move. The potential inaccuracies in reporting the precise time of an intention may lead to misinterpretations (Danquah et al., 2008; Miller et al., 2010; Pockett & Miller, 2007). Indeed, participants find it difficult to keep their attention focused when they asked to report the precise time of their intention (Lau et al., 2004). Thus, many researchers see the subjective reports of mental processes as one of the big problems challenging the reliability of results (Nisbett & Wilson, 1977; Schwitzgebel, 2008).



**Figure 1-3-2.** A schematic neural fluctuation and the time-windows. The time-windows (rectangular shape) are placed in a constant phase of the fluctuations (the blue line). Horizontal dashed lines in the time-windows represent a threshold. Averaged time-window (below) of the three time-windows (above) is shown.

#### **1.3.4. Experience of self-agency: Intentional binding**

Humans experience themselves as having the capacity to alter the world through their actions. That is, being aware of our own actions endows us with a sense that we are interacting with the world, i.e., the *sense of agency*. The link between a voluntary action and its consequent effect leads to the experience of control. A key challenge for scientific investigation regarding the sense of agency has been the development of appropriate measures (Moore & Obhi, 2012).

The ‘clock-methodology’ used by Libet has also prompted the scientific investigation of the psychological and neurobiology processes of self-agency (for a recent review see Wolpe & Rowe, 2014). For over a decade there has been a growing interest in understanding a specific effect related to self-agency, which was reported for the first time by Haggard and colleagues (Haggard et al., 2002) and termed ‘intentional binding’. They showed that when a voluntary action causes a sensory outcome, the action and the consequent effect are perceived as being closer together in time than they really are. Action-binding (the temporal attraction of action towards its consequent effect) and effect-binding (the temporal attraction of the effect towards action) were measured separately in order to investigate the phenomenon of intentional binding (see **Figure 3-4-1** in Study 4).

The intentional binding paradigm was applied in a number of experiments to study human agency, such as self-causation (Dogge et al., 2012), action selection (Barlas & Obhi, 2013), shared actions (Stroher et al., 2010), uncertainty of the effect (Wolpe et al., 2013), emotional states (Yoshie & Haggard, 2013), affective valence (Takahata et al., 2012) and beliefs in free will (Aarts & Bos, 2011). Although many studies have assessed how intentional binding is modulated, the underlying neural mechanisms remain relatively unexplored (Moore & Obhi, 2012). Recently, a study investigated the contribution of specific brain areas to intentional binding (Moore et al., 2010). A transient disturbance of the activity in the pre-SMA by transcranial magnetic stimulation (TMS) reduced the temporal linkage between action and the effect. This was mainly due to the fact that the sensory consequence was perceived as less shifted in time towards action. In contrast, the disruption of the contralateral sensorimotor area had no or much less influence on the temporal binding effect. These results suggested that the pre-SMA plays a crucial part in intentional binding, especially on effect-binding. Because the pre-SMA is seen as a key structure involved in conscious intention to act (Fried et al., 1991; Lau et al., 2004) and intentional binding is specifically related to intentional action (Haggard et al., 2002), this brain area is likely to be associated with the binding effects.

The intentional binding experiment starts with a self-generated action. This is similar to the Libet-type experiment which assesses preconscious brain activation (the RP), preceding a voluntary action (Libet et al., 1983). Since the pre-SMA activity plays a crucial role in intentional binding (David et al., 2008; Moore et al., 2010) and the early RP activity is localized in the bilateral pre-SMA (Shibasaki & Hallet, 2006), one can presume that the early RP might also be of importance for the temporal binding effect.

### **1.4. Methodological Approaches to Studying Consciousness**

#### **1.4.1. First-person data: Conscious experience**

One of the most crucial steps to studying consciousness in the science of the mind is to explain how we consciously experience. Chalmers (1995) has opened the discussion about the problem of consciousness, by dividing it into ‘easy’ and ‘hard’ problems. The easy problems of consciousness are those that can be explained in terms of computational or neural mechanisms that are associated with the notion of consciousness. For instance, it involves the conscious states (e.g., wakefulness and sleep), the integration of information by a cognitive processes, cognitive control of behavior, the ability to react consciously to external stimuli. Although we do not have clear explanations for each case, an appropriate cognitive or neurophysiological model might explain *functional* and *structural* properties of them. This is why Chalmers termed these phenomena as ‘easy’ problems.

However, even after these explanations there is still the question of “why is it conscious”? The really ‘hard’ problem of consciousness is the problem of explaining why any physical state is conscious and how we *experience*, in which terms such as ‘conscious experience’, ‘phenomenal consciousness’ and ‘qualia’ are also used. The hard problem of consciousness goes beyond problems about functional and structural properties. The usual methods of science might explain neural oscillations associated with perceived information that is bound and stored in memory (Crick & Koch, 1990), and how the contents of consciousness are accessible such as a global workspace theory (Baars, 1988). These explanations might eventually lead to a general account of functional and structural properties of consciousness, but it would not tell us about why the relevant contents of consciousness are experienced.

There are properties of experience that can be partly characterized in terms of function and information processing. For instance, for the visual system, every distinction between color experiences has corresponding distinctive processes. Waveforms of light are discriminated and analyzed accordingly and it is relevant to later processing in the brain. However, these

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characterized functional and structural properties cannot explain individual experiences. Each individual might have different visual experiences, because of individual difference of the relationship between external objects and visual perceptual experience of them (representative theory, Jackson, 1977).

It has been suggested that in order to address the hard problem of consciousness and free will (Chalmers, 1995) results from quantitative measures of neural activity need to be combined with first-person reports about the subject's inner experience (Varela, 1996; Thompson, 2010), a research method termed *neurophenomenology*. Neurophenomenology is a methodological remedy to investigate conscious experience and sheds light on the mind-brain relation. It involves rigorous and extensive use of first-person data about subjective experience to describe and quantify neural processes of consciousness. However, while many publications emphasize the need for first-person data, only a few studies have been conducted so far. The reason for this mismatch may be that the gap between first- and third-person data is still large and there are no established methods to bridge it. This might be due to the fact that the basic idea to describe and understand our experience is derived from *communal* effort of humanity (Walach, 2011). One important element in such a communal effort is *observation* from outside that can be shared by others and others can make in principle identical observation (which is usually taken to mean the third-person perspective). This requirement is often termed *objectivity*, which is a systematic inquiry for the way of collecting knowledge (traditional empirical methods in science). On the other hand, from the first-person perspective, an observation is made from the point of view of the subject that is influenced by personal past experience. So that one person cannot share another person's subjective point of view and cannot measure from outside observation what this other person is experiencing (Overgaard et al., 2008). This means that first-person data "appears" to be inter-subjectively inaccessible and thus not inter-subjectively verifiable.

Nevertheless, one of the early positive examples is the study by Lutz et al. (2002), where first-person data obtained through verbal reports were actually used for interpreting the underlying neural processes of subjective experience related to attentional abilities. Participants were first trained to become aware of moment-to-moment fluctuations of their thought (phenomenological contents). This process training was conducted because untrained persons have usually poor accuracy of subjective reports (Nisbett & Wilson, 1977), but this skill be improved by training (Lutz & Thompson, 2003; Fox et al., 2012). During a simple visual task, subjective reports about their thought content and their brain dynamic were recorded.

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Clustering and analyzing each trial according to the first-person data, specific brain patterns were found for each cluster depending on the degree of attentional stability and task preparation.

### **1.4.2. Contemplative practice: An approach to studying inner experience**

To investigate specific aspect of conscious experience, one needs to turn to the first-person perspective. From this perspective, humans are unique due to their ability to report their experience. However, the abilities such as cognitive access to experience, being able to report it, and describe it with precision vary substantially across individuals (Thompson, 2009). Therefore, despite self-reports about experience are indispensable for studying consciousness, many researchers still consider the first-person reports of their mental states as an obstacle challenging the *reliability* and *validity* of results.

One difficulty to become aware of experience and thus to report it reliably is the instability of attention. Moment-to-moment fluctuations of the attentional focus often result in mind wandering. Attention itself can be considered as a semi-automatic process which is not entirely under volitional control. Thus, sustained attention on an intended object requires top-down cognitive control involved in monitoring the focus of attention and disengaging attention from the source of distraction (Lutz et al., 2008). This self-awareness capacity can be increased by systematic training of attention, involving self-monitoring of one's inner experience from moment-to-moment. Such methods exist in many different contemplative meditative traditions (Lutz et al., 2008). One example is developing and improving levels of a mental faculty termed 'mindfulness', which is understood as the ability of maintaining one's attention non-judgmentally to the experience of the present moment (Kabat-Zinn, 2003). This includes monitoring the quality of attention and immediate awareness of affective states and thoughts, and thus, it is routinely applied in clinical contexts and health programs (Kabat-Zinn et al., 1985; for a review see Grossman et al., 2004). Furthermore, there is strong evidence indicating positive effects of meditation on attention control and self-regulation (e.g., Chan & Woollacott, 2007; MacLean et al., 2010; Sahdra et al., 2011; Valentine & Sweet, 1999). For instance, a study by Lutz et al. (2009) has shown enhanced attentional stability after intensive meditation training. Reduced variability in attentional responses to deviant attended tones was observed in an intervention group, suggesting increased cognitive control capacity. Jha et al. (2007) examined three functionally distinct cognitive networks (using the so called attention network task, ANT, Fan et al., 2002) to index attentional functions that are altered by mindfulness training. In this study, an improved performance of the attention network has



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been shown in experienced meditators relatively to those in novice groups. Moreover, it was shown that even a short intervention was enough to obtain a significant improvement of attentional capacities. Tang et al. (2007) demonstrated that an integrative short-term meditation program (IBMT, integrative body-mind training) involving five days of twenty-minutes group training resulted in an improved attention network in the IBMT group.

Another difficulty of first-person methods is whether self-reports about one's experience is validated. When one is asked to report or describe one's experience, introspection or meta-awareness is required in order to become aware of the experience. However, some research demonstrates that we usually have poor accuracy of introspective access to our experience and cognitive processes (Nisbett & Wilson, 1977; Johansson et al., 2005).

A recent study provides evidence that it is possible to enhance the capacity for accessing one's cognitive processes by asking subjects more elaborate about their experience itself (Petitmengin et al., 2013). In addition, improvement of introspection through training can provide access to their inner experience and thus result in more accurate introspective reports (Lutz et al., 2002). Within this context, Fox et al. (2012) examined introspective accuracy with experienced mediators since meditation practice is highly introspective in nature, involving several techniques of directing one's attention towards inner experience. Subjective reports on introspection were measured by a survey requiring participants to observe and evaluate the intensity of their bodily experiences for twenty body regions during body-scan meditation. Introspective accuracy was then assessed by comparing this subjective report with objective measures of two-point discrimination threshold and mean size of body representation area in primary somatosensory cortex. Expert meditators displayed higher correlations of their introspective report with objective measures than novices (non-meditators), indicating higher introspective accuracy in meditators. Moreover, overall meditation experience predicted individual introspective accuracy, which means that long-term meditators provide more accurate introspective reports. In accordance with this finding, meditators revealed higher level of self-reported visceral awareness as compared to controls who either had dance training (which emphasize attention to somatic activity) or normal controls who had neither those kinds of training (Sze, et al., 2010). Furthermore meditators showed the highest level of emotion-related coherence between self-reported emotional experience and heart period (which is commonly reflected in emotion metaphors) during film-induced emotional episodes, followed by dancers with intermediate level of coherence while controls had the lowest coherence levels.

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In a recent fMRI study, neural activation of the posterior cingulate cortex (PCC, which is a brain region found to be activated during mind-wandering and deactivated during meditation, Brewer et al., 2011) was analyzed according to moment-to-moment subjective experience of focused attention on the breath (Garrison et al., 2013b). Expert meditators showed a significant correspondence between subjective reports of inner experience and real time neuro-feedback from the PCC, regardless of prior knowledge what the meaning of the feedback graph is. Using this fMRI neuro-feedback paradigm, first-person reports from expert meditators (neurophenomenology) provided refined aspects of conscious context, which are relevant to PCC activity (Garrison et al., 2013a).

Taken together, meditators have increased attentional control (Chan & Woollacott, 2007; Lutz et al., 2009; MacLean et al., 2010; Sahdra et al., 2011; Valentine & Sweet, 1999), and thus, report more accurately their body sensations (Fox, et al., 2012; Mirams, et al., 2013), mental experiences (Nielsen & Kaszniak, 2006), and show more coherence between physiological signals and emotional content (Sze, et al., 2010), as well as substantial correspondence between subjective experience and brain activity (Garrison et al., 2013a, 2013b). Therefore, an avenue to gain more reliable subjective reports regarding inner experience is to work with trained experts in meditation with a long history of meditative practice. It could be expected that an experienced meditator who trained in contemplative practices for many years can give more reliable first-person perspective accounts, since s/he would have developed enhanced capacities of keeping his or her attention stable on a certain experience; moreover, s/he will have a more refined awareness of sensing and differentiating internal processes (Brown & Ryan, 2003; Lutz, et al., 2007). Therefore, these findings strengthen the view that meditation experience enhances the capability of keeping one's attention consistently focused on a task that requires full attention, as this is the case in the Libet experiment.

### **1.5. Study Aims and Overview**

The feeling of being in control of voluntary movement is a crucial feature for the experience of free will. However, neuroscientists have proposed that some specific brain activity can predict our voluntary action even *before* we have any experience of an intention to act (Libet, et al., 1983a; Soon, et al., 2008). Instead, it is suggested that some specific brain function contributes to the *emergence* of a conscious intention to act (Fried, et al., 1991; Desmurget, et al., 2009). These findings seem hard to reconcile with the view that such an action is our 'own' voluntary action.

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The present thesis contains four empirical studies aiming to demonstrate the underlying mechanism of intentional processes and its correlations of brain dynamics. From Study 1 to Study 3 the nature of the RP is examined with different groups (meditators vs. controls) using different types of the Libet task. In Study 4, the sense of agency, which is a general sense of being in control of an intended movement, is examined with respect to intentional processes.

In Study 1, we assume that if the average RP reflects the spontaneous fluctuation of neural activity instead of movement preparation (Bennett & Hacker, 2003; Schurger et al., 2012), then the same components of the RP will be observed not only in a self-initiated movement condition, but also in a no-movement condition. To test this hypothesis, we split the slow cortical potential (SCP) into ongoing negative and ongoing positive shifts. Participants perform either a self-initiated movement (Libet et al., 1983a), or listen to a simple auditory stimulus occurring at random times for the no-movement condition.

The basic aim of Study 2 is to get a better understanding of the relationship between accounts of inner experience and brain dynamics that are recorded in parallel with respect to conscious decision-making. Here the idea is to identify inner experiences or inner strategies which can in some meaningful way relate to the EEG data recorded at the same time. Hence, we attempt to provide reliable and valid measures of the first-person perspective in conjunction with brain dynamics. Therefore, rather than using a third person quantitative approach, we decided to choose an  $N = 1$  design with an expert meditator. We develop an iterative neurophenomenological research protocol with the following steps: (i) performance of the Libet task, (ii) interview with the meditation expert on his inner experience, (iii) interpretation of the EEG results based on the first-person accounts, and (iv) modification of the Libet task, the analyses strategy and the response strategies. Then we start again with (i) performance of the now modified Libet task.

In Study 2, we show that an expert meditator displays reliable subjective reports on conscious intention, and thus shows several different correspondences between his subjective reports and the RP amplitudes (Jo, et al., 2014a). In support of this view, many studies have shown enhanced attentional control in experienced meditators, or after meditation practice for meditation-naïve individuals, during a specific task condition (Chan & Woollacott, 2007; Lutz et al., 2009; MacLean et al., 2010), and more accurate reports of their body sensations (Fox et al., 2012; Mirams et al., 2013). Taken together, these results suggest that experienced meditators might be better aware of their intentional processes. To address this issue, we perform a third study (Study 3) in which brain dynamics are recorded with EEG during the

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conditions, where participants either direct their attention towards their inner process of initiating a voluntary act or not. This study enable us to study elicited first-person access to an intention to act, and thus to examine subjective experience and its relation to the brain process contributing to the emergence of a conscious intention to act. The relationship between behavioral performances and neural dynamics of intention to act is investigated in both experienced meditators and non-meditators.

For Study 4, the sense of agency is tested with regards to the brain dynamic related to the emergence of conscious intention, as found in the previous studies. Perceived sense of agency is measured using the intentional binding paradigm (Haggard et al., 2002), which is calculating temporal binding effects between voluntary action and consequent outcome. The aim of Study 4 is to investigate (i) whether the early neural activity preceding the voluntary action has an effect on intentional binding and (ii) to explore its effect in experienced meditators by examining whether these brain correlates would be displayed differently with respect to behavioral performance. In order to do so, we record EEG activity, while participants engage in the intentional binding task, comparing a group of experienced meditators with matched non-meditating controls. Behavioral and electrophysiological data are analyzed on the basis of single trials.

## **2. METHODS**

### 2.1. The Libet Experiments

An analogue clock was presented on a computer screen (visual angle: 3 degrees in diameter) with a clock-hand rotating clockwise with a revolution period of 2,550 msec (see **Figure 1-3-1**). Subjects gazed the center of the clock, with their right index finger placed on the left button of a computer mouse. The clock-hand appeared after a short period (1-2 sec) and started rotating from a random position. They were instructed to spontaneously press the button with their index finger at a moment of their own choice when they felt the urge to move after the clock-hand had finished the first revolution. After a random interval of 1 to 2 sec following the button press, the clock-hand stopped and disappeared. Subjects were then asked to indicate the clock-hand position at the moment when they felt the urge to move (w-time). They were encouraged to minimize eye movement and blinking during the clock-hand rotation. Presentation of the clock and collection of the response data were performed by the E-Prime 2.0 software (Psychology Software Tools, USA).

### 2.2. Participants

Experienced mindfulness meditators volunteered for the present study. They had at least three years of continuous experience in regular mindfulness meditation practice and had continuous meditation practice for at least two hours per week during the last eight weeks. Matched controls in gender, age and education level, were recruited. Control subjects had never attended any course of meditation practice including Yoga, Tai-Chi and similar techniques. All participants had normal or corrected-to-normal vision and had no known psychological or neurological deficits. Participants were paid 10 € per hour for taking part in the experiment. The ethics committee of the University Medical Center Freiburg approved this study and written informed consent was obtained from all participants

### 2.3. Self-reported Measures

The Freiburg Mindfulness Inventory (FMI, Walach et al., 2006) was administered to assess the level of self-reported mindfulness. It has a two-dimensional structure with the factor “presence” referring to the ability to attend to the present moment and the factor “acceptance” referring to a non-judgmental attitude (Kohls et al., 2009). A 14-item short version has been developed which was used here.

Task difficulty and participants’ own confidence into their w-time report were measured after each task with a questionnaire ranging from 1 (very easy or very bad, respectively) to 5 (very

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hard or very good, respectively). The single-items were “How easy was it for you to synchronize the onset time of conscious intention with the clock-hand position?” for task difficulty, and “How confident are you in synchronizing the onset time of conscious intention with the clock-hand position?” for the confidence rating.

### **2.4. Electrophysiological Data**

Brain activity were was recorded from the scalp with a 64 channel DC-EEG recording amplifier using active electrodes (Brain Products, Germany) in an acoustically and electromagnetically attenuated chamber. Electrode impedance was kept under 5 K $\Omega$ . Four electrooculography (EOG) electrodes were placed to record both horizontal and vertical movements. To estimate the onset of finger movement, a single axis accelerometer (1.7g) was placed on the mouse button to measure the exact onset time of the button press. All electrophysiological data was recorded at a sampling rate of 1,000Hz.

Data analyses were performed with the help of EEGLAB (Delorme et al., 2004) in MatLab (MathWorks Inc.). After re-referencing the EEG data to the linked mastoids, it was band-pass filtered from 0.01 to 35 Hz (24 dB/octave zero-phase filter). On each trial, the recorded epoch was segmented from -2.5 s to 1 s towards the onset of the finger movement, the first burst of the accelerometer activity preceding a button press. The first 200 ms of each epoch were used for baseline correction. Ocular and movement artifacts were attenuated from each epoch based on independent component analysis (ICA) with EOG recordings. For the analysis of the RP, epochs from 9 electrodes around the contralateral hand region or around the vertex (Cz) were averaged (see the method for each study).

To estimate the effects of slow cortical fluctuations on the RP amplitude, the occurrences of all of the button presses were examined during infra-slow EEG fluctuations (ISFs; Vanhatalo et al., 2004), in which the time scale of this fluctuation corresponded to a range spanning from 0.01 to 0.2 Hz. Mastoids-referenced EEG from a block was both high-pass and low-pass filtered (0.01 – 0.2 Hz, 24 dB/octave zero-phase filter) to extract the ISF wave. Then the Hilbert transformation was applied to the average of 9 electrodes around Cz, ISFavg, in order to obtain the complex numbers,  $z$ . Following this, the ISF phase was obtained by  $\text{atan2}[\text{imag}(z), \text{ISFavg}]$ . The probability indicates the number of button presses in each uniform phase (four ISF phases), divided by the total number of button presses. The phase occurrences of button presses during the tasks were pooled together across subjects to estimate their relationships with the RP amplitude.

### **2.5. Cortical Source Reconstruction**

Source imaging analysis was performed using the software package Brainstorm 3.2 (Tadel et al., 2011), which is documented and freely available for download online under GNU general public license (<http://neuroimage.usc.edu/brainstorm/>). We used default cortical surface of a template MNI brain (colin27) distributed with Brainstorm, which has been fixed with 15,002 vertices and each vertex of the cortex is considered as a dipole. The forward head model was constructed by using a symmetric boundary element method from the open-source software (OpenMEEG; Kybic, et al., 2005; Gramfort et al., 2010), consisting of three layers (scalp, skull and brain). The noise covariance matrix was computed from the first 200 ms of the epoch. Cortical current sources were estimated for each participant by applying the minimum norm estimate (MNE) method implemented in Brainstorm. To examine which cortical areas are significantly different between two task conditions, the cortical source activation values were entered into paired t-test with the level of significance set at  $p < 0.05$  (Bonferroni-corrected for multiple comparisons). Clusters of at least 10 significant cortical vertices in the distributed sources model were considered.



## **3. EXPERIMENTAL STUDIES**

### 3.1. Study 1: Voluntary Movement and The Readiness Potential <sup>1</sup>

**Summary** It has been repeatedly shown that specific brain activity related to planning movement develops before the conscious intention to act. This empirical finding strongly challenges the notion of free will. Here, we demonstrate that in the Libet experiment, spontaneous fluctuations of the slow cortical potentials (SCPs) account for a significant fraction of the readiness potential (RP). The individual potential shifts preceding self-initiated movements were classified as showing a negative or positive shift. The negative and positive potential shifts were analyzed in a self-initiated movement condition and in a no-movement condition. Comparing the potential shifts between both conditions, we observed no differences in the early part of the potential. This reveals that the apparently negative RP emerges through an unequal ratio of negative and positive potential shifts. These results suggest that ongoing negative shifts of the SCPs facilitate self-initiated movement but are not related to processes underlying preparation or decision to act.

#### 3.1.1. Introduction

Following the discovery of the readiness potential (RP; Kornhuber & Deecke, 1965), a slow negative shift in EEG which can be seen by averaging several epochs, Libet's famous experiment (Libet et al., 1983) has incited hot debate concerning the question of free will (Haggard, 2008). In many different replications of this experiment it was shown that the RP precedes the subjective intentions to act (Haggard & Eimer, 1999; Sirigui et al., 2004; Miller et al., 2011; Rigoni et al., 2011; Schurger et al., 2012; Schlegel et al., 2013). This pre-conscious brain activity, starting approximately 2 sec before movement onset and well before the conscious intention to act (see **Figure. 3-1-1a**), is often interpreted as an indicator that freely voluntary act begin unconsciously (Libet et al., 1983; Shibasaki & Hallet 2006). That is, a 'decision' to move has already been initiated by the brain before any reportable conscious awareness.

However, since participants in Libet experiment were instructed to perform a movement whenever an urge to act appear, within the context of voluntary movement it is unclear whether self-initiated movements were purely 'voluntary' act or simple reaction to an internal stimulus (Bennett & Hacker, 2003; Kotchoubey, 2012). In the latter case, it might be argued

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<sup>1</sup> This study is based on the article: Jo, H. -G., Hinterberger, T., Wittmann, M., Borghardt, T. L., & Schmidt, S. (2013). Spontaneous EEG fluctuations determine the readiness potential: Is preconscious brain activation a preparation process to move? *Exp. Brain Res.* 231, 495-500.

that pre-conscious brain activity may reflect the general fluctuations of internal activity instead of decision process to move. A recent study aroused a controversial issue on the interpretation of the RP by employing a stochastic accumulator model for neural activity occurring before self-initiated movements (Schurger et al., 2012). The fluctuating time series average produced by their model was well fitted to the RP, which is time locked to movement onset and averaged over trials, suggesting that the shape of the climbing RP only appears to build up steadily, but may rather reflect spontaneous fluctuations of neural activity.

In this study, we thus assume that if the average RP reflects the spontaneous fluctuation of neural activity instead of movement preparation, then the same components of the RP would be observed not only in a self-initiated movement condition, but also in a no-movement condition. To test this hypothesis, we split the slow electro-cortical potential (SCP) into ongoing negative and ongoing positive shifts. Participants performed either a self-initiated movement (W-Task; Libet et al., 1983), or a simple auditory stimulus occurring at random times (T-Task) for the no-movement condition.

#### **3.1.2. Methods**

##### **Participants**

Thirteen normal adults (five females; mean age, 37.8 years; range, 22-54 years) carried out the Libet-type self-initiated movement and auditory stimulus tasks. The experiment was approved by the Department of Psychosomatic Medicine at the Albert-Ludwig University in Freiburg, and written informed consent was obtained.

##### **Apparatus and procedures**

Participants performed the Libet-type experiments for the movement condition, the so-called W-task (Libet et al., 1983). An analogue clock was presented on a computer screen (visual angle: 3 degrees in diameter) with a clock-hand rotating clockwise with a revolution period of 2,550 msec. Subjects gazed the center of the clock, with their right index finger placed on the left button of a computer mouse. The clock-hand appeared after a short period (1-2 sec) and started rotating from a random position. They were instructed to spontaneously press the button with their index finger at a moment of their own choice when they felt the urge to move after the clock-hand had finished the first revolution. After a random interval of 1 to 2 sec following the button press, the clock-hand stopped and disappeared. Subjects were then asked to indicate the clock-hand position at the moment when they felt the urge to move (w-

time). They were encouraged to minimize eye movement and blinking during the clock-hand rotation. Presentation of the clock and collection of the response data were performed by the E-Prime 2.0 software (Psychology Software Tools, USA). The control condition, a no-movement condition (T-task), followed. It was identical to the W-task except that subjects were asked to report the onset time of the tone (t-time) that occurred at a random time from 2.5 to 7.5 sec after the beginning of each trial. After a random interval of 1 to 2 sec following the tone, the clock-hand stopped and disappeared, and then subjects were asked to indicate the onset time of the tone. In this T-task, subjects were not asked to press the button spontaneously. Each task contained 40 trials in separate blocks and each trial was initiated by the participant when he or she felt ready. Between these two tasks, two or three other Libet-type tasks were performed for other purposes. Two subjects missed the T-task for technical reasons. Therefore, a comparison between tasks was done with eleven subjects.

#### **Electrophysiology recordings**

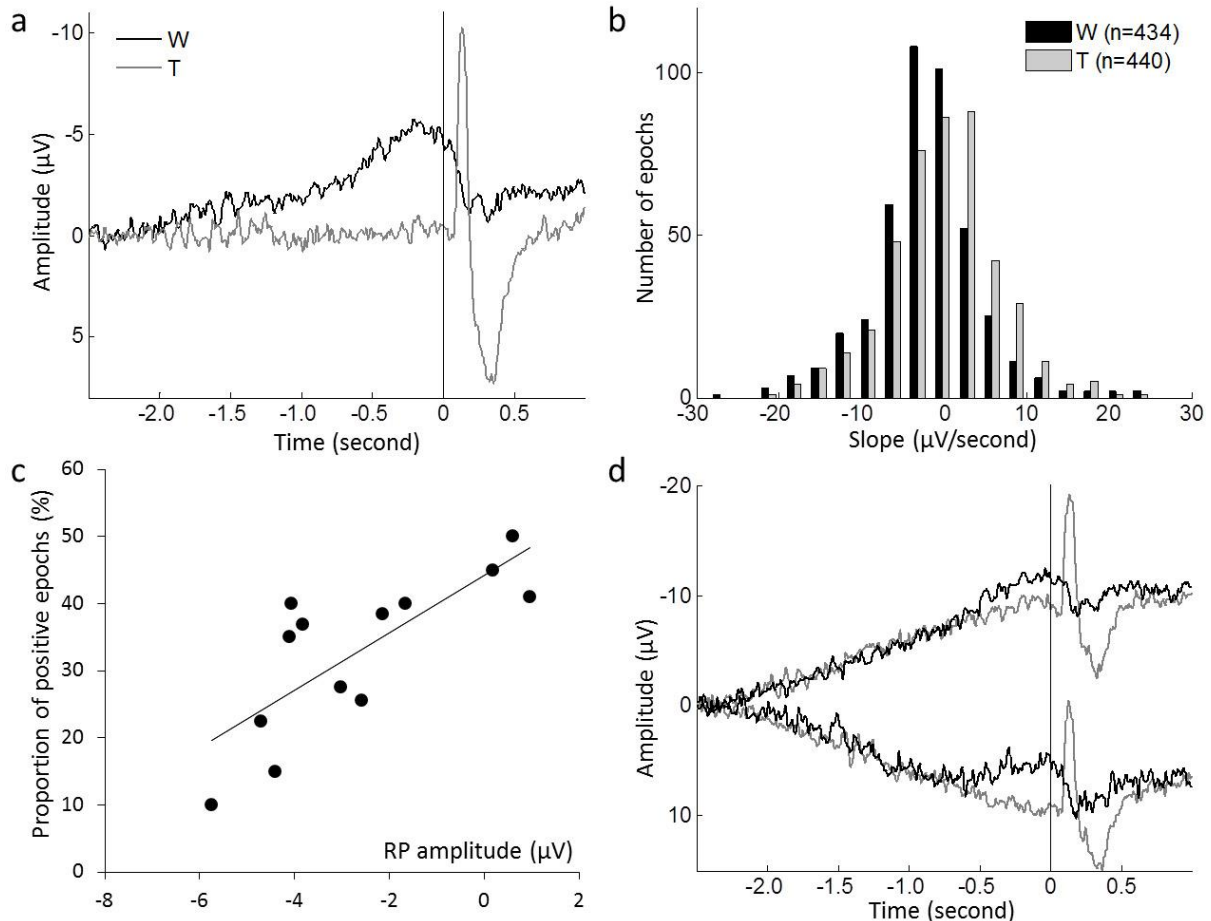
Brain activity were recorded from the scalp with a 64 channel DC-EEG recording amplifier using active electrodes (Brain Products, Germany) in an acoustically and electromagnetically attenuated chamber. Electrode impedance was kept under 5 K $\Omega$ . Four electrooculography (EOG) electrodes were placed to record both horizontal and vertical movements. To estimate the onset of finger movement, a single axis accelerometer (1.7g) was placed on the mouse button to measure the exact onset time of the button press. All electrophysiological data was recorded at a sampling rate of 1,000Hz.

#### **Data analysis**

Data analyses were performed with the help of EEGLAB (Delorme & Makeig, 2004) and ERPLAB (<http://erpinfo.org/erplab>). EEG data was re-referenced to linked mastoids before being bandpass filtered (high-pass 0.01Hz, low-pass 35Hz, 24 dB/octave). The data stream was then segmented into event-locked epochs ranging from 2.5 sec before the events (either the button press or the onset of the tone) to 1 sec afterwards. The first 200 msec of each epoch was used for baseline correction. Eye movement and muscle artifacts were reduced based on independent component analysis (ICA) and with EOG through visual inspection. In addition, on average, in 3.8% of the epochs the button press occurred during the first rotation, mostly by one subject, and these were excluded. The slope of each epoch was estimated by fitting a first order polynomial function to the averages of 9 electrodes around the vertex (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, and CP2) before the events. According to either negative or

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positive slope, each epoch was classified as either negative or positive epoch, respectively. Subsequently, both negative and positive epochs were averaged separately across 13 subjects for the W-task and 11 subjects for the T-task.



**Figure 3-1-1.** Grand average of 9 electrodes around the vertex and its single epochs. **(a)** Grand averages of the W-task (black trace,  $n=13$ ) and the T-task (gray trace,  $n=11$ ) are shown. The vertical thin line indicates the event times, either the button press or the tone. The subjective reports of mean w-time and t-time were  $-239$  ms and  $-67$  ms, respectively (two-tailed unpaired t-test,  $p=.036$ ). **(b)** The slopes of each single epochs pooled together from 11 subjects show normal distribution in both tasks (mean slope; W-task= $-2.1$ , T-task= $0.1$ ; two-tailed unpaired t-test,  $p<10^{-5}$ ). The slope was measured by a first order polynomial fit before the events. **(c)** According to the slope, each epoch was distinguished either as negative or positive epoch. The overall RP amplitude showed a linear relationship with the proportion of positive epochs across 13 subjects ( $r=.77$ ,  $p=.002$ ). The mean RP amplitude was measured from  $-1.0$  to  $-0.5$  sec before the button press. **(d)** Grand average of negative and positive epochs at the C3 electrode across 11 subjects. No difference was found in subjective reports between negative and positive epochs (w-time,  $p=.533$ ; t-time,  $p=.458$ ).

For statistical analysis, the averaged negative and positive shifts were segmented into 25 non-overlapping 100 msec-bins. All statistical comparisons for matched pairs were performed with paired two-tailed t-tests; if unpaired, an unpaired two-tailed t-test was performed, unless otherwise stated.

#### 3.1.3. Results

The SCP epochs preceding either the movement or the tone by 2,500 msec were classified as showing a negative or positive shift. In order to distinguish these shifts, a first order polynomial fit was applied to the average of 9 electrodes around the vertex. If the slope of the fitted function of a single-trial epoch was negative, it was classified as negative epoch: otherwise as positive epoch. The ratio between negative and positive epochs revealed that for the W-task, the proportion of positive epochs was smaller in comparison to the T-task (grand mean of percentage, W=32.84 %, T=50.45 %; n=11, p=.002). The pooled epochs across 11 subjects are shown in **Figure 3-1-1b**. Next we assessed how the proportion of positive epochs correlated with overall amplitude of the RP in the W-task across 13 participants (**Figure 3-1-1c**). This significant correlation of  $r=.77$  (Pearson correlation, p=.002) demonstrates that smaller proportions of positive epochs are related to larger negative RP amplitudes (VaezMousavi and Barry, 1993; additional supporting information in 3.5.1. Supplementary Material).

To examine the differences in negative and positive potential shifts preceding the events in both conditions (movement onset and tone presentation, respectively), we took data solely from the C3 electrode over the contralateral central area of the right hand, where the RP is maximal. In order to compare the specific shape of either positive or negative epochs we inverted the positive epochs by multiplying a negative sign (**Figure 3-1-2a, b**). As can be seen in the **Figure 3-1-2a**, the significant difference between the average of negative epochs (tick trace) and of positive epochs (thin trace) in the W-tasks occurs around 500 msec before the button press, while the early part shows no difference. This boundary is consistent with the onset time of the late RP reported in the literature (Shibasaki & Hallet 2006). Since the RP amplitude is influenced by the proportion of positive epochs and the two polar shifts show the same slope until around 500 msec before the button press, the assumption that the early part of the RP appears to be an averaging artifact reflecting the ratio of negative and positive epochs rather than a sign for a decision or a preparation process to move can be made. In addition, in the T-task, in which no decision had to be made, the shape of negative and positive shifts shows no difference until the onset of the tone (**Figure 3-1-2b**). Here, since

negative (49.55%) and positive (50.45%) epochs are equally distributed, a lack of any averaged potential shift before the tone results (**Figure 3-1-1a**).

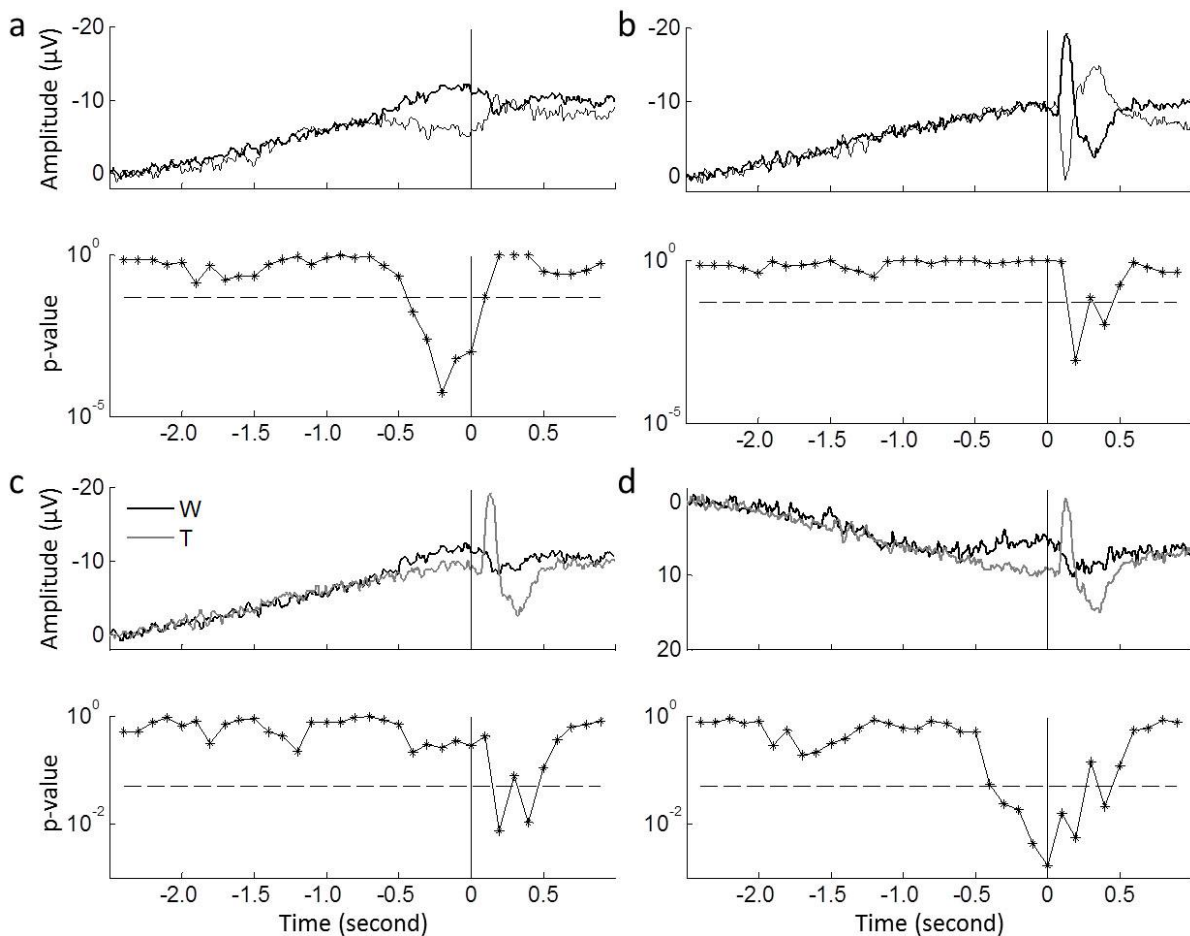
To test the implication of our results, i.e. that the early RP may not be related to preparatory processes to move, we compared the two different polar shifts between movement (W-task) and no-movement (T-task) conditions. The difference between tasks in both negative and positive shifts was observed in the late part from around 500 ms before the events, but not in the early part (**Figure 3-1-1d**). We performed a two-factor repeated measure ANOVA for both positive and negative shifts, separately. The *task* (W and T) and *time* (23 100 msec-bins from -2.3 sec to the events) were used as factors and the amplitude as the dependent variable. Analyses revealed a significant main effect of *time* in both negative ( $F_{1,42,14,22}=31.29$ ,  $p<10^{-4}$ ) and positive ( $F_{1,58,15,79}=21.92$ ,  $p<10^{-4}$ ) shifts. These results reflect the slow ongoing negative or positive shifts, respectively. In negative shifts, no significant effect was observed in the *task*  $\times$  *time* interaction ( $F_{1,99,19,90}=1.39$ ,  $p=.27$ ), while a significant effect of the *task*  $\times$  *time* interaction ( $F_{3,21, 32,07}=3.54$ ,  $p=.023$ ) was found in positive shift trials. To determine the precise time at which potential shifts in the two tasks started to differ, we performed paired t-tests on the averaged epochs in 100 msec-bins. It can be seen that the positive shift in the W-task turns into the negative direction at around 500 msec before the button press (see the black trace in **Figure 3-1-2d**). However, no difference was observed in negative shifts, though the W-task on average showed a slightly more negative amplitude as compared to the T-task in the late part (see the black trace in **Figure 3-1-2c**). This stronger negative deviation during positive shifts was clearly observed when the ongoing shifts are detrended (see **Figure 3-1-3a**). The slope from -600 ms to the button press was steeper for positive shifts as compared to negative shifts (-7.53 uV/s and -1.74 uV/s, respectively;  $p=.001$ ; see **Figure 3-1-3b**).

#### 3.1.4. Discussion and conclusion

The present study demonstrated how an apparently negative RP emerges through an unequal ratio of negative and positive potential shifts preceding self-initiated movement. We investigated ongoing potential shifts prior to the events of movement onset and the tone presentation in both W-task and T-task, respectively. The ongoing potential shifts were compared within task and between tasks. In the W-task, we observed no difference of shape between the ongoing negative and positive potential shifts until around -500 ms before the button press. In addition, these two potential shifts showed the same pattern as in the T-task, in which participants were asked to refrain from a movement (see **Figure 3-1-1d**). However, we observed difference ratios of negative and positive shifts between the W-task and T-task,

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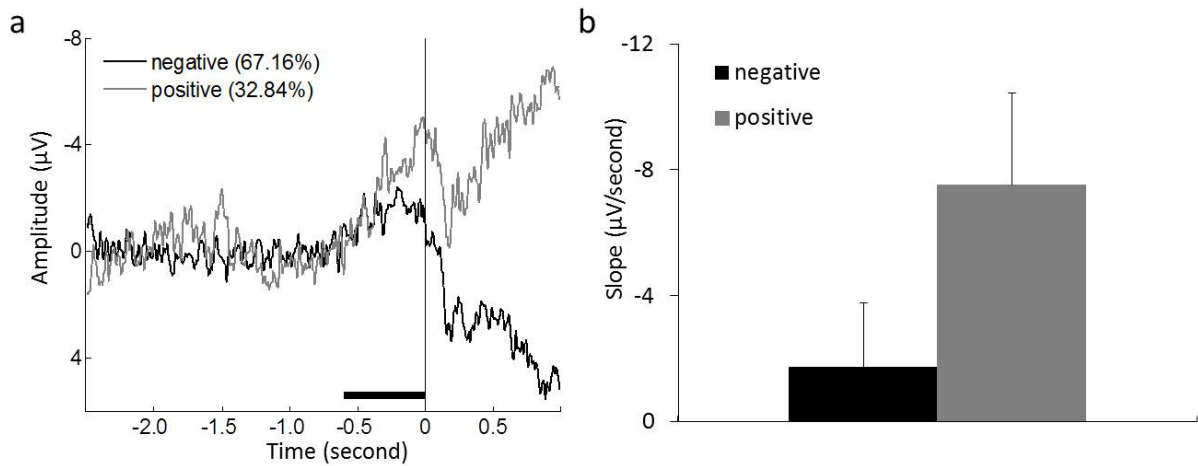
which results in different shapes of event-related potentials (ERP; see **Figure 3-1-1a**). Given these results, it is clear that the unequal ratio of ongoing potential shifts of SCPs has a significant effect on the RP amplitude. Moreover, it is in agreement with recent reports that spontaneous SCP fluctuations appear to have an essential impact on promoting a decision on self-initiated movements, with negative shifts making them more likely (Schurger et al., 2012).



**Figure 3-1-2.** (a, b) Comparisons between ongoing negative and positive (inverted) shifts. The grand averages of potential shifts at the C3 electrode within 11 subjects are time-locked to the button press (W-task; black traces in **a**) or to the onset of the tone (T-task; gray traces in **b**). The polarity of ongoing positive shifts (thin line) was switched for the comparison with negative shifts (tick line). (c, d) Comparisons between movement (W) and no-movement (T) tasks. Ongoing potential shifts were compared between the W- and the T-task for both negative (c) and positive shifts (d). The grand averages of potential shifts at the C3 electrode were time-locked to the button press for the W-task (black trace) and to the onset of the tone for the T-task (gray trace). Lower panels below the ERPs show the p-value in 100 ms-bins. The dashed horizontal line indicates  $p=0.05$  (two-tailed paired t-test). Note that the p-value is in logarithmic scale.



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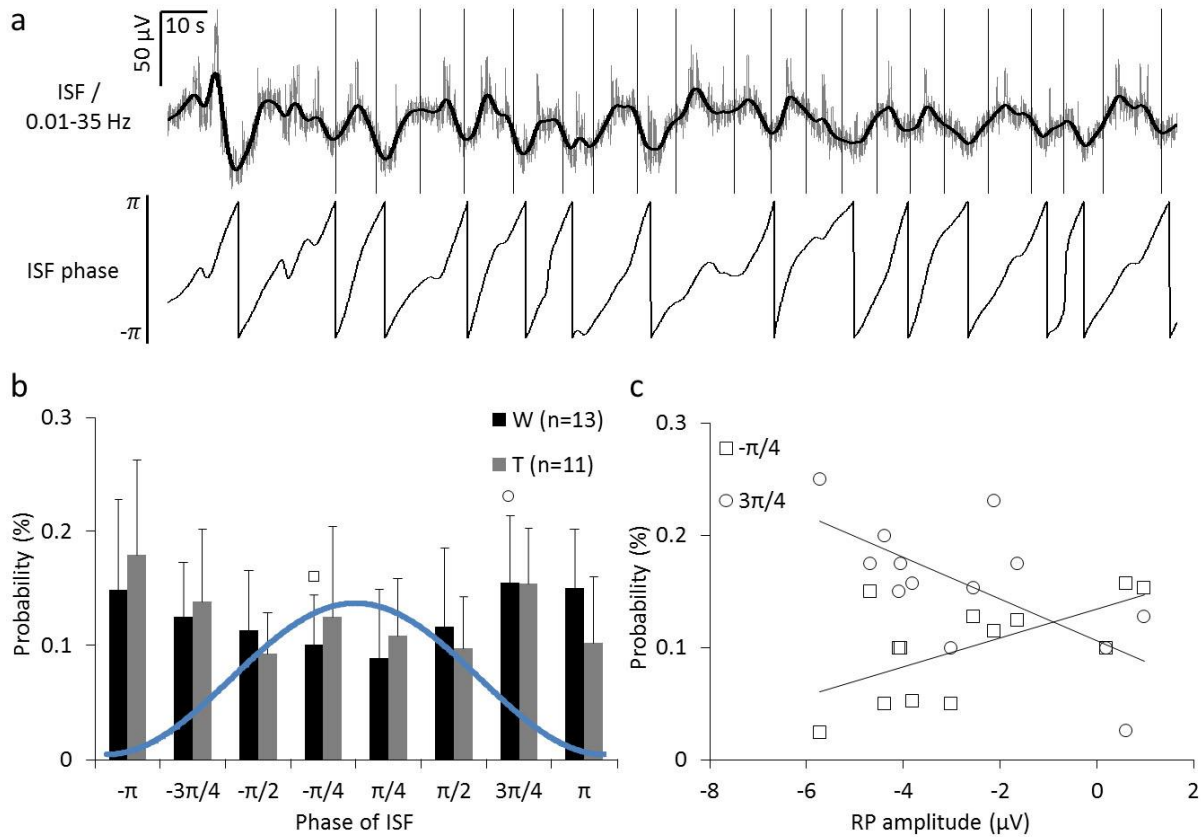
**Figure 3-1-3.** Detrended negative and positive shifts of the W-task. **(a)** Grand average of detrended negative and positive shifts at the C3 electrode are shown. A first order polynomial fit was applied from -2.5 to -0.5 sec before the button press to estimate the trends of negative and positive shifts across 13 participants. These trends were subtracted from each other over the range of the whole epoch. The percentages in parenthesis indicate the proportion of the grand mean. **(b)** A steeper slope was observed in positive shifts as compared to negative shifts during the interval indicated by the horizontal black bar in **a**, from -600 ms to the button press (grand mean of the slope; negative shifts = -1.74 uV/sec, positive shifts = -7.53 uV/sec; n=13, two-tailed paired t-test, p=.001). The error bars represent the standard error of the mean.

The difference of positive and negative slopes in the ongoing potential shifts as seen in the late RP in the W-task may suggest different underlying neuronal processes (see **Figure 3-1-3**). One interpretation is that ongoing negative shifts are related to less effort in starting a movement as compared to positive shifts. According to the theory behind SCP shifts, a negative electrical potential shift on the scalp is associated with an increase of negative charges in the apical dendrites of the cortical pyramidal neurons, which leads to a lowering of the excitatory threshold and, thereby, an increased probability of movement execution (Mitzdorf, 1985; Birbaumer et al., 1990; McCallum & Curry, 1993). If such a lowering of the threshold is experienced as an urge to move in the Libet task, a self-initiated decision can be interpreted as an agreement with an inner activity, which is reflected in the negative SCP shift. That is, the negative deflections of SCPs facilitate a movement in the near future, but they are not a neural sign of decision processes to move.

Taken together present results in Libet experiment suggest that the negative potential shift before a movement does not reflect a ‘causal’ factor of voluntary act, in agreement with recent studies (e.g., Herrmann et al., 2008; Trevena & Miller, 2010; Miller et al., 2011; Schlegel et al., 2013). In contrast, negative deflections of SCPs have a higher probability of button press occurrences, since it may favor a feeling of the intention to act than positive

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deflections (Schurger et al., 2012). Participants might just let the intention to act cause their finger to press the button.



**Figure 3-1-4.** The phase occurrences during infra-slow EEG fluctuation (ISF, 0.01-0.2Hz) and its relationships to the RP amplitude. **(a)** An example of the ISF wave during the W-task (upper black trace), as well as with bandpass filtered EEG at 0.01–35Hz (upper gray trace) and the phase of ISF (lower panel) are shown. The vertical lines overlaid on the upper panel indicate the latencies of the button press. These latencies represent the phase occurrences in the ISF phase. **(b)** In the histogram, the probabilities of button presses during the W-task (n=13, black bar) and of the tone during the T-task (n=11, gray bar) are plotted against the ISF phase. The error bars represent the standard deviation of the mean. A schematic ISF wave (blue trace) was superimposed in the graph. **(c)** The RP amplitude during the W-task was significantly correlated with the probability of button presses during the ISF phase at  $-\pi/4$  (the rising phase;  $r=.63$ ,  $p=.022$ ) and  $3\pi/4$  (the falling phase;  $r=-.68$ ,  $p=.011$ ) as in **b**. These relationships demonstrated that the higher probability of button presses during the falling phase (ongoing negative shift) represents an increase in the overall RP amplitude, while the higher probability of button presses during the raising phase (ongoing positive shift) represents the reduction of the RP amplitude. The mean RP amplitude was measured from -1.0 to -0.5s before the button press. No correlation was found for T-task.

In this study, our results suggest that individual negative and positive shifts of SCPs have different effects on self-initiated movement, suggesting that negative shifts make a movement more likely. This indicates that at least the early part of the RP, which is often interpreted as the time when neural processes prepare for an action, is not a neural correlate of preconscious motor preparation but may reflect spontaneous neural activity during the task.

#### **3.1.5. Supplementary material**

The occurrences of the button press were examined during infra-slow EEG fluctuations (ISFs; Vanhatalo et al., 2004), in which the time scale of this fluctuation corresponds from 0.01 to 0.2Hz. Mastoids-referenced continuous EEG recorded from a block (either a whole W-task or T-task) was both high-pass and low-pass filtered (0.01–0.2Hz, 24dB/octave) to extract the ISF wave. Then the Hilbert transformation was applied to the average of 9 electrodes around the vertex (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, and CP2), ISFavg, in order to obtain the complex numbers,  $z$ . Then the ISO phase was obtained so that  $\text{atan2}[\text{imag}(z), \text{ISFavg}]$ , see **Figure 3-1-4a**. As can be seen in the graph, the negative ISO phase indicates ongoing positive shifts of the ISF wave and the positive phase represents the ongoing negative shifts of the ISF wave. The probability indicates the number of event occurrences in each uniform phase (8 bins from  $-\pi$  to  $\pi$ ), divided by the total number of event occurrences.

## 3.2. Study 2: First-Person Approaches in Neuroscience of Consciousness <sup>2</sup>

**Summary** The belief in free will has been frequently challenged since Benjamin Libet published his famous experiment in 1983. Although Libet's experiment is highly dependent upon subjective reports, no study has been conducted that focused on a first-person or introspective perspective of the task. We took a neurophenomenological approach in an N = 1 study providing reliable and valid measures of the first-person perspective in conjunction with brain dynamics. We found that a larger readiness potential (RP) is attributable to more frequent occurrences of self-initiated movements during negative deflections of the slow cortical potentials (SCP). These negative deflections occur in parallel with an inner impulse reported by an expert meditator, which may in turn lead to a voluntary act. We demonstrate in this proof-of-principle approach that the first-person perspective obtained by an expert meditator in conjunction with neural signal analysis can contribute to our understanding of the neural underpinnings of voluntary acts.

### 3.2.1. Introduction

The basic aim of the present study is to get a better understanding of the relationship between accounts of inner experience and the parallel recorded brain dynamics with respect to conscious decision-making. Here the idea is to identify inner experiences or inner strategies which can in some meaningful way relate to the EEG data recorded at the same time. Hence, we attempt to provide reliable and valid measure of the first-person perspective in conjunction with brain dynamics. It is important to note, that we do not attempt to show potential modulating effects of contemplative practice on performance in this task.

Rather than using a third person quantitative approach, we decided to choose an N=1 design with an expert meditator. We developed an iterative neurophenomenological research protocol with the following steps: (i) performance of the Libet task, (ii) interview on the inner experience, (iii) interpretation of the EEG results based on the first-person accounts, and (iv) modification of the Libet task, the analyses strategy and the response strategies. Then we started again with (i) performance of the now modified Libet task.

Here we will report on three sessions. In session one, we replicated the original Libet task in order to explore the reliability of subjective timing and its relation to the neural activity

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<sup>2</sup> This study is based on the article: Jo, H. -G., Wittmann, M., Borghardt, T. L., Hinterberger, T., & Schmidt, S. (2014). First-person approaches in neuroscience of consciousness: Brain dynamics correlate with the intention to act. *Conscious. Cogn.* 26, 105-116.

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recorded on the scalp with EEG. Furthermore, we compared the performance of the expert meditator with matched controls regarding subjective timing of events and the neural dynamics during the tasks. In session two, to investigate the subjective experience of the intention to act, neural signal analysis was combined with the first-person perspective, which was obtained from a new experimental paradigm. In session three the same Libet task was conducted under different psychological conditions to further validate the correlation of the first-person perspective with neural signals. For all sessions, a single-trial based analysis technique of the Libet paradigm was performed to estimate whether perceiving an intention is correlated with neural dynamics measured on the scalp.

Regarding the epistemological status of our research strategy we state clearly that this neurophenomenological N=1 approach is restricted to selection of persons who have acquired these meditative skills. In this sense this is a proof-of-principle study. In our experiments we have the chance to obtain detailed insights into the process of voluntary acting provided by a highly skilled expert which are very difficult to acquire elsewhere. It is important to note that the Libet task is demanding regarding attention skills, i.e. it is difficult for a normal participant to keep attention focused on the task and also to note at the same time the position of the clock hand, as well as to remember its position and to report it later. Therefore, we decided to probe the task on an experienced meditator with decades of meditation practice. Our intention is to use these insights to create fruitful *hypotheses* regarding the relationship of first and third person data. Whether these hypotheses generalize beyond our expert meditator has to be proved in separate studies on representative samples as have been shown by recent studies (Jo et al., 2013; Vinding et al., 2014). However, this innovative approach may result in unique insights and new hypotheses which are not mere speculations but already have an empirical foundation by a careful alignment to the respective EEG recordings.

#### **3.2.2. Methods**

##### **Participants**

We invited a male expert meditator, who is a former MD and Lama from a Tibetan Buddhist tradition, and who has been meditating for 35 years and has lived 17 years as a teacher in a retreat center (TL; 54 years old; for many years up to 12 hours meditation per day / at the present time roughly two hours per day). Five matched controls of the same gender, age and education level were recruited through advertisements in the University Medical Center of Freiburg (S1, MD, 50 years old; S2, 51 years old; S3, 49 years old; S4, 50 years old; S5, 53

years old). All participants were required to be free of any neurological or psychiatric disorders, and to sign a consent form approved by the Department of Psychosomatic Medicine, University Medical Center Freiburg, Germany.

#### **Libet-type tasks and procedures**

The experiment was based on the method introduced by Libet et al. (1983a). In session one, all participants conducted an *M-task* and a *W-task* in a separate block. In the *W-task*, a small analogue clock with a clock-hand revolving with a period of 2550 ms duration was presented on a monitor screen (visual angle: 3°). When they were ready to start each trial, participants pressed the mouse button and the clock appeared. After a random period between 1 s and 2 s, a clock-hand appeared and started rotating. During the clock-hand rotation, subjects were instructed to focus on the center of the clock and to refrain from eye blinking. If they nevertheless had to blink, they were asked to wait for one more rotation. Participants were asked to press the left mouse button with their right index finger whenever they felt the urge to do so. This was to be done spontaneously after the first rotation of the clock hand; pre-planning of the movement was to be avoided. If participants pressed the button, the clock-hand continued rotating for a random period between 1 s and 2 s and then disappeared. Subsequently, participants were asked to report the time when they first felt the intention to move (w-time) on the clock circle using the mouse. The task contained 40 trials. The *M-task* was identical to the *W-task* except that participants were asked to report the first moment when they started to move their finger (m-time). Before the task started, we gave the participants as much time as they needed for practice in order to become accustomed to the tasks. The reported times of each participant were treated as outliers if they were larger than  $q_3 + 1.5(q_3 - q_1)$  or smaller than  $q_1 - 1.5(q_3 - q_1)$ , where  $q_1$  and  $q_3$  are the 25<sup>th</sup> and 75<sup>th</sup> percentiles, respectively. All the values are shown in mean  $\pm$  standard deviation including outliers. Presentation of the clock and collection of reported times were performed by the E-prime 2.0 software (Psychology Software Tools, USA).

In session two, TL was invited again and he performed at first the *W-task* and then the  *Holding-task* in different blocks. The  *Holding-task* was identical to the *W-task* except that TL was asked to hold his intention for as long as possible after sensing it, and not to press the button immediately but only when he was no longer able to hold the intention. For the timing he was asked to report the very last moment of intention that 'pushed him' to press the button.

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In session three, we invited TL once again and conducted first a *less-effort-task* and second a *strong-effort-task* in subsequent blocks. Both tasks were identical to the *W-task* in session one except that TL was asked either to make a ‘decision’ of pressing the button without any effort (*less-effort-task*) or to make the decision with a strong effort (*strong-effort-task*). In other words, we asked TL to be more passive and composed when making a decision in the less-effort condition. Here TL was trying to follow upcoming inner impulses and to transform them effortlessly to the initiation of button presses (see also below). In contrast, in the strong-effort condition, TL was trying to actively initiate a decision to press the button in the absence of any upcoming impulses. After a random period of clock-hand rotation following the button press, TL reported the time when he first decided to move, and then, he also reported how weak or strong the effort was on an effort scale. This effort scale was presented on the screen after each trial and results were recorded using a mouse pointing on a horizontal gradient bar (from none to very strong effort which has 400 pixels resolution). This session focused on the effort of making a decision rather than the decision time itself. Thus, TL was asked to concentrate on the effort.

#### **Electrophysiology recording**

EEG data were collected with a 64 channel EEG amplifier using active electrodes (Brain Products, Germany) shielded in an acoustically and electromagnetically attenuated chamber of the neurophysiologic laboratory of the University Medical Center of Freiburg. Electrode impedances were kept below 5 K $\Omega$ . Four bipolar electrodes at the lateral canthus in the bilateral eyes, and above and below the left eye were attached for eye movement recordings. To detect the precise time of finger movement, a high precision and single axis accelerometer (1.7 G) was placed on the left mouse button. All the data were sampled at 1000 Hz.

#### **Data analysis**

Data analyses were performed with the help of EEGLAB (Delorme et al., 2004) in MatLab (MathWorks Inc.). After re-referencing the EEG data to the linked mastoids, it was band-pass filtered from 0.01 to 35 Hz (24 dB/octave zero-phase filter). On each trial, the recorded epoch was segmented from -2.5 s to 1 s towards the onset of the finger movement, the first burst of the accelerometer activity preceding a button press. For the  *Holding-task* in session two, the epoch length was extended from -5 s to 1 s. The first 200 ms of each epoch were used for baseline correction. Ocular and movement artifacts were attenuated from each epoch based on independent component analysis (ICA) with EOG recordings. One subject (S2) showed large

eye-blink and movement artifacts, and was therefore discarded from the EEG analysis. For the analysis of the RP, epochs from 9 electrodes around the contralateral hand region (FC<sub>3</sub>, FC<sub>1</sub>, FCz, C<sub>3</sub>, C<sub>1</sub>, Cz, CP<sub>3</sub>, CP<sub>1</sub>, and CPz for the right hand) were averaged.

To estimate the effects of slow cortical fluctuations on the RP amplitude, the occurrences of all of the button presses were examined during infra-slow EEG fluctuations (ISFs; Vanhatalo et al., 2004; see **Figure 3-2-3A**), in which the time scale of this fluctuation corresponded to a range spanning from 0.01 to 0.2 Hz. Mastoids-referenced EEG from a block (either an entire *M-task* or *W-task*) was both high-pass and low-pass filtered (0.01 – 0.2 Hz, 24 dB/octave zero-phase filter) to extract the ISF wave. Then the Hilbert transformation was applied to the average of 9 electrodes around Cz, ISF<sub>avg</sub>, in order to obtain the complex numbers,  $z$ . Following this, the ISF phase was obtained by  $\text{atan2}[\text{imag}(z), \text{ISF}_{\text{avg}}]$ , see **Figure 3-2-3B**. The probability indicates the number of button presses in each uniform phase (four ISF phases), divided by the total number of button presses. The phase occurrences of button presses during both *M-task* and *W-task* were pooled together across subjects to estimate their relationships with the RP amplitude.

#### **Post-task questionnaire**

Structured data on subjective experiences while conducting session one was collected by the use of a post-task questionnaire after the tasks. The two-item questionnaire was scored regarding the subjective difficulty with a range from 1 (very easy) to 5 (very hard). The single items were “How easy was it for you to synchronize the onset time of conscious intention with the clock-hand position?” for the *W-task*, and “How easy was it for you to synchronize the onset time of movement execution with clock-hand position?” for the *M-task*.

#### **Recording interviews**

During the sessions with TL we asked at several stages for his subjective report of what he perceived and experienced when conducting the tasks. All his statements were in English. They were recorded on audio and were later transcribed. Reports were recorded at two different stages. (i) During training trials: each of the tasks reported here required some training trials, both to explain the task and for the participant to get acquainted with them in order to give a steady performance. (ii) Directly after each experimental task: at the end of each task the experimenter entered the chamber and TL was prompted to report his experience. Discussion with TL on the Libet experiment is provided in 3.2.5. Appendix A.



### 3.2.3. Results

#### Session one

In our first session, we “revisited” the Libet task with the expert meditator. We explored the reliability of his subjective reports on perceived time, by comparing his reports with that of five matched controls. Electroencephalography recordings were examined regarding neural dynamic correlates with subjective reports, and compared to the correlations in matched controls.

On average, 3.25% of epochs from five controls were excluded because of false trials, where the button press occurred during the first rotation of the clock-hand. In addition, 3.94% of epochs were considered as outliers of *w*-time and *m*-time. In contrast, TL performed the experiment without any false trials, i.e. neither pressed the button during the first rotation nor had outliers in subjective reports.

**Table 3-2-1.** Subjective reports of perceived time (*m*-time, *w*-time) and task difficulty across participants.

	m-time			w-time		
	Mean (ms)	SD (ms)	Task Difficulty	Mean (ms)	SD (ms)	Task Difficulty
S5	-47.4	377.2	2	10.9	111.6	2
S4	13.35	99.6	1	17.7	95.1	2
S3	116.7	215.7	2	37.2	364.6	3
S2	-340.5	294.3	2	-398.8	364.4	4
S1	15.7	102.1	1	-331.3	139.1	4
TL	-59.5	61.6	1	-230.0	79.1	3

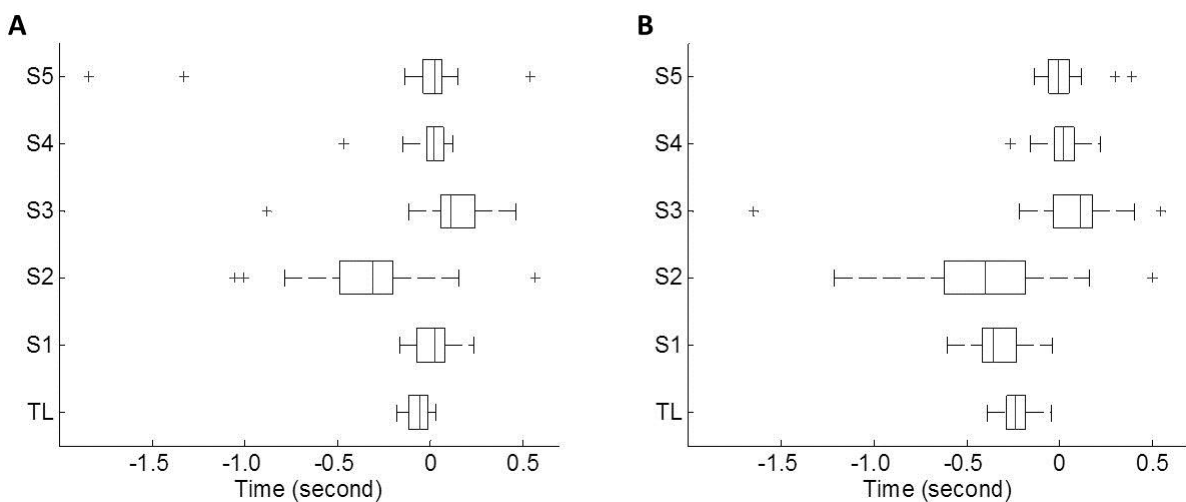
The post-task questionnaire scores of task difficulty are ranged from 1 (very easy) to 5 (very hard).

According to the post-task questionnaire, five of the six participants including TL (but not S5) rated the *W*-task (reporting the decision time) to be more difficult than the *M*-task (reporting the movement time) (**Table 3-2-1**). This is consistent with a previous report that paying attention to one’s intention is more difficult than paying attention to one’s motor response (Lau et al., 2004). The higher variability (standard deviation, SD) of *w*-time reports as compared to *m*-time also reflects the task difficulty. Additionally, the existence of outliers in four of five controls, from S2 to S5, seems to represent the difficulty of consistently focusing one’s attention in order to report the exact time of the experience (**Figure 3-2-1A, B**). Three control participants reported on average that *w*-time occurred after the actual button press.

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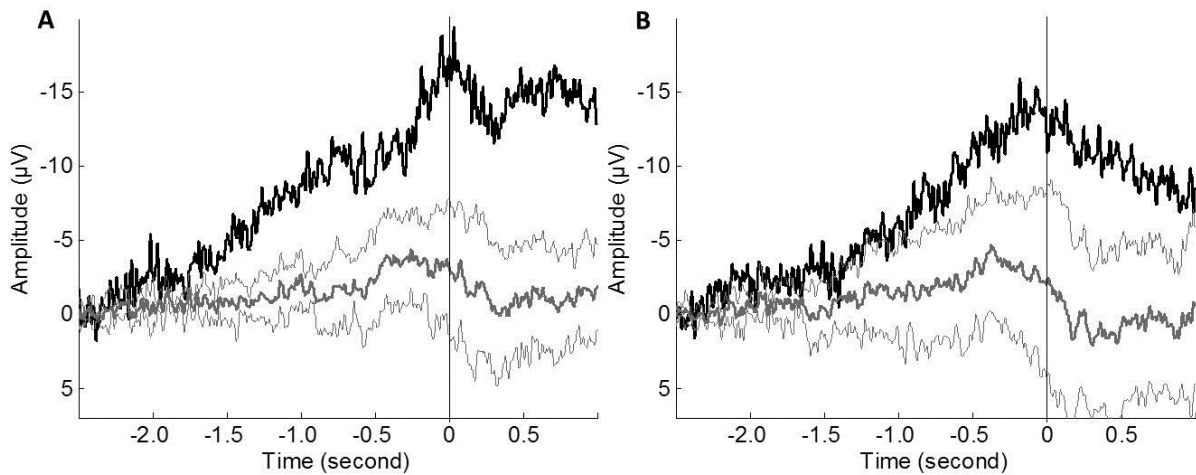
This subjective time report is not unusual and it seems to be related to the difficulties in determining the decision time to move (Miller et al., 2011). Taking together all subjective reports of w-time and m-time from both tasks, TL showed the lowest variation in reporting subjective time.

The mean of m-time and w-time reported by TL were -60 ms and -230 ms, respectively. This is within the range of the five controls (m-time,  $-48 \text{ ms} \pm 174$ ; w-time,  $-133 \text{ ms} \pm 214$ ; see **Table 3-2-1**) and is also consistent with previous reports (Libet et al., 1983a). We found no prominent difference in mean waiting-time (the time from the start of a trial to the button press; 5.9 s for *M-task* and 6.4 s for *W-task* in TL) as compared to controls in both tasks ( $7.6 \text{ s} \pm 4.4$  for *M-task* and  $6.9 \text{ s} \pm 2.9$  for *W-task*). In contrast, we observed prominent RP amplitudes for TL. **Figure 3-2-2** shows the grand average of RP in both the *M-task* and the *W-task*. We quantified the RP amplitude by estimating the mean value from -500 ms to -100 ms before the button press. TL showed the highest negative amplitude being approx. 3.5 times higher as compared to that of the controls in both the *M-task* (TL,  $-12.20 \text{ } \mu\text{V}$ ; controls,  $-3.45 \text{ } \mu\text{V} \pm 2.98$ ) and the *W-task* (TL,  $-12.45 \text{ } \mu\text{V}$ ; controls,  $-3.35 \text{ } \mu\text{V} \pm 4.40$ ). These amplitudes are also in the higher range as compared with the previous literature (Libet et al., 1983a; Haggard & Eimer, 1999; Trevena & Miller, 2002; Sirigu et al., 2004; Rigoni et al., 2011; Schurger et al., 2012; Jo et al., 2013; Vinding et al., 2014).



**Figure 3-2-1.** Boxplots of subjective reports for the *M-task* (A) and *W-task* (B). The outliers of each subject are marked by a cross.

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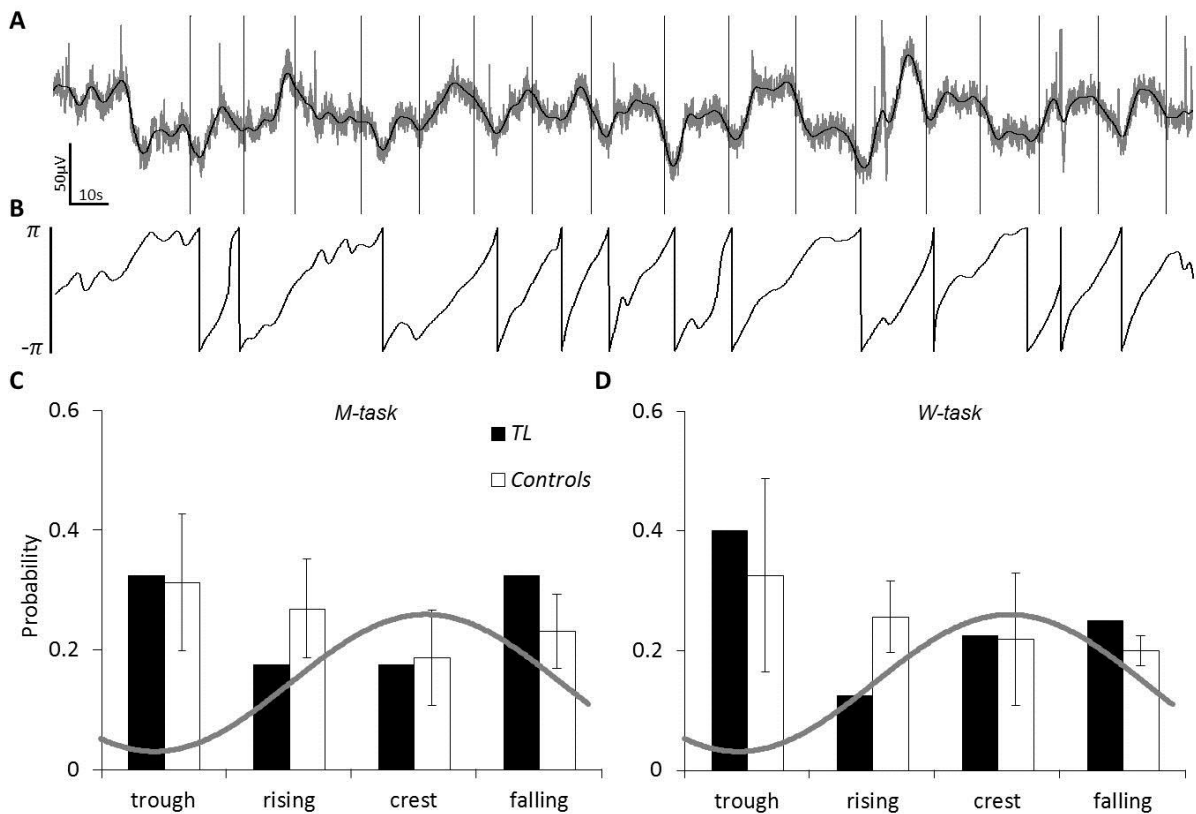
**Figure 3-2-2.** Readiness potential (RP) for the *M-task* (A) and *W-task* (B). Black traces correspond to the mediator and gray traces to the controls (thin gray lines represent standard deviation of the grand mean). The vertical line indicates the time of the button press. Note that the polarity of the RP amplitude is inverted.

To understand in depth the subjective experience before and during the intention to perform the self-initiated movement, interview records were obtained from TL after each Libet-type task (see appendix A for more details). In the follow-up interview TL described the moment of occurrence of his intention to act during the *W-task* as follows: “*I feel this process of clicking the mouse is actually experienced by myself as giving full permission to the organism to follow that first inner impulse that is perceived.*” Given this report, it seems that TL pressed the button in agreement with his inner impulse that led him to push the button. Accordingly, TL stated: “*This is not a task for free will. Rather a test for unconscious impulses. (...) If you did not allow these impulses to happen, then you looked for the next one of this kind and there will always be one (...) I’m not deciding to have the inner impulses, because the whole frame of the experiment is to have these impulses.*” These initial descriptions suggest that a spontaneous and unspecified inner activity, which he terms *inner impulse*, during the task, may be the basis for his subsequent button press.

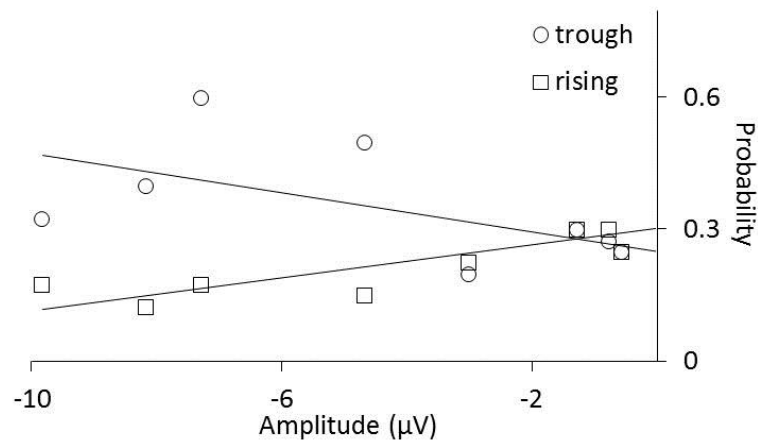
To further investigate whether his personal accounts paralleled fluctuations of the cortical potentials, ISF was extracted to estimate the SCPs during the tasks and to test its relationship to the RP amplitude. In the *M-task*, TL showed a lower probability of button presses during positive deflections (the rising and the crest phases) as compared to negative deflections (65% during the trough and the falling phases; see black bars in **Figure 3-2-3C**). In the *W-task*, the same pattern was observed (65% during negative deflections; see **Figure 3-2-3D**) and showed that TL had a prominent lower probability of button presses during the rising phase (positive deflections) than controls (TL = .13, controls =  $.26 \pm .06$ ) while a prominent higher

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probability of button presses occurred during the falling phase (negative deflections) as compared with controls (TL = .25, controls =  $.20 \pm .02$ ). As can be seen in the correlation plot in **Figure 3-2-4**, a higher probability of button presses during the rising phase corresponded with smaller RP amplitudes (Pearson correlation,  $r = .87$ ;  $n = 10$ ;  $p = .001$ ). Contrary to the rising phase, the RP amplitude was increased as the probability of button presses increased during the trough phase (Pearson correlation,  $r = -.60$ ;  $n = 10$ ;  $p = .044$ ). These correlations are in line with a recent study by Jo et al. (2013) showing that the more button presses occurred during negative deflections the more negative was the RP amplitude. Thus, the larger RP amplitude in TL as compared to five controls was associated with higher occurrences of a button press during negative deflections.



**Figure 3-2-3.** (A) An example of the ISF wave (black trace) as well as with bandpass filtered EEG at 0.01–35 Hz (gray trace) are shown, negative deflections are downward. The vertical lines overlaid on the traces indicate the latencies of the button press. (B) ISF phase obtained by Hilbert transformation are plotted against the corresponding time in A. In the histograms (C, D), the probabilities of button presses from the *M-task* (C) and *W-task* (D) are plotted against the four ISF phases. Schematic ISF waves (gray trace) were superimposed in the graphs. The error bars represent the standard deviation of the mean.



**Figure 3-2-4.** The RP amplitude was significantly correlated with the probability of button presses during the trough phase ( $r = -.60$ ,  $n = 10$ ,  $p = .044$ ) and during the rising phase ( $r = .87$ ,  $n = 10$ ,  $p = .001$ ). The probabilities of button presses were calculated from the pooled data across all participants in both the *M-task* and *W-task*.

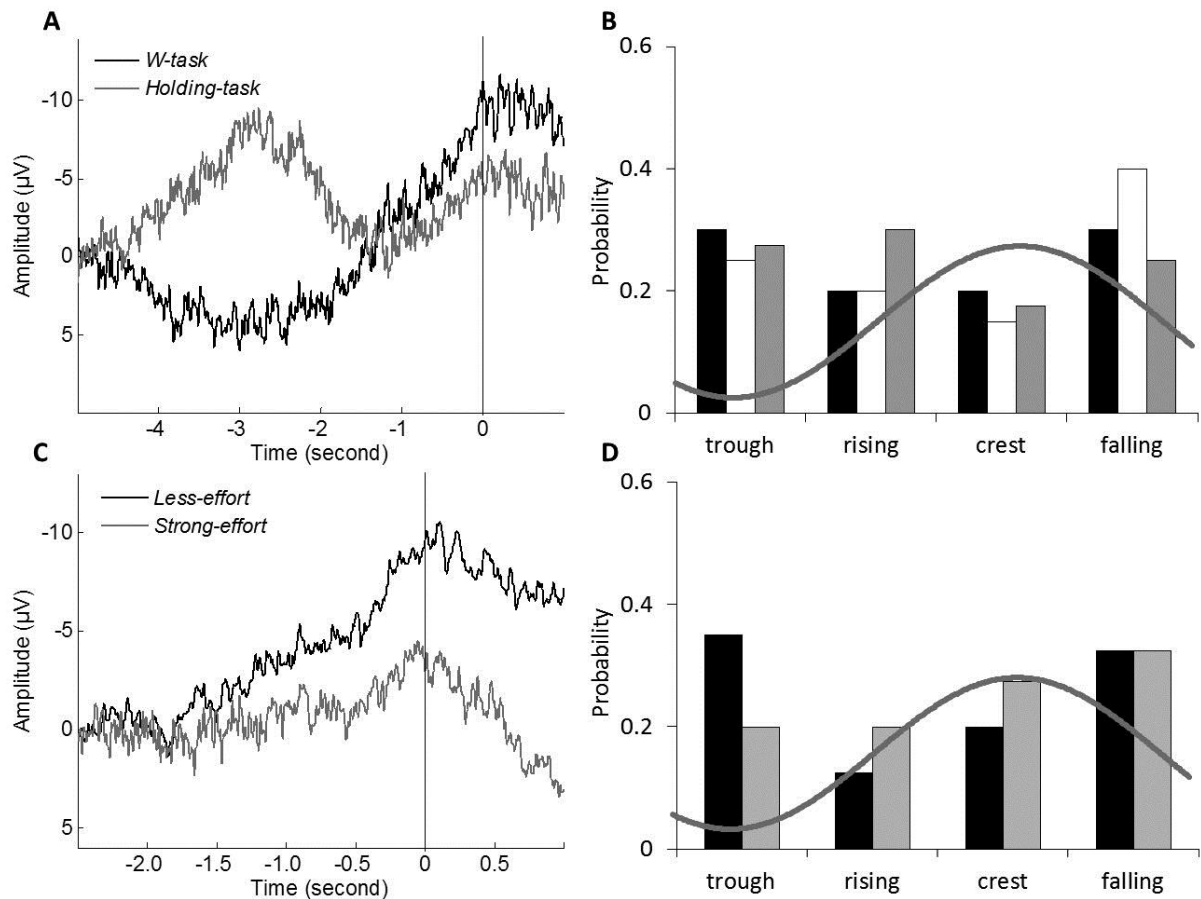
In sum, TL showed a higher reliability between subjective reports and neural dynamic correlates of intentional behavior, in which TL pressed the button mostly during negative deflections according to the feeling of an inner impulse.

### Session two

As we observed in session one, if the negative deflection is indeed associated with the inner impulse, then a similar pattern of negativity might be observed even when TL is not required to press the button immediately after the feeling of an inner impulse. To test for such an effect, we invited TL again and, first, repeated session one with the *W-task* to assess the reliability of associations between correlations of the cortical potential and behavioral indices. Then we conducted a  *Holding-task* where TL is required to sense the inner impulse but not to press the button immediately.

In the *W-task*, we observed the same pattern of phase occurrence as in the *W-task* in session one (see the black bars in **Figure 3-2-3D** and in **Figure 3-2-5B**). That is, in both *W-tasks* TL performed the button presses with a lower probability during positive deflections and a higher probability during negative deflections (65% for session one and 60% for session two), which results in a prominent negative potential shift before the button press. Four epochs in the *W-task* which showed a short waiting-time of less than 5 s had to be excluded from the average RP for this analysis. Comparison of w-times during the *W-tasks* between session one and two revealed no obvious difference ( $-230 \text{ ms} \pm 79$  and  $-219 \text{ ms} \pm 100$ , respectively;  $p = .596$ ).

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**Figure 3-2-5.** RPs and ISF phase occurrences in session two and three. (A) RPs for the *W-task* (black) and *Holding-task* (gray) in session two are shown. The vertical line indicates the time of the button press. Note that the polarity of the RP amplitude is inverted. (B) Occurrences for the button press as in A are plotted against ISF phase. White bars represent the probability of phase occurrences at the moment preceding the button press by 3s in the *Holding-task*. A schematic ISF wave (gray trace) was superimposed in the graph. (C) RPs for the *less-effort-task* (black) and *strong-effort-task* (gray) in session three are shown. (D) Occurrences for the button press as in C are plotted against ISF phase.

In the *Holding-task* TL was asked to hold his intention after sensing the first inner impulse without acting physically for as long as possible, and only then, finally, to press the button. After the task, he reported that he was able to hold his intention approximately for one to one-and-a-half rotations of the clock, corresponding to 2.6 s to 3.8 s. Regarding the brain dynamics, we observed no prominent phase occurrences of the button press reflecting different RP forms (53% during negative deflections; see the gray line and gray bars in **Figure 3-2-5**) as compared to the *W-task*. Interestingly, we found a peak of ongoing negative shift around -3 s which is approximately at the same time when he felt the first intention to move (the gray line in **Figure 3-2-5A**), a neural signature that is in agreement with a recent study by Vinding et al. (2014). This likely association between the interview data and the RP-

like signal supports once more the interpretation derived from the data in session one that the emergence of the intention comes with the occurrence of negative deflections. When we tested the phase occurrences in that time latency, 3 s before the button press (65% during the trough and falling phases; see the white bars in **Figure 3-2-5B**), we found the same pattern of phase occurrences as in the *W-task*. Since TL reported the time of the last moment that directly pushed him to press the button, no obvious difference in the reported w-time in the  *Holding-task* was observed as compared to the *W-task* ( $-219 \text{ ms} \pm 100$  vs.  $-208 \text{ ms} \pm 116$  for *W-task* and  *Holding-task*, respectively;  $p = .657$ ).

These results extend the findings from session one. The striking parallels between SCP shifts with his first-person reports once again support the view that a negative deflection of SCPs facilitates an urge to move that may become conscious at a moment in the near future.

#### **Session three**

Consistent with recent studies (Jo et al., 2013; Vinding et al., 2014), the results of the previous two sessions suggest that SCPs have an essential impact on promoting a decision on self-initiated movements, with negative shifts making them more likely. If the negative potential favors the self-initiation of a movement, then such a process should be associated with less inner effort to press a button as compared to moments in which a positive slow cortical potential is present. To test for such a hypothesis, we conducted a more direct test of negative deflections by having TL perform either with almost no effort or with strong effort. In the description of TL this would translate into either waiting for an upcoming inner impulse and to easily initiate a button press (less effort condition) or to actively initiate the button press in moments when there is no inner impulse present (strong effort condition). Thus, this approach also tested the hypothesis whether the ‘upcoming inner impulse’ as TL described in the first person perspective is related to the fluctuations of the SCP in the third person perspective.

Before the experiment started, TL needed a few trials of practice in order to become accustomed to the effort task. His mean effort rating was substantially smaller in the *less-effort-task* ( $65.9 \pm 36$ , possible range from 1 to 400) than in the *strong-effort-task* ( $346.1 \pm 59$ ;  $p < 10^{-25}$ ), confirming that TL spent more effort on the decision during the *strong-effort-task*. Regarding the cortical potential, we observed much higher negative amplitude in the *less-effort-task* as compared to the *strong-effort-task* (**Figure 3-2-5C**). As was expected, the probability of button presses during negative deflection (trough and falling phases) was reduced from 68% to 53% in the *strong-effort-task* (**Figure 3-2-5D**), thus explaining the

reduced RP amplitude. The ongoing negativity in mid-central electrodes started around 1.3 s before the button press when TL was spending less effort for making a decision to act (**Figure 3-2-6** left), while this activity was absent or much lower in the *strong-effort-task*. Instead, latero-central electrodes were mostly activated near to the onset time of the button press (**Figure 3-2-6** right).

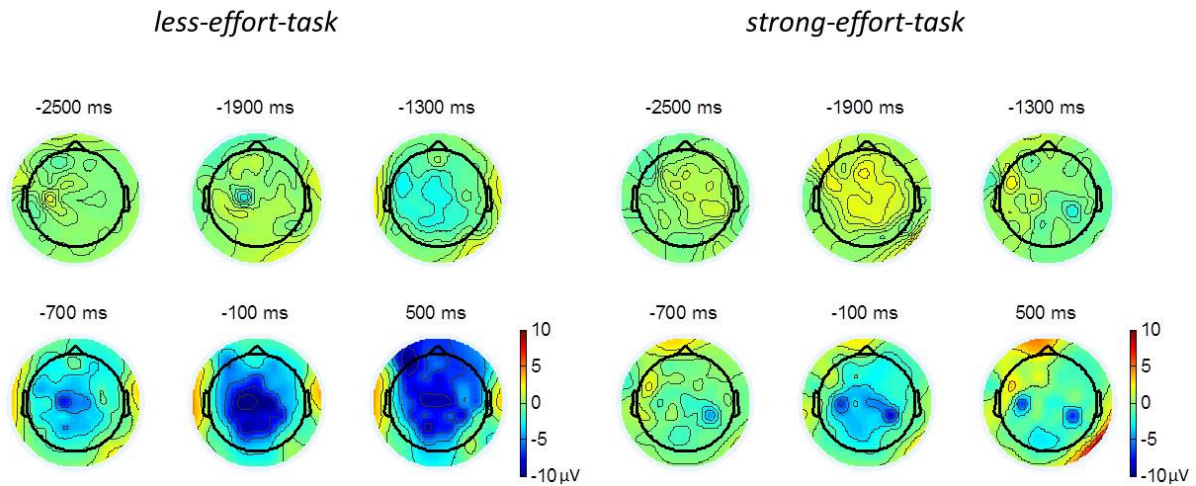
The mean time of the decision to move was  $-404 \text{ ms} \pm 172$  for the *less-effort-task* and  $-447 \text{ ms} \pm 218$  for the *strong-effort-task*, showing no obvious difference between tasks ( $p = .363$ ). However, these decision times remarkably differ as compared to the w-times in the previous sessions. One interpretation is that the retrospective reporting of two aspects, i.e. decision time and the effort, make the task to report the precise moment more difficult. Since the purpose of the present session for TL was to concentrate on effort rather than on the decision time, we do not make clear inferences on decision time.

#### **3.2.4. Discussion and conclusion**

Previous studies have shown that meditation experience enhances the ability to sustain attention. Our observations support this interpretation since TL performed the task with less variability and showed striking correlates between his subjective reporting and objective neural and behavioral indices (see below).

In session one, TL pressed the button with a higher probability during negative deflections of the SCP as compared with controls. This may indicate that TL performed the task using a more consistent strategy. Based on our findings, we assume that he pressed the button more consistently when he sensed the inner impulses (first-person perspective), which was correlated with the cortical potential shifts (third-person data) with a larger likelihood of acting during negative deflections. If we suppose furthermore – and in accordance with his description in session one – that an ongoing negative deflection favors an urge to act, then a more precise response to this inner urge should also result in larger average RP amplitudes. Indeed large RP amplitudes in TL exceeded those of matched control participants as consistently seen in both tasks of session one. We further tested whether the RP amplitude increased significantly from lower to higher probabilities of button presses during negative deflections of the ISF wave. We found that this was true for the correlation with the trough and the rising phases, in agreement with Jo et al. (2013). Taken together, it seems reasonable to assume that the emergence of the intention occurred more often with negative deflections of SCP, and that this has significant effects on the RP amplitude.





**Figure 3-2-6.** Topographical maps in session three. Each map is the average activity before and after the button press. Note that, the ongoing negativity around mid-central area occurs much stronger (blue color) and earlier in the *less-effort-task* than the *strong-effort-task*.

It has been shown that an ongoing negative shift in the EEG potential precedes the predefined time for a motor response, even when participants cancelled their intention to act and did not actually move (veto-experiment, see Libet et al., 1983b). Moreover, the earlier part of the RP that is from the onset of the RP to 500 ms prior to movement did not differ from a condition of merely imagining such a movement (Cunnington et al., 1996; Jankelowitz et al., 2002). The fact that the RP was also observed during the imagination of such a movement without actual movement suggests that the negative shift is more attributable to processes underlying the urge to act, than to processes underlying the movement execution itself. This principle was successfully applied in SCP driven brain-computer interfaces that allow paralyzed patients to select letters on a computer screen through self-regulation of SCPs by voluntary mental strategies (Birbaumer et al., 1999; Hinterberger et al., 2004). Our results extend these previous findings. In the  *Holding-task* in session two, TL did not press the button immediately after an intention emerged but was able to hold this intention for approximately 3 s. In this case a negative shift is seen until the start of the holding phase (at -3 s, see **Figure 3-2-5A**), which can be interpreted as a result of adding up many negative deflections since the start of the holding phase may be also more likely to take place during this phase. Again we assume here that the negative deflection in SCP is related to what he describes as an “upcoming inner impulse” and thus, this finding can be conceived of as specific correspondence between a self-report and a neural signature for an experience of intention. Furthermore, a recent study by Vinding et al. (2014, see Figure 2) showed similar results in their distal condition, where participants were asked to wait one full rotation of the clock after they felt the intention to move. While in their study the holding period (one full rotation) was instructed by the

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experimenter, in the present study we used the holding period from the first-person report to interpret the neural signal. These findings strengthen our measures of first-person approaches and further support the above hypothesis that negative deflections facilitate the occurrence of an intention to act.

In summary there are several different correspondences between TL reporting ‘inner impulses’ or an ‘urge to act’ and negative deflections of SCPs. Since the probability of self-initiated movement was higher during those negative deflections, we further hypothesized that ongoing negative potentials are associated with *less effort* on a decision to press the button than positive deflections. ‘Effort’ is here conceptualized as the perceived inner labor that is necessary to start the performance of the requested act. If there is already an ‘urge to act’ only little effort will be necessary to make the final step towards movement execution. In the absence of any inner tendency on the other hand there will be more effort needed to initiate the physical act. We investigated this hypothesis by conducting the same Libet task under different instructions. In session three, TL was asked to focus on the effort itself and instructed to either perform the task with almost no effort, i.e. in moments when TL could sense an inner impulse or with rather strong effort, i.e. in the absence of any inner impulse. According to our hypothesis we observed higher RP amplitudes and a higher probability of button presses during negative deflections in the *less-effort-task* than the *strong-effort-task*. A notable feature is that this ongoing negativity starts much earlier in the *less-effort-task* at mid-central electrodes. These findings are further evidence in support of the hypothesis that negative deflections of SCPs favor a self-initiated movement with less effort than positive deflections. Based on the SCP theory, synaptic activities of apical dendrites in the upper cortical layers are the main source contributing to the ongoing potential deflections on the scalp (Birbaumer et al., 1990). The ongoing negative potential is primarily due to synchronous depolarization of apical dendrites increasing firing probability, thereby manifesting sensory and motor resource excitability into respective cortical area. On this view, negative SCP lowering the threshold of excitability can be seen as experience of *less effort* to act.

It could be argued that TL might have spent more effort on the button press force itself rather than on making a decision. However, an fMRI study showing a correlation between intrinsic fluctuation of brain activity and the button press force suggests that this is not very likely (Fox et al., 2007). In this study also spontaneous button presses had to be performed. It was shown that enhanced brain activity measured in the somato-motor cortex before the button press was

associated with soft button presses while reduced brain activity was observed for hard button presses. In contrast, in an instructed condition, in which participants were asked to press the button either hard or soft, no difference in brain activity before the button press was found. Since we observed the opposite direction of RP amplitude, that is, higher RP amplitude in the *less-effort-task*, the fact that TL spent more effort on the *strong-effort-task* suggests that the change of RP amplitude could not be due to concentrating on the button press force itself.

Our finding that negative deflection of SCPs may facilitate a movement instead of indicating a neural preparation process for the forthcoming movement is in agreement with the study by Schurger et al. (2012), which is based on an accumulator model. The fact that the shape of the RP fits a stochastic accumulator model suggests that the RP is merely an aggregation of spontaneous fluctuation in neural activity. The present findings from all three sessions extend this view by demonstrating that information from the first-person perspective complements the analysis of the neural signal. TL reported insights that demonstrate a correspondence with the parallel neural signal. This may not be representative of the general population since usually SCP activity cannot be sensed as was shown by Kotchoubey et al. (2002). But the same study also showed that feedback training can be used to successfully train participants to perceive or/and self-regulate their SCP. Thus, one future session with TL could investigate his capabilities in different neuro-feedback tasks involving SCP regulation.

We have taken an innovative methodological approach in the study of the Libet task. Working in an iterative process with a well-trained meditator demonstrated that for this person an impressive correspondence between personal accounts and third person EEG data could be found. We used this neurophenomenological approach to establish several well-founded hypotheses regarding the process of volitional acting. On the basis of this approach it is suggested that: (a) the larger RP amplitude is attributed to frequent occurrences of self-initiated movement during negative deflections, and (b) these negative deflections of SCPs are correlated with an inner event, which may in turn lead to a voluntary action. We propose that Libet's task might test the ability to act upon inner events rather than probing free will.

#### **3.2.5. Appendix A**

First-person reports from TL are here combined and paraphrased for several topics. All paraphrasing was validated by TL himself.

What is happening in the standard Libet task?

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*When the trial has started I am waiting for an impulse to show up in my mental space. This is similar to a cat waiting in front of the mouse hole. Once it is there I don't have to give myself a second command to click the button. It seems the impulse immediately goes through my hand to click. Well, I'm deciding to do so because it's the rule of the game, it's like there's a sign with 'No double clicking, no none-clicking, only single clicking allowed'. I feel this process of clicking the mouse is actually experienced by myself as giving full permission to the organism to follow that first inner impulse that is perceived.*

What are these impulses?

*These inner impulses are non-conceptual movements of the mind. Since they are pre-conceptual one can recognize them not by their content but as slight movements of the mind, which have a certain taste. This taste goes along with some 'neediness' wanting to think, which results in 'looking for an object'. There are many different kinds of such pre-conceptual movements (precursors of emotions, volitions, concepts, intuitions or memories) and here only those ones are selected and followed which enable the requested mouse click. In a general sense all behavior (or actions) starts pre-conceptual. Conceptualization is only the very last step. This last step is where usually people realize to have made a decision.*

*With a trained calm mind one can observe this pre-conceptual readiness to act. One needs to trust the mind and to relax anxiety and control (i.e. relax the mind). Also with a calm mind one has the possibility not to follow these impulses and continue relaxing which is much softer than a more active inhibition ('No') later on in the process.*

*With an even calmer mind these inner impulses and tendencies get weaker. I could be sitting here and no inner impulse would arise for a long time. It depends on how much I relax my mind from the task.*

Is the moment we are asking you to report (i.e. the first intention to act) a sharp moment in time or a longer lasting process?

*The character of this process, mostly called decision, to do, or not to do, something depends on the emotional content of any given decision. If the issue were emotion-laden (e.g. avoid imminent danger to life) then the decision is quick the curve leading up to the decision would feel steep. The decision then is felt to be a sharp event. But if this is not the case then the whole decision process is much more relaxed and may take more time, even oscillating forth and back and sometimes even no decision is made.*

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Is this experiment testing free will?

*This is not a task for free will. Rather a test for unconscious impulses. Free will would be to introduce other choices, e.g. to not click, to double click . . . decision making. But this here is not free will. I'm not deciding to have the inner impulses, because the whole frame of the experiment is to have these impulses. The only free decision is to participate in this experiment.*

*However, if I am very mindful to this process I can mentally deal with the impulse once it is there. I could delay the time between perceiving the impulse and the physical action.*

### 3.3. Study 3: Awareness of Intentions to Act and Neural Substrates<sup>3</sup>

**Summary** Intuitively, being aware of one's inner processes to move should be crucial for the control of voluntary movements. However, research findings suggest that we are not always aware of the processes leading to movement execution. The present study investigated induced first-person access to inner processes of movement initiation and the underlying brain activities which contribute to the emergence of voluntary movement. Moreover, we investigated differences in task performance between mindfulness meditators and non-meditators while assuming that meditators are more experienced in attending to their inner processes. Two Libet-type tasks were performed; one in which participants were asked to press a button at a moment of their own decision, and the other one in which participants' attention was directed towards their inner processes of decision making regarding the intended movement which lead them to press the button. Meditators revealed a consistent readiness potential (RP) between the two tasks with correlations between the subjective intention time to act and the slope of the early RP. However, non-meditators did not show this consistency. Instead, elicited introspection of inner processes of movement initiation changed early brain activity that is related to voluntary movement processes. These findings are supported by cortical source imaging analysis on brain activity in the pre-supplementary motor area (pre-SMA), in which directing the subjective experience towards inner process to move led to a decreased activation in non-meditators, while no or less change was found in meditators. Our findings suggest that compared to non-meditators, meditators are more able to access the emergence of negative deflections of slow cortical potentials (SCPs), which could have fundamental effects on initiating a voluntary movement with awareness.

#### 3.3.1. Introduction

A self-initiated movement is considered as *voluntary* if one experiences her or his own volition preceding a movement, which is not directly determined by any external stimulation. The generation of such a voluntary movement is, therefore, strongly related to an individual's internal states. An internal starting point for a movement could be an *inner impulse* or urge, which can be described as a pre-conceptual movement of the mind. Such an inner impulse may be possible to access with awareness as a certain "taste" of a mind movement, but it is unspecified and not conceptualized at first (Jo et al., 2014a). This impulse may be occasionally so strong that it is hard to restrain from action execution (e.g., addictive

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<sup>3</sup> This study is based on the article: Jo, H. -G., Hinterberger, T., Wittmann, M., & Schmidt, S. (under review). Do meditators have higher awareness of their intentions to act?

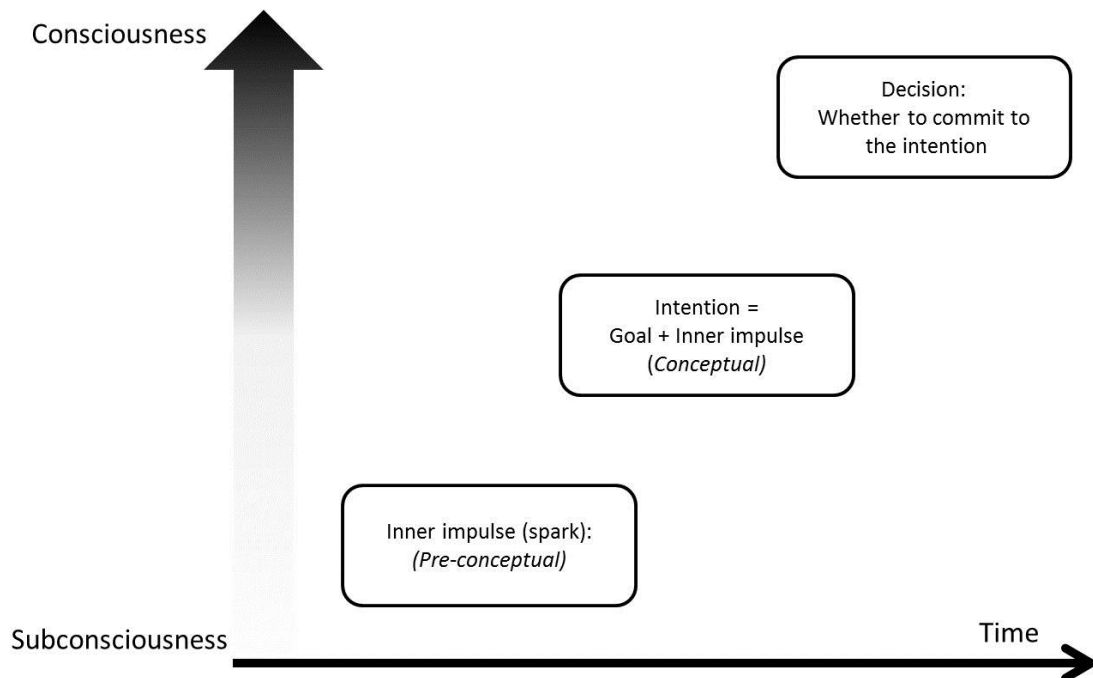
behaviors or autonomic behaviors to avoid imminent danger to life). But sometimes it may be so subtle that it is hard to be experienced. Such inner impulses might be taken up and combined with a personal goal forming an *intention*. Whether to commit to this intention can be determined by a final *decision* process, which is also known as ‘late whether decision’ of human volition in the model by Haggard (2008). Thus, becoming aware of an inner impulse might be the first stage where people can realize that they are about to execute a voluntary movement (a theoretical framework of the inner process of voluntary movement is illustrated in **Figure 3-3-1**). In the present study we focus on the inner process of voluntary movement, especially becoming aware of such an inner process (i.e., inner impulse or intention) and its correlates with the neural dynamics that are relevant to the emergence of a conscious intention to act.

Human volitional movement has been studied by using the Libet task, in which participants were asked to perform a spontaneous finger movement driven by their own urge, desire, or decision (Libet et al., 1983). Interestingly enough, participants are often not aware of having moved even after having been trained to introspectively attend to their movements (Keller & Heckhausen, 1990). Moreover, a recent study showed that participants sometimes initiate a voluntary movement while their mind is wandering or while they are thinking about something else (Schneider et al., 2013). That is, they were not aware of their inner state of voluntary movement or of a preparation of this voluntary movement, while the brain progressively builds up neural activity that could lead to the emergence of conscious intention (Desmurget, 2013). Those studies recorded Electroencephalography (EEG) to investigate neural representations of the temporal course of volitional movement. Especially the negative deflections of the slow cortical potentials (SCPs), i.e., the so called readiness potential (RP) and the contingent negative variation (CNV) depend on the task demands (Birbaumer et al., 1990), are of interest as they are indicative of movement preparation. Although the causal relationship between the RP and conscious decision-making is questioned, a common understanding of the RP is that a negative potential shift before a self-initiated movement creates decision processes related to voluntary action (Shibasaki & Hallet, 2006). Here we thus presume that the negative deflections of SCPs might be relevant to the inner process of voluntary movement initiation, even if not a decision-making process (Jo et al., 2013).

Recent evidence shows that a voluntary movement is more likely initiated during negative deflections of SCPs, resulting in an averaged negative potential before movement onset (Jo et al., 2013; Schurger et al., 2012). Averaging these negative potentials over trials leads to the

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characteristic signature of the RP. In addition, it was demonstrated that a conscious intention to act is paralleled by ongoing negative deflections of SCPs, showing that RP-like negative potentials are found when participants are aware of an inner impulse or intention to act even without immediate movement execution (Jo et al., 2014a; Vinding et al., 2014). Furthermore, voluntary actions that were following the subjective experience of intention resulted in higher RP amplitude as compared to the actions that were performed during the absence of intention experience (Jo et al., 2014a; Keller & Heckhausen, 1990). In contrast, relative positive deflections of SCPs, which overall lead to smaller negative RP amplitudes, seem to be associated with a decision process to withhold an action (Misirlisory & Haggard, 2013), suggesting the absence or a diminished degree of intention as compared to when relative negative deflections are recorded. Taken together, these findings suggest that the emergence of a conscious intention to act is associated with ongoing negative deflections of SCPs, which result in a negative RP amplitude. Therefore, the extent of the RP amplitude rather than the onset time of it would be of interest regarding the subjective experience of the emergence of intention.



**Figure 3-3-1.** A theoretical framework of immediate voluntary movement. An *inner impulse* that is a pre-conceptual movement of the mind can be considered as the spark, initiating a behavior in accordance with one's goals and plans. The inner impulse is conceptualized by taken up and combined with a personal goal, leading to from an *intention*. Whether to commit this intention can be determined by a final *decision* process.



In the present study, we investigate if the emergence of conscious intention correlates with the extent of negative deflections of neural dynamics, and whether we are usually aware of such negative deflections as an inner impulse or intention when we are performing voluntary actions. To address these issues, we engaged participants in two Libet-type tasks. The task conditions were identical in terms of voluntary movement and reporting the emergence time of intention, but differed in the instruction which specified what participants should attend to. In the first task, the *standard task*, participants performed voluntary movements by their own decision without specific instruction to minimize experimental bias, encouraging them to perform a voluntary action as usual. For the second task, the *introspective task*, participants were asked to specifically pay attention to their inner process to move that emerges internally and to act accordingly. This introspective task was aimed at directing subjective experience towards inner states of volitional movement. The relation between subjective reports on intention timing and brain processes contributing to the emergence of a conscious intention to act are examined. Compared to the standard task, this specified instruction enabled us to study the role of introspecting voluntary movement initiation, and thus, to examine whether individuals are able to report the emergence times of intention in accordance with the brain processes.

Furthermore, we have recently shown that an expert meditator was able to give reliable reports of his inner processes underlying volition, showing several correspondences between his subjective reports and the extent of the RP amplitudes recorded in parallel (Jo et al., 2014a). In support of this view, many studies have shown enhanced attentional control in experienced meditators or after meditation practice for meditation-naïve individuals (Chan & Woollacott, 2007; Lutz et al., 2009; MacLean et al., 2010). Meditators also show more accurate reports of their body sensations (Fox et al., 2012; Mirams et al., 2013). Taken together, it is likely that experienced meditators might have higher awareness of their inner processes such as of voluntary movement initiations. Therefore, subjective experience of intention timing and its correlates with neural dynamics are of interest when comparing non-meditators with meditators.

#### **3.3.2. Methods**

##### **Participants**

Twenty individuals experienced in mindfulness meditation (seven males; mean age 40.7 years, SD = 7.5, range 28 to 50 years) volunteered for the present study. They had at least

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three years of continuous experience in mindfulness meditation (mean: 10.4 years, SD = 6.9, range = 3 - 32) and had maintained a meditation practice of at least two hours per week (mean = 7.4 hours, SD = 5.0, range = 2 - 21) during the last eight weeks. Twenty matched controls in gender, age (mean age 40.3 years, SD = 7.4) and education level, were recruited. Control subjects had no prior experience of meditation practice including also Yoga, Tai-Chi and similar techniques. All participants had normal or corrected-to-normal vision and had no psychological or neurological illnesses as assessed in a short standardized interview. Participants were remunerated with 10 € per hour for taking part in the experiment. The ethics committee of the University Medical Center Freiburg approved of this study and written informed consent was obtained from all participants.

The 14 item short form of the Freiburg Mindfulness Inventory (FMI, Walach et al., 2006) was administered to assess the level of self-reported mindfulness. It has a two-dimensional structure with the factor “presence” referring to the ability to attend to the present moment and the factor “acceptance” referring to a non-judgmental attitude (Kohls et al., 2009).

#### **Procedure**

The experimental paradigm used in this study was based on the method introduced by Libet et al. (1983). First, in the *standard task*, an analogue clock (visual angle, 3° in diameter) was presented in the center of the screen. A clock-hand appeared after a short period (from 1 to 2 s) and started rotating clock-wise with a revolution time of 2,550 ms. Participants were asked to perform a voluntary movement (pressing the left mouse button) whenever they wanted to, by their own decision, but not earlier than after one full rotation of the clock-hand. No further description was given. Pre-planning of the movement was to be avoided. After the button press, the clock-hand continued rotating for a short interval (from 1 to 2 s) and disappeared. Participants were then asked to indicate with the mouse pointer on the clock face at which moment they made a ‘decision’ to press the button (w-time, which is a relative time towards movement onset). Following a block of several trials of practice until the participant felt ready data was recorded for forty trials. At the same time the EEG of the participant was monitored.

The second task, the *introspective task*, was identical to the standard task except for the instruction that specified what participants should attend to. Participants were asked to pay attention to their ‘inner impulse’, ‘intention’ or ‘inner feeling’ that emerges internally in the process of making a voluntary movement, i.e., the button press. After the clock-hand stopped, they were asked to report the first moment when they felt this ‘inner impulse’ (w-time) to the

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button press. Recording was started after several trials of practice. When they were being instructed for the second introspective task, some participants reported that they had experienced such an inner impulse or inside feeling in the standard task. For instance, during practice trials for the introspective task a control subject said “*Hard to explain, but it seems similar to the first task*” and a meditator said “*Sometimes I felt the impulse (in the first task), but decided consciously whether to press or not.*” In case of such reports, they were asked to keep their attention to inner processes and to press the button accordingly. Since the present study focuses on the relation between the emergence times of intention and the underlying neural dynamics, we do not clarify and assess these subjective descriptions (see also the discussion).

Participants performed the two task conditions and then performed several different tasks for other purposes (Jo et al., 2014b).

#### **Post-task questionnaire**

Task difficulty and participants’ own confidence into their w-time report were measured after each task with a questionnaire ranging from 1 (very easy or very bad, respectively) to 5 (very hard or very good, respectively). The single-items were “How easy was it for you to synchronize the onset time of conscious intention with the clock-hand position?” for task difficulty, and “How confident are you in synchronizing the onset time of conscious intention with the clock-hand position?” for the confidence rating.

#### **EEG recordings and data analysis**

EEG was recorded using a Quickamp amplifier using 64-channel active electrodes (Brain Products, Germany) in an acoustically and electromagnetically attenuated chamber. The ground electrode was placed on the forehead and an initial reference was placed at P9 according to the 10-20 system. Electrode impedance of all electrodes was kept under 5 k $\Omega$ . A one channel electrooculography (EOG) was recorded to detect ocular artifacts. To estimate the onset of finger movement, a single axis accelerometer (1.7 gravity) was placed on the left mouse button to measure the exact onset time of the movement. All electrophysiological data were recorded at a sampling rate of 1,000 Hz.

Pre-processing of data was performed with the help of EEGLAB version 12.02 (Delorme and Makeig, 2004). EEG records were downsampled to 250 Hz and re-referenced to linked mastoids. Then a band-pass filter from 0.01 to 45 Hz (zero-phase filter with -6 dB cutoff) was

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applied. Continuous EEG data was segmented into event-locked epochs ranging from 2.5 sec before the button press to 1 sec afterward with baseline correction of the first 200 ms. A few bad electrodes in individual measurements were replaced through spherical interpolation (on average  $1.3 \pm 0.27$  electrodes) and then epochs affected by artifact ( $\pm 100 \mu\text{V}$ ) of any electrodes except ocular movement were excluded for further analysis. Remaining ocular artifacts were corrected using independent component analysis (ICA; Makeig, et al., 1996) and EOG through visual inspection. About two ocular components, i.e., horizontal and vertical eye movements, were removed for each participant (on average 1.9 components for meditators and 1.8 components for controls). The trials with a button press during the first rotation of the clock-hand were also excluded. On average, 92.0 % (standard task, 91.6 %; introspective task, 92.4 %) of all epochs were analyzed.

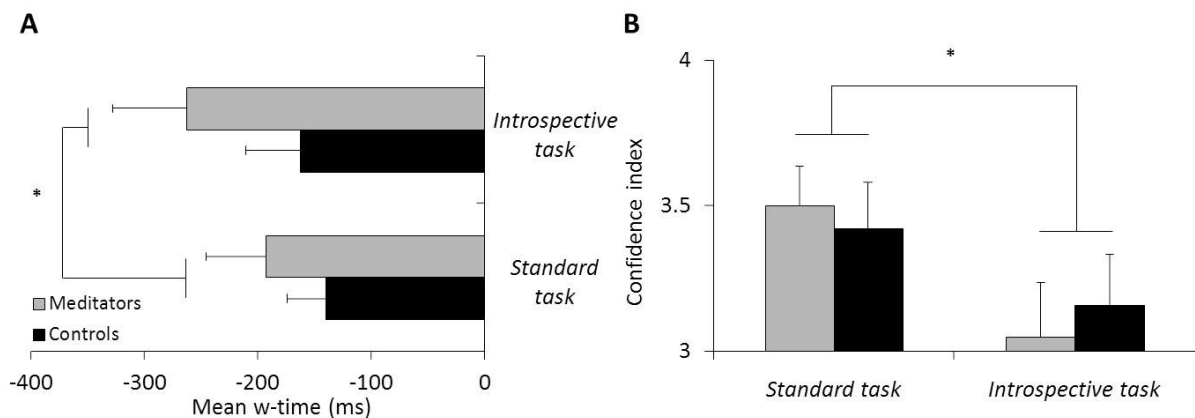
The RP was measured as average over the nine electrodes around Cz (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2). To further examine the RP, we divided it into early and late components as we had found different roles in subjective experience (Jo et al., 2014b), below and above ca. -0.8 and -0.7 sec before movement onset. Since the RP is baseline corrected for 0.2 sec from -2.5 to -2.3 sec, the mean amplitude for 0.2 sec from -1.0 to -0.8 sec is the amplitude change over the span of 1.5 sec. Therefore, the slope of the early RP could be calculated by dividing the mean amplitude from -1.0 to -0.8 sec by 1.5 sec, which is the duration of the early RP. The analogous calculation was performed for the late RP slope. The amplitude difference between the mean from -0.7 to -0.5 sec and the mean from -0.2 to 0 sec was divided by 0.5 sec. Next the early RP slope was subtracted from the slope of the late RP in order to account for the effect of the early RP component within the slope of the late RP. It should be noted that the mean amplitude from -0.2 to 0 sec might not represent the minimum amplitude because the RP usually has a peak just before movement initiation that is within the late RP (Jo et al., 2013). All the values are mentioned with standard errors, unless otherwise stated.

#### **EEG source reconstruction**

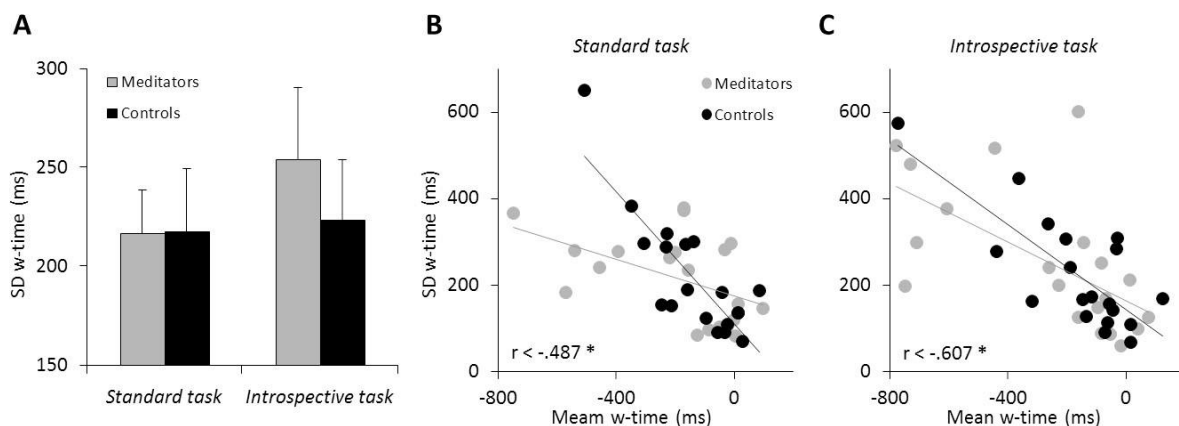
Source imaging analysis was performed using the software package Brainstorm 3.2 (Tadel et al., 2011), which is documented and freely available for download online under GNU general public license (<http://neuroimage.usc.edu/brainstorm/>). We used default cortical surface of a template MNI brain (colin27) distributed with Brainstorm, which has been fixed with 15,002 vertices and each vertex of the cortex is considered as a dipole. The forward head model was constructed by using a symmetric boundary element method from the open-source software

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(OpenMEEG; Kybic, et al., 2005; Gramfort et al., 2010), consisting of three layers (scalp, skull and brain). The noise covariance matrix was computed from the first 200 ms of the epoch. Cortical current sources were estimated for each participant by applying the minimum norm estimate (MNE) method implemented in Brainstorm. To examine which cortical areas are significantly different between two task conditions, the cortical source activation values were entered into paired t-test with the level of significance set at  $p < 0.05$  (Bonferroni-corrected for multiple comparisons). Clusters of at least 10 significant cortical vertices in the distributed sources model were considered.



**Figure 3-3-2.** Subjective reports for the standard task and for the introspective task. Average mean w-time (A) and confidence rating of w-times (B) are shown for both tasks. Error bars represent standard errors of the means. The asterisks highlight the difference between task conditions,  $p < .05$ .



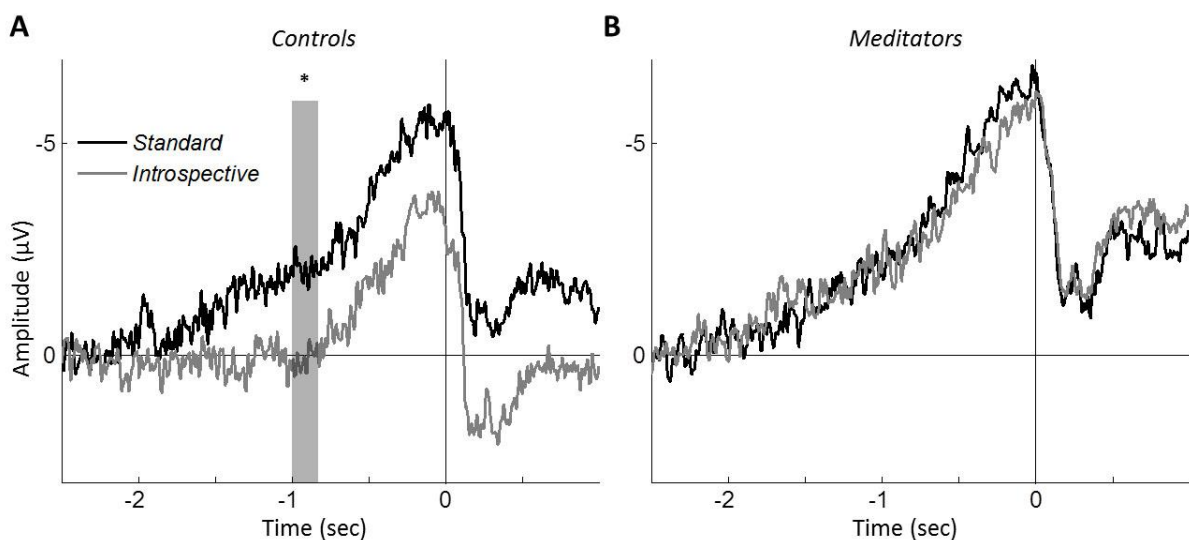
**Figure 3-3-3.** The relation between mean w-time and Std. w-time. (A) Std. w-time revealed neither task nor group effects. (B, C) Significant correlations between mean w-time and Std. w-time for both groups in the standard task (B; meditators,  $r(20) = -.487$ ; controls,  $r(19) = -.828$ ) and in the introspective task (C; meditators,  $r(20) = -.607$ ; controls,  $r(19) = -.769$ ) are shown. The asterisks highlight significant correlations between mean of w-time and SD of w-time,  $p < .05$ .

### 3.3.3. Results

One control subject dropped out because of personal reasons. Since we recruited matched controls, comparison between groups was performed with nineteen matched-pairs. Meditators on average had a meditation experience of 10.1 years ( $SD = 6.4$ ) and in the last 8 weeks had on average meditated for 7.6 hours ( $SD = 5.2$ ) per week. The scores of the self-report mindfulness scale (FMI) revealed significant differences between the two groups (meditators,  $44.4 \pm 1.1$ ; controls,  $36.5 \pm 1.2$ ;  $t(19) = 4.991$ ,  $p < .001$ ), indicative of higher ‘acceptance’ (meditators,  $24.8 \pm 0.8$ ; controls,  $20.1 \pm 0.7$ ;  $t(19) = 4.670$ ,  $p < .001$ ) and ‘presence’ (meditators,  $19.6 \pm 0.4$ ; controls,  $16.4 \pm 0.6$ ;  $t(19) = 4.382$ ,  $p < .001$ ) in meditators.

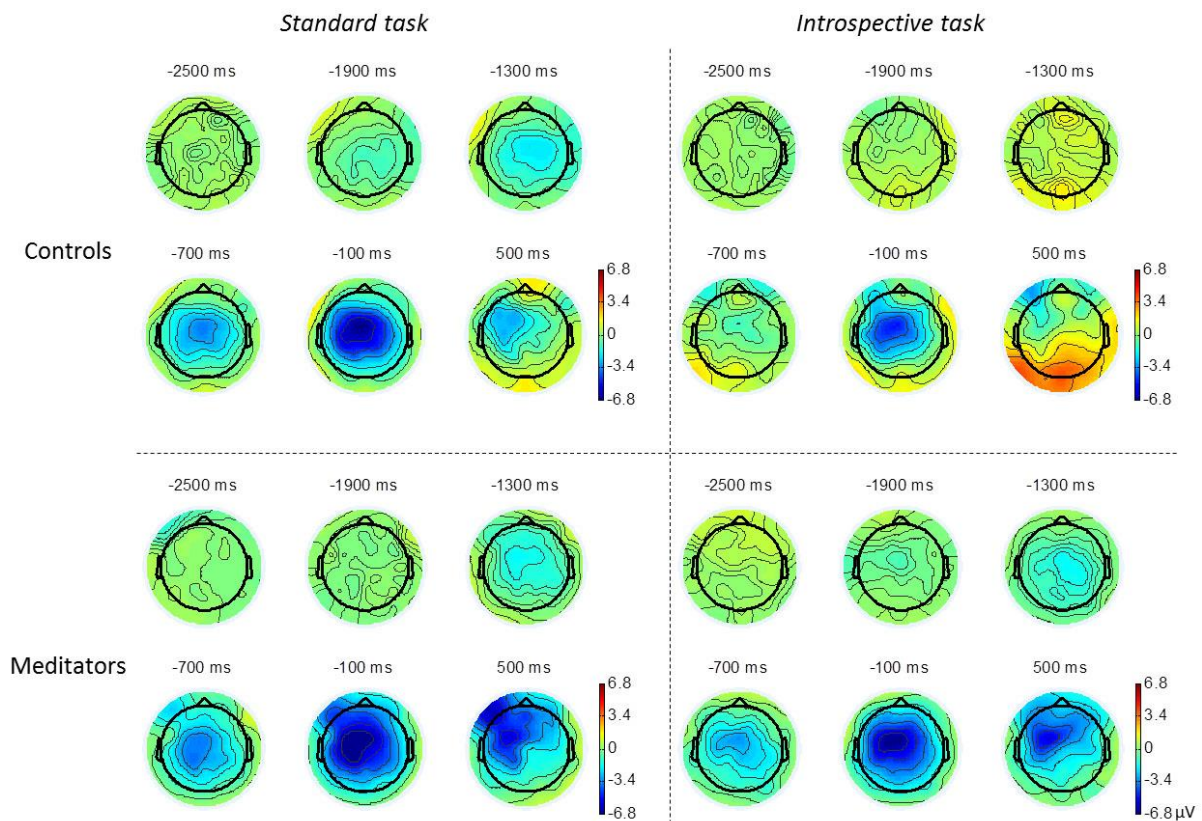
#### Subjective reports

We analyzed subjective reports, i.e. the w-time reports, with a repeated measure ANOVA with *task* (standard task vs. introspective task) as within-subjects factor and *group* (controls vs. meditators) as between-subjects factors. Participants reported their perceived intention time significantly earlier in the introspective task as compared to the standard task,  $F(1,37) = 5.492$ ,  $p = .025$  (**Figure 3-3-2A**). In both tasks, meditators (standard task,  $-193.2 \text{ ms} \pm 51.7$ ; introspective task,  $-263.2 \text{ ms} \pm 65.4$ ) showed earlier w-time than controls (standard task,  $-140.1 \text{ ms} \pm 34.5$ ; introspective task,  $-163.0 \text{ ms} \pm 47.0$ ) though, this difference was not significant (*group* effect,  $F(1,37) = 1.204$ ,  $p = .280$ ). Also there was no *task*  $\times$  *group* interaction ( $F(1,37) = 1.411$ ,  $p = .242$ ).



**Figure 3-3-4.** Grand-averaged RPs for the standard task (black traces) and in the introspective task (gray traces) in controls (A) and meditators (B) are shown. Vertical lines indicate the onset of the button press. Gray vertical bar indicated by an asterisk,  $p < .01$ .

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**Figure 3-3-5.** Topographical maps for controls (upper panels) and meditators (lower panels) are shown in the standard task (left) and in the introspective task (right). Each map is the grand-averaged activity before and after the button press.

With respect to the confidence rating, participants felt less confidence in their w-time for the introspective task compared to the standard task ( $F(1,37) = 6.884$ ,  $p = .013$ ; **Figure 3-3-2B**), but no significant *group* difference ( $F(1,37) = 0.006$ ,  $p = .939$ ) or *task*  $\times$  *group* interaction was found ( $F(1,37) = 0.473$ ,  $p = .496$ ). Regarding task difficulty, both groups reported that the introspective task (meditators,  $3.30 \pm 0.19$ ; controls,  $3.32 \pm 0.17$ ) was more difficult than the standard task (meditators,  $3.55 \pm 0.21$ ; controls,  $3.53 \pm 0.16$ ). However, we observed no significant effects of *task* ( $F(1,37) = 2.190$ ,  $p = .147$ ), *group* ( $F(1,37) < 0.001$ ,  $p = .985$ ), and *group*  $\times$  *task* interaction ( $F(1,37) = 0.016$ ,  $p = .900$ ).

Taken together, these results confirm that our experimental paradigm effectively manipulated subjective experience comparable between groups, while physical task constraints were kept constant. These results suggest that directing subjective experience towards inner processes to act led to relative earlier w-time but also to less confidence into the w-time report.

Growing evidence suggests that meditation practice enhances the ability to sustain attention during a task (e.g., Jha et al., 2007; Lutz et al., 2009). Therefore, higher attentional stability measured from trial-to-trial variability would be expected in meditators relative to controls.

To examine subjective report variability, the standard deviation of the w-time was subjected to a repeated measure ANOVA analysis. We found no significant *task* effect ( $F(1,37) = 1.708$ ,  $p = .199$ ), *group* effect ( $F(1,37) = 0.133$ ,  $p = .717$ ), and *task*  $\times$  *group* interaction ( $F(1,37) = 0.909$ ,  $p = .346$ ; **Figure 3-3-3A**). Notably, however, we observed that the standard deviation (SD) of the w-time was associated with the mean w-time for the standard task (**Figure 3-3-3B**; meditators,  $r(20) = -.487$ ,  $p = .029$ ; controls,  $r(19) = -.828$ ,  $p < .001$ ) and for the introspective task (**Figure 3-3-3C**; meditators,  $r(20) = -.607$ ,  $p = .005$ ; controls,  $r(19) = -.769$ ,  $p < .001$ ), indicating that an individual who reports an earlier mean w-time has a higher variability of w-time. Thus, one should be cautious when testing SD of w-time itself as a measure of attentional stability. Since meditators reported earlier w-times than controls in both tasks (see **Figure 3-3-2A**), we do not make clear inference on the SD of w-time.

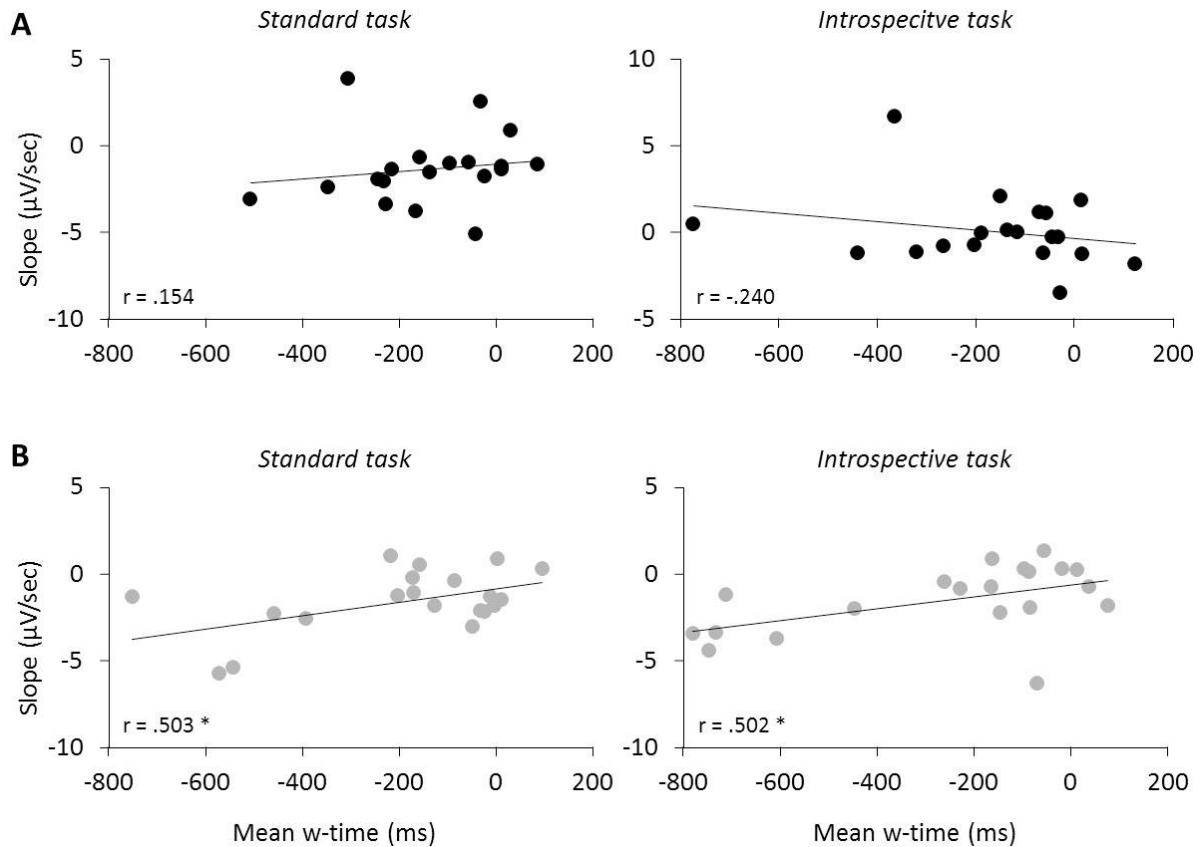
### EEG data

The RP for the standard task and for the introspective task is shown in **Figure 3-3-4**. A repeated measure ANOVA analysis on the early RP with *task* (standard task vs. introspective task) as within-subjects factor and *group* (controls vs. meditators) as between-subjects factors revealed a significant *task* effect ( $F(1,37) = 4.681$ ,  $p = .037$ ) and a marginally significant *task*  $\times$  *group* interaction ( $F(1,37) = 3.954$ ,  $p = .054$ ), but no *group* effect ( $F(1,37) = 2.828$ ,  $p = .101$ ). To further test this interaction, paired t-tests for each group were performed. In controls, we found that the early RP was significantly smaller in the introspective task ( $0.05 \mu\text{V}/\text{sec} \pm 0.48$ ) as compared to the standard task ( $-1.35 \mu\text{V}/\text{sec} \pm 0.48$ ;  $p = .006$ ). The ongoing negativity in mid-central electrodes that started around 2 sec before the button press was absent in the introspective task relative to the standard task (upper panels in **Figure 3-3-5**). In contrast, however, we did not find this task effect in meditators (standard task,  $-1.58 \mu\text{V}/\text{sec} \pm 0.40$ ; introspective task,  $-1.52 \mu\text{V}/\text{sec} \pm 0.44$ ;  $p = .907$ ; see also lower panels in **Figure 3-3-5**).

With respect to the late RP, ANOVA analysis showed no significant *task* effect ( $F(1,37) = 0.564$ ,  $p = .457$ ), *group* effect ( $F(1,37) = 0.347$ ,  $p = .559$ ), and *task*  $\times$  *group* interaction ( $F(1,37) = 0.700$ ,  $p = .408$ ), indicating that the experimental paradigm had no or less effect on the late RP. Therefore, the crucial difference between tasks particularly for controls lies in the early RP. These findings suggest that directing subjective experience towards internal processes affected controls within the range of the early brain processes before an action was made, but no such effect could be found in meditators.

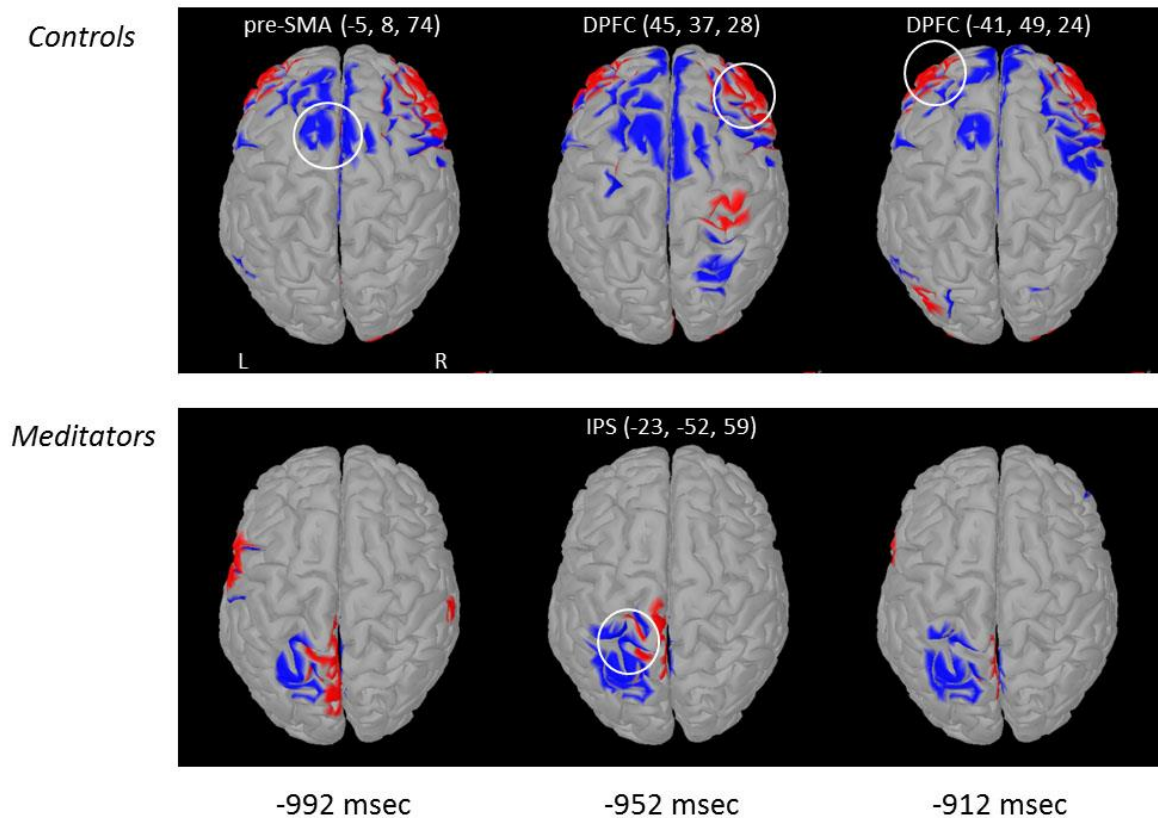


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**Figure 3-3-6.** The relation between the early RP and w-time in the standard task (left panels) and in the introspective task (right panels) for controls (**A**) and for meditators (**B**). Note that significant correlations were found in meditators in both task conditions, but not in controls. Significant level of correlation is indicated by asterisks,  $p < 0.05$ .

Next, we examined the relation between the RP components' slope and w-time, and tested whether the brain processes contributing to the emergence of a conscious intention is also associated with subjective reports of the intention time. In controls, we found no significant correlation of w-time neither with the early RP slope nor with the late RP slope (all  $p > .097$ ; see **Figure 3-3-6A**). In contrast, however, in meditators w-time correlated significantly with the early RP slope in both task conditions (standard task,  $r(20) = .503$ ,  $p = .024$ ; introspective task,  $r(20) = .502$ ,  $p = .024$ ; **Figure 3-3-6B**). Since w-times are significantly different between the task conditions (see **Figure 3-3-2**), the correlations found in both tasks reinforce the relationship between subjective intention time to act (w-time) and the early RP. There was no significant correlation between w-times and the late RP (standard task,  $r(20) = -.252$ ,  $p = .284$ ; introspective task,  $r(20) = -.415$ ,  $p = .069$ ), supporting recent evidence that the emergence of a conscious intention to act is associated with the early neural process rather than the late RP (Jo et al., 2013; Shibasaki & Hallet, 2006). Taken together, meditators revealed correspondences between the subjective experience of intention and objective measure of the early RP regardless of task conditions, while controls did not.



**Figure 3-3-7.** Cortical source images before the button press that correspond to the time when the early RP is present are shown. It shows regions of the brain with significantly ( $p < .05$ , Bonferroni-corrected) increased (red) and decreased (blue) activities when performing the introspective task as opposed to the standard task. Pre-SMA, DPFC and IPS refer to pre-supplementary motor area, dorsal prefrontal cortex and intraparietal sulcus, respectively. MNI coordinates in brackets represent the voxel locations indicated by white circles.

### Cortical source imaging

To shed more light on the brain processes that contribute to the emergence of conscious intentions, we performed brain source imaging analysis at three time points before the button press that reflects the early RP. **Figure 3-3-7** shows the brain with increased and decreased activities when performing the introspective task as opposed to the standard task. During the introspective task, brain activation in the pre-supplementary motor area (pre-SMA), which is the cortical sources of the early RP (Shibasaki & Hallet, 2006), was significantly ( $p < .05$ , Bonferroni-corrected) reduced in controls. However, no significant change of the pre-SMA activity was observed in meditators, which is in agreement with that meditators revealed consistent RP amplitude between task conditions. These results further suggest that controls performed the introspective task in the absence of the pre-SMA-related brain processes relative to the standard task, while meditators performed both tasks consistently without change of the pre-SMA activity. Notable, controls showed increased brain activation in the

dorsal prefrontal cortex (DPFC), while decreased activation in the left intraparietal sulcus (IPS) was observed in meditators. These two cortical regions have appeared to be related to performing an action with attentional demands (Lau et al., 2004; Rowe et al., 2002a, b).

#### **3.3.4. Discussion and conclusion**

The present study examined subjective experiences and underlying brain activity in task conditions that directed participants' attention towards inner states of voluntary movement initiation. Directing attention towards one's inner process of voluntary movement initiation (the introspective task) led to a change in the early RP in controls, but not in meditators. In contrast, without specified instruction (the standard task), both controls and meditators showed comparable behavioral and neurophysiological results. Importantly, in meditators but not controls, w-time correlated significantly with the early RP slope in both task conditions. These findings allow further discussions of the apparent correspondences between subjective experiences and objective measures of the brain recordings.

In the standard task, we replicated the main behavioral and electrophysiological findings for the voluntary movement task by showing w-times and the RPs to be consistent with the literature (e.g., Libet et al., 1983; Sirigu et al., 2004; Jo et al., 2013). In addition, the results of cortical source reconstruction are in good agreement with previous studies, which have shown that the early RP is localized in the pre-SMA (Shibasaki & Hallet, 2006).

In the introspective task both controls and meditators reported earlier w-times compared to the standard task. It has been shown that earlier w-times are associated with preplanned movements while unplanned spontaneous movements result in later w-times (see 'type I' by Libet et al., 1983). However, it is not very likely that the present results of early w-times were due to preplanning of movements, because the instruction to refrain from preplanned movements was identical in both tasks. Furthermore, in controls we observed a much earlier RP onset in the standard task as compared to the introspective task (see **Figure 3-3-4**). While earlier RP onsets are more likely in preplanned than in unplanned spontaneous movements (Libet et al., 1983), the opposite result of the RP onset argues against the possibility that participants performed a preplanned movement in the introspective task than the standard task.

In the introspective task, controls performed self-generated button presses in the absence of the early part of the RP, while in the standard task they revealed comparable RP amplitudes as found in the literature. This is in line with the finding of reduced pre-SMA activity in the

introspective task. The proportion of trials that shows an ongoing positive potential (each trial was classified as either a negative or a positive potential shift; see Jo et al., 2013) is significantly increased in the introspective task ( $39.36\% \pm 2.6$ ) as compared with the standard task in controls ( $32.51\% \pm 2.9$ ; two-tailed paired t-test,  $p = .009$ ). This larger amount of positive trials results, when averaged across trials, in a relative small negative slope of the early RP (Jo et al., 2013, 2014b). This could reflect the fact that controls pressed the button less frequently during ongoing negative potentials of SCPs in the introspective task. In contrast, meditators pressed the button with respect to SCP fluctuations in a brain state that is comparable between the task conditions. Given the consistent RPs between the tasks, it could reflect that meditators pressed the button during ongoing negative potentials of SCPs consistently regardless of the task conditions (proportion of ongoing positive potentials for the standard task and for the introspective task are  $31.59\% \pm 2.9$  and  $33.87\% \pm 2.8$ , respectively; two-tailed paired t-test,  $p = .537$ ). In accordance with this, the pre-SMA was active consistently for both task conditions in meditators. Within this context, it is likely that meditators were able to access the emergence of negative deflections of SCPs in both tasks, and thus might have reported more accurately the emergence times of intention than controls (see below).

It is notable that we could find a medium-sized to large correlation of subjective intention time (w-time) with the RP, while previous studies have demonstrated no relationship (Haggard & Eimer, 1999; Schlegel et al., 2013). This discrepancy could be explained by the fact that in the present study w-time was associated with the slope of the early RP rather than with the onset time of the RP, showing that individual meditators who reported earlier w-time values displayed steeper slopes. Recent studies have demonstrated that the onset and slope of the RP could reflect ongoing fluctuations of brain dynamics (Jo et al., 2013, 2014a; Schurger et al., 2012) and that the perceived time of the apparent sensory feedback is associated with the slope of the early RP (Jo et al., 2014b). Therefore, it could be more fruitful to investigate the slope (the extent of the RP amplitude) rather than the onset time of the RP. Research findings suggest that the early part of the RP reflects the continuous emergence of a conscious intention to act, while the late part is more directly associated with movement execution (Desmurget, 2013; Jo et al., 2013; Keller & Heckhausen, 1990; Shibasaki & Hallet, 2006; Schurger et al., 2012). In agreement with this view, meditators showed a relationship of w-time with the early RP, but not with the late RP. The observation of this correlation not only in the standard task but also in the introspective task strengthens this view. This is also in correspondence with the instruction of the introspective task which emphasized to attend to an

upcoming inner impulse to start an action. In addition, these results converge with findings from a recent study (Jo et al., 2014a), in which an expert meditator showed several different correspondences between his subjective reports and the early RP amplitudes. However, we did not find this relation for controls, suggesting that meditators were able to report the moment of intention more reliably in accordance with the early RP.

Although the cortical source imaging in the present study must be interpreted carefully, it yielded an approximate estimation of the location and distribution of the neural activity during the task conditions. In accordance with previous studies (Desmurget et al., 2009; Guggisberg et al., 2011; Lau et al., 2004; Sirigu et al., 2004), we found the pre-SMA, DPFC and left IPS to be implicated in intentional movement (**Figure 3-3-7**). While the pre-SMA has appeared to be of relevance with the emergence of intention to act, the left IPS and the DPFC are suggested to be associated with meta-cognition, i.e., *thinking* or *monitoring* about own mental states of an intentional movement execution (Guggisberg et al., 2011; Lau et al., 2004). Accordingly, previous fMRI studies have reported that enhanced brain activations in the IPS and DPFC are found when participants performed actions with attentional demands directed towards their action as compared to performing them without attention (Rowe et al., 2002a, b). Within this context, the observation of reduced left IPS activity in the introspective task relative to the standard task might imply that meditators were not very likely thinking or reflecting about their movement execution when they were asked to attend to inner impulses. Instead, the correlations of subjective intention time with the early RP that is distributed in the pre-SMA rather suggest that meditators were able to access the emergence of negative deflections of SCPs consistently. For the controls, in contrast, reduced pre-SMA and increased DPFC activities in the introspective task relative to the standard task might imply that they were thinking and reflecting about intentional movements when they were asked to attend to their inner process to move. However, further studies with anatomically more precise methods are necessary to explore the cortical origin of our effects.

This finding allows for the interpretation that the instruction of the introspective task served well for the meditators. They were able to observe introspectively upcoming inner impulses, which seems to be related to the fluctuating SCP (Jo et al., 2014a). They were then also able to transform these upcoming impulses into voluntary actions. In this view, meditators might have reported earlier stages of the emergence of intention timing during the introspective task than the standard task, as we observed earlier w-time in the introspective task. On the other hand the controls did not benefit from the introspective task instruction. They might have

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rather spent higher processing demands on thoughts about their inner processes and thus could not act according to the negative SCP deflections, which could have led to more actions during positive SCPs. This could have resulted in a diminished early RP and weaker correlation between w-time and early RP slope in controls. While meditators due to their regular practice are most likely well acquainted with observing internal processes, it seems likely that controls got distracted or even confused by the more specific instruction. Compared to the observing *mode of direct experience* of the meditators, controls might have entered a more *cognitive elaborative mode*, although this specific interpretation needs to be addressed in follow-up studies. This view supports the results of recent studies (Jo et al., 2014a; Garrison et al., 2013) that experienced meditators are suitable participants for the difficult task of relating introspective first person data with third person measurements.

Though the present study provides further information about the neural correlates of subjective experience pertaining to the emergence of an intention, potential limitations should be considered. Since subjective experience to attend to their inner impulse or inner feeling is 'private', the strategy for performing the tasks and the experienced intention timing could be inter-subjectively different. Indeed, a few participants described that they experienced performing the standard task as similar as the introspective task, although they showed substantial different w-time and RP amplitude between the tasks. However, on average, both groups performed the introspective task with less confidence and reported earlier w-time than the standard task (**Figure 3-3-2**), indicating that our experimental paradigm effectively manipulated subjective experience differently between the task conditions. Another concern is that the RP might not only reflect decision-related neural processes but also an epiphenomenon for performing the Libet task i.e., the requirements of monitoring the Libet's clock and reporting a clock-hand position of the clock (Miller et al., 2011). Thus, our paradigm could not rule out a potential role of other cognitive processes for performing the Libet task. It should be also noted that experienced meditators could have a different brain anatomy (Luders et al., 2012; Pagnoni & Cekic, 2007), which might produce different neural activity, so that the present findings from meditators might not be generalized to non-meditators. Therefore, further studies with anatomically more precise methods are necessary to explore the cortical origin of our effects.

### 3.4. Study 4: The Readiness Potential and Self-Agency <sup>4</sup>

**Summary** When a voluntary action is causally linked with a sensory outcome, the action and its consequent effect are perceived as being closer together in time. This effect is called intentional binding. Although many experiments were conducted on this phenomenon, the underlying neural mechanisms are not well understood. While intentional binding is specific to voluntary action, we presumed that preconscious brain activity (the readiness potential, RP), which occurs before an action is made, might play an important role in this binding effect. In this study, the brain dynamics were recorded with electroencephalography (EEG) and analyzed in single-trials in order to estimate whether intentional binding is correlated with the early neural processes. Moreover, we were interested in different behavioral performance between meditators and non-meditators since meditators are expected to be able to keep attention more consistently on a task. Thus, we performed the intentional binding paradigm with twenty mindfulness meditators and compared them to matched controls. Although, we did not observe a group effect on either behavioral data or EEG recordings, we found that self-initiated movements following ongoing negative deflections of slow cortical potentials (SCPs) result in a stronger binding effect compared to positive potentials, especially regarding the perceived time of the consequent effect. Our results provide the first direct evidence that the early neural activity within the range of SCPs affects perceived time of a sensory outcome that is caused by intentional action.

#### 3.4.1. Introduction

The link between a voluntary action and its consequent effect leads to the experience of controlling one's own actions, i.e., the sense of agency. For over a decade there has been a growing interest in understanding a specific effect related to human agency, which was reported by Haggard and colleagues (Haggard et al., 2002) and termed 'intentional binding'. They showed that when a voluntary action causes a sensory outcome, the action and the consequent effect are perceived as being closer together in time than they really are. Action-binding (the temporal attraction of action towards its consequent effect) and effect-binding (the temporal attraction of the effect towards action) were measured separately in order to investigate the intentional binding effects (see **Figure 3-4-1**).

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<sup>4</sup> This study is based on the article: Jo, H. -G., Wittmann, M., Hinterberger, T., & Schmidt, S. (2014). The readiness potential reflects intentional binding. *Front. Hum. Neurosci.* 8:421. doi: 10.3389/fnhum.2014.00421

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The intentional binding experiment starts with a self-generated action. This is similar to the Libet-type experiment which assesses preconscious brain activation (readiness potential, RP), preceding a voluntary action (Libet et al., 1983). In the literature, the RP can be divided into two components based on the scalp distribution and the slope of negative potential (Shibasaki & Hallet, 2006). The early RP starts about 2 sec before a voluntary movement and consists of a prolonged and increasing negativity. This activity is localized in the bilateral pre-SMA. In contrast, the late RP has a steeper slope seen in the contralateral premotor cortex starting around -0.5 sec before movement onset. Since the pre-SMA activity plays a crucial role in intentional binding (David et al., 2008; Moore et al., 2010), one can presume that the early RP might also be of importance for the temporal binding effect.

Many studies have implicated that the onset of the RP is a neural signature indicating initiation or preparation of a movement (for review, see Shibasaki & Hallet, 2006; Haggard, 2008), but recent studies suggested that the early RP is not necessarily causally related to movement preparation (Schurger et al., 2012; Jo et al., 2013, 2014). These studies rather suggest that a transient negativity of the continuously fluctuating slow cortical potentials (SCPs) facilitates the initiation of a movement in the near future. Only by averaging many single trials of this kind the early readiness potential emerges. These findings suggest that the emergence of a conscious intention to act may differ in each trial as a result of differences in spontaneous brain states. Therefore, it may be more fruitful to investigate the temporal binding effect and the related brain dynamic on the level of single trials.

A number of studies have shown the positive effects of meditation on attention control and self-regulation (e.g., Jha et al., 2007; Tang et al., 2007; MacLean et al., 2010; an overview is provided in Wittmann & Schmidt, 2014). Thus, we were further interested in the effects of experience in contemplative practices on temporal attraction in an intentional binding paradigm. We hypothesized that experienced meditators would display a different temporal attraction as they are better in continuously keeping the focus of attention on the specific task conditions (Chan & Woollacott, 2007; Lutz et al., 2009; MacLean et al., 2010). Less temporal attraction in intentional binding would be indicative of less deviation from the timing of the actual event. Moreover, growing evidence of positive effects on neural systems involved in attention processes have been shown after meditation practice (Slagter et al., 2007; Lutz et al., 2009; Moore et al., 2012). Thus, different behavioral performance on intentional binding between meditators and non-meditators would be of interest regarding the question of the underlying neural mechanism of the temporal binding effect.



The aim of the present study is to investigate (i) whether the early neural activity preceding the voluntary action has an effect on intentional binding and (ii) to explore its effect in experienced meditators by examining whether these brain correlates would be displayed differently as related to behavioral performance. In order to do so, we recorded electroencephalography (EEG) activity, while participants engaged in the intentional binding task, comparing a group of experienced meditators with matched non-meditating controls. Behavioral and electrophysiological data were analyzed on the basis of single trials.

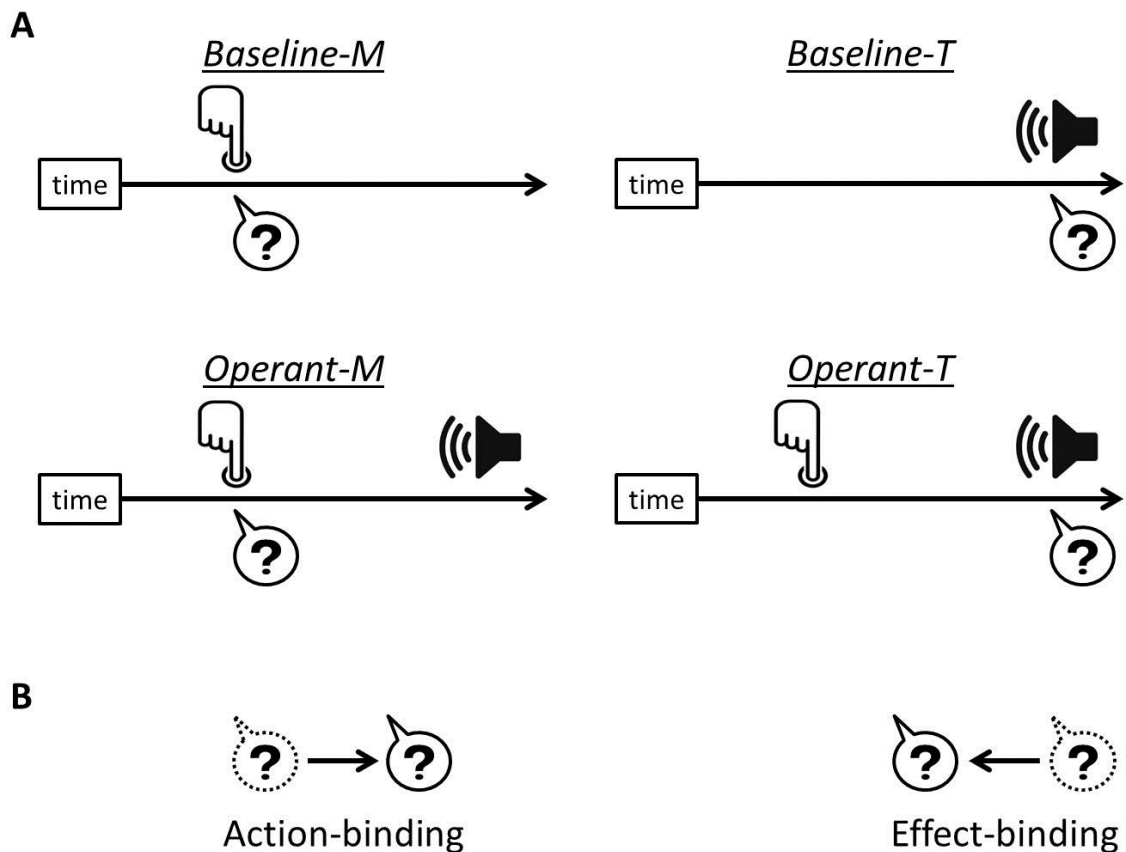
#### **3.4.2. Methods**

##### **Participants**

Twenty experienced mindfulness meditators (seven males; mean age 40.7 years,  $SD = 7.5$ , range 28 to 50 years) volunteered for the present study. They had at least three years of continuous experience in regular mindfulness meditation practice and had continuous meditation practice for at least two hours per week during the last eight weeks. Twenty matched controls in gender, age (mean age 40.3 years,  $SD = 7.4$ ;  $p = .278$ ) and education level, were recruited. Control subjects had never attended any course of meditation practice including Yoga, Tai-Chi and similar techniques. All participants had normal or corrected-to-normal vision and had no known psychological or neurological deficits. Participants were paid 10 € per hour for taking part in the experiment. The ethics committee of the University Medical Center Freiburg approved this study and written informed consent was obtained from all participants. Participants were invited to come twice within a period of two weeks to two different laboratories; first for the assessment of meditation experience cognitive performance, time perception, and personality, which will be reported elsewhere, and secondly for the Libet-type tasks with EEG recording (see below the apparatus and procedure).

##### **Self-report measures**

The Freiburg Mindfulness Inventory (FMI, Walach et al., 2006) was administered to assess the level of self-reported mindfulness. It has a two-dimensional structure with the factor “presence” referring to the ability to attend to the present moment and the factor “acceptance” referring to a non-judgmental attitude (Kohls et al., 2009). A 14-item short version has been developed which was used here.



**Figure 3-4-1.** Intentional binding paradigm. (A) In each task, participants reported either finger movement time or the onset time of the tone, indicated by the question marks. In operant tasks, i.e., *Operant-M* and *Operant-T*, a voluntary finger movement causes the tone effect 250 ms after. (B) Action-binding represents the temporal attraction of finger movement time towards the tone onset in *operant-M* relative to *baseline-M*, while effect-binding represents the temporal attraction of the tone onset time towards the onset of finger movement in *operant-T* relative to *baseline-T*.

### Apparatus and procedure

The experiment followed the procedure introduced by Haggard et al. (2002) as shown in **Figure 3-4-1**. Participants sat in front of a monitor and performed two baseline condition tasks (*baseline-M* and *baseline-T*) and two operant condition tasks (*operant-M* and *operant-T*) in a pseudo-random sequence. They were asked to report either the first moment of their finger movement (m-time) or the onset time of the tone (t-time). Each task contained forty trials.

In *baseline-M*, an analogue clock (visual angle, 3° in diameter) was presented in the center of the screen. A clock-hand appeared after a short period (of 1 to 2 s delay) and started rotating clock-wise with a revolution period of 2,550 msec. Participants were asked to perform a voluntary movement (pressing the left mouse button) whenever they wanted to, but not earlier

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than after one full rotation of the clock-hand. After the button press, the clock-hand continued rotating for a short interval (between 1 to 2 s) and disappeared. Participants were then asked to indicate with the mouse pointer the clock-hand position on the clock circle at the moment when they started to move their finger to press the button. The *operant-M* condition was identical to the *baseline-M* condition apart from the fact that a 500 Hz tone (presented for 100 msec) followed the button press after a delay of 250 msec. The *operant-T* condition was identical to the *operant-M* condition, but participants were asked to indicate the onset time of the tone instead of the movement onset. In the *baseline-T* condition, participants performed no voluntary button press. Instead, a tone occurred at random times between 2.6 and 7.7 sec after the clock-hand started rotating. After the tone, the clock-hand continued rotating for a short interval (between 1 and 2 sec) and then disappeared. Participants were then asked to indicate the clock-hand position of the tone onset.

Because of EEG recordings (see below) participants were asked to focus on the center of the clock and to refrain from eye blinking during clock-hand rotation. Presentation of the clock and collection of the response data were performed by the E-Prime 2.0 software (Psychology Software Tools, USA). Before the experiment started, participants performed two blocks of a Libet-type task, which will be reported elsewhere, and then performed a few trials of practice for each task condition.

#### **Electrophysiological recordings**

EEG was recorded from a Quickamp amplifier using 64-channel active electrodes (Brain Products, Germany) in an acoustically and electromagnetically attenuated chamber. Ground electrode was placed on the forehead and an initial reference was placed at P9 according to the 10-20 system. Electrode impedance of all electrodes was kept under 5 k $\Omega$ . One channel electrooculography (EOG) was recorded to detect ocular artifacts. To estimate the onset of finger movement, a single axis accelerometer (1.7 g) was placed on the left mouse button to measure the exact onset time of the movement. All electrophysiological data were recorded at a sampling rate of 1,000 Hz.

Pre-processing of data was performed with the help of EEGLAB version 12.02 (Delorme & Makeig, 2004). EEG records were down sampled to 250 Hz and re-referenced to linked mastoids. A band-pass filter from 0.01 to 45 Hz (zero-phase filter with -6 dB cutoff) was applied. Continuous EEG data was segmented into event-locked epochs ranging from 2.5 sec before the event, either the onset of the button press or the tone, to 1 sec after the event with

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baseline correction of the first 200 msec. Epochs affected by artifact ( $\pm 100 \mu\text{V}$ ) of any electrodes except ocular movement were excluded for further analysis. Remaining ocular artifacts were then corrected using independent component analysis (ICA). The trials with a button press during the first rotation of the clock-hand were also excluded. On average, 92.7 % (SD = 8.6) epochs were analyzed.

Event-related EEG was measured as average over the nine electrodes around Cz (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2). The signal was baseline corrected for a time point -2.5 sec prior to the button press. The amplitude of the RP was then quantified calculating the mean signal during the period from -0.2 to 0 sec before this button press (or before the tone onset for *baseline-T* task). Next, the RP was divided into an early and a late component (see **Figure 3-4-2**). We calculated separate slopes for the each part of the RP. The late RP slope was computed by dividing the amplitude difference between the mean from -0.7 to -0.5 sec and the mean from -0.2 to 0 sec by 0.5 sec. Thereby we have divided the estimated increase of the amplitude during the last 0.5 sec by its duration. For the early RP we did the analogous calculation. Since the amplitude is by definition 0 at -2.5 sec the overall increase was estimated the mean amplitude from -1.0 to -0.8 sec and then divided by 1.5 sec, which is the duration of the early RP. In order to account for the slope of the early RP already contained in the late RP we finally subtracted the slope of the early RP from the late RP. By this procedure we can see whether there is an additional increase in the late RP compared to already ongoing trend.

To test whether ongoing potential shifts have different effects on temporal attraction, the slope of each epoch was estimated by fitting a first-order polynomial function to the average of nine electrodes before the events. According to either a negative or positive slope, each epoch was classified into either a negative or positive epoch, respectively, and then averaged for each subject.

#### **Data analysis**

Analysis of medians rather than of simple means was applied in the present study as recommended for the Libet-type experiment (Pockett and Miller, 2007). The m-time and t-time were subtracted from the actual movement and the tone onset times, respectively. Action-binding was calculated by subtracting m-time during *baseline-M* from *operant-M*, and effect-binding was calculated by subtracting t-time during *baseline-T* from *operant-T*. Overall-binding is computed by subtracting effect-binding from action-binding. The reported

times (i.e. m-time or t-time) and RP amplitudes were subject to a repeated measure ANOVA with type of reported time (m-time vs. t-time) and agency condition (baseline vs. operant) as within-subject variables, and the group (meditators vs. controls) as between-subject variables. Comparisons for matched pairs between groups were performed with paired t-test.

#### 3.4.3. Results

One control subject dropped out because of personal reasons. Therefore, comparison between groups was performed with nineteen matched-pairs. Meditators on average had meditation experience of 10.1 years (SD = 6.4) and in the last 8 weeks had on average meditated for 7.6 hours (SD = 5.2) a week.

#### Self-reported data

Scores of the self-report mindfulness scale revealed significant differences between the two groups (meditators,  $44.4 \pm 1.1$ ; controls,  $36.5 \pm 1.2$ ;  $t(19) = 4.991$ ,  $p < .001$ ), indicative of higher 'acceptance' (meditators,  $24.8 \pm 0.8$ ; controls,  $20.1 \pm 0.7$ ;  $t(19) = 4.670$ ,  $p < .001$ ) and 'presence' (meditators,  $19.6 \pm 0.4$ ; controls,  $16.4 \pm 0.6$ ;  $t(19) = 4.382$ ,  $p < .001$ ) in meditators. This result shows that meditators report themselves to be more mindful than controls.

#### Behavioral data: reported times

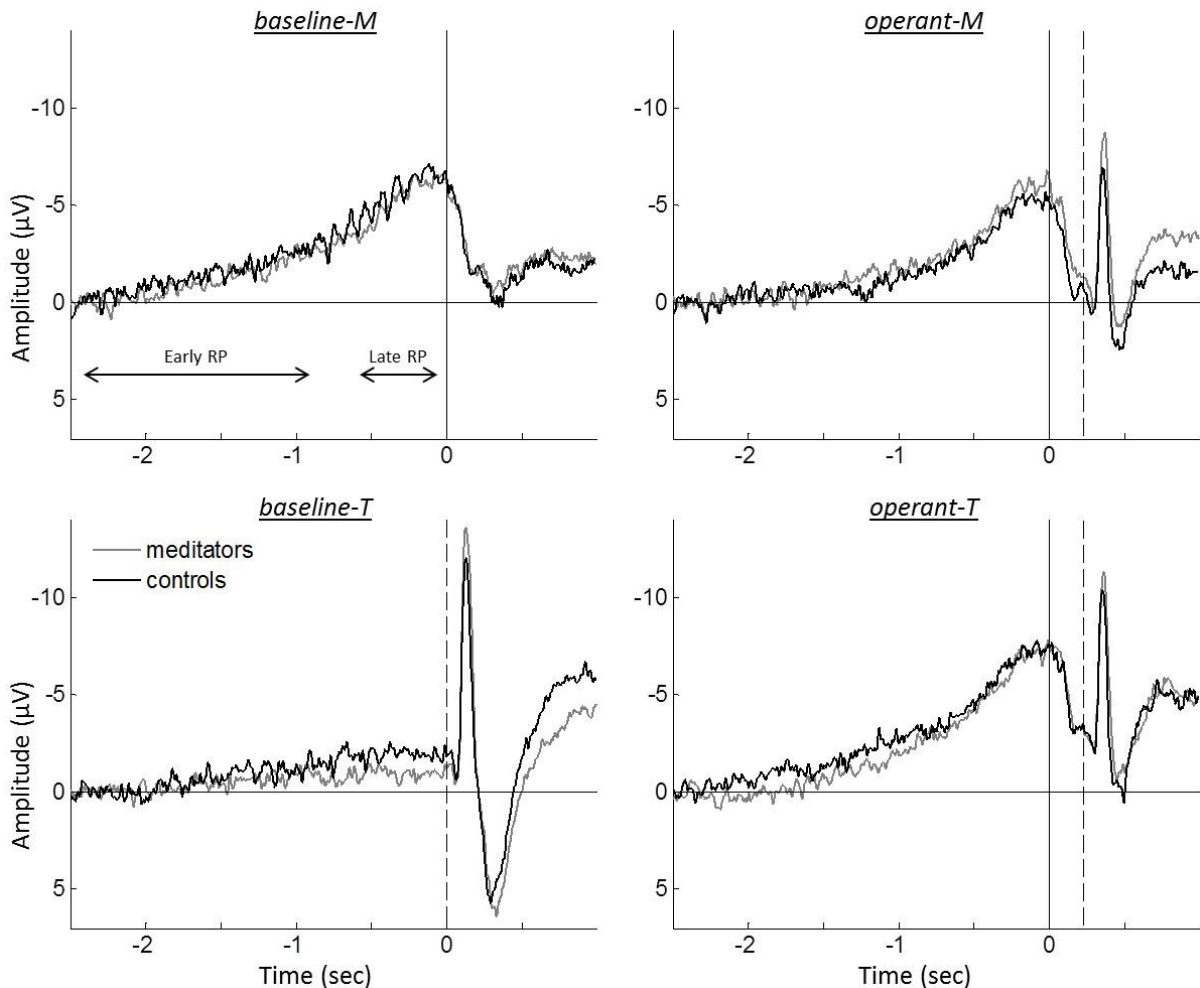
A repeated measure ANOVA analysis revealed a significant interaction between reported time (m-time vs. t-time) and agency condition,  $F(1,37) = 14.961$ ,  $p < .001$ . To clarify this interaction, we examined the temporal binding effects for reported times, see **Table 3-4-1**. The reported time of the tone was shifted towards action in comparison to the baseline condition ( $t(39) = -5.293$ ,  $p < .001$ ), showing effect-binding in 81.1 % of the participants. In contrast, we found no significant difference in m-time between *baseline-M* and *operant-M* ( $t(39) = 0.336$ ,  $p = .739$ ; action-binding being seen in 48.7 % of the participants). That is, overall-binding was driven mainly by enhanced shift of t-time towards action in the *operant-T* task.

Notably, we found neither significant group effect nor group by task interactions (ANOVA analysis, all  $p > .193$ ). Although on average we observed an earlier m-time in meditators than controls in both *baseline-M* and *operant-M* (see **Table 3-4-1**), further analysis of reported-times for all the tasks showed no difference between groups (two-tailed paired t-test, all  $p > .198$ ).

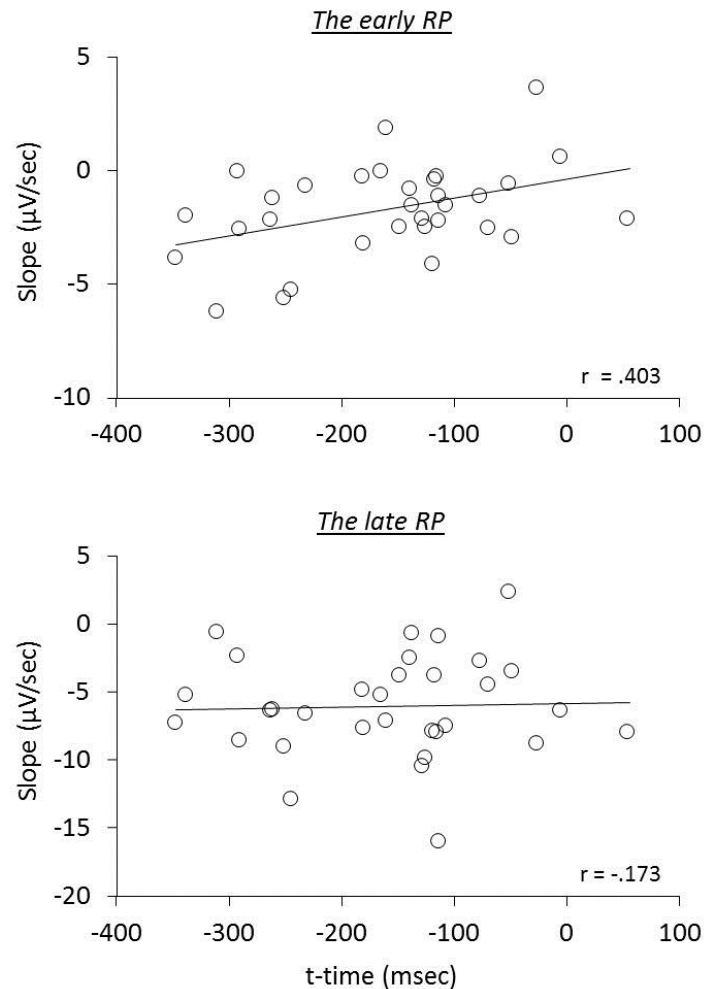
**Table 3-4-1.** Means of reported times and temporal binding effects during intentional binding tasks.

		meditators	controls	p-value	all participants
m-time	baseline	-68.35 (41.9)	-7.16 (24.0)	.198	-38.54 (24.6)
	operant	-66.30 (25.4)	-18.34 (28.5)	.248	-42.94 (19.2)
Action-binding		2.05 (26.8)	-11.18 (8.6)	.639	-4.40 (14.2)
t-time	baseline	-32.88 (11.3)	-32.40 (18.8)	.796	-32.64 (11.7)
	operant	-131.58 (27.6)	-122.82 (28.1)	.856	-127.31 (19.4)
Effect-binding		-98.70 (27.4)	-90.42 (23.5)	.774	-94.67 (17.9)
Overall-binding		100.75 (39.1)	79.24 (24.1)	.614	90.27 (23.0)

The m-time and t-time are obtained by subtracting the actual event time from reported time in msec (SE). Action-binding and effect-binding indicate the mean shifts in time from baseline to operant tasks for m-time and t-time, respectively. Overall-binding is the difference between effect-binding and action-binding. p-values were calculated based on nineteen matched-paired between groups.



**Figure 3-4-2.** Grand averaged event-related EEGs for meditators (gray traces) and controls (black traces), during intentional binding tasks. Solid vertical lines represent the onset of the finger movement, while dashed vertical lines indicate the tone onset. The division for the early RP and the late RP are represented by both-sided arrows.



**Figure 3-4-3.** The relation of the RP slopes to reported time of the tone during the *operant-T* task.

We also conducted a one-way repeated measure ANOVA on mean waiting-time (the time from the start of a trial to the button press) with the self-generated movement tasks (*baseline-M*, *operant-M*, and *operant-T*) as a within-subject factors and group (meditators vs. controls) as between-subject variables. It revealed no task effect ( $F(2,74) = 0.465$ ,  $p = .630$ ) and no group by task interaction ( $F(2,74) = 2.260$ ,  $p = .111$ ). The mean waiting-times across participants were 7.21 sec for *baseline-M*, 6.98 sec for *operant-M*, 7.06 sec for *operant-T*, and 5.06 sec for *baseline-T*.

### Neurophysiological data: event-related EEG

**Figure 3-4-2** shows the grand averaged event-related EEG for the different tasks. A repeated measure ANOVA analysis on the RP amplitudes revealed a significant interaction between the reported time and the agency condition,  $F(1,37) = 37.149$ ,  $p < .001$ . To further test this interaction, RP amplitudes were examined for reported times (i.e., m-time and t-time). While

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comparison between *baseline-M* and *operant-M* revealed no differences (*baseline-M*,  $-6.40 \mu\text{V} \pm 0.81$ ; *operant-M*,  $-5.66 \mu\text{V} \pm 0.73$ ;  $t(39) = -1.448$ ,  $p = .156$ ), *operant-T* showed higher amplitude as compared to *baseline-T* (*baseline-T*,  $-1.37 \mu\text{V} \pm 0.49$ ; *operant-T*,  $-7.19 \mu\text{V} \pm 0.75$ ;  $t(39) = -7.330$ ,  $p < .001$ ), indicating absence of the RP in *baseline-T*. However, we found neither significant group effect nor group by task interactions (ANOVA analysis, all  $p > .260$ ), displaying no difference for each task (two-tailed paired t-test, all  $p > .371$ ). Since we found no difference between groups in both behavioral data and EEG recordings, we pooled all participants for further comparisons of the tasks.

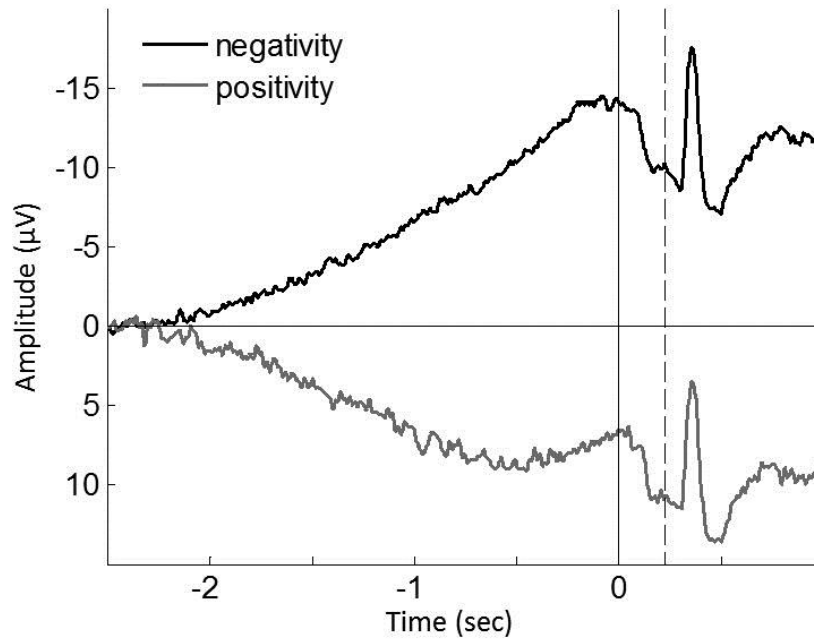
We next examined the relation of reported times to RP components, i.e. whether the early neural activity before the action influences the temporal attraction. A significant correlation was found in the *operant-T* condition, namely that the more negative the early RP, the larger the shift of t-time towards action ( $r(32) = .403$ ,  $p = .022$ ; seven participants, including three meditators, who showed no effect-binding were excluded). However, we did not find this correlation in the late RP ( $r(32) = -.173$ ,  $p = .345$ ; see **Figure 3-4-3**). Notably, no significant correlations in the other three tasks were found regarding both the early and the late RPs (all  $p > .215$ ), indicating the specificity of results for the *operant-T* condition. This result suggests that the perceived time of the consequent effect is related to the neural processes of the early RP, but not with the late RP.

To further test this implication, each single trial of the individual participants was classified regarding having a negative or positive slope of the epochs, and then averaged (**Figure 3-4-4**). In agreement with the previous study (Jo et al., 2013), we found a significant correlation of the ratio of positive epochs with the early RP slope (*baseline-M*,  $r(39) = .590$ ,  $p < .001$ ; *operant-M*,  $r(39) = .644$ ,  $p < .001$ ; *operant-T*,  $r(39) = .802$ ,  $p < .001$ ; see **Figure 3-4-5**), demonstrating that smaller portions of positive epochs are related to larger negative early RP. However, we observed no correlation with the late RP (*baseline-M*,  $r(39) = .272$ ,  $p = .094$ ; *operant-M*,  $r(39) = .224$ ,  $p = .171$ ; *operant-T*,  $r(39) = .051$ ,  $p = .758$ ). That is, the ongoing potential shifts are specifically related to the early part of the RP. We then performed paired t-tests to compare reported times between ongoing negative and positive slope epochs, and found a significant difference in the *operant-T* condition (negative,  $-131.8 \text{ msec} \pm 19.2$ ; positive,  $-117.8 \text{ msec} \pm 19.2$ ;  $t(39) = 2.370$ ,  $p = .023$ ). The shift of t-time towards action was larger in negative slope epochs as compared to positive ones. This supports the relation that more negative amplitudes result in stronger effect-binding. Importantly, however, we did not find the difference in the other three tasks (*baseline-M*,  $t(39) = 0.079$ ,  $p = .937$ ; *operant-M*,

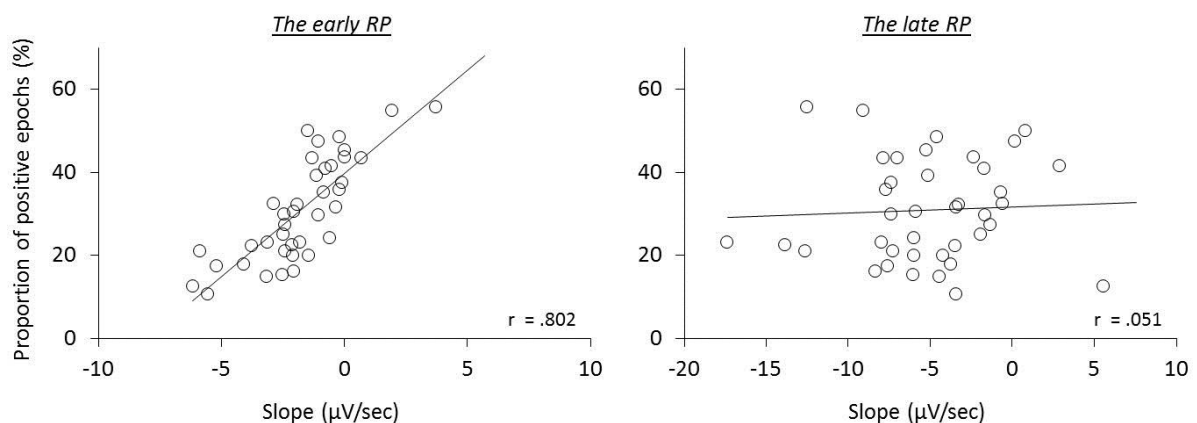


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$t(39) = -0.510, p = .613$ ; *baseline-T*,  $t(39) = -0.681, p = .500$ ), indicating that neither the reported time of action nor the effect that is isolated with intentional action was different between negative slope epochs and positive ones. Taken together, these results provide evidence that the early neural activity affects the perceived time of a sensory outcome that is caused by intentional action.



**Figure 3-4-4.** Grand averaged ongoing negative potential (black trace) and positive potential (gray trace) during the *operant-T* task. Solid vertical line represents the onset of the finger movement, while dashed vertical line indicates the tone onset. The shift of perceived time of the tone towards action was increased in ongoing negativity ( $p = .023$ ; see the text). The grand mean of the proportion of positive epochs is  $30.91\% \pm 2.0$ , which results in prolonged ongoing negativity in the early RP (see **Figure 3-4-5**).



**Figure 3-4-5.** The relation of the proportion of ongoing positive epochs to the RP slopes during the *operant-T* task.

#### 3.4.4. Discussion and conclusion

In the present study, we aimed to investigate (i) the RP correlates of the intentional binding effect and (ii) to explore these correlates in experienced meditators compared to non-meditating controls. The latter comparison did not yield any significant effect, neither in the behavioral data nor in the neurophysiological ones. On the other hand, we found that the early neural activity correlates with reported time across all participants. This finding adds to the current discussion on the underlying neural mechanisms of the sense of agency.

It is of interest that we could replicate only effect-binding but not action-binding, the latter having been shown in several other studies (Dogge et al., 2012; Wolpe et al., 2013; Barlas & Obhi, 2013). This lack of replication might be explained by the following facts: Firstly, in the present study participants were asked to report ‘the first moment of their finger movement’ rather than the time they pressed the button. Secondly, participants were asked to gaze at the center of the clock and refrain from eye-movement, i.e. they did not trace the clock-hand movement. These two aspects have been demonstrated to significantly affect the perceived time of the events in Libet-type experiments (Pockett & Miller, 2007). Nevertheless, it is important to note that a much stronger effect-binding compared to action-binding, as found here, has been consistently shown in many other studies (e.g., Haggard et al., 2002; Stroher et al., 2010; Moore et al., 2010; Aarts & Bos, 2011; Moore et al., 2012; Barlas & Obhi, 2013; Yoshie & Haggard, 2013). One explanation of this typical finding in intentional binding studies could be that participants feel a stronger sense of agency when they are asked to focus on the consequent effect rather than focusing on the action.

Regarding the RP amplitude, we found that individuals who showed a larger negative amplitude of the early RP had a higher shift of reported time towards the action (effect-binding) in the condition when participants needed to focus on the consequent effect. Consistent with this result, the ongoing shifts of the SCP within participants had a significant influence on this type of reported time, with negative slopes of the early RP being related to a larger shift towards action. Importantly, these results were only found in the *operant-T* condition, demonstrating that the early neural activity prior to movement plays a significant role in the consequent effect especially with respect to the sense of agency. Since the early RP has been related to activity in the pre-SMA (Shibasaki & Hallett, 2006), our results showing that effect-binding is specific to the early RP, but not the late RP, support the previous study by Moore et al. (2010). They reported that the transient disruption of pre-SMA using TMS showed a reduced effect-binding but not a reduced action-binding. Notably, the disruption of

contralateral sensorimotor areas, which have been discussed as providing the source of the late RP, had no significant influence on temporal binding. In other words, if the pre-SMA activity had a facilitating effect, enhanced temporal attractions would be expected as a result of increased effect-binding. Overall, the present data represent the first direct evidence that the early RP plays a crucial role in the temporal attraction contributing to the effect-binding.

Notably, we found that trial-to-trial variability of the ongoing shift of SCP determined the *t*-time even when the physical condition was held constant, i.e., within the *operant-T* task. While ongoing brain fluctuation was shown to affect intrinsic motor behavior (Fox et al., 2007; Jo et al., 2014) and the early RP could reflect ongoing fluctuating SCPs (Schurger et al., 2012; Jo et al., 2013), this observation raises the possibility that temporal attraction occurs differently in dependence of the status of spontaneous brain states. Additionally, one can assume that preceding brain activity has a stronger influence on effect-binding when the action is intrinsically generated rather than triggered by external imperative stimuli. For instance, stronger effect-binding was reported in the voluntary action condition as compared to an involuntary action, though inducing the belief of self-causation could modulate the effect-binding (Dogge et al., 2012). There is strong evidence indicating that negative deflections of the spontaneous fluctuating SCPs are associated with an increasing probability of neural firing (Birbaumer et al., 1990). Therefore, an action is more likely to be executed during negative shifts of the SCP. In line with this, it has repeatedly been found that a conscious intention to act could arise more likely during an ongoing negativity of the SCP, which on average results in an increased negative RP (Schurger et al., 2012; Jo et al., 2013, 2014). Within this context, the present result of the relation between the early RP and the *t*-time further suggests that if a voluntary action follows an ongoing negative potential of SCP it will more likely lead to temporal attraction of the consequent effect than with positive deflections. That is, the neural representation of conscious intention to act, ongoing negative potentials of SCP, might be associated with an enhanced sense of agency by predicting possible consequent effects of action.

There is increasing evidence that the experience of agency is generated by both predictive and postdictive processes (Synofzik et al., 2013). Regarding predictive processes, the intentional motor representation before an action is related to the experience of agency for the given action. Regarding postdictive processes, anticipation of an action's outcome and the intention-outcome matching play the crucial role for inferring self-agency (Wegner & Wheatley, 1999). Although, many studies have repeatedly found these both effects in intentional binding

(Moore & Obhi, 2012), there is still ongoing debate on whether temporal attraction is specific to intentional movement or a property of general causality perception between action and outcome (Buehner, 2012; Buehner & Humphreys, 2009). For instance, causality perception between action- and outcome-synchronized auditory signals modulated the intentional binding effect (Kawabe et al., 2013).

In the *baseline-T* condition, we observed a slightly negative amplitude. But since there is no action preceding the tone no amplitude should be expected. A possible explanation could be that participants might have anticipated the external event. For instance, if participants learned the temporal expectancy of events, expectancy-related CNV (contingent negative variation) keeps rising until the time point of the expected event is reached even when no motor preparation is involved (Mento et al., 2013). Although the occurrence of the tones varies within an interval of 5 sec, similar explanations can be applied to the result presented in the *baseline-T* condition. It should be noted, though, that the results of this task showed neither relation between event-related EEG and t-time nor differences in t-time between negative and positive epochs. Thereby one can conclude that the relation of ongoing potential shifts to t-time during *operant-T* are not likely due to temporal expectancy of the tone that is isolated from the sense of agency.

Although EEG recordings allow the examination of neural correlates with high temporal resolution, the temporal brain dynamics underlying human agency is not well understood (David, 2012). Several studies have observed that the brain predicts the sensory consequence of an action. The N1 amplitude was smaller in predictive sensory outcome when it was self-generated as compared to computer-generated feedback (Schafer & Marcus, 1973; Gentsch & Schütz-Bosbach, 2011; Hughes et al., 2013). Thus, N1 attenuation has been discussed as an indicator of the forward sensory model that combines self-generated motor commands and sensory information processes to predict sensory outcome. The same mechanism seems to hold in the intentional binding paradigm, as we observed sensory attenuation for the tone-evoked N1 that was self-generated (*operant-M* and *operant-T*) as compared to computer-generated (*baseline-T*; see **Figure 3-4-2**). However, the possibility cannot be ruled out that event-related EEG of the button press might affect the N1 amplitude.

One curious result of the present study is that the *operant-M* condition showed a lower RP amplitude as compared to the *operant-T* condition ( $p = .015$ ), although both conditions contain the same action and the same consequent effect but differ in the reporting task. It can be speculated that in the different conditions participants might have changed their subjective

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criteria for performing a voluntary button press. Indeed, several participants reported that they tried to disregard the tone effect following their action in the *operant-M* condition. It could be that the consequent tone after the button press was seen as distractor since participants did not need to focus on it.

Regarding the group comparison, we found no differences between mindfulness meditators and controls. Meditators and controls showed the same temporal attraction in effect-binding and no action-binding. With respect to event-related EEG, no significant difference was found in the RP amplitudes for the entire tasks. We also examined whether there was any ongoing potential shift and early RP-related group differences, and found no group effect. It is possible that the selection criteria were not strong enough to recruit individuals who had sufficient experiences of mindfulness meditation. Although the FMI scores showed strong differences between groups, conceptual difficulties in the meaning of ‘mindfulness’ and also comprehension disagreements of questionnaire items (Belzer et al., 2013) have led to doubts of whether it is possible to assess the experience of mindfulness through self-report items (Grossman, 2008). Thus, the self-report measure might not differentiate between ‘levels’ of mindfulness but differences found here might describe different levels of conceptual knowledge. Another possible explanation is that meditators may have performed the task by focusing on their perceived time rather than the actual event time. For instance, we observed earlier m-time in meditators than controls in both *baseline-M* and *operant-M* conditions (see **Table 3-4-1**), though it revealed no significant difference. It might be that meditators reported the moment of ‘intention’ to act, which is shortly before the actual movement onset. Therefore, further work may concern the possible divergences of subjective criteria, whether focusing on perceived-events or actual events.

In conclusion, our results do not support the hypothesis that mindfulness meditators would display different performance on the intentional binding paradigm as compared to controls. However, the present findings of the early RP correlates with the temporal attraction shed light on the underlying neural mechanism of human agency. Our results suggest that the early neural activity within the range of ongoing potential shifts affects the perceived time of the sensory outcome that is caused by intentional action.

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Free will is a perennial and challenging problem that is still being debated by many philosophers, psychologists, and neuroscientists. Even the definition of what voluntary acts in behavior are, and under which conditions we believe in having control, leads to many philosophical issues. The present thesis contributes to this discussion on how a voluntary action emerges, by providing empirical evidence regarding the neural correlates of intentional processes in conjunction with subjective experiences. The brain processes giving rise to the conscious intention to act and the implications of the present findings will be discussed.

Although many empirical studies support Libet's findings (see 1.3.3. State of neuroscience research), all the results are dependent upon the accuracy of the participants' subjective reports, i.e. their introspective capabilities. That is, the Libet experiment relies on the self-reported timing of one's intention to move. The potential inaccuracies in reporting the precise time of an intention may lead to misinterpretations (Pockett & Miller, 2007; Danquah et al., 2008; Miller et al., 2010). Indeed, participants find it difficult to keep their attention focused when asked to report the precise time of their intention (Study 2; Lau et al., 2004). Thus, many researchers see the subjective reports of mental processes as one of the larger problems challenging the reliability of these results (Nisbett & Wilson, 1977).

However, while most researchers try to minimize the impact of potentially flawed subjective reports, we proposed an alternative strategy. Since research efforts are all concerned with the subjective experience of free will, we cannot dismiss introspection, but rather have to try to improve its reliability. Recently, Frith (2013) emphasized the distinction between the third-person view and the first-person view on voluntary behavior. Since voluntary behavior is internally generated, voluntary behavior cannot be fully examined and, therefore, might not be understood from an outside observation (i.e. from the third-person perspective). Taking into account the first-person perspective (e.g., individual experience of action and experience of self-agency, which cannot be observed independently) could provide explanations of unique aspects of volitional behavior. These two first- and third-person perspectives on volition could provide different stories about volitional behavior, and both together in parallel could promote recent discussions on volition.

An avenue to gain more reliable subjective reports regarding the precise moment of a decision is to work with trained experts in meditation with a long history of meditative practice (see 1.4.2. Contemplative practice: an approach to studying inner experience). Meditators have increased attentional control (Valentine & Sweet, 1999; Chan & Woollacott, 2007; Lutz et al., 2009; MacLean et al., 2010; Sahdra et al., 2011), report more accurately their body sensations

(Fox et al., 2012; Mirams et al., 2013, for a contrary result see Khalsa et al., 2008) and mental experiences (Nielsen & Kasznik, 2006), as well as showing more coherence between physiological signals and emotional content (Sze et al., 2010). Given these results, we assumed that an experienced meditator who has trained in contemplative practice for many years can give more reliable first-person perspective accounts, since s/he would have developed enhanced capacities of keeping his or her attention stable on a certain experience; moreover, s/he has a more refined awareness of sensing and differentiating internal processes (Brown & Ryan, 2003; Lutz et al., 2007). Furthermore, these findings also strengthen the view that meditation experience enhances the capability of keeping one's attention consistently focused on a task that requires full attention, as this is the case in the Libet experiment. We hypothesized that these enhanced capabilities of experienced meditators can contribute to our understanding of the neural underpinnings of voluntary acts. We therefore attempted to address underlying neural mechanisms of voluntary movement by exploring these issues with an expert meditator and several other experienced meditators combining the first-person and the third-person perspective.

### **4.1. Summary of The Empirical Findings**

One crucial experimental question posed by the Libet experiment is whether the onset of the recorded RP is a valid indicator of the time when cerebral processes begin to produce an action (Libet, 1985). Recent reports studying Libet's experimental setup have revealed the occurrence of negative potential shifts in conditions other than movement preparation (Trevena & Miller, 2010; Miller et al., 2011). Moreover, the shape of the RP was fitted to a stochastic accumulator model, suggesting that the RP might be merely an average of spontaneous fluctuations in neural activity (Schurger et al., 2012). To address this question, we first investigated the effects of spontaneous SCPs on the RP by sorting the ongoing potential shifts before the button press into negative and positive shifts, and compared these shifts between a self-initiated movement condition and a no-movement condition.

Study 1 demonstrated how an apparently negative RP emerges through an unequal ratio of negative and positive potential shifts preceding self-initiated movement. We investigated ongoing potential shifts prior to the events of movement onset (W-task) and a simple tone presentation (T-task) with no movement. The ongoing potential shifts were compared within task and between tasks. In the W-task, we observed no difference of shape between the ongoing negative and positive potential shifts in the early RP. In addition, these two potential shifts showed the same pattern as in the T-task, in which participants were asked to refrain



from a movement. However, we observed difference ratios of negative and positive shifts between the W-task and T-task, which results in different shapes of the RP. Given these results, it is clear that the unequal ratio of ongoing potential shifts of SCPs has a significant effect on the RP amplitude.

This finding challenges the common interpretations of Libet's experiment. Do participants actually perform a volitional movement during the task? Participants may be waiting for an upcoming feeling of the intention to act and then perform a movement according to this feeling rather than carry out a "voluntary" movement. In other words, an individual who has focused attention on internal events (Keller & Heckhausen, 1990) or has more awareness of his or her inner activity might press the button more often during negative deflections of SCPs, resulting overall in larger RP amplitudes. In this view, attention to intention of movement may lead a participant to sense the negative deflections of SCPs that might be influenced by the experimental paradigm (Birbaumer et al., 1990).

Therefore, for the next study, we investigated how brain activity is related to the conscious awareness of an intention to act. A critical question would be to assess the subjective experience during the transition from pre-conscious processes to conscious awareness. To investigate the underlying mechanisms of these intentions, we further studied task-related brain activity in conjunction with first-person reports of an expert meditator. In Study 2, we took an innovative methodological approach in the study of the Libet task. Working in an iterative process with a well-trained meditator we were able to demonstrate an impressive correspondence between personal accounts and third person EEG data for this person (see below).

The first-person reports obtained from an expert meditator (TL) suggest that when asked to perform a self-initiated movement the according decision process consists of two parts. One would be to identify and take up an inner tendency to act (sensing the inner impulse), the second one would be to give this inner tendency the 'full permission' to perform the action. We were able to demonstrate that the first part shows strong correspondence to the third-person data of SCP fluctuations. On the basis of this neurophenomenological approach with an expert meditator it is suggested that: (i) the larger RP amplitude is attributed to frequent occurrences of self-initiated movement during negative deflections, and (ii) these negative deflections of SCPs are correlated with an inner event, which may in turn lead to a voluntary action. For the second part, the 'full permission', so far no corresponding neural signal could be identified. But also here TL's description is consistent with existing third person data, e.g.

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the so called veto experiments (Brass & Haggard, 2007; Libet et al., 1983b). Haggard (2008) presented a naturalized model of human volition. This includes a ‘late whether decision’ similar to TLs description, which can block or enable the action execution in the very last moment.

In Study 3, we were able to demonstrate that the performance in the Libet task is highly dependent on whether an observer pays attention to his or her inner processes. It revealed that the instruction of the introspective task served well for the meditators. They were able to observe introspectively upcoming inner impulses, which seems to be related to the fluctuating SCP (Study 2). They were then also able to transform these upcoming impulses into voluntary actions. On the other hand the controls did not benefit from the introspective task instruction. They might have rather spent higher processing demands on thoughts about their inner processes and thus could not act according to the negative SCP deflections. This could have led to more actions during positive SCPs in non-meditators. This might have resulted in a diminished early RP and a weaker correlation between w-time and the early RP slope in controls. While meditators due to their regular practice are most likely well acquainted with observing internal processes without interfering with them too much, it seems likely that controls got distracted or even confused by the more specific instruction. Compared to the observing *mode of direct experience* of the meditators, controls might have entered a more *cognitive elaborative mode*, although this specific interpretation needs to be further researched in a follow-up study. In line with this position, previous studies have suggested that experienced meditators provide more accurate first-person reports on their inner processes than novices (Fox et al., 2012; Mirams, et al., 2013; Nielsen and Kasznik, 2006; Sze et al., 2010). This view supports the results of previous studies (Jo et al., 2014a; Garrison et al., 2013a, b) that experienced meditators are suitable participants for the difficult task of relating introspective first person data with third person measurements (i.e., neurophenomenology).

In Study 4, we found that individuals who showed larger negative amplitudes of the early RP had a higher shift of reported time towards the action (effect-binding) in the condition when participants needed to focus on the consequent effect. Consistent with this result, the ongoing potential shifts of SCP within participants had a significant influence on this type of reported time, with negative slopes of the early RP being related to a larger shift towards action. Importantly, these results were only found when participants are attending to the self-generated consequent effect, demonstrating that the early neural activity prior to movement

plays a significant role in the consequent effect especially with respect to the sense of agency. The current finding of the relation between temporal attraction of the consequent effect and the early RP, but not with the late RP, suggests that the emergence of an intention to act affects intentional binding later on.

Notably, we found that trial-to-trial variability of the ongoing potential shifts of SCP determined the t-time even when the physical condition was held constant. The present result of the relation between the early RP and the t-time further suggests that if a voluntary action follows an ongoing negative potential of SCP it will more likely lead to temporal attraction of the consequent effect than with positive deflections. That is, the neural representation of conscious intention to act, reflected by an ongoing negative potential of SCP, might be associated with an enhanced sense of agency by predicting possible consequent effects of action. Taken together, the results of Study 4 suggest that the early neural activity within the range of ongoing potential shifts affects the perceived time of the sensory outcome that is caused by intentional action.

#### **Concluding remarks**

The present thesis enables a new perspective on the underlying neural mechanisms of intentional processes. The finding provides evidence that (i) the emergence of a conscious intention to act is associated with ongoing negative deflections of SCPs, which over several trials leads to the seemingly building up of the RP. In addition, (ii) execution of voluntary movement during this ongoing negative deflection enhances the sense of agency via temporal attraction between intended action and outcome. Finally, the finding suggests that (iii) first-person experiences, i.e. phenomenal states, reported by experienced meditators contribute to our understanding brain mechanisms and free will.

#### **4.2. Antecedent Brain Correlates to Action Control**

The cognitive processes of action control have often been investigated with experimental paradigms of response inhibition, describable as the suppression of actions and they have frequently been investigated with Go/No-go paradigms (for reviews see Chambers et al., 2009 and Huster et al., 2013). Participants are required to respond with high frequency to one sort of stimulus (the Go signal) while they are instructed to withhold responses to a second type of stimulus (the No-go signal). Failed inhibition occurs if the participant produces a response to the No-go signal. Event related brain activities time-locked with the stimuli are distinct between response and response inhibition. Typically, these evoked brain activities have been

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of interest, because they are assumed to be direct indicators of inhibitory processes. Growing evidence suggests that the pre-SMA, which contributes to motor planning, is crucial for response inhibition in the Go/No-go task paradigm (Simmonds et al., 2008).

Numerous studies employing these Go/No-go paradigms have demonstrated functional networks of neural processes with a focus particularly on the brain activity that emerges after the cueing stimulus when participants decide whether to respond or not. However, in recent years, converging evidence has implicated that intrinsic and ongoing neural fluctuations play an important role for action initiation (e.g., Fox et al., 2007; Misirlisoy & Haggard, 2013; Schurger et al., 2012). In line with this view, the present studies demonstrated an association between the subjective experience of an intention to act and ongoing SCPs. We showed that the experience of inner impulses, intentions or urges to act is paralleled by ongoing negative potential phases of SCPs, and thus, the emergence of this experience favors an action in the near future. In addition, recent studies have shown that self-controlling behavior measured by delaying an action occurred more likely during relative positive potential shifts (Filevich et al., 2013). Moreover, relative positive deflections of SCPs, which overall lead to smaller negative RP amplitudes, seem to be associated with a decision process to withhold an action (Misirlisoy & Haggard, 2013), suggesting the absence or a diminished degree of impulses as compared to when relative negative deflections are recorded.

From these recent findings, it seems that action control is not only attributable to task-related cognitive processes, but is also related to the ongoing spontaneous fluctuations of neural activity. It seems that there are more appropriate and less appropriate brain states for action initiation. However, the association between ongoing antecedent neural fluctuations and response inhibition remains unclear since it has not been systematically investigated so far. Thus, further studies on different behavioral responses in the Go/No-go task are of interest regarding the functions of ongoing neural fluctuations. Because an action is more likely initiated during ongoing negative deflections of SCP as has been shown in the present studies, it is presumed that negative deflections of SCP might be associated with false positive responses, while positive one might be associated with false negative responses. Accordingly, Heinrich et al. (2004) have previously reported that SCP self-regulation training in children with attention deficit hyperactivity disorder (ADHD) led to a decrease of impulsivity errors and an increase of the CNV in a continuous performance task. It seems that after SCP training they were more able to allocate or regulate neural resources (SCP) that might have improved self-regulatory capacities of behavioral responses.

### 4.3. Conscious Will to Act

People's philosophical view about free will has a profound impact on people's attitudes to moral responsibility, which has functional aspects with respect to social behaviors (see 1.2.1. Belief in free will). People in general conceptualize human free will and moral responsibility as a psychological concept, which involves choice in alignment with desire, rather than a metaphysical concept, in which free will involves a soul as an uncaused first agent (Monroe et al., 2014). That is, the folk concept of free will is generally grounded on psychological capacities. But the folk concept of psychological capacities can be constrained when human behaviors are related with neurological and chemical processes (a mechanistic view). It has been repeatedly shown that exposure to such scientific claims, which induce disbelief in free will, is influential in social attitudes and moral behaviors (for a review see Schooler, 2010). In other words, our philosophical concept of free will and social behaviors is highly relevant to our scientific understanding of free will.

Although, the interpretation of Libet's finding is still in dispute, it has been widely considered within the neurosciences that freely willed action is initiated from a specific neural activation in the brain (the RP) rather than conscious will. Related, the sense of having free will seems to be an illusion and thus it seems that conscious will has no role in a 'willed action' (alternatively, it has been argued that "free won't" is the basis of our freedom, see 1.3.2. Free won't). However, the present studies raise a question of whether the RP is actually a necessary and sufficient condition for an action initiation. Firstly, Study 1 and 4 showed that a voluntary action occurred not only after negative potential shifts but also after positive potential shifts of SCPs (Jo et al., 2013, 2014b). About 30% of voluntary actions occurred during positive deflections of SCPs. This finding implies that the RP (at least the early part of ongoing negative potentials) would not be a necessary condition for a voluntary action. Secondly, RP-like ongoing negative potentials that are not followed by an action are also found as has been shown in Study 2 (Jo et al., 2014a; Vinding et al., 2014), suggesting that ongoing negative potentials might not be a sufficient condition of the action. Instead, the form of the negative ongoing RP might be an averaging artifact of ongoing neural fluctuations (see **Figure 1-3-2**).

These two examples demonstrate clearly that a plausible causal effect of voluntary action cannot be limited to the RP although it is correlated with immediately following action. Given the empirical results in the present thesis, we rather suggest that the ongoing negative potential is associated with the emergence of conscious experience of will (or intention) to act,

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and thus, makes a voluntary movement in the near future more likely. In other words, the ongoing negativity of SCPs facilitates an action, but it itself does not determine whether one is committing an action. Put another way, feeling hungry is obviously correlated with eating, but it does not mean that hunger itself is a decision-making process to eat. Instead, hunger leads to a higher probability of a decision to eat.

Another concern of the present findings is the possible influence of mental training on our daily lives. Meditation based training develops and improves levels of mindfulness that refers to the ability to maintain attention to the experience of the present moment in a non-judgmental fashion (Kabat-Zinn, 2003). This includes monitoring the quality of attention and immediate awareness of affective states and thoughts. In agreement with this view, the finding of Study 2, 3 as well as other recent evidence (e.g., Fox et al., 2012; Garrison, et al., 2013a) suggest that meditation training could allow for enhanced introspection about present moment experiences (see also 1.4.2. Contemplative practice: an approach to studying inner experience).

The capacity for directly observing the willing of an act (an interpretation of one's thought as the cause of the act) contributes to the build-up of self-consciousness. However, converging empirical evidence casts doubt on whether conscious processes cause the action. A movement is often initiated while the mind is wandering or one is thinking about something else (Schneider et al., 2013), and thus participants are often even not aware of having moved (Keller & Heckausen, 1990). What happens if participants then *see* their own action (a button press in this case)? This situation necessitates a proper explanation. In the brain the mismatch between the absence of conscious intention and a movement obviously caused by one has to be processed. In this case, it might be possible that participants infer their experience of intention after the execution (Lind et al., 2014; Nisbett & Wilson, 1977; Johansson et al., 2005). Indeed, a study showed that participants inferred the intention time according to apparent auditory feedback rather than to conscious awareness of the intention (Banks & Isham, 2009). Moreover, stimulating the SMA using transcranial magnetic stimulation (TMS) after action execution shifted the perceived intention time (Lau et al., 2007), suggesting that certain neuronal processes *after* an action has been made could influence the perceived intention time (Rigoni et al., 2010).

In agreement with this view, the findings in Study 3 suggest that the capability of being aware of intentional processes to act is usually poor and unreliable (as can be seen in control subjects). But, it also suggests that it is likely possible to enhance the capability for accessing

the intentional processes by carrying out specific mental practices consisting of being mindful (as the results of experienced meditators; see also Study 2). Experienced meditators due to their regular practice are most likely well acquainted with observing internal processes with effortless awareness and that might have fundamental effects on performing a voluntary action in daily lives.

#### **4.4. Neuroscience Beyond The Problem of Free Will**

The debates on free will highly focus on the questions whether “determinism is true” and whether “free will is compatible with determinism” (Kane, 2011). This in turn means that the most straightforward scientific challenge to the problem of free will would be the discovery of either the truth or the falsehood of determinism (Nahmias, 2010). Scientific experiments might provide evidence for the truth or falsehood of determinism, i.e. in the false case the truth of indeterminism, which is claiming that every event is related to chance and thus any event is unpredictable. In any case, however, empirical findings might be not favorable to the existence of free will (see 1.1.1. The problem of free will).

Since the basis of scientific approaches entails the position that all events are the necessary consequence of pre-existing events, this seems to favor determinism. The concept that all effects in nature are of causal nature is the basis of every science. However, a closer inspection reveals that the idea of a causality as the only effect mediator is an unproven presupposition (Walach & Schmidt, 2005). Furthermore, it should be noted that certain deterministic systems (e.g., chaotic dynamics) have appeared to be irregular or to show random behavior, and are highly sensitive to initial conditions (for an overview see Werndl, 2009). Due to exponential or rapid divergence of solutions, it is impossible to determine the outcome of the system from any bundle of initial conditions (e.g., the butterfly effect). This means that every event is not necessarily predictable by past events even in deterministic system and researchers speak here on ‘deterministic chaos’ (Atmanspacher, 2000). Also in quantum mechanics it is shown that, within a deterministic framework, unpredictable events take place. While for e.g. the Schrödinger equation gives the exact probability for the behavior of a quantum mechanic system to show several outcomes for a set of events, it cannot be predicted the outcome of a single event. Importantly, this unpredictability on the level of the single event is not due to limited information or lack of precise measurement. It is an intrinsic property of the system. It seems that quantum physics led to accept a new form of determinism that the laws of nature determine the *probabilities* of various futures, rather than determining the future with certainty (Hawking & Mlodinow, 2010, p. 72).

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Nevertheless, it is widely believed and claimed by many scientists that scientific knowledge entails clear-cut predictions. This approach is based on the Newtonian mechanics, which is still the dominating framework beyond the realm of quantum mechanics and led to a generalization of the concepts determinism and predictability.

Up to date, the prevailing argument that free will is an illusion has risen through studies showing that neural precursors predict forthcoming voluntary action. Libet (1983a) discovered that voluntary movement is preceded by the RP, which occurs *before* participants became aware of the ‘intention’, ‘desire’, or ‘urge’ to move. This finding has been extended in an fMRI study by Soon et al. (2008). Participants were asked to press a button either left or right when they became aware of the urge to do so. Consistent with Libet’s finding the fMRI data showed specific brain activity that predicted whether they will press the left or right button up to seven seconds before the movement. This is a long latency between brain events and the subjective awareness of the ‘decision’. This result seems to confirm that one’s actions are derived from unconscious neural processes in the brain rather than from one’s conscious deliberation. This scientific evidence might have challenged free will on the basis of an argument that “*free will requires that one’s actions properly derive from one’s conscious reasoning, decision and intentions*” (Nahmias, 2010, p. 348), and thus, the truth of determinism seems to be discovered. This in turn would imply that subjective experience of conscious will might be no more than an illusion.

By contrast, recent studies cast doubt on the argument of this purely deterministic view. Schurger et al. (2012) contend that their data suggest that the RP could be an averaging artifact of spontaneous brain activities. If participants do voluntary movements in a specific brain state, averaging the brain signals backwardly aligned to the onset of the movements can emphasize a certain spontaneous brain signal that is in fact an apparent correlation with the action. In addition, Bengson et al. (2014) proposed that our cognitive decision might be a consequence of spontaneous brain activity within any given moment. A state of the brain *direct* before a stimulus (when a participant makes a decision to attend to the left or to the right) determined in which direction the participant will attend. Notably, these brain states were influenced by the momentary state of spontaneous brain activity but not by prior contingencies or strategic factors, suggesting that neural random firing, which is firing all the time regardless of the task condition (the so called background noise), might be the source of our decisions. This finding implies that a decision to act derives from random process of



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neural activity in the brain, which is in line with the position of the indeterministic view (an event is undetermined up to the moment when it occurs).

The discoveries in neuroscience are often based on statistic correlations that might favor finding a neural precursor (determinism) over background noise (indeterminism). For instance, Soon and colleagues (2008) could show that the early brain activity predicted one's decision at 60 % of accuracy, which is only 10 % above chance but nevertheless significant. But it should also be noted that hit rate of about 60 % is also observed when people are asked to generate a random sequence in a two-alternative choice task (Lages et al., 2013), which is a similar methodological issue as in Soon's study. This sort of mechanism could lead to an appearance of neural precursor that seems to determine one's decision in advance of conscious will; a neural precursor might even not be a decision-making process at all.

In the present thesis, we found that fluctuating brain states could account for the *probability* of action initiation, rather than determining the action (Study 1 and 2). Voluntary action occurs with approximately 70 % of probability during negative deflections of SCP and 30 % of probability during positive one. Since the SCP is influenced by various causes of surrounding circumstances (Birbaumer et al., 1990), fluctuating SCPs are not reflecting pure randomness. Instead, they might reflect a general property of the complexity of human nature, which is strongly influencing our behavior when combining and interacting with our biology, past experience and current situation (Baer, et al., 2008). SCP can also be self-regulated with practice in a way that makes a certain decision more probable (Heinrich et al., 2004). In addition, we further observed individual differences in subjective timing of the intention to act and of the consequent effects with respect to the RP amplitudes (Study 2, 3 and 4). The higher amplitude of the RP resulted in the stronger sense of an intention to act and self-agency. Within these findings we would suggest that human behavior can be predicted by observing brain activity, but with a certain probability depending on the ongoing brain states (see below).

A neural precursor, which is reflecting an intrinsic driving force to move (e.g., negative deflections of SCP), could be sometimes so strong that it is hard to restrain from the act. It seems that one could not have done otherwise (the truth of determinism). On the other hand, sometimes the movement of the neural precursor could be so subtle that it is too weak to determine one's decision (see 3.2.5. Appendix A.). In the second case one could have done otherwise because one's decision was undetermined in advance (the falsehood of determinism). According to this account, neuroscience might reject the conceptual question of free will whether determinism is true or not. Instead, a way in which neuroscience could

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enrich thinking about human behavior is how ‘the neural precursors’ turn out to influence a decision. Research on the *extent* to which one’s decision is determined may help to advance scientific challenges to free will.

## **5. SUMMARY**

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The feeling of being in control of voluntary movement is crucial for the experience of free will. However, neuroscientists have often proposed that specific brain activity can predict our voluntary action even before we have made any decision concerning the action. This seems to confirm that a conscious will to act is an additional phenomenon arising after brain activity. These findings seem hard to reconcile with the view that such an action is our ‘own’ voluntary action.

The present thesis contains four empirical studies aiming to demonstrate the underlying mechanism of intentional processes and its correlates to brain dynamics. We first demonstrated that in the Libet experiment ongoing neural fluctuations of the slow cortical potentials (SCPs) account for a significant fraction of the readiness potential (RP). The individual potential shifts preceding self-initiated movements were classified as showing a negative or positive shift. The negative and positive potential shifts were analyzed in a self-initiated movement condition and in a no-movement condition. Comparing the potential shifts between both conditions, we observed no differences in the early part of the potential. This reveals that the apparently negative RP emerges through an unequal ratio of negative and positive potential shifts. These results suggest that ongoing negative shifts of the SCPs facilitate self-initiated movement but are not related to processes underlying preparation or decision to act.

Although Libet’s experiment is highly dependent upon subjective reports, no study has been conducted that focused on a first-person or introspective perspective of the task. Therefore, for the second study, we took a neurophenomenological approach in an  $N = 1$  study providing reliable and valid measures of the first-person perspective in conjunction with the brain dynamics. We found that a larger RP is attributable to more frequent occurrences of self-initiated movements during negative deflections of SCPs. These negative deflections occur in parallel with an inner impulse reported by an expert meditator, which may in turn lead to a voluntary act. We demonstrated in this proof-of-principle approach that the first-person perspective obtained by an expert meditator in conjunction with neural signal analysis can contribute to our understanding of the neural underpinnings of voluntary acts.

For the third study, we investigated induced first-person access to inner processes of movement initiation and the underlying brain activities which contribute to the emergence of voluntary movement. Moreover, we investigated differences in task performance between mindfulness meditators and non-meditators while assuming that meditators are more experienced in attending to their inner processes. Two Libet-type tasks were performed; one

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in which participants were asked to press a button at a moment of their own decision, and the other one in which participants' attention was directed towards their inner processes of decision making regarding the intended movement which lead them to press the button. Meditators revealed a consistent RP between the two tasks with correlations between the subjective intention time to act and the slope of the early RP. However, non-meditators did not show this consistency. Instead, elicited introspection of inner processes of movement initiation changed early brain activity that is related to voluntary movement processes. These findings are supported by cortical source imaging analysis on brain activity in the pre-supplementary motor area (pre-SMA), in which directing the subjective experience towards inner process to move led to a decreased activation in non-meditators, while no or less change was found in meditators. Our findings suggest that compared to non-meditators, meditators are more able to access the emergence of negative deflections of SCPs, which could have fundamental effects on initiating a voluntary movement with awareness.

For the last study, we examined the general sense of being in control of an intended movement. When a voluntary action is causally linked with a sensory outcome, the action and its consequent effect are perceived as being closer together in time. This effect is called intentional binding. Although many experiments were conducted on this phenomenon, the underlying neural mechanisms are not well understood. While intentional binding is specific to voluntary action, we presumed that preconscious brain activity (the RP), which occurs before an action is made, might play an important role in this binding effect. Therefore, the brain dynamics were recorded with EEG and analyzed in single-trials in order to estimate whether intentional binding is correlated with the early neural processes. Moreover, we were interested in different behavioral performance between meditators and non-meditators since meditators are expected to be able to keep attention more consistently on a task. Thus, we performed the intentional binding paradigm with twenty mindfulness meditators and compared them to matched controls. Although we did not observe a group effect in either behavioral data or EEG recordings, we found that self-initiated movements following ongoing negative deflections of SCPs result in a stronger binding effect compared to positive potentials, especially regarding the perceived time of the consequent effect. These results provide the first direct evidence that the early neural activity within the range of SCPs affects perceived time of a sensory outcome that is caused by intentional action.

The present thesis enables a new perspective on the underlying neural mechanisms of intentional processes. The finding provides evidence that (i) the emergence of an conscious

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intention to act is associated with ongoing negative deflections of SCPs, which leads to the seeming build-up the RP. In addition, (ii) execution of voluntary movement during this ongoing negative deflection enhances the sense of agency via temporal attraction between intended action and outcome. Finally, the finding suggests that (iii) first-person experiences of phenomenal states reported by experienced meditators contribute to our understanding brain mechanisms and free will.

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## Declaration

I hereby declare that this thesis is the result of my own efforts, except where otherwise stated. This thesis has not previously been applied in substance for any degree and is not being concurrently submitted in candidature for any degree.

Freiburg im Breisgau, November, 2014.

Han-Gue Jo 