



UNIVERSITÀ  
DEGLI STUDI  
DI PADOVA

Università degli Studi di Padova

Dipartimento di Psicologia dello Sviluppo e della Socializzazione

Scuola di dottorato di ricerca in **Scienze Psicologiche**

Indirizzo **Scienze Cognitive**

Ciclo XXIII°

**Experiencing free will: electrophysiological correlates of  
preparation and monitoring of intentional actions**

**Direttore della Scuola** : Ch.ma Prof.ssa Clara Casco

**Coordinatore d'indirizzo**: Ch.ma Prof.ssa Francesca Peressotti

**Supervisore**: Ch.mo Prof. Giuseppe Sartori

**Dottorando**: Davide Rigoni



# Index

---

<b>Summary of the research</b>	p. 5
<b>Riassunto della ricerca</b>	p. 7
<b>1. Free will in neuroscience</b>	
1.1. Introduction: free will and conscious intentions	p. 10
1.2. ‘Measuring’ intentions: the Libet’s paradigm	p. 11
<b>2. ERP components of motor preparation and action monitoring</b>	
2.1. The readiness potential: a neural marker of intentional motor preparation	p. 17
2.2. Action monitoring and action-effect negativity	p. 19
<b>3. Experiment 1 – Post-action determinants of the reported time of conscious intentions</b>	
3.1. Introduction: inferential processes of intentions	p. 22
3.2. Method	p. 30
3.3. Results	p. 32
3.4. Discussion	p. 37
3.5. Conclusion	p. 44
<b>4. Experiment 2 – Attention to intention enhances ERP correlates of preparation and monitoring of intentional actions</b>	
4.1. Introduction: preparation and monitoring of intentional actions	p. 46
4.2. Method	p. 51
4.3. Results	p. 54
4.4. Discussion	p. 57
<b>5. Experiment 3 – Free will beliefs and motor preparation</b>	
5.1. Introduction: a new approach to the problem of free will	p. 62
5.2. Method	p. 65

5.3. Results	p. 67
5.4. Discussion	p. 74
<b>6. Conclusive thoughts</b>	p. 77
<b>References</b>	p. 80
<b>Appendix A</b>	p. 89

## **Summary of the research**

In the last decades there has been growing interest in cognitive neuroscience for the understanding of neural underpinnings of voluntary motor actions. The interest in willed behaviour is somehow fuelled by the philosophical problem of free will. A fundamental aspect of the experience of free will is the experience of intention, that is, the experience of planning or being about to do something.

The aim of the present thesis was to examine neurophysiological processes associated with preparation and monitoring of intentional actions, by employing Event-Related Potentials (ERP).

In Experiment 1, I examined whether action-monitoring (i.e. processes reflecting the monitoring of the consequences of actions) is involved in the subjective experience of intention. In particular, an intentional action task and an action-monitoring approach were combined in order to investigate whether post-action ERP components reflecting action-monitoring are involved in people's experience of 'when' they become aware of their intention to act. Although the idea that post-action events can influence the reported time of intentions might seem counterintuitive, empirical evidence suggests that intentions can be partially inferred from events occurring after action execution. Here it was demonstrated that the time at which people become aware of their intention to act is partially inferred from the apparent time of the motor response, rather than the actual response. In addition, a specific ERP component, namely action-effect negativity (Nae), was found to reflect the comparison between the representation of the expected action effect and the actual effect. These findings suggest that conscious intentions are not entirely based on action preparation processes, but they are partially inferred from post-action

events.

Experiment 2 extended this finding by showing that ERP components reflecting motor preparation and action-monitoring are specifically enhanced in intentional actions. Participants performed self-paced voluntary actions and attended either to their intention to act or to the actual movement. When they attended to their intention, brain activity reflecting motor preparation – i.e. the readiness potential (RP) – was increased. This result confirms previous evidence that preparation of intentional actions involves the anticipation of the effects of the action itself and that the representation of the intended effect is reflected by the RP. Also the Nae was larger when participants attended to their intention, as compared to when they attended to the movement. This finding is taken as evidence that action-monitoring plays a crucial role in binding together the representation of the intended outcome and the actual action-effect.

Experiment 3 aimed at investigating whether brain correlates of intentional motor preparation can be influenced by abstract beliefs such as beliefs about free will. Neurophysiological activity was recorded while participants executed self-paced key presses and we found that the RP, that reflects intentional action preparation, was reduced in individuals previously induced to disbelieve in human will. This effect was evident more than 1 second before participants consciously decided to move, suggesting that our manipulation affects intentional actions at a preconscious stage. These findings indicate that abstract belief systems might have a much more fundamental impact than we ever thought.

## Riassunto della ricerca

Negli ultimi decenni si è sviluppato, nell'ambito delle neuroscienze cognitive, un crescente interesse per la comprensione delle basi neurofisiologiche delle azioni intenzionali. Il comportamento intenzionale, o volontario, è strettamente connesso al problema filosofico del libero arbitrio. Un aspetto importante dell'esperienza volitiva è l'esperienza di intenzione, che può essere definita come la consapevolezza di pianificare o di essere sul punto di fare qualcosa volontariamente.

L'obiettivo della ricerca era di studiare i processi neurofisiologici associati alla preparazione e al monitoraggio delle azioni volontarie tramite l'utilizzo dei Potenziali Evento-Relati (ERP).

Nell'Esperimento 1, si è voluto indagare se i processi che riflettono il monitoraggio degli effetti di un'azione motoria siano implicati nell'esperienza soggettiva di intenzione. In particolare, un compito ideato per lo studio dell'azione intenzionale è stato combinato con un approccio derivato dalla letteratura sul monitoraggio dell'azione, al fine di esaminare se componenti ERP seguenti all'azione motoria fossero implicate nell'esperienza di *quando* la persona ritiene di aver avuto l'intenzione di agire. L'idea che eventi successivi all'azione possano influenzare l'esperienza dell'intenzione, può sembrare controintuitiva; tuttavia evidenze empiriche hanno dimostrato che le intenzioni possono basarsi, almeno parzialmente, su un processo inferenziale che deriva dalla valutazione di eventi successivi all'esecuzione dell'azione. I risultati dell'esperimento hanno dimostrato che nel riportare quando hanno avuto l'intenzione, i soggetti erano influenzati dalla risposta apparente, derivante da una manipolazione del feedback uditivo, piuttosto che dalla effettiva risposta motoria. Inoltre, una specifica componente ERP, denominata

action-effect negativity (Nae), era legata al confronto tra la rappresentazione degli effetti attesi dell'azione e quegli effettivi. Questi risultati dimostrano che le intenzioni coscienti non sono basate solamente su processi legati alla preparazione dell'azione, ma sono influenzate anche da processi di tipo inferenziale.

Nell'Esperimento 2 sono stati approfonditi gli aspetti legati al monitoraggio dell'azione indagati nel primo esperimento. È stato dimostrato che componenti ERP associate sia alla preparazione che al monitoraggio dell'azione motoria sono più pronunciate nelle azioni intenzionali. I soggetti eseguivano dei semplici movimenti (pressione pulsante), in modo del tutto volontario e senza costrizioni temporali. Durante il compito, i soggetti dovevano prestare attenzione alla loro intenzione ricompiere il movimento oppure al movimento stesso. Quando prestavano attenzione all'intenzione, l'attività neurofisiologica associata alla preparazione motoria, rappresentata dal readiness potential (RP), era maggiore. In linea con precedenti evidenze sperimentali, questo risultato indica che nelle azioni intenzionali gli effetti dell'azione stessa vengono anticipati e che la rappresentazione degli effetti è associata al RP. Inoltre, anche l'ampiezza della Nae era maggiore quando i soggetti prestavano attenzione all'intenzione, rispetto a quando essi prestavano attenzione al movimento stesso. Da una parte, questo risultato suggerisce che il monitoraggio dell'azione ha un ruolo nel confrontare la rappresentazione degli effetti attesi e la rappresentazione degli effetti effettivi; dall'altra, enfatizza il ruolo dei processi di monitoraggio nell'esperienza soggettiva dell'azione intenzionale.

L'Esperimento 3 aveva l'obiettivo di indagare se i correlati neurofisiologici di preparazione motoria possono essere modulati da credenze astratte sul libero arbitrio. È stata registrata l'attività neurofisiologica mentre ai soggetti veniva chiesto di premere a piacimento un pulsante, senza alcuna costrizione temporale. È stato evidenziato che i soggetti indotti a credere che il libero arbitrio è un'illusione



mostravano un ridotto RP. Questo effetto, che dimostra una riduzione dell'attività neurofisiologica associata alla preparazione del movimento, era evidente più di un secondo prima che i soggetti decidessero di effettuare il movimento. Ciò suggerisce che indurre una prospettiva deterministica, in cui il libero arbitrio viene considerato un'illusione, ha un effetto nelle stadi pre-consci della preparazione delle azioni intenzionali. Questi risultati dimostrano che sistemi astratti di credenze, come la credenza nel libero arbitrio, hanno un impatto ad un livello molto basilare del comportamento umano.

# 1. Free will in neuroscience

## 1.1. Introduction: free will and conscious intentions

The subjective feeling of controlling our own actions is an intuitive and pervasive component of human experience. When switching on the TV to watch the news or when entering a pub to order a cappuccino, we have the clear feeling of voluntarily and freely determining our own choices. The question of how we can voluntarily control our behaviour has always fascinated researchers from different disciplines such as philosophy and psychology. This question is fundamental to what it means to be a human being and is tightly related to socially relevant issues, such as personal responsibility and self-control.

The fascination for intentional behaviour is to some degree fuelled by the *vexata quaestio* of free will. In the last decades, cognitive neuroscientists and experimental psychologists focused on intentional actions, sometimes assuming – more or less explicitly – that understanding brain processes involved in conscious and voluntary actions (i.e. those actions that we perceived as free) would provide an answer to the question whether free will exists or not, or at least would modify our notion of volition. However, it is highly questionable whether the fields of neuroscience and experimental psychology have tools for answering the question whether free will, in philosophical terms, exists. As Roskies concluded in her recent review (Roskies, 2010, p. 123), “*neuroscience has not much affected our conception of volition [...]*” but “*[...] it has typically challenged traditional views of the relationship between consciousness and action*”. Therefore, in order to avoid any confusion on what is meant here with ‘free will’, it must be said that when neuroscientists argue about free will, they actually mean the ‘feeling of having a free will’, or the ‘perception of

volition' (Hallett, 2007).

From a phenomenological point of view, we may consider as free those actions that are performed intentionally and with a minimum of external constrictions. Intentional actions involve a distinct subjective experience that is typically absent or reduced in automatic actions (e.g. reflexes). This is the experience of *intention*, that is, planning to do or being about to do something<sup>1</sup> (Haggard, 2008). The concept of intention covers several distinct processes within the chain of psychological events leading to behaviour. Searle (1983), for instance, has distinguished between *prior intention* and *intention-in-action*. A prior intention is a deliberate and explicit planning of a future action. It is defined as the initial representation of the goal of an action prior the initiation of the action itself. Conversely, an intention-in-action is the proximal cause of the physiological chain leading to an overt behaviour. This type of intention is simultaneous to the motor action.

Much of research in cognitive neuroscience has focused on conscious states associated with simple manual actions (e.g. wrist flexion, button presses, fingers movement). These conscious states have been referred to as motor intentions (Soon et al., 2008) or conscious intentions (Haggard, 2005) and they correspond roughly to Searle's intentions-in-action. Here the term *intention* will refer to the latter type of conscious state.

## **1.2. Measuring intentions: the Libet's paradigm**

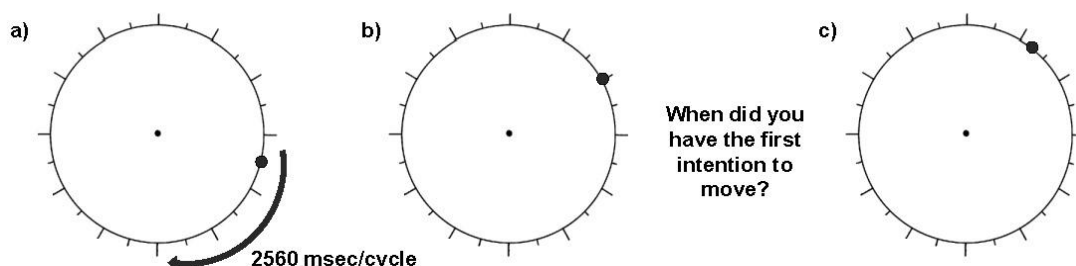
A first line of research within the field of cognitive neuroscience has focused on whether conscious intentions played a causal role in the initiation of behaviour. In a

---

<sup>1</sup> Another experience specifically involved in intentional actions is the feeling of *agency*, which is the feeling that one's action has indeed caused a particular external event (i.e. the feeling that 'I' did that). For a recent review on agency and intentional actions see Haggard (2008).

pioneering experiment, Benjamin Libet and colleagues (Libet et al., 1983) applied neurophysiological methods to study the relationship between the electrophysiological brain activity associated with voluntary movements and conscious intentions. The main interest was on the temporal relationship between motor-related brain potentials, as recorded with the electroencephalogram (EEG), and the ‘conscious feeling of intending to act’. Thus, the question was: when do people become aware of their own decision to do a certain movement? And what happens in the brain in the meantime?

An implicit problem in investigating internal representations such as the intention to perform a movement, is that it is impossible – at present, at least – to obtain a direct and objective measure of when a person becomes aware of his or her conscious intention. It is not possible to have a direct access to the ‘internal world’ of others and therefore, to obtain an estimation of when people had the conscious intention to execute a movement, experimenters must rely on introspection (i.e. subjective reports of inner states). Libet and colleagues (1983) developed a method that allowed to compare subjective self-reports with brain activity (Fig. 1.1).



**Figure 1.1** Experimental procedure of the Libet’s task. (a) Participants make a voluntary and spontaneous finger movement while watching a dot moving clockwise around a clock face. (b) After the finger movement, the dot keeps on going and then stops. (c) Then, participants are asked to report the position the dot was when they had the first intention to make the movement.

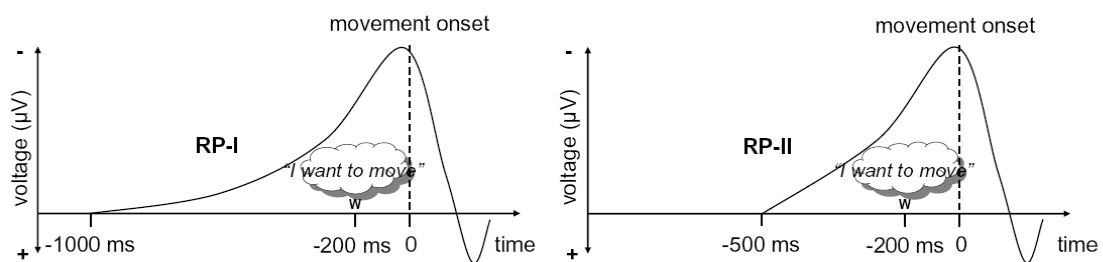
In a typical Libet experiment, participants seat in front of a screen displaying a clock

with a rapidly moving spot and they are asked to execute a rapid movement (i.e. a wrist flexion or a button press), at will. Afterwards, they are asked to report what time it was (i.e. the position of the spot in the clock) when they had the first subjective experience of intending to act. Libet referred to this reported time as the will judgment (W-judgment).

By the simultaneous recording of the EEG activity, it is possible to compare the introspective report of when participants had the intention to act – i.e. the W-judgment – with the motor-related cortical potentials (MRCP) (Libet et al., 1983). In particular, Libet was interested in the Bereitschaftspotential or readiness potential (RP) (Kornhuber & Deecke, 1965), that will be described in details in Chapter 2. The RP is a slowly increasing negative potential which starts up to 2 seconds before voluntary and spontaneous movements and is bilaterally symmetrical over the pre- and post-central region, with a maximum at the vertex (Shibasaki et al., 1980; Shibasaki & Hallett, 2006). The RP is generated by the supplementary motor areas, and is associated with spontaneous and voluntary movements, as it is absent or greatly reduced before involuntary movements or movements made in an automatic manner (Shibasaki & Hallett, 2006).

In the original experiment (Libet et al., 1983), participants' movements were preceded by two types of RP that differed regarding their onsets (Fig. 1.2). RP-I's had earlier onsets and were found in blocks where subjects reported the experience of planning and consciously preparing their actions, on at least some trials. Conversely, RP-II's had later onset and were found in blocks where subjects reported that their actions were unplanned, and that they occurred more spontaneously. Thus, participants' voluntary movements were preceded by a RP beginning 500 ms to about 1000 ms before movement onset (Fig. 1.2). This suggested that the onset of the RP was linked to the intentional planning of the motor action. The W-judgment,

indicating when people had the first intention to move, was approximately 200 ms before the motor response. Therefore, the brain potentials reflecting motor preparation began about 300 to 800 ms before the person consciously intended to act. Conscious intentions would thus seem, the authors concluded, to be a latecomer in the process of decision, rather than the generator of the action.



**Figure 1.2** Graphical representation of the main findings by Libet and colleagues (Libet et al., 1983). Brain correlates of motor preparation began around 1 s (RP-I) or 500 ms (RP-II) prior movement onset, as defined by the EMG. Participants became aware of the intention to move (W-judgment) around 200 ms prior the movement onset, thus 800 or 300 ms later than the beginning of motor preparation reflected by the RP-I and the RP-II, respectively.

Several theoretical and methodological aspects of the Libet’s clock paradigm have been extensively questioned (Hallett, 2007; Pockett & Miller, 2007; Haggard, 2008; Roskies, 2010). However, despite the numerous critiques the Libet’s clock has been widely used to investigate conscious intentions and it still offers “*one of the few viable methods for experimental studies of awareness of action*” (Haggard, 2005, p. 291). Furthermore, the main result of Libet’s experiment has been repeatedly confirmed by other empirical studies that clarified the temporal relationship between conscious intentions and brain processes underlying motor preparation. For instance, Haggard and Eimer (1999), replicated the original findings and found that the reported W correlates only with the late part of the RP – i.e. the lateralized RP – that represents the stage at which the representation of an abstract action is translated into representation of a specific movement (i.e. “Do that!”). This finding suggests that we

become aware of our own intention to perform a voluntary movement only when information about which specific movement has to be made is represented in pre-motor areas (Haggard & Eimer, 1999).

These data show that motor actions are preceded by preconscious brain activity, which enters awareness only at a later stage, just before the action is executed. Therefore, a plausible conclusion is that conscious intentions are not the first source of our behavior as voluntary actions would be primarily determined by brain activity that enters consciousness only at the later stages (Hallett, 2007).

However, these conclusions are far from being uncontroversial. For instance, Trevena and Miller recently questioned the assumption that the RP is specifically associated with voluntary movements (Trevena & Miller, 2010). They thought to show that the RP is not necessarily followed by an overt movement and therefore it cannot be considered a specific marker of voluntary movement preparation. However, their experimental setup has also been criticized (Gomes, 2010). Therefore, further research is still needed to better clarify the relationship between brain processes underlying voluntary movements preparation and the subjective experience of intention.

Although from a phenomenological perspective the intention to perform an action seems to 'cause' the action itself, these data suggest that both the intention and the physical movement might be caused by brain activity. Free will would then be a perception, rather than the instigator of behaviour (Hallett, 2007).

Another thread of research provides evidence for this hypothesis by showing that events occurring after an action is executed can influence the characteristics of the experience of intention (Haggard, 2008). According to this hypothesis, the consequences of our actions influence the way we experience the intention to act (Lau et al., 2007; Kühn & Brass, 2009; Banks & Isham, 2009). This implies that

action-monitoring processes are relevant for the experience of intention. However, while brain processes associated with the preparation of intentional actions have been extensively investigated (Libet et al., 1983; Haggard & Eimer, 1999; Lau et al., 2004; Soon et al., 2008), much less effort has been put on understanding how action-monitoring processes are specifically linked to intentional actions.

The next chapter will present ERP components specifically linked to action preparation and action monitoring, namely the RP and action-affect negativity (Nae), respectively. It is well-established that the RP is associated with the preparation of intentional motor actions (e.g. Kornhuber & Decke, 1965; Libet et al., 1983). As mentioned above, this component is absent or greatly reduced in involuntary movements (e.g. tics) and movements performed in an automatic manner (Shibasaki & Hallett, 2007). In addition, its onset depends on whether the action is pre-planned in advance (Fig. 1.2) (Libet et al., 1983). Conversely, it is not clear whether components reflecting action-monitoring have a specific role in intentional actions. Research on action monitoring focused mainly on error detection (e.g. Gehring et al., 1993; Holroyd & Coles, 2002) and on performance feedback (e.g. Miltner et al., 1997; Holroyd & Coles, 2002), and showed that performance monitoring processes are linked to activity of the medial-frontal cortex (MFC). Recently, it has been suggested the Nae might reflect action-effect binding (Band et al., 2009), a phenomenon that is crucial for intentional actions (Haggard, 2008).



## **2. ERP components of motor preparation and action monitoring**

### **2.1. The readiness potential: a neural marker of intentional motor preparation**

There is extensive literature on the electrophysiological processes involved in the preparation of motor actions (e.g. Shibasaki et al., 1980; Shibasaki & Hallett, 2006). Among the different MRCP, the RP has received much attention within neuroscientific research on intentional actions (e.g. Libet et al., 1983; Haggard & Eimer, 1999; Sirigu et al., 2004; Waszak et al., 2005; Keller et al., 2006).

The RP is a pronounced negative-going potential that begins up to 2 seconds before the onset of a voluntary movement and that is typically absent or greatly reduced prior automatic or involuntary movements (Kornhuber & Deecke, 1965; Libet et al., 1983; Shibasaki & Hallett, 2006), or prior movements performed without the subjective experience of intentionality (Lang, 2003). For hand movements, it is maximal at the midline centro-parietal area, and symmetrically and widely distributed over the scalp. The onset of the RP, as measured backward from the movement onset, differs significantly among different conditions and among subjects. For instance, in experimental settings in which participants have to repeat the same movement (e.g. index finger flexion) at a self-paced rate, the RP starts much earlier as compared to movements performed in more natural conditions (Shibasaki & Hallett, 2006).

The RP is not a homogenous potential and can be divided into various subcomponents. In particular, about 500 ms prior the movement onset, the RP typically shows a sudden increase of its gradient<sup>2</sup>. Shibasaki and colleagues (1980)

---

<sup>2</sup> The timing of the RP obviously depends on how the movement onset is defined. In case of finger movements, the most commonly used measure is the peak of the EMG, but other measures can be taken as the fiducial point. For instance, the peak activity of the motor

found that this late shift of the RP shows a clearly different scalp distribution as compared to the early slow RP, with the late RP asymmetrical and maximal over the contra-lateral central area. In addition, the early and the late part of the RP are influenced by different factors (Lang, 2003; Shibasaki & Hallett, 2006). The early-RP is influenced by the level of intention, preparatory state, movement selection, learning and skill acquisition, praxis movement, perceived effort, and speed of the movement. Conversely, the late-RP is influenced by precision, discreteness and complexity of the movement. Both subcomponents are altered in pathological conditions of various brain structures (e.g. Parkinsonism, cerebellar lesion). The early-RP is mainly generated by the pre-SMA, SMA proper and the lateral premotor area (BA 6), all bilaterally. Conversely, the late-RP is generated by premotor (BA 6) and motor areas (BA 4).

It is clear that both the early- and the late-RP are related to the preparation and/or execution of voluntary movements, because neither of them is associated with involuntary movements. Although the precise relationship of the two subcomponents to the intention to move is not fully understood, there is strong evidence suggesting that the RP, in particular the early-RP, is associated with the planning of intentional action. First, the early-RP is generated by brain regions (i.e. preSMA, SMA proper and lateral premotor area) that have been found to be consistently involved in the preparation of voluntary actions (e.g. Lau et al., 2004; Kriehoff et al., 2009). Second, it is modulated by the level of intentional involvement and it is greatly reduced for actions that are performed in an automatic manner (Libet et al., 1982; Kornhuber, 1984; Keller & Heckhausen, 1990). It has been suggested that it is

---

cortex contralateral to the responding hand after Laplacian transformation roughly corresponds to the EMG peak (Bulle et al., 2004; Meynier et al., 2009; Vidal et al., 2003). Other studies have taken the button press as a measure of movement onset (e.g. Haggard & Eimer, 1999).

restricted to movements that are executed with the “*introspective feelings of the willful realization of the intention to move at a particular time*” (Lang, 2003). Therefore, the RP can be considered a neural marker of the intentional preparation of motor actions.

## **2.2. Action monitoring and action-effect negativity**

So far, most of the studies on willed behaviour and conscious intentions focused on brain activity *preceding* motor actions (e.g. Libet et al., 1983; Haggard & Eimer, 1999; Lau et al., 2004; Soon et al., 2008). However, events occurring *after* the action is executed seem to have an impact on the experience of intention (Lau et al., 2007; Banks & Isham, 2009). In Haggard’s model of voluntary action (Haggard, 2008), two specific cognitive processes contribute to the experience of an action as intentional. First, the intention predicts the action and the desired effect to which it refers. Second, the sensory experience of the action and of its effect triggers a reconstruction of the intention to act. Therefore, monitoring the consequences of the action is crucial for the experience of an action as voluntary. In addition, to be capable of voluntary control, one has to monitor the effects of an action and compare them with the desired effects.

Several studies support the idea that the brain has a dedicated system for monitoring performance (e.g., Miltner et al., 1997; Holroyd & Coles, 2002; Band et al., 2009). At a behavioural level, this is clearly demonstrated by people’s ability to identify their own errors and to adjust their actions accordingly (Yeung & Sanfey, 2004). Indeed, in the literature on performance monitoring, much interest has been devoted to the electrophysiological correlates of error detection. The error-related negativity (ERN), is an ERP component elicited when people commit errors and when feedback

about such errors is provided (e.g. Gehring et al., 1993). The ERN is a negative-going voltage that immediately follows the response and that is maximal over the fronto-central scalp locations. The functional interpretation of this component has developed for years, because similar components are elicited by other events than overt errors. For instance, a similar component is the feedback-related negativity (FRN) (Miltner et al., 1997), that is elicited by performance feedbacks. This component peaks between 200 and 400 ms after feedback presentation, shows a fronto-central distribution and is more negative for unfavourable than for favourable feedbacks (Holroyd & Coles, 2002). Holroyd and Coles (2002) proposed a unified account of the ERN and the FRN: these components would reflect the transmission of a negative reinforcement signal from the mesencephalic dopamine system to the ACC, which in turn drives adaptive processes that modulate the probability of future responses.

More recently, it has been proposed that these components reflect the activity of a general system for deviations detection (Oliveira et al., 2007; Band et al., 2009). Under this perspective, the MFC would work as an expectancy-deviation system, that detects errors or performance that is worse than expected. The ERN and the FRN would therefore reflect the outcome of the monitoring system, that compares expected performance outcomes with the actual performance outcomes and is larger when a mismatch between the two is detected (Oliveira et al., 2007).

The idea of a general system for performance monitoring was supported by Band and colleagues (2009), who reported that task-irrelevant action effects are monitored as relevant feedbacks. In particular, they found that task-irrelevant information (i.e. random stimuli that were not relevant for the experimental task) were elaborated as task-relevant stimuli. The monitoring of irrelevant action-effects was reflected by the Nae, a negative component that peaked around 200 ms after the irrelevant action-

effect. These findings support the idea of a shared mechanism for the evaluation of both action-relevant and incidental effects of an action, and suggests a linkage between theories on reinforcement learning and theories of ideomotor action control (Band et al., 2009). According to this view, overt errors, response conflicts and unfavourable feedbacks, would be the more salient cases of ‘deviations’ from the expectations. In addition, these findings indicate that action-effect representations that are irrelevant for a given task are used to predict the most likely outcome of a given action and are matched against the actual outcome (Wolpert et al., 1995). Thus, action effects play a role in action monitoring processes, and not just in action selection.

### **3. Experiment 1 – Post-action determinants of the reported time of conscious intentions<sup>3</sup>**

#### **3.1. Introduction: inferential processes of intentions**

In voluntary actions we experience that the intention to perform an action precedes the action itself. In other words, when we form the intention to press a key we have the feeling that our intention determines or causes the key press. A series of empirical studies in experimental psychology and neuroscience attempted to challenge this intuitive experience by focusing on cognitive and brain mechanisms underlying the evaluation of the consequences of our actions, as these processes seem to influence the subjective experience of conscious intentions (Banks & Isham, 2009; Kühn & Brass, 2009; Lau et al., 2007; Wegner & Wheatley, 1999).

A study by Lau and colleagues (2007) provided evidence in favour of this *reconstruction hypothesis*. They applied a Transcranial Magnetic Stimulation (TMS) over the preSMA after the execution of a simple spontaneous movement while participants were performing a Libet's task. They found that when the TMS pulse was applied 200 ms after movement execution, the perceived onset of the conscious intention shifted backward in time, indicating that the experience of conscious intentions involves activity of the pre-SMA taking place after the execution of action. Banks and Isham (2009) used a modified version of the Libet's procedure in which participants were asked to press a button at will and to report the W-judgment – i.e. the time they had the intention to press the button. Immediately after each button press, an auditory feedback was delivered at variable delays in order to signal a response later than the actual one. Although participants were not aware of the delay, their W judgment moved forward in time linearly with the delay of the auditory feedback, indicating that people estimate the timing of their conscious intentions on

---

<sup>3</sup> Authors: D.R., Marcel Brass, Giuseppe Sartori

the basis of the apparent time of response, rather than the actual response. In other words, people report when they had the intention on the basis of the consequence of the action.

Taken together, these empirical findings show that action-effects have an impact on the subjective experience of intention – at least on the subjective estimation of *when* participants had the intention to act.

Other studies moved a step further and provided evidence that people may retrospectively reconstruct the experience of volition for actions that are executed unintentionally. For instance, Kühn and Brass (2009) combined a stop-signal paradigm and an intentional action paradigm: participants were asked to press a button as fast as possible when a stimulus, say a letter, was displayed on a computer screen (*primary response* trials). Sometimes, right after the stimulus, either a stop-signal or a decision-signal was presented: with the stop-signal, participants had to inhibit the pending response, with the decision-signal they could decide whether responding to the stimulus or aborting the pending response (*decide* trials). In the decision trials in which participants provided a response, participants were also asked whether it was a voluntary response or a failed inhibition – i.e. participants were not able to stop the response. The aim of the study was to compare the reaction times (RTs) in the *decide* trials in which the subjects decided voluntarily to press the button with RTs in *primary response* trials in order to explore whether subjects were able to discriminate between acting without being able to stop (i.e. failed inhibition) and deciding voluntarily to resume the prepared action. If participants were able of distinguishing those states, there should be no *decide* trials in which subjects stated to have chosen voluntarily to resume the prepared action in the range of *primary response* RTs. That was because the process of stopping an ongoing action and reinitiating it voluntarily should take time. On the basis of this RT analysis, the

authors showed that participants judged as voluntary responses that were in the time range of primary response RTs and were thus given unintentionally (i.e. failed inhibitions). Therefore, in some cases, participants had the experience of a conscious decision for unintentional responses.

A radical view proposes the so-called theory of *apparent mental causation* (Wegner & Wheatley, 1999). According to this hypothesis, people feel that their conscious intentions are the source of their actions because they think about that action in advance of its occurrence, and because alternative sources of the action are not available. The human mind would assume a causal path from the intention to act to the action itself in order to explain the correlation between them (Haggard, 2008). This correlation occurs because both the subjective experience of intention and the action are generated by a common process, that is the neural preparation of the movement. Several studies support the idea that sometimes conscious will is fabricated from the *perception* of a causal link between the thought and the action. For instance, Wegner and Wheatley (1999) demonstrated empirically that people have the subjective experience that they performed intentional actions that were actually performed by another person. As Wegner commented, “*conscious will is not inherent in action*” (Wegner, 2002, p. 11): conscious intention is not an intrinsic part of the process by which somebody acts, but it is an extrinsic accompaniment to that process.

Taken together, all these studies provide evidence that the experience of volition is biased by factors concerning the consequences of behaviour. Volition is conceptualised as a perception, rather than the generator of behaviour: our brain motor’s system would produce a movement as a product of its different inputs and would inform consciousness of the movement, that would be perceived as being freely chosen (Hallett, 2007).



As above mentioned, the feeling of consciously intending to act would be influenced by events occurring after the supposed moment of decision (Lau et al., 2007; Banks & Isham, 2009). In particular, Banks and Isham (2009) recently provided an experimental demonstration of this hypothesis, showing that the critical cue for judgment of intention is the perception of the response, thus reversing the assumed causal relation between intention and action. They used a variant of the Libet's task (Libet et al., 1983) in which they gave participants delayed-response feedback to create the illusion that their response was later than it actually was. If the perceived time of action is a prominent factor in judging the beginning of the intention, then a delay in the perceived time of the action would result in a delay in the reported time of W. They found that the reported Ws changed accordingly with the delayed feedback, meaning that W is based largely on the apparent time of response and not on the motor response or other prior brain events.

The current experiment addresses the issue of what neural mechanisms underlie the inferential process of the conscious intention by recording ERP while subjects are performing the variant of the Libet's task developed by Banks and Isham (2009). If the feeling that we all have of consciously causing an action, is inferred, at least partially, from something occurring *after* the action is produced by the subject (Lau et al., 2007; Banks & Isham, 2009; Kühn & Brass, 2009), there must be some neural events accounting for this retrospective timing of conscious intentions. Although previous studies provided empirical demonstrations that the timing of our conscious decisions is influenced by post-action brain processes (e.g. Lau et al., 2007), and is based on an inference rather than a perception (Banks & Isham, 2009), little is known about neural mechanisms actually driving this reconstructive process.

ERPs are a useful method to investigate the temporal profile of neural processes underpinning cognitive functions. This method has been utilized previously in the

research on free will with the objective of identifying a relationship between the preparatory motor activity (i.e. the RP or the lateralized RP) and the estimated time people become conscious of their own intention to produce a response (Libet et al., 1983; Haggard & Eimer, 1999). For instance, Haggard and Eimer (1999) showed that the reported W correlates better with the late part of the RP, namely the lateralized RP, than with the RP, as originally reported by Libet et al. (1983). However, we investigated ERPs occurring *after* participants produced a response using a variant of the Libet's original task (Libet et al., 1983). Delayed auditory feedbacks were provided 5, 20, 40 or 60 ms after participants' response (i.e. a button press). If the time at which we become conscious of the intention to act, that is the W, is inferred largely by the apparent time of response (i.e. the auditory feedback), then we expected ERP feedback-related components to change across delayed feedbacks.

Our specific hypothesis was that the reconstructive process of conscious decisions is modulated by the activity of an action-monitoring system that involves the MFC (Oliveira et al., 2007; Band et al., 2009). Several studies support the idea that the brain has a specific mechanism for monitoring performance (Miltner et al., 1997; Holroyd & Coles, 2002; Yeung & Sanfey, 2004; Oliveira et al., 2007; Band et al., 2009). Converging lines of evidence stress the role of the MFC and in particular the ACC, in action monitoring and in the evaluation of behavioural performance (Miltner et al., 1997; Oliveira et al., 2007; Band et al., 2009). It has been shown that the medial frontal cortex is involved in conflict monitoring (Yeung & Sanfey, 2004), error processing (Miltner et al., 1997) and reinforcement learning (Holroyd & Coles, 2002). For instance, the error-related negativity (ERN) and the feedback-related negativity (FRN) are elicited when participants commit an error or received a feedback worse than expected, respectively, and are thought to reflect an increased activity of the ACC.

It has been suggested recently that both FRN and ERN would mirror the activity of a system that detects deviations from expectancy rather than negative feedbacks or performance errors (Oliveira et al., 2007; Band et al., 2009). Consistent with the idea of a general system of action-monitoring, Oliveira and colleagues (2007) showed that the FRN is elicited when a feedback is different from the expected feedback, regardless of whether it is a positive or a negative one. In a different study, Band and colleagues (2009) showed that a negative wave peaking in the typical FRN time range was elicited by task-irrelevant action effects, that is, by action-contingent information that was not relevant for the task. These findings support the idea of an action-monitoring system that not only detects errors and negative feedbacks, but that is sensitive to violations of expectancies. According to this *expectancy-deviation hypothesis* (Oliveira et al., 2007), the medial frontal cortex would act as a part of a general system that detects deviations from expectancy; the system compares people's expected feedback to the actual feedback and is activated when a mismatch between the two is detected.

The expectancy-deviation hypothesis is in line with a more general theoretical framework of internal models (Wolpert & Ghahramani, 2000; Blakemore et al., 2002). Specifically, the 'forward model' provides predictions of the sensory consequences of our own actions. Whenever such predictions are confirmed by the afferent sensory information, or in other words, when there is no discrepancy between the model's prediction and the actual sensory consequences of the action, then there is no conflict between sensory predictions and sensory consequences of our actions. On the contrary, if there is a mismatch between the model's prediction and afferent sensory information, then a resolution of the conflict would be required. A number of studies have shown that people tend to modify their behavioural performance on the basis of false feedbacks, although they are unaware of the

mismatch between the sensory predictions and the (false) sensory consequences of the action (Goodale et al., 1994; Blakemore et al., 2002). Under this framework, the shift forward of the reported W found by Banks and Isham (2009) would arise from the increased activity of the action-monitoring system, reflecting the comparison between the model's prediction (i.e. the auditory feedback is expected to be simultaneous to the button press) and the actual sensory consequences of the action (i.e. the auditory feedback is delayed relative to the button press). This, in turn, would result in a 'resolution' of the conflict by adjusting the perceived time of conscious decisions, as measured by the W judgment.

As mentioned above, it has been proposed that feedback- and performance-related negativities reflect the activity of the medial frontal cortex and are elicited when the actual outcome of the performance violates the predicted outcome (Oliveira et al., 1997). Furthermore, the Nae is also elicited in case of task-irrelevant feedbacks that are only contingent with the motor action (Band et al., 2009). Here we tested the hypothesis that delayed feedbacks following voluntary movements would elicit larger Nae as a function of an increase in the temporal mismatch between the actual and the perceived time of response. Our prediction is that an increase in the mismatch between participants' actual response and the delayed feedback would lead to increased activity in the action-monitoring system, resulting in larger Nae for later delayed feedbacks as compared to earlier delayed feedbacks. In addition, we expected the activity of the action-monitoring system – reflected by the Nae – to result in a resolution of the conflict by adjusting the timing of conscious decisions to move, thus shifting the reported W toward the apparent time of response indicated by the delayed auditory feedback. Therefore, if our hypothesis is correct, we should find the amplitude of the Nae being predictive of the changes in the reported Ws across delayed feedbacks.

Response-feedback not only evoke a negativity over fronto-central areas in the 250 and 350 ms time range, but also a positive deflection around 300–600 ms after stimulus onset (Overbeek et al., 2005; Waszak & Herwig, 2007; Band et al., 2009). This component, namely P3, is considered to consist of two mutually related components that may be elicited in tandem: the P3a has a fronto-central distribution, is elicited by deviant or novel stimuli and is considered to reflect the orienting of attention; the P3b has a more posterior distribution and is elicited by infrequently occurring stimuli that are task-relevant, or involve a decision (Waszak & Herwig, 2007). In the current study, feedbacks signaling the button press may elicit a positive waveform. Typically, however, P3 components have been investigated in tasks involving deviant stimuli that differed in terms of physical parameters and/or probability of occurrence (Nittono, 2006; Waszak & Herwig, 2007) and that involved a decision (Knight, 1996; Waszak & Herwig, 2007). On the contrary, in the current study the auditory feedbacks have equal physical parameters, duration, and probability of occurrence and were not related to any decision-making process. Furthermore, it has been proposed that early negative and late positive components reflect two separate action-monitoring systems that differ in terms of the degree of awareness involved (Falkenstein et al., 1991; Kaiser et al., 1997; Nieuwenhuis et al., 2001; Overbeek et al., 2005). This idea is supported by empirical observations that the degree of awareness of an error covaries with the amplitude of the P3, but not with the amplitude of the preceding negative component (Kaiser et al., 1997; Nieuwenhuis et al., 2001). Consistent with these observations, Nieuwenhuis and colleagues (2001) suggested that the two components reflect the activity of two distinct action-monitoring processes, of which only that reflected by the P3 is associated with conscious error recognition. In the current study, we expected participants to be unaware of the temporal mismatch between the response and the

delayed feedback. Therefore, we expected only the Nae to be modulated by the experimental manipulation, whereas the P3 was expected to be insensitive to the experimental manipulation.

## **3.2. Method**

### *3.2.1. Participants*

Sixteen undergraduates (7 females, 9 males; age range 19–24 years) from the University of Padova volunteered for the present study. All participants had normal or corrected-to-normal vision, gave informed written consent and were debriefed at the end of the experiment. Participants were paid 8€ for taking part in the experiment.

### *3.2.2. Apparatus and procedure*

The experiment followed the procedure used by Banks and Isham (2009) and is based on the method used by Libet et al. (1983) (see Fig. 1.1). Participants sat in front of a computer screen. In each trial, a cursor on the computer screen moved in a clockwise direction around a clock face, completing three revolutions in 8.1 s. The clock was 90 mm in diameter with 60 evenly spaced spots. Presentation of the clock and recording of responses was controlled by E-Prime 1.1 software.

Participants were requested to fixate the centre of the clock and to rest their right index finger on the response button, which was the keyboard spacebar. The participant's hand was not visible to the participant. Participants were instructed to press the button spontaneously and suddenly at a time of their own choosing, following at least one rotation of the cursor. They were asked not to plan the time of the button press and were told that they could choose not to make a button press in any trial. Participants were explicitly told that an auditory feedback was delivered

simultaneously with each button press. In fact, the computer emitted a 200-ms beep by a computer-generated random sequence at 5, 20, 40, or 60 ms right after the button press. After the button press the cursor rotated for a random interval between 800 and 1,500 ms and then stopped. Then, participants were asked to report the position of the cursor at the instant they made the decision to respond.

Participants performed a practice session of 16 trials. Then, the experimental session started. There were 40 trials at each delay, for a total of 160 trials, administered in two separate blocks. Some trials did not yield data because participants chose not to respond (<1%). At the end of the experimental session, we asked participants whether they experienced a temporal mismatch between button press and the auditory feedback. None of the participants acknowledged a temporal mismatch between the two events.

### *3.2.3. EEG recording*

Scalp voltages were recorded using a 59-channel electrocap with Ag/AgCL electrodes, arranged according to the 10–20 system. A frontal electrode (AFz) was connected to the ground. Mastoids served for reference and electrode impedance was kept under 10 K $\Omega$  for all recordings. Vertical and horizontal ocular movements were also recorded. Signals were amplified and digitized with a Neuroscan system at a sampling rate of 500 Hz. Off-line analyses were performed with Brain Vision Analyzer. The signal was off-line filtered (high pass 0.01 and low pass 30 Hz, 24 dB/octave attenuation). Ocular movements' artefacts were corrected using the algorithm provided by Brain Vision Analyzer (Gratton et al., 1983). Electrical recordings were segmented in epochs starting 100 ms before the presentation of the auditory feedback and lasting until 900 ms after its onset. The epochs were aligned to the 100 ms pre-stimulus baseline relative to the auditory feedback. Epochs affected

by artefacts ( $\pm 80 \mu\text{V}$ ) were excluded from averaging (rejected epochs  $\sim 5\%$ ).

#### *3.2.4. EMG recording*

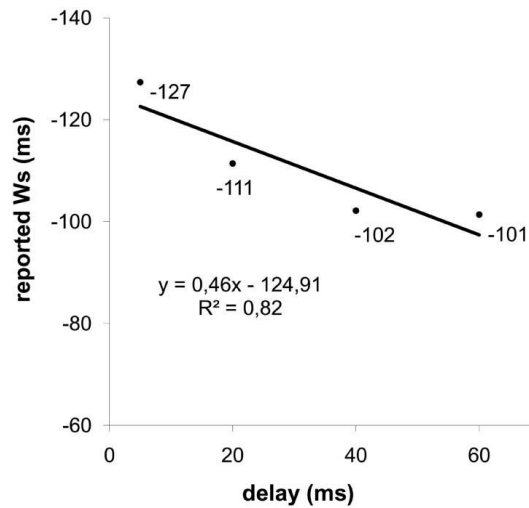
The electromyographic signal (EMG) was recorded from the flexor carpi radialis and nearby muscles by two electrodes pasted on the velar surface of the right forearm. The onset of the EMG was determined by an algorithm provided by Van Boxtel et al. (1993) followed by a visual re-check of the EMG onset search procedure. EMG onset was measured as the first point at which the EMG signal reached 3 standard deviations from the baseline.

### **3.3. Results**

#### *3.3.1. Behavioural performance*

Trials with no responses provided by the participant, and with reported  $W$  exceeding  $\pm 3$  standard deviations from individual averages, were considered as errors and were discarded from the data analysis ( $\sim 2\%$ ). One participant showed a high rate of trials exceeding this criterion ( $>1/3$ ) and was therefore excluded from further analyses. A repeated-measure ANOVA was performed with delay (5, 20, 40, and 60 ms) as within subjects' factor and the reported  $W$  as dependent variable. We found a significant effect of the delay factor ( $F(3,42)=8.26$ ,  $p=.004$ ,  $\eta_p^2=.37$ ). The averaged reported  $W$ s at delays of 5, 20, 40, and 60 ms were -127, -111, -102, and -101 ms, respectively, relative to time of response (see Figure 3.1). The observed power was 0.88.

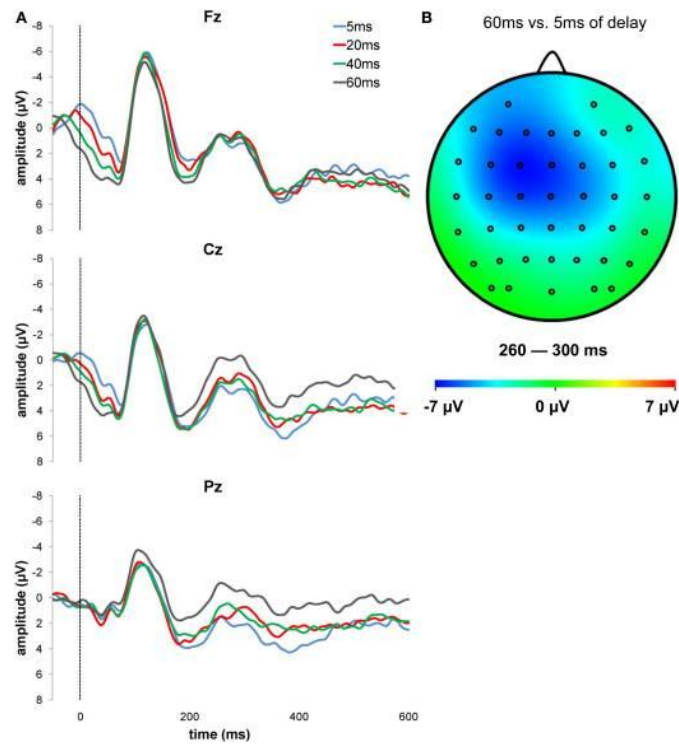




**Figure 3.1** Reported time of deciding to press a button (Ws) as a function of delay of response feedback after the button press (i.e. 5, 20, 40, and 60 ms). The W is measured relative to the time of the button press.

### 3.3.2. ERP data

For the analyses, only trials in which participants provided a response were used. Figure 2.2 shows grand average ERPs following delayed auditory feedbacks in three different electrodes. We quantified Nae amplitude in the averaged waveforms for each participant as the base-to-peak difference between the average voltage within 260–300 ms after stimulus onset and the average voltage of the immediately preceding positive peak in the 180–220 ms time window. We used the average amplitude of the Nae instead of peak amplitude because there were no clear maxima in the selected time range. We also measured P3 amplitude. The amplitude of the P3 was quantified as the most positive peak in the waveform in the 300–400 ms period after stimulus onset, as compared to the 100 ms pre-stimulus baseline.



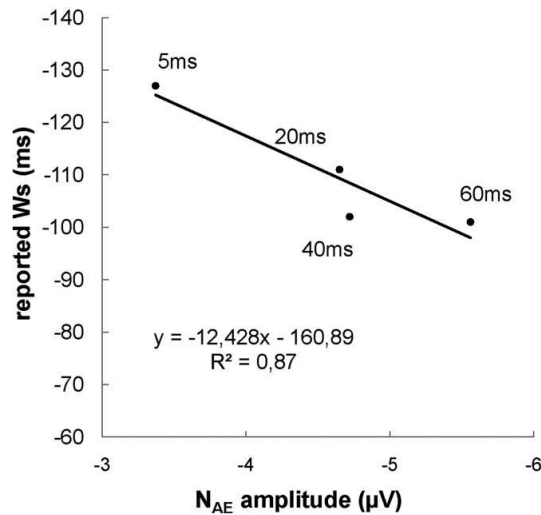
**Figure 3.2.** (A) Grand-averaged ERPs for the different delays of the auditory feedback at Fz, Cz, and Pz. The waveforms are time-locked to the delayed feedback onset, that is represented in the figure by the vertical black line at time 0. (B) Topographic difference in the Nae time range (260–300 ms) for 60–5 ms of feedback delay is displayed.

Component amplitudes were preliminarily entered into a repeated-measure ANOVA with electrode site (Fz, FCz, Cz, CPz, Pz) as within subjects' factor in order to identify scalp locations in which Nae and P3 showed their maximum amplitude. The Greenhouse–Geisser correction for violations of the assumption of sphericity was applied where appropriate. The analyses revealed a significant effect of electrode site, both for the Nae ( $F(4,56)=13.61$ ,  $p<.0001$ ,  $\eta_p^2=.49$ ) and for the P3 ( $F(4,56)=5.19$ ,  $p=.001$ ,  $\eta_p^2=.27$ ). Nae showed a central scalp distribution, with a maximum over Cz, followed by FCz, CPz, Fz, and Pz. P3 was more pronounced over fronto-central electrodes, with a maximum over FCz, followed by Fz, Cz, CPz, and Pz.

Visual inspection of grand-averaged ERPs revealed a positive wave over fronto-central sites, namely the P200, occurring within 150–250 ms time window after

stimulus onset. In order to exclude that this early component was sensitive to the experimental manipulation, we determined P200 amplitude through a base-to-peak procedure as the positive peak within 150–250 time window relative to the preceding negative peak in the 50–150 time window. A repeated-measure ANOVA was performed with feedback delay (5, 20, 40, 60 ms) and electrode site (Fz, FCz, Cz, CPz, Pz) as within subjects' factors and the amplitude of the P200 as the dependent variable. The analysis showed a significant effect of electrode site ( $F(4,56)=7.81$ ,  $p<.0001$ ,  $\eta_p^2=0.36$ ), with P200 being larger over FCz, followed by Fz, Cz, CPz, and Pz, but no effect of feedback delay ( $p=.77$ ) and no interaction ( $p=.22$ ).

To test our prediction that the Nae would increase as a function of feedback delay, the Nae amplitude over Cz was subjected to a repeated-measure ANOVA with the feedback delay (5, 20, 40, 60 ms) as within subjects factor. The analysis yielded a significant effect ( $F(3,42)=3.42$ ,  $p=.026$ ,  $\eta_p^2=.2$ ), with larger Nae amplitude for more delayed feedbacks -2.87, -4.15, -4.22, and -5.06  $\mu\text{V}$  for feedbacks delayed by 5, 20, 40 and 60 ms, respectively (Fig. 3.2). Fig. 3.2 shows the topographical distribution map of the difference in the signal between the condition with the larger (i.e. 60 ms) and the smaller Nae (i.e. 5 ms). This result confirms our prediction that the Nae is sensitive to the temporal mismatch between the actual response and the delayed auditory feedback. More delayed auditory feedbacks are associated with larger Nae amplitudes, suggesting that the amplitude of the Nae increases as a function of the delay of the feedback. The linear component of the feedback delay effect was significant ( $F(1,14)=6.16$ ,  $p=.026$ ,  $\eta_p^2=.31$ ).



**Figure 3.3.** Reported time of the decision to press a button (Ws) as a function of Nae amplitude at 5, 20, 40 and 60 ms of feedback delay. The reported Ws shift forward in time (i.e. closer to the actual response) for larger (i.e. more negative) Nae amplitudes.

P3 amplitude over FCz was subjected to a repeated-measure ANOVA with the feedback delay (5, 20, 40, 60 ms) as within subjects' factor. The analysis yielded a marginal effect ( $F(3,42)=2.65, p=.061$ ), with smaller P3 amplitudes for more delayed feedbacks (6.36, 6.58, 5.65, and 4.63 µV for feedbacks delayed by 5, 20, 40 and 60 ms, respectively).

### 3.3.3. Nae and reported W

Next, we performed a hierarchical multiple linear regression analysis to test the prediction that the shift of the W-judgement toward the apparent time of response is associated with the increased amplitude of the Nae induced by the delay of the auditory feedback. The amplitude of Nae for each participant and for each delayed feedback was entered at the first block and the level of feedback delay (5, 20, 40 and 60 ms) was entered at the second block; W-judgement was the dependent variable. We found that the amplitude of the Nae predicted the W-judgement significantly ( $\beta=-.32, t=-2.58, p=.012; F(1,58)=6.66, R^2=.1$ ). When the proportion of variance in the reported W explained by Nae amplitude was removed from the model, the

feedback delay factor failed to predict the change in the reported W ( $p > .1$ ). This result strongly indicates that changes in the reported W are indeed associated with changes in the Nae amplitude, regardless of the delay of the feedback.

#### 3.3.4. EMG data

The EMG onset was measured as the point of the first steep increase in the EMG record in the 400 ms interval preceding the button press. The EMG preceded the button press by ~99 ms, with little variability between delays (99, 100, 100, and 98 ms for the four delays, respectively). In order to assess whether the onset of the movement was related to the W, a linear regression analysis was performed with the EMG onset as predictor and the reported Ws as dependent variable. The analysis showed that the relationship is not significant ( $p = .42$ ), suggesting that the W is not related to the actual onset of the movement.

### 3.4. Discussion

Recent findings showed that the subjective experience of conscious decisions is influenced by events occurring after a motor response is actually produced (Lau et al., 2007; Banks & Isham, 2009; Kühn & Brass, 2009). The feeling of causing an action consciously and deliberately seems to be, at least in part, based on a reconstructive process that depends largely on post-action events. Under this view, external cues related to the consequence of our actions, and compatible with our sensory prediction of the consequences of the action (Wolpert et al., 1995), are processed by the brain and influence the feeling that we intended that action consciously and voluntarily. In these terms, it has been argued that the feeling that we have free will is, at least partially, dependent on an *a posteriori* reconstruction (Lau et al., 2007; Banks & Isham, 2009; Kühn & Brass, 2009).

The aim of the present study was to investigate psychophysiological mechanisms underlying the reconstructive process of conscious decisions. In order to do so, we recorded ERPs while participants were performing a variant of the classical Libet's task (Banks & Isham, 2009). So far, ERP research on free will have focused on preparatory activity (i.e. RP or lateralized RP) occurring before an action was produced (Libet et al., 1983; Haggard & Eimer, 1999). On the contrary, in the present study we focused on post-action brain events that may be related to the reported time of when a conscious decision to execute an action was made. In order to do so we asked participants to press a button at will and at the same time to monitor a red spot moving around a clock face. They were then asked to report the location of the spot when they had the first intention to move. This measure is called the W judgment (Libet et al., 1983). Participants were also told that an auditory feedback, simultaneous to the button press, signalled that the response was provided. Indeed, unbeknown to the participants, the auditory feedback was not temporally overlapping the actual response, but could be delayed forward by 5, 20, 40, and 60 ms.

It has been suggested that people have an internal representation of the sensory consequences of their own actions (Wolpert & Ghahramani, 2000; Blakemore et al., 2002) and that they use these internal representations to form predictions about the outcome of behavior. Wolpert and Ghahramani (2000) suggest that two kinds of internal models lie behind these functions. The 'forward model' uses efference copy to predict the sensory consequences of motor commands whenever a movement is made. By contrast, the 'inverse model' provides motor commands that are necessary to achieve a desired outcome. An important aspect of the forward model is that it predicts the sensory consequences of movement and compares this with the actual feedback (Blakemore et al., 2002). This comparison occurs after a movement is

made, and people are normally unaware of the actual state of the motor system and the actual sensory consequences of a movement. Furthermore, we are also unaware of the results of the comparison between the predicted and actual sensory feedback, as long as the desired state is achieved successfully. If the predictions made by the forward model are confirmed by the afferent sensory information, then there is no discrepancy between the model's prediction and the actual sensory consequences and, therefore, there is no conflict between the sensory predictions and the sensory consequences of the actions. On the contrary, a mismatch between the model's prediction and afferent sensory information would require a resolution of the conflict (Goodale et al., 1994; Blakemore et al., 2002).

In line with the idea that people form internal representations of the consequences of the actions, the *expectancy-deviation* hypothesis (Oliveira et al., 2007; Band et al., 2009) poses that feedback- and performance-related ERP components, such as the FRN and the ERN, reflect the activity of the medial frontal cortex and are elicited when the actual outcome of the performance violates the predicted outcome (Oliveira et al., 2007; Band et al., 2009). In the present study, participants were told explicitly that the auditory feedback was delivered simultaneously with the button press. Therefore, we assumed that participants expected the sensory consequences of the action to be simultaneous with the button press. With this in mind, the auditory delayed feedbacks signalling the motor response later than it actually was, may be considered as a form of mismatch between the predictions of the sensory consequences and the actual sensory consequences of the action. Therefore, our first hypothesis was that the delay of the response feedback would result in an increased activity of the action-monitoring system (Oliveira et al., 2007; Band et al., 2009), reflecting the comparison between the model's prediction and the actual sensory consequences of the action.

At a behavioural level, we replicated the finding that the delay of the feedbacks influenced the reported  $W$  (Fig. 3.1). Participants shifted the reported time at which they had the intention to press the button (i.e. the  $W$ ) forward in time, according with the delayed feedbacks. These results are in line with those obtained by Banks and Isham (2009) and are in accordance with the reconstructive hypothesis of the sense of free will (Aarts et al., 2005; Lau et al., 2007; Banks & Isham, 2009; Kühn & Brass, 2009). However, the feedback delay was not completely reflected in the reported  $W$ . If the report of  $W$  was locked perfectly to the feedback, the slope relating  $W$  to delay of feedback would have been equal to 1. The slope of 0.46 suggests that constant cues unrelated to the tone affected the perception of response time. Indeed, it is not possible to exclude that somatosensory and tactile cues, as well as the effort at the beginning of the button press, may in fact have had an impact on the perceived time of response.

We found no relationship between the  $W$  and the actual onset of the movement as recorded by the EMG. This suggests that changes in the subjective timing of conscious decisions were not attributable to changes in the actual onset of the movement, as measured by the EMG activity.

As regards ERP components, we found that the auditory feedbacks following voluntary button presses elicited a negative wave in the 260–300 ms time range. We referred to this component as action-effect negativity (Nae), in accordance with a previous study by Band et al. (2009). Crucially, our experimental manipulation had a significant effect on the Nae. Its amplitude was maximal over frontal-central scalp locations and was enhanced as a function of the delay of the feedback signalling the time of response (Fig. 3.3). In other words, the longer the delay between the actual response and the auditory feedback, the greater the Nae amplitude. This result supports our hypothesis that the activity of the action-monitoring system, reflected in



the current study by the Nae, is enhanced when delayed feedbacks signal that the response was later than it actually was. Interestingly, although the Nae was maximal over Cz, the topography of the difference between 60 and 5 ms of feedback delay (Fig. 3.2) showed a lateralization over the contralateral frontal-central sites. We can speculate that this lateralization is due to the motor lateralization induced by response execution processes. It has been suggested that the propagation of the primary motor cortex activity towards pre-motor areas (Roger et al., 2010) may result in a lateralization of performance-related negativities following motor responses.

The relationship between the delay of the feedback and Nae amplitude may not be linear, as indicated by Fig. 3.2 and 3.3 showing that Nae amplitudes with feedbacks delayed by 20 or 40 ms are almost overlapping. This suggests that other feedbacks from the environment, such as somatosensory and tactile cues, as well as the effort at the beginning of the button press, may be processed by the action-monitoring system and have an impact on the amplitude of the Nae. In other words, the Nae, as well as the reported W, may reflect the integration of several action-related feedbacks – not just the effect of the delayed auditory feedback.

The auditory feedback also evoked a positive component, namely the P3, peaking at around 360 ms after stimulus onset. A number of studies showed that P3 amplitude is involved in the performance-monitoring process (Overbeek et al., 2005); this component is typically larger for stimuli that deviate from expectations, such as errors or unexpected feedbacks. The lack of effect on the P300 amplitude strengthens the point the participants were unaware of the feedback delay, given that this component is sensitive to stimulus awareness (Overbeek et al., 2005). Unexpectedly, we found P3 amplitude being smaller for more delayed feedbacks – and thus more deviating from the predictions of the sensory consequences – as compared with less

delayed feedbacks. However, the effect was not significant; it seems likely that the variability in the preceding Nae contributed to the marginal effect found for the P3 amplitude.

A second hypothesis was that the activity of the action-monitoring system, reflected by the Nae, is involved in the reconstructive process of conscious decisions. This prediction was based on previous studies showing that when there is a conflict between the predictions of the sensory consequences and the actual sensory consequences of an executed voluntary action, individuals tend to adjust their behavioural performance in order to reduce the conflict (Goodale et al., 1994; Blakemore et al., 1999). In the current study, we used a Libet task (Libet et al., 1983; Banks & Isham, 2009) and asked participants to report the time (i.e. W) of the conscious decision of a voluntary button press. If the hypothesis that the action-monitoring system is involved in the timing of conscious decisions is correct, we would expect the reported W to be linked to the increased activity of the action-monitoring system, here reflected by the Nae. We found that the amplitude of the Nae predicted the reported W significantly, with increased Nae amplitudes resulting in reported Ws closer to the button press. Crucially, when controlled for Nae amplitude, the feedback delay factor failed to predict the reported W, indicating that changes in the reported W are indeed associated with changes in the amplitude of the Nae, and not just to the delay of the auditory feedback. This result is consistent with our hypothesis that the activity of the action-monitoring system, reflected in the current study by the amplitude of the Nae, plays a role in the reconstructive process of our conscious decisions, as measured by the W judgment.

A remaining question is how the Nae obtained in the current study should be classified with regard to the fronto-central negativities peaking around 250 ms (Folstein & Van Petten, 2008). For instance, the mismatch negativity (MMN)

(Näätänen & Alho, 1997) is a negative-going component that follows deviant auditory stimuli. However, it is only elicited when there is a substantial difference between the overall probability of a standard and a deviant auditory stimulus, whereas in the current study the delayed auditory feedbacks have an equal probability of 0.25. Another N2 component, namely the control-related N2, is elicited by stimuli inducing response conflict and/or requiring response inhibition (Folstein & Van Petten, 2008). In the current study, it is unlikely that the delayed auditory feedbacks induced response conflict or response inhibition, since the response was already executed before the presentation of the auditory stimulus. Regardless of the exact classification of the Nae, however, this study supports the idea of a system that detects deviation from expectancies (Oliveira et al., 2007; Band et al., 2009).

To summarize we showed that reported time of decisions was predictable on the basis of the amplitude of a negative component related to the action-effects (Band et al., 2009), occurring 260–300 ms after the presentation of an auditory feedback. These results suggest that when people are asked to report *when* they made the decision to execute an action, they are strongly influenced by the consequences of the action. Furthermore, we showed that this retrospective process relies on the activity of an action-monitoring system that, it has been argued, involves the medial frontal cortex (Miltner et al., 1997; Holroyd & Coles, 2002; Oliveira et al., 2007; Band et al., 2009).

#### *3.4.1. Current findings and the Libet's paradigm*

There is an extensive debate on the question as to what extent results from this kind of experiment have implications for our understanding of volition and intent (Hallett, 2007; Pocket & Miller, 2007). Our results indicate that if asked to report *when* they

decided to execute an action, people rely – presumably at an implicit level – on the perceived sensory consequences of the action. With respect to the free will debate, these findings support the idea that the Libet paradigm may not be the best approach to investigate the reported time conscious intentions of motor actions. It is not possible to exclude that people use systematic strategies in this task, either consciously or in an automatic manner, to judge the time of conscious decisions. For instance, they might remember the position of the clock at the time of the feedback (e.g. the auditory tone and/or somatosensory and tactile feedbacks), and then infer that the decision ‘must’ have taken place somewhere *before*. In any case, if people infer, at least partially, the time they decided to act from the consequences of the action (e.g. a tone signalling the response), then the reported W used in the Libet paradigm may not be a reliable measure for the investigation of *when* a decision to act enters subjective awareness (for a review on limitations of the Libet paradigm refer to Pockett & Miller, 2007).

### **3.5. Conclusion**

In the present work, a small disruption of the temporal parameter of an auditory feedback, caused people to shift forward in time the W judgment, suggesting that the timing of our conscious decisions is at least partially based on a reconstructive process (Banks & Isham, 2009; Kühn & Brass, 2009). Our participants were unaware of the delay, and this provides further evidence that the comparison between the intended sensory consequences and the actual sensory consequences is unavailable to awareness (Wolpert & Ghahramani, 2000; Blakemore et al., 2002). Under this view, the shift in the W judgment may be the result of a sort of expectancy violation related to the predicted sensory feedback of our action. The fact that participants were unaware of the delay suggests that the action-monitoring system operates at an

implicit level and this is in line with previous data showing that people are unaware of the mismatch, even with longer delays between the predicted and the actual sensory consequence of the action (Blakemore et al., 1999). Nevertheless, it is possible that such an implicit monitoring system has a kind of temporal threshold after which feedback is not considered as belonging to the action anymore. However, this idea is very speculative and would need further investigation.

Our interpretation of the result, is that the temporal mismatch between the predicted and the actual sensory feedback was detected by the action-monitoring system (Oliveira et al., 2007; Band et al., 2009), as reflected by the Nae amplitude, and caused a shift in the subjective timing of when the action was decided. To our knowledge, this is the first study employing ERPs recording for investigating psychophysiological mechanisms underlying reconstructive processes of conscious decision. Changes in the reported *W* were related to what we called Nae, a negative potential involved in response and feedback- and action-monitoring (Oliveira et al., 2007; Folstein & Van Petten, 2008; Band et al., 2009). Taken together these findings indicate that the reported time of conscious decisions are influenced strongly by the consequences of our actions, that are constantly monitored by a dedicated system involving the medial frontal cortex.

## **4. Experiment 2 – Attention to intention enhances ERP correlates of preparation and monitoring of intentional actions<sup>4</sup>**

### **4.1. Introduction: preparation and monitoring of intentional actions**

Recent research in cognitive neuroscience demonstrated that brain activity for intentional actions – i.e. actions associated with the subjective experience of intentions – differs from that for the same actions performed in response to an external stimulus or in an automatic manner (Lau et al., 2004; Waszak et al., 2005; Keller et al., 2006). The neuroanatomical circuit of intentional actions involves a specific pattern of brain circuits that include the preSMA, the SMA proper, and parietal regions (Deiber et al., 1999; Jenkins et al., 2000; Lau et al., 2004; Brass & Haggard, 2008).

The preferential activation of a specific brain circuit underlying intentional actions has been confirmed by empirical studies in which participants were asked to attend to their conscious intentions to act (Lau et al., 2004; Sirigu et al., 2004). Lau and colleagues (2004) measured the brain activity while participants were performing voluntary finger movements in a variant of the well-known Libet task (Lau et al., 2004; Libet et al., 1983). After each movement, participants were asked to judge the time they had the intention to act (I-condition) or the time they actually executed the movement (M-condition). Brain activities associated with the two conditions were then compared. The authors found that the activity of the preSMA was enhanced in the I-condition as compared to the M-condition. The authors concluded that preSMA reflects the representation of intentions.

Other studies showed that specific electrophysiological processes are involved in the preparation of voluntary motor actions (see chapters 1 and 2) (Kornhuber & Deecke,

---

<sup>4</sup> Authors: D.R., Clémence Roger, Giuseppe Sartori, Marcel Brass.

1965; Libet et al., 1983; Shibasaki & Hallett, 2006). For instance, the RP typically precedes intentional actions, but it is absent or greatly reduced in automatic reactions (e.g. reflexes). Therefore, the RP is generally considered an electrophysiological marker of the intentional involvement in movement preparation (Lang, 2003). Sirigu and colleagues (2004) applied the procedure used by Lau and colleagues (2004) to an ERP experiment and found larger RP when participants attended to their intentions, rather than to the movement itself (Sirigu et al., 2004)<sup>5</sup>.

Waszak and colleagues (2005) investigated preparatory ERP potentials in a response selection task in which participants had to decide whether to press a right or left button on the basis of their intention (i.e. intention-based action) or of an external stimulus (i.e. stimulus-based action). They reported larger negativities prior movement onset for intention-based than for stimulus-based action. The difference between the two conditions was due to the need of intentionally plan the action in the intention-based condition (Waszak et al., 2005; Keller et al., 2006).

According to the ideomotor approach (James, 1890; Prinz, 1987), intentional actions arise automatically through the anticipation of their sensory effects. Thus, mental representations of the intended action-effect *causes* the planning and the execution for the appropriate movement for bringing about the intended effect. This action-effect linkage occurs because the underlying perceptual and motor codes are bound together in a common representation (Hommel, 2003; Prinz, 1987). Such binding leads to the activation of a combined action-effect representation when an individual imagines a desired goal effect, that is, when he or she has the intention to act.

Taken together, these findings indicate that intentional actions are associated with specific brain circuits that are involved in the preparation of intentional actions.

---

<sup>5</sup> However data were recorded from only two subjects (Sirigu et al., 2004).

However, the studies described so far have focused only on brain activity that precedes the execution of intentional actions, that is on brain activity associated with action preparation. According to Haggard's model of intentional actions (Haggard, 2008), also the consequences – e.g. somatosensory or auditory feedbacks – of the performed action strongly influence the subjective experience of the action itself. In particular, intentional actions are characterized by two binding processes (Haggard, 2008). First, intentions predict the action itself and the desired effect to which it refers. Then, the sensory experience of the action and of its effects trigger a reconstruction of the intention to act. Therefore there is a strong and reciprocal attraction between the awareness of actions and the awareness of the effects of an action, a phenomenon called 'intentional binding' (Haggard & Clark, 2003). This action-effect linkage depends critically on the intention to produce the effect: when the same effect is produced by a non intended action (e.g. involuntary movements), the intentional binding is greatly reduced or absent (Haggard, 2003; Haggard et al., 2002; Tsakiris & Haggard, 2003).

A thread of research investigated how the consequences of intentional actions influenced the experience of the action itself (Banks & Isham, 2009; Lau et al., 2007; Rigoni et al., 2010). For instance, Lau and colleagues (Lau et al., 2007) applied the Transcranial Magnetic Stimulation (TMS) over the preSMA after the execution of a simple spontaneous movement while participants were performing a Libet's task (Libet et al., 1983). They found that when the TMS pulse was applied 200 ms after movement execution, the perceived onset of the conscious intention – the so-called W-judgment – shifted backward in time, indicating that the experience of conscious intentions depend in part on neural activity of the preSMA taking place after the execution of action. Other studies have demonstrated that the apparent time of the response contributes to the reported time of intentions (Banks & Isham, 2009; Rigoni



et al., 2010). Banks and Isham (2009) showed that the reported time of conscious intentions is moved forward in time linearly with the delay of an auditory feedback signaling the apparent time of the response. This result indicates that people estimate the timing of their conscious intentions on the basis of the consequences of the actions, rather than the action itself. This finding was confirmed in Experiment 2 (Rigoni et al., 2010), that also reported that an action-monitoring ERP component, namely the action-effect negativity (Nae) (Band et al., 2009) is associated with the changes in the reported time of intentions.

Thus, processes associated with the monitoring of the consequences of our actions are crucial for the experience of the action itself (Haggard, 2008). However, electrophysiology of action monitoring in intentional actions remains poorly understood. To our knowledge, a few studies investigated action monitoring processes of intentional actions. For instance, Waszak and colleagues (2005) investigated electrophysiological correlates of action selection and found that stimulus-locked P3 component is greatly reduced or absent in the intention-based actions. This finding has been interpreted as that P3 reflects the formation of a link between stimulus processing and the response, and therefore it is virtually absent in intentional actions, given that they are internally generated (Waszak et al., 2005; Keller et al., 2006).

In the present study, we wanted to investigate electrophysiological mechanisms associated with both preparation and monitoring of intentional action. To this end, we adopted an “attentional spotlight” approach (Lau et al., 2004; Eagleman, 2004) to compare ERP activity underlying actions in which participants attended to their intention (i.e. I-condition) with actions in which participants attended to the movement itself (i.e. M-condition). ERPs were recorded while participants performed a Libet’s task (Fig. 1.1) (Libet et al., 1983) in order to examine

preparatory and monitoring electrophysiological processes of intentional actions. The rationale behind this method was that it allowed to compare two conditions in which participants perform exactly the same motor task, but that vary as regard the internal representation they attend to. It has been shown that modulating neural activity through attention is a powerful tool for neuroscientific research. For instance, it has been shown that paying attention to a sensory stimulus increases brain activity in the corresponding sensory part of the brain (Kastner & Ungerleider, 2000). This method has been successfully used also for looking “inward”. For instance, Griffin and Nobre (2003) showed that it is possible to investigate neural processes underlying the orientation of selective spatial attention to internal representations held in working memory (Griffin & Nobre, 2003).

As regard the preparatory activity, the RP is widely considered as a measure of intentional involvement in the preparation of intentional actions (Shibasaki & Hallett, 2006; Lang, 2003). Previous studies reported the RP to be enhanced in intention-based actions (Waszak et al., 2005; Keller et al., 2006) and when people attend to their own intention to act (Sirigu et al., 2004). Therefore, we expected the RP to be larger in the I-condition than in the M-condition.

However, we were also interested in post-action ERP activity reflecting action monitoring. In particular, we focused on the Nae, a negative-going ERP component that occurs in the typical N2 time range (Folstein & Van Petten, 2008) and that is elicited by action-effects processing (Band et al., 2009; Rigoni et al., 2010). This component is thought to reflect the linkage between an action and its effect, even when the effect is totally irrelevant for the task (Band et al., 2009). Given that the linkage between action and action-effects is stronger in intentional than in unintentional actions (Haggard, 2008), we expect that this process will be enhanced when participants attend to their intention to act. Therefore, our prediction was that

the Nae will be larger in I-condition than in M-condition.

A central-parietal P3 was also found to be affected by whether participants had to select which action to perform on the basis of their own intention or of an external cue (Waszak et al., 2005). This component reflects stimulus-response linkage and therefore was almost absent in the intention-based condition. Thus, we did not expect to find a parietal P3 in the present study, as participants only decided ‘when’ to execute the action on the basis of their own intention.

## **4.2. Method**

### *4.2.1. Participants*

A total of 14 undergraduate students of the University of Padova (6 males and 8 females, age range from 21 to 26) volunteered for this experiment. All participants were right handed, had normal or corrected-to-normal vision, signed an informed consent form and were debriefed at the end of the experiment. The study was conducted according to the Declaration of Helsinki and was approved by the ethical committee of the University of Padova. Participants were paid 12 euro for participation.

### *4.2.2. Procedure*

The experimental procedure is an adaptation of the procedure used by Lau and colleagues (Lau et al., 2004) and is based on the method introduced by Libet and colleagues (Libet et al., 1983). Participants sat comfortably in front of a computer screen. In each trial, a cursor on the computer screen moved in a clockwise direction around a clock face at the speed of 2560 ms/cycle. The clock was 90 mm in diameter with 60 evenly spaced spots. Participants were requested to fixate the centre of the clock and to rest their right index finger on the response button – i.e. the keyboard

spacebar. Participants were asked not to pre-plan the time of the button press and were instructed to press the button spontaneously and suddenly at a time of their own choosing, following at least one rotation of the cursor. The computer emitted a 50-beep simultaneously with each button press. After each button press, the cursor rotated for a random interval between 800 and 1500 ms and then stopped. In the I-condition, participants were asked to report the position of the cursor at the instant they had the first intention to press the button. In the M-condition, participants were asked to report the position of the cursor at the instant they actually started the movement. In both conditions, after each button press participants used the mouse with their left hand to position the cursor. When the cursor was placed in the appropriate position, participants had to click the mouse. Then, a blank screen was displayed for 500 ms, after which the following trial started. Participants performed a brief practice session in order to familiarize with the task. Then, the experimental session started. There were 30 trials for each condition, for a total of 60 trials, administered in two separate blocks. The order of the two conditions was counterbalanced across participants. Presentation of the experimental stimuli and recording of responses was controlled by E-Prime 1.1 software.

#### *4.2.3. ERP recording*

Electroencephalogram (EEG) and electrooculogram (EOG) were recorded using Synamps amplifiers (NeuroScan, El Paso, Texas, USA) and analyzed off-line with Brain Vision Analyzer software (Brainproducts, Munich, Germany). Scalp voltages were recorded using a 58-channel electrocap with Ag/AgCL electrodes, arranged according to the 10-20 international system (Fp1, Fpz, Fp2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz,

P2, P4, P6, P8, PO7, PO5, PO3, POz, PO4, PO6, PO8, O1, Oz, O2). A frontal electrode (AFz) was connected to the ground and all the electrode recordings were referenced online to the average of the left and right mastoids. Electrode impedance was kept under 5 K $\Omega$  for all recordings. Vertical and horizontal ocular movements were recorded by fixing electrodes close to the eyes. The EEG signal was digitized at a sampling rate of 500 Hz. The signal was filtered offline (0.016-70 Hz, 24 dB/octave attenuation). Ocular movements' artefacts were corrected using the algorithm provided by Brain Vision Analyzer (Gratton et al., 1983). Electrical recordings were segmented into epochs starting - 2000 ms before the button press and lasting until 1000 ms after its onset. Epochs with absolute amplitudes exceeding 75  $\mu$ V were rejected and excluded from averaging (rejected trials < 5%).

#### *4.2.4. Movement onset*

To obtain an estimated onset of the motor response, we measured the latency of the peak amplitude over the motor cortex contralateral to the responding hand. Previous studies revealed that the activity over the motor areas contralateral to the responding hand prior the response is maximum at the movement onset, as measured by electromyography (Burle et al., 2004, Meynier et al., 2009; Vidal et al., 2003). We applied a Laplacian transformation to improve the spatial definition of the monopolar EEG recordings (Vidal et al., 2003). The Laplacian transformation enhances spatial resolution by applying a high-pass filter and thus by minimizing the blurring effects of the current diffusion through the skull. Thus, we used the latency of the peak amplitude over the motor cortex contralateral to the responding hand (i.e. C3) as estimation of movement onset.

### 4.3. Results

#### 4.3.1. Behavioural results

Trials with reported Ws and Ms exceeding  $\pm 3$  standard deviations from individual averages, were considered as errors and were discarded from the data analysis. One participant showed a high rate of trials exceeding this criterion ( $>1/3$ ) and was therefore excluded from further analyses.

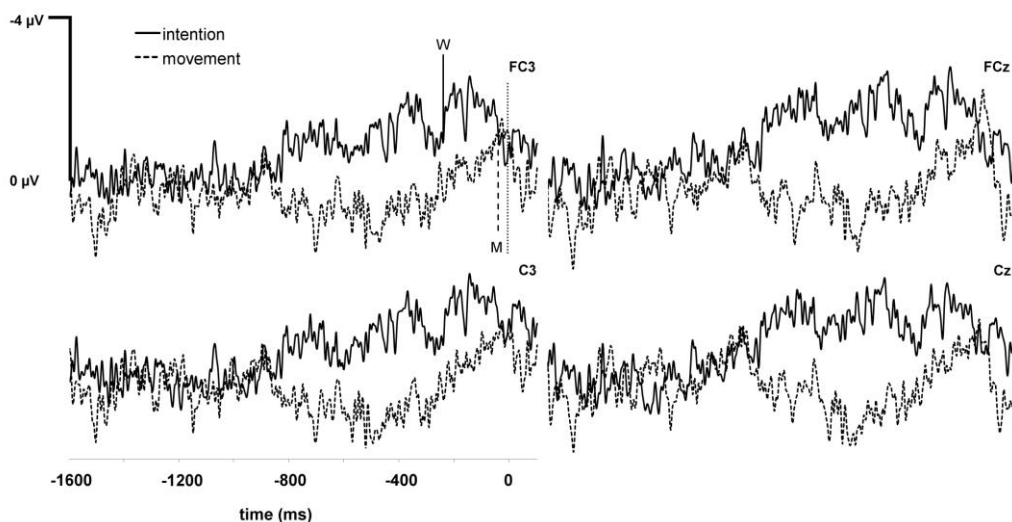
A two-ways mixed ANOVA was performed using a  $2 \times 2$  experimental design with *condition* (I, M) as within subjects factor and *order* (I-M, M-I) as between subjects factor. W-judgements were reported earlier than M-judgements ( $F(1,11)=21.49$ ,  $p=.001$ ,  $\eta_p^2=.66$ ): the average of W-judgement was  $-267 \pm 175$  ms and the average of M-judgements was  $-76 \pm 132$  ms, prior to the movement onset (Fig. 4.1). We found neither *order* factor nor *condition*  $\times$  *order* interaction to be significant (all  $p_s > .05$ ). As shown in previous research (Banks & Isham, 2009; Rigoni et al., 2010), the W-judgment did not correlate with movement onset ( $p > .05$ ). This result is consistent with the idea that the W-judgment is not related to the actual onset of the movement (Banks & Isham, 2009; Rigoni et al., 2010).

#### 4.3.2. Pre-movement ERP activity

The epoch length before movement onset – not including the baseline interval from -2000 to -1800 ms – was divided into 9 non-overlapping 200 ms segments. The mean amplitude across all time points in each segment was used as measure of the RP in the statistical analysis. A four-way repeated-measures ANOVA was performed using a  $2 \times 9 \times 5 \times 3$  experimental design: *condition* (I, M), *time* (9 segments), *region* (F: frontal, FC: fronto-central, C: central, CP: centro-parietal, P: parietal), and *laterality* (3: left, z: central, 4: right). When appropriate, the Greenhouse–Geisser correction was used.

Crucially, the analysis revealed a significant *condition*  $\times$  *time* interaction ( $F(8,1)=3.58, p=.001, \eta_p^2 = .23$ ), indicating that the slow negative-going increase in the amplitude of the RP differed between the two conditions, being larger in the I-condition than in the M-condition (Fig. 4.1). In line with the literature (Shibasaki & Hallett, 2006), the increase of the RP was not homogeneous across scalp. The RP increased in amplitude more over frontal-central and central areas as compared to frontal, central-parietal and parietal areas, as indicated by the *region*  $\times$  *time* interaction ( $F(32,1) = 2.19, p < .0001, \eta_p^2 = .15$ ). The increase of the RP was also more pronounced along the midline and the electrode sites contralateral to the responding hand as compared with the ipsilateral electrode sites, as shown by the *laterality*  $\times$  *time* interaction ( $F(16,1) = 4.68, p < .0001, \eta_p^2 = .28$ ).

To determine the time at which the RP started to differ between the two conditions, paired t-tests were performed on the time windows over the averaged electrodes of interest in which the RP showed its maximum (FCz, FC3, Cz, and C3). This analysis revealed that the RP was larger for the I-condition than the M-condition already around -800 ms before the button press (Fig. 4.1) ( $t(12)=2.32, p<.05$ ).



**Figure 4.1.** ERP traces representing pre-movement activity over FC3, C3, FCz and Cz. W and M signal the time relative to the movement onset (time 0, black dotted line) at which

participants reported their intention (-267 ms) and the onset of the actual movement (-76 ms), respectively. The RP was larger in the I-condition than in the M-condition already -800 ms prior movement onset.

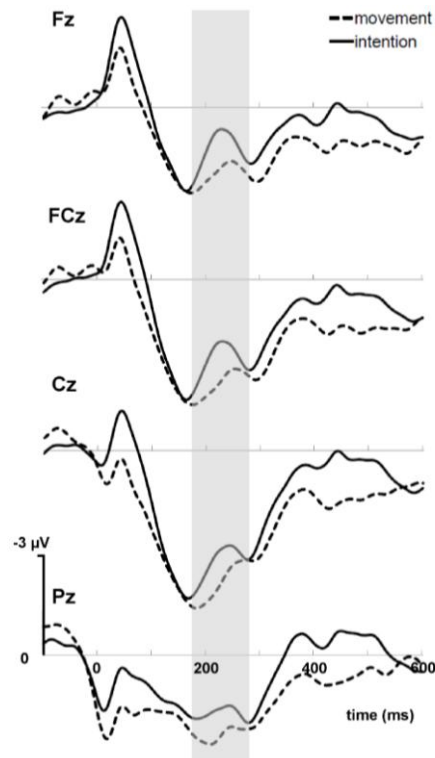
#### 4.3.3. Post-movement ERP activity

An additional filter (high-pass 1 Hz and low-pass 12 Hz, 24 dB/oct) was applied in order to smooth the EEG signal. Segments were time-locked to the presentation of the tone and previous 200 ms were taken as baseline. Nae was quantified as the most negative peaks within 180-280 ms time windows after tone onset, as measured from the baseline. The Nae amplitude was then entered into a repeated-measure ANOVA using a  $2 \times 5 \times 3$  experimental design: *condition* (I-condition, M-condition), *region* (F: frontal, FC: frontal-central, C: central, CP: central-parietal, P: parietal), and *laterality* (left: 3, midline: z, right: 4). Greenhouse–Geisser correction for violations of the assumption of sphericity was applied where appropriate.

The analysis revealed a significant effect of the *condition* ( $F(1,12)=5.33$ ,  $p=.04$ ,  $\eta_p^2=.31$ ), indicating more negative Nae for I-condition than for M-condition condition (.94  $\mu\text{V}$  vs. 1.67  $\mu\text{V}$ , respectively). The *condition*  $\times$  *region* indicated that the effect of the condition was not uniform across the scalp, although the effect was only marginally significant ( $F(4,48)=2.15$ ,  $p=.089$ ,  $\eta_p^2=.15$ ). The effect was stronger over frontal and frontal-central electrodes and decreased in the more posterior electrode sites. In general, the Nae showed its maximum over frontal electrodes (-.124  $\mu\text{V}$ ), followed by frontal-central (1.11  $\mu\text{V}$ ), parietal (1.31  $\mu\text{V}$ ), central-parietal (2.07  $\mu\text{V}$ ), and central (2.14  $\mu\text{V}$ ) electrodes, as indicated by the effect of *region* ( $F(4,48)=6.62$ ,  $p<.0001$ ,  $\eta_p^2=.36$ ). The effect of the *laterality* ( $F(2,24)=4.48$ ,  $p=.022$ ,  $\eta_p^2=.15$ ), was qualified by the *region*  $\times$  *laterality* interaction ( $F(8,96)=3.38$ ,  $p=.002$ ,  $\eta_p^2=.22$ ), that indicated that the effect of the laterality (i.e. Nae more negative for electrodes ipsilateral to the responding hand) was stronger over central, frontal-



central and central-parietal electrodes than over frontal and parietal electrodes. Neither other factors nor interactions reached or approached significance (all  $p_s > .05$ ).



**Figure 4.2** Post-movement activity over representative electrodes (i.e. Fz, FCz, Cz, and Pz). The action-effect negativity (Nae) is indicated in the pale grey box. The Nae is larger in the I-condition, as compared to the M-condition.

#### 4.4. Discussion

The objective of the present study was to investigate the electrophysiological mechanisms involved in the preparation and monitoring of intentional actions. In particular, here we wanted to investigate whether ERP components reflecting action preparation and action monitoring are enhanced when participants attend to their intention to act. It has already been demonstrated that attention to intention enhances activity of preSMA related to motor preparation (Lau et al., 2004). In addition, other studies demonstrated that the RP, a slow negative-going ERP component reflecting the intentional involvement in the preparation of voluntary movements, was larger

when participants attended the time of their intention than when they attended to the movement itself (Sirigu et al., 2004; Waszak et al., 2005; Keller et al., 2006).

We applied an “attentional spotlight” approach to a variant of the Libet’s task (Libet et al., 1983; Lau et al., 2004) in which we asked participants to press a button with their right index finger at the time of their own choosing. After each button press participants had to report either the time they had the intention to move (W-judgment, I-condition) or the time they actually made the movement (M-judgment, M-condition). This procedure allowed a comparison between two conditions that were equated for working memory load, action preparation and action execution processes (Lau et al., 2004), but that differed regarding the focus of participants’ attention. The assumption behind this procedure is that attending “inward” toward an internal representation increases the activity of the brain regions associated with that representation (Lau et al., 2004; Eagleman, 2004). Therefore, we expected the electrophysiological processes underlying preparation and monitoring of intentional actions to be enhanced in the I-condition as compared to the M-condition.

At a behavioral level, participants’ W- and M-judgments were -267 and -76 ms prior movement onset, respectively (Fig. 4.1). This result is in line with previous research showing that people are reliable in reporting the two judgments as two distinct psychological events (Haggard & Eimer, 1999). In addition, we found that the W-judgment did not correlate with the actual onset of the movement. This result is a replication of the finding that awareness of intention is not related to the actual movement (Banks & Isham, 2009; Rigoni et al., 2010).

By applying the “attentional spotlight” procedure to the Libet’s task we were able to compare ERP activity reflecting both action preparatory and monitoring processes in two conditions that differed only regarding the focus of participants’ attention. As regard action preparation, we focused on the RP, a slow negative-going potential that

starts up to 2 s before a voluntary finger movement (Kornhuber & Decke, 1965; Libet et al., 1983). It reflects the intentional involvement in the performed action (Libet et al., 1982; Kornhuber, 1984; Keller & Heckhausen, 1990) and it is thought to be restricted to movements that are executed with the “*introspective feelings of the willful realization of the intention to move at a particular time*” (Lang, 2003). Therefore, our hypothesis was that the RP would be larger in the I-condition than in the M-condition. We found larger RP in the I-condition than in the M-condition (Fig. 4.1). This is in line with previous research (Sirigu et al., 2004; Waszak et al., 2005; Keller et al., 2006). Interestingly, the difference between the two conditions was significant already 800 ms prior the movement onset (Fig. 4.1), suggesting that the experimental manipulation had an effect already in the early stages of motor preparation. This result extends previous findings showing that late stages of motor preparation are larger in intention-based actions than in stimulus-based actions (Waszak et al., 2005; Keller et al., 2006). Here we report that participants exhibit larger RP when they attend to their own intention than when they attend to the movement itself. The difference between the two conditions was detectable already 800 ms prior the motor response (Fig. 4.1). It has been reported that the RP can be divided into at least two subcomponents reflecting distinct processes (Shibasaki & Hallett, 2006). In particular, there is an early component that starts up to 2 seconds and ends at around 500 ms prior movement onset. This component is referred to as early BP, is generated by the preSMA and reflects the slow increasing of cortical excitability and the pre-conscious readiness for the forthcoming movement. The later part of the RP (i.e. late RP) begins around 500 ms before movement onset and is associated with the activity of the primary motor cortex and SMA proper (Shibasaki & Hallett, 2006). Therefore, our results suggest that our manipulation affected the amplitude of the RP already during the early stages of motor preparation.

Recent studies have shown that task-irrelevant action-effect representations can be used to predict the outcome of a given action and are matched with the actual outcome (Band et al., 2009; Rigoni et al., 2010). This supports the idea that action effects do not only play a role in action preparation and action selection, but also in action monitoring. According to this hypothesis, we focused on a negative ERP component that follows auditory stimuli and that reflects the linkage between an action and its effects (Band et al., 2009; Rigoni et al., 2010). We referred to this component as action-effect negativity (Nae) (Band et al., 2009). Given that the linkage between action and its effects strongly depends on the intention to produce the effect, we expected the Nae to be enhanced in the *intention* condition. Our experimental manipulation had a significant effect in the amplitude of the Nae, as we found the Nae to be larger in the I-condition than in the M-condition (Fig. 4.2). This finding might be taken as evidence that monitoring of effects of intentional action is involved in action-effect binding.

Taken together, these findings are in line with experimental evidence that action-effects binding do not play a role only in action preparation, the process most ideomotor theories focus on (Prinz, 1987; Waszak et al., 2005; Keller et al., 2006), but also in action monitoring (Band et al., 2009; Rigoni et al., 2010).

In addition, we observed that the RP was more pronounced for I-condition than for M-condition already at 800 ms prior movement onset. This difference might be taken as evidence that the planning of intentional actions involves the anticipation of the sensory consequences of the action itself (Prinz, 1987). Although in the present study both conditions involved actions that were intentional, we assume that in the I-condition, as compared with the M-condition, action-effect binding processes were increased. The fact that the Nae was larger in the I-condition than in the M-condition, might reflect enhanced action-effect binding in action monitoring.

Monitoring the consequences of an action is crucial for the experience of intentionality: the sensory experiences of the executed action and of its effects – e.g. tactile and proprioceptive feedbacks, auditory or visual information – trigger a reconstruction of the intention to act (Haggard 2008; Haggard et al., 2002).

In conclusion, here we provided evidence that both preparatory and action-monitoring processes, reflected by the RP and the Nae, respectively, are crucial for binding together the represented action and its effects. However, further research is needed in order to clarify whether other processes are involved in action-effect binding, and what brain regions are specifically involved.

## **5. Free will beliefs and motor preparation<sup>6</sup>**

### **5.1. Introduction: a new approach to the problem of free will**

Recent discoveries in psychology and neuroscience seem to challenge the existence of free will by showing that free will has an illusionary nature (Wegner, 2002) or that it is just a perception arising from unconscious brain activity (Libet et al., 1983; Soon et al., 2008; Hallett, 2007; Haggard, 2008). However, despite the scientific and philosophical relevance of these findings, people seem to naturally believe in free will (Baumeister et al., 2009). But does it really matter whether people believe in free will or not? Would we behave differently if it turns out that free will is really an illusion?

Believing in free will, that is, believing that we can exert control over our own behaviour, is essential for our well-being and it is a psychological and biological necessity (Leotti et al., 2010). Previous research already demonstrated that control and agency beliefs affect people's intention to act, motivations and behaviour (e.g. Ajzen, 2002; Bandura, 1982). For instance, when people believe they cannot exercise control over their own behaviour and over the events that affect their lives, they tend to behave ineffectually, even though they know what to do (Bandura, 1989).

More recent studies in social psychology have shown that believing in free will has important implications also for our social behaviour. For instance, it has been demonstrated that increasing people's sense of responsibility can shift their behavior toward a more desirable performance (Harmon-Jones & Mills, 1999; Mueller & Dweck, 1998). Under this perspective, one might expect that reducing people's sense of responsibility by exposing them to a deterministic worldview may promote undesirable behaviour.

---

<sup>6</sup> Authors: D.R., Simone Kuhn, Giuseppe Sartori, Marcel Brass

Recently, Vohs and Schooler (2008) addressed this question and carried out a study in which they examined whether inducing participants to believe that human behavior is predetermined would encourage cheating. Two groups of participants were exposed either to a deterministic (i.e. statements claiming that high-minded people now agree in that free will is an illusion) or to a neutral message (i.e. statements about consciousness which did not discuss free will). Afterwards, participants were given a series of complex mental-arithmetic problems. They were told that due to a computer glitch, the correct answer would appear on the screen while they were attempting to solve the problem and that they could stop the answer from being displayed by pressing the space bar after the arithmetical problem appeared. Furthermore, they were told that although the experimenter would not know whether they pressed the space bar, they should try to solve the problem honestly. Unbeknownst to the participants, the dependent measure was indeed the number of times they pressed the space bar to prevent the answer from appearing. Results showed that the participants who were exposed to a determinist message cheated more frequently than those who were exposed to a neutral message. In the same study, the authors showed that also when the task requires a more active behavior in order to cheat (i.e. stealing money from the researchers), participants exposed to a deterministic message behave more immorally than others.

Baumeister and colleagues (2009) extended Vohs and Schooler (2008) findings into a broader context. More precisely, they showed that a disbelief in free will increases antisocial attitudes such as aggression and at the same time reduces pro-social behavior such as helpfulness.

While this research shows that undermining beliefs in free will influences performance and complex social behaviour, the question arises whether such an influence can already be demonstrated on a more basic motor level.

In the current experiment, we investigated whether inducing the idea that free will plays no role in the determination of human actions influences brain correlates of voluntary motor preparation. The main hypothesis was that dismissing free will would deplete the intentional involvement in the preparation of voluntary motor actions. Thus, the prediction was that a disbelief in free will affects brain correlates of volitional processes at the earliest stages of voluntary actions. We recorded ERPs while participants were performing a modified version of the Libet's task (Fig. 1.1.) (Libet et al., 1983; Banks & Isham, 2009). It is well known that voluntary manual movements and the intention to move are preceded by the RP (see chapters 1 and 2). The RP can be subdivided in at least two subcomponents: an early component (i.e. early-RP) reflecting movement preparation, and a late component (i.e. late-RP) involved in the specific programming for movement execution (Kornhuber & Deecke, 1965; Shibasaki & Hallett, 2006; Kornhuber, 1984; Keller & Heckhausen, 1990; Lang, 2003). The early-RP starts up to 2000 ms before movement execution and has been proposed to be generated by the preSMA. The late-RP begins around 500 ms before movement onset and has been associated with the activity of the primary motor cortex and SMA proper (Shibasaki & Hallett, 2006). The early-RP is modulated by the level of intentional involvement (Libet et al., 1982; Kornhuber, 1984; Keller & Heckhausen, 1990) and it had been suggested that it is restricted to movements that are executed with the "*introspective feelings of the willful realization of the intention to move at a particular time*" (Lang, 2003). Conversely, the late-RP is influenced by factors concerning motor execution such as precision, discreteness and complexity of the executed movement (Shibasaki & Hallett, 2006). Therefore, we focused on the early-RP, as we were primarily interested in electrophysiological processes reflecting intentional involvement in motor preparation.

Our hypothesis was that inducing disbelief in free will would lead to a reduction of



the early-RP. Prior to the task, participants were randomly assigned to one of two groups: the no-free will group had to read a text claiming that scientists now recognize that free will is an illusion; the control group read a text on consciousness that did not mention free will at all. This procedure has been shown to affect people's belief about free will (Vohs & Schooler, 2008).

Besides the influence of disbelief in free will on the RP, we were also interested in the question whether the free will manipulation affects post-action influences on conscious intentions (Lau et al., 2007; Kuhn & Brass, 2009; Banks & Isham, 2009; Rigoni et al., 2010). As reported in Experiment 1, it has been shown that people are influenced by false external action feedback when they have to report when they had the intention to act. For instance, false feedbacks signalling a response different or later than the actual one modify individuals' estimates of *when* they wanted to act (Banks & Isham, 2009; Rigoni et al., 2010); this indicates that people rely also on external feedbacks (e.g. tones signalling the response, somatosensory and tactile cues) when estimating internal events such as the intention to execute an action. We wanted to test whether the influence of external feedback becomes amplified in the no-free will group. To answer this question we manipulated the feedbacks following the individual response. Each button press was associated with either a simultaneous or a delayed auditory feedback and then participants were asked to report the time they had the first intention to press the button (Fig. 5.1).

## **5.2. Method**

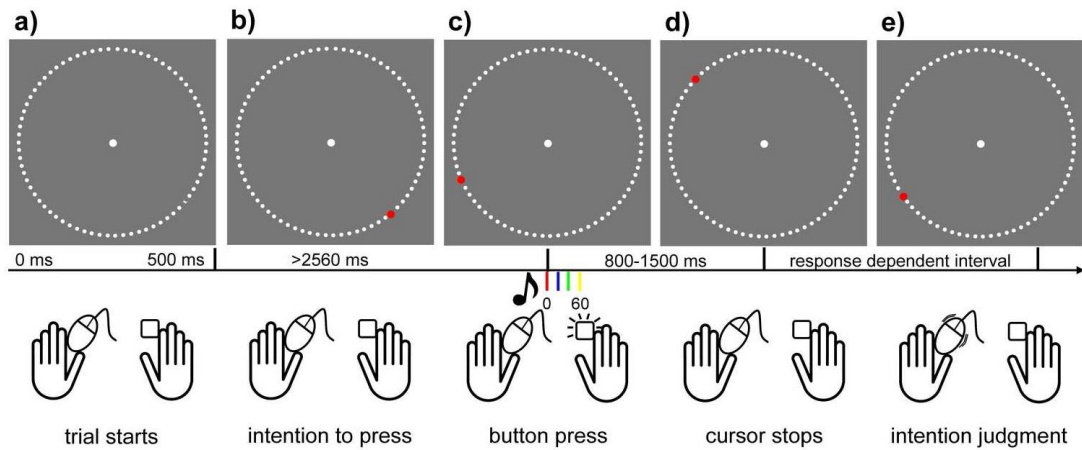
### *5.2.1. Participants*

Data were recorded from 30 participants (20 females, age range 18-24 yrs). All participants were right handed according to the Edinburgh inventory (Oldfield, 1997), had normal or corrected-to-normal vision and participated on the basis of

informed consent. The study was conducted according to the Declaration of Helsinki, with approval of the local ethical committee. Participants were paid 15 euro for participation.

### 5.2.2. *Experimental design*

According to the condition to which they were randomly assigned, participants read one of two passages taken from Francis Crick's book *The Astonishing Hypothesis* (see Appendix A): the no-free will group internalized messages claiming that scientists now recognize that free will is an illusion; the control group internalized messages on consciousness that did not mention free will. Participants were instructed to read the assigned material carefully and anticipated that a comprehension test would be administered at the end of the experiment. Then, participants performed a modified version of the Libet task (see Fig. 5.1) (Libet et al., 1983; Banks & Isham, 2009; Rigoni et al., 2010). Participants first practiced with the task and then started the experimental session (120 trials administered in two blocks). Afterwards, participants completed the Free Will and Determinism scale (FWD) (Rakos et al., 2008) in order to assess whether the reading manipulation affected their beliefs about free will. Fourteen items of the FWD scale assess personal beliefs about other people having free will ("*Human beings actively choose their actions and are responsible for the consequences of those actions*") and form the general FWD subscale. The other 8 items assess beliefs about free will related to oneself ("*My decisions are influenced by a higher power*"), forming the personal FWD subscale. Participants were also administered the Tangney self-control scale (Tangney et al., 2004) and the Marlow-Crowne social desirability scale (Tatman et al., 2009).



**Figure 5.1** Task procedure. (a) At time 0 the clock appeared. (b) After 500 ms the red cursor appeared at a random position and started to rotate clockwise. Participants were instructed to press the button spontaneously with their right index finger at a time of their own choosing, after at least one rotation of the cursor. (c) Auditory feedback followed each button press. The feedback could be delivered simultaneously (red line) or delayed by 20, 40 or 60 ms (blue, green and yellow lines, respectively). (d) After a random interval of 800 to 1500 ms, the cursor stopped. (e) Participants were then asked to report the position of the cursor at the time they experienced the first intention to press the button.

### 5.2.3. ERP recordings

ERP was recorded with a 30-channel elastic electrode cap (EasyCap) according to a modified 10-20 setting. The activity of both left and right mastoids was recorded. Electrode impedance was kept below 5 k $\Omega$  for all the recordings. Amplified voltages were sampled at 512 Hz. The electro-oculogram (EOG) was recorded with bipolar montage. Continuous EEG data were analyzed offline using Brain Vision Analyzer (Brainproducts, Munich): the signal was re-referenced to the average signal of the mastoids and filtered (notch filter of 50Hz, band-pass filter of 0.016-70 Hz, 24 dB/octave attenuation), and epochs were time-locked to the button press (time window from -2500 ms prior and 500 ms after the button press, using the first 200 ms as baseline). Ocular movements' artefacts were corrected using a semiautomatic blink detection algorithm (Gratton et al., 1983). Epochs containing artefacts were rejected on the basis of visual inspection and automatic artifact detection (peak-to-peak < 100 $\mu$ V). On average, there were 101 $\pm$ 16.62 artifact-free trials (104 $\pm$ 13.26 and

98±19.06 for the no-free will group and the control group, respectively). Data from one participant in the no-free will group not showing a clear negativity prior to the actual movement was excluded from further analysis.

### **5.3. Results**

#### *5.3.1. Self-report scales*

Groups' scores were compared by means of independent t-tests. The analysis revealed a difference regarding the personal FWD subscale ( $29.79 \pm 3.95$  vs.  $33.6 \pm 3.22$ ,  $t(27)=-2.86$ ,  $p<.01$ ), indicating that the experimental manipulation was effective in weakening participants beliefs in free will in the no-free will group concerning beliefs in free will related to oneself. Conversely, the general FWD subscale did not differ between the two groups ( $p=.26$ ); the no-free will group scored lower in the global FWD scale, although the effect was only marginally significant ( $80.93\pm 10.13$  vs.  $86.13\pm 9.27$ ;  $t(27)=-1.45$ ,  $p=.08$ ). No differences were found concerning the Tangney Self-Control scale and the Marlow-Crowne Social Desirability scale (all  $p_s>.1$ ).

#### *5.3.2 Reported time of intentions (W)*

To test whether the experimental manipulation had an effect on the reported time of intentions, an ANOVA was performed with the factor *group* (control, no-free will) and the reported W as dependent variable. The analysis revealed no significant effect ( $p = .41$ ), indicating that the free will manipulation did not influence the reported time of conscious intentions (Fig. 5.2). In addition, a two-way mixed ANOVA was performed with the factors *group* (control, no-free will) and *feedback delay* (0, 20, 40, 60 ms) and the reported W as dependent variable. The averaged reported Ws at delays of 0, 20, 40, and 60 ms were -237, -220, -199, and -225 ms, respectively,

relative to time of response. However, the analysis revealed that this effect was not significant ( $F(3, 81)=2.13, p=.1$ ). There was neither an effect of *group* ( $p=.64$ ) nor an interaction effect ( $p=.43$ ). This result indicates that the free will manipulation did not influence action monitoring processes related to the reported time of conscious intentions.

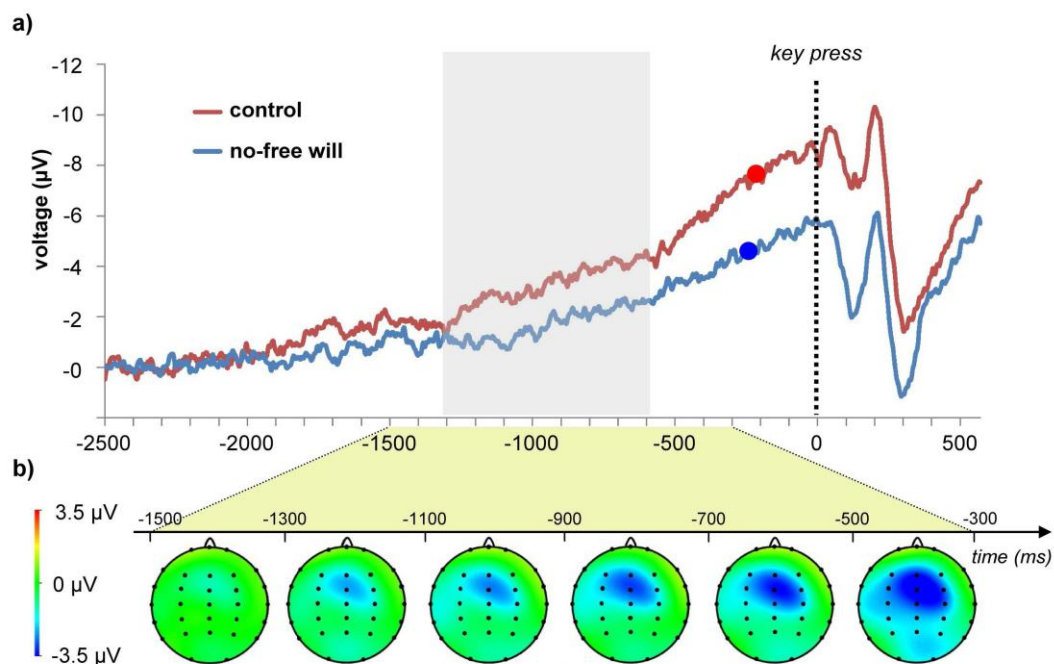
### 5.3.3. ERP data

In a first analysis, the epoch before the movement from -2300 to -100 ms was divided into 11 non-overlapping 200 ms segments. The mean amplitude across all time points in each segment was then entered into a mixed ANOVA with a  $2 \times 11 \times 3 \times 3$  design: *group* (control, no-free will), *time* (11 segments), *laterality* (3, z, 4), and *region* (CP: centro-parietal, C: central, FC: fronto-central). When appropriate, the Greenhouse-Geisser correction was used.

The RP differed between the two groups, as revealed by the *time*  $\times$  *group* interaction ( $F(10) = 2.353, p = .011, \eta_p^2 = .086$ ), with larger amplitude in the control group than in the no-free will group. The analysis revealed a main effect of *time* ( $F(10,270) = 47.834, p < .0001, \eta_p^2 = .639$ ), reflecting the slow negative-going increase in the amplitude of the RP prior to the motor response. The increase of the RP was not uniform across the scalp as reflected by the *time*  $\times$  *laterality* ( $F(20,540) = 8.029, p < .0001, \eta_p^2 = .229$ ) and the *time*  $\times$  *region* ( $F(20,540) = 3.551, p < .019, \eta_p^2 = .116$ ) interactions. The RP was larger over the midline and over the sites contralateral to the hand movement than over the ipsilateral sites, and it was more pronounced over central and fronto-central scalp locations than over centro-parietal scalp locations (Fig. 5.2). These results are consistent with the most relevant literature on the RP (Shibasaki & Hallett, 2006). The lack of a significant *time*  $\times$  *laterality*  $\times$  *group* and *time*  $\times$  *region*  $\times$  *group* interactions revealed that the RP had a similar scalp

distribution in the two groups. No other effects reached or approached significance level (all  $p_s > .1$ ).

To determine the time at which the two groups start to differ, t-tests were performed on the 11 time windows over the averaged electrodes of interest in which the RP showed its maximum (FCz, FC3, Cz, and C3). This analysis revealed that the RP was smaller in the no-free will group than in the control group already around -1300 ms before the button press (Fig. 5.2) ( $t(27)=2.45, p=.01$ ). A measure of the early-RP was then obtained by defining a window of interest from -1300 ms to -600 ms prior the button press. This window was meant to capture only the activity reflecting early motor preparatory stages (Shibasaki & Hallett, 2006). As predicted, the amplitude of the early-RP was reduced in the no-free will group as compared to the control group (Fig. 5.2) ( $F(1,28) = 4.43, p < .05, \eta_p^2 = .136$ ).

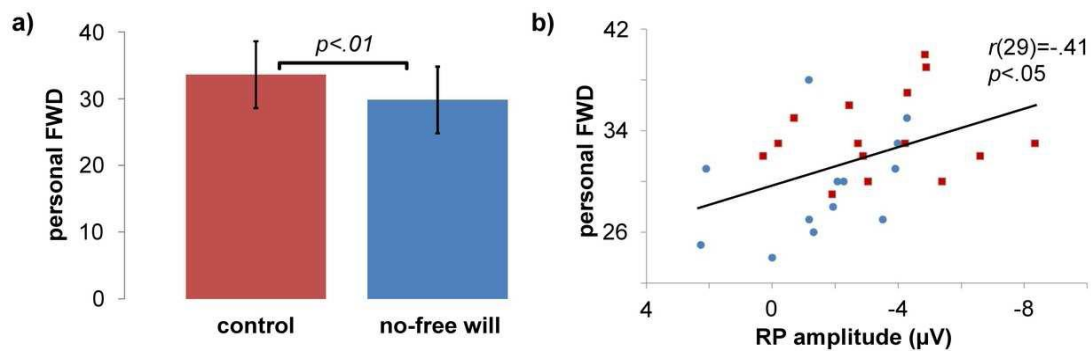


**Figure 5.2** (a) ERPs for averaged electrodes. The pale grey box indicates the activity between the time at which the two groups start to differ significantly and the beginning of the late-RP. The red and the blue circles in the ERP signal indicate the average W-judgments for the control and the no-free will group (-242 and -223 ms before the key press, respectively). (b) The maps show the topographic difference (control – no-free will)

regarding the pre-movement brain activity. The no-free will group shows a less pronounced negativity already around 1300 ms before the button press over fronto-central areas.

#### *5.3.4. Early-RP and free will belief*

To test the hypothesis that the amplitude of the RP was linked to participants' disbelief in free will, we correlated the personal FWD scores (Rakos et al., 2008) with the amplitude of the early-RP across all participants. In accordance with the prediction that disbelief in free will is negatively related to the early-RP, the analysis revealed a negative correlation (Fig. 5.3) ( $r(29)=-.404, p<.05$ ). However, computing the correlation across all the participants leaves the possibility that the negative correlation is primarily driven by the experimental manipulation rather than by a specific link between the amplitude of the RP and the free will beliefs more generally. Therefore, we computed the correlation for the no-free will group separately and found a marginally significant effect ( $r(14)=-.41, p=.07$ , one-tailed). Although the effect was only marginally significant presumably due to a lack of statistical power, this result suggests a specific link between the amplitude of the RP and the induction of a disbelief in free will in the no-free will group. The peak amplitude in the time window from -600 to -100 ms prior the button press (i.e. the late RP) did not correlate with the level of free will endorsement ( $p=.173$ ).



**Figure 5.3** (a) Participants in the no-free will group reported weaker beliefs in free will than those in the control group. (b) Scatter-plot of the correlation analysis designed to investigate whether the level of endorsement of beliefs in free will is associated with early-RP amplitude. Along the x-axis, more negative values indicate increases in the amplitude of the RP. Along the y-axis, more positive values indicate greater endorsement of beliefs in free will.

### 5.3.5. Specificity of the effect for motor preparation

In order to assess whether the effect found in the no-free will group was specific for brain processes related to motor preparation, we investigated whether sensory evoked potentials (i.e. processes that were non-related to motor preparation) were influenced by the same experimental manipulation.

According to our hypothesis, the free will manipulation only influenced brain processes related to action preparation. Therefore we should not find a difference between the two groups in brain activities unrelated to volition or to motor preparation, such as sensory evoked potentials. More precisely, we expect not to find increased activity in sensory evoked potentials in the control group as compared to the no-free will group. To address this issue, we time-locked the ERP traces to the auditory tone with a time window from 200 ms prior and 300 ms after the auditory tone. We used the 200 ms pre-stimulus interval as baseline. By using this time window, we were reasonably confident that the activity related to the motor preparation to report the W (i.e. by using the mouse)



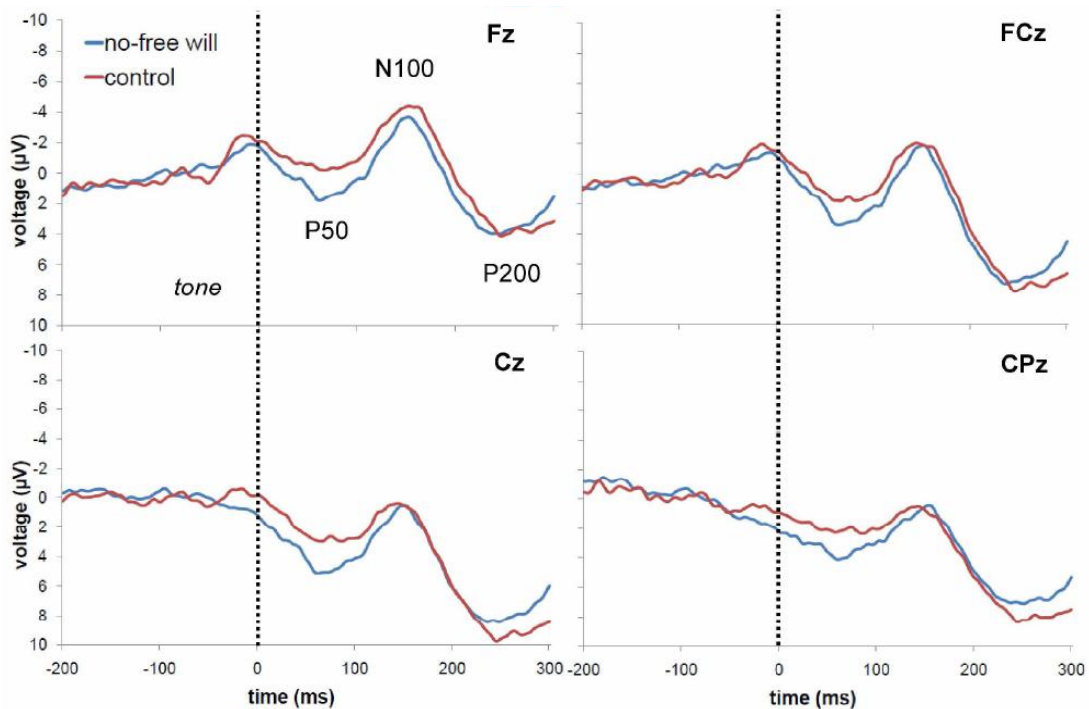
was not included.

The auditory tone elicited three clearly visible components (see Fig. 5.4), namely P50, N100 and P200, peaking at around 70, 150 and 250 ms, respectively, after the auditory tone. For each component, an ANOVA was performed using a  $2 \times 4$  design: *group* (control, no-free will), and *site* (Fz, FCz, Cz, CPz). The dependent variable was the peak amplitude of the component (i.e. peak amplitude between 0 and 100 ms, 100 and 200 ms and 200 and 300 ms, for P50, N100 and P200, respectively) relative to the pre-stimulus baseline.

**P50.** The analysis revealed a main effect of *site* ( $F(3,81) = 24.749, p < .0001, \eta^2 = .478$ ), with P50 being larger over CZ, followed by CPz, FCz, and Fz. Neither the *group* factor ( $p > .11$ ) nor the *group*  $\times$  *site* interaction ( $p > .9$ ) were significant. Although there is almost a statistical trend for the P50, the direction is opposite from what one would expect if the no free will manipulation would lead to a general attenuation of brain activity.

**N100.** The analysis showed a main effect of *site* ( $F(3,81) = 24.749, p < .0001, \eta^2 = .663$ ), with N100 being larger over frontal areas (i.e. Fz, followed by FCz, Cz, and CPz). Neither the *group* factor ( $p > .63$ ) nor the *group*  $\times$  *site* interaction ( $p > .61$ ) were significant.

**P200.** The analysis showed a main effect of *site* ( $F(3,81) = 24.749, p < .0001, \eta^2 = .58$ ), with P200 being larger over Cz, followed by CPz, FCz, and Fz). Neither the *group* factor ( $p > .6$ ) nor the *group*  $\times$  *site* interaction ( $p > .7$ ) were significant.



**Figure 5.4** Grand-averaged post-action ERPs. ERPs are time-locked to the auditory stimulus, which was presented after the response. Sensory evoked potentials (i.e. P50, N100, and P200) did not differ between the two groups.

#### 5.4. Discussion

Here we demonstrate that weakening the belief in free will affects brain processes underlying early stages of motor preparation. In particular, the early-RP was reduced in the no-free will group as compared with the control group (Fig. 5.2). Furthermore, the no-free will group scored lower on the personal FWD subscale than the control group (Fig. 5.3). Crucially, the degree of disbelief in free will correlated with the amplitude of the early-RP (Fig. 5.3), indicating smaller RPs for participants with weaker beliefs in free will. Conversely, the amplitude of the late RP did not correlate with the level of free will approval, suggesting that beliefs in free will are related to early motor preparation rather than processes associated with motor execution. Furthermore, we excluded the possibility that other brain processes, unrelated to volition and preparation to action, such as sensory processes, were attenuated in the no-free will group (Fig. 5.4). Finally, we could show that the W-judgment is not

affected by the manipulation (Fig. 5.2): the induction of disbelief in free will does not affect people's estimates of when the intention to move enters awareness. This result is consistent with our ERP observation that the belief manipulation affected only the early-RP but not the late RP. Indeed, other studies (Haggard & Eimer, 1999; Haggard, Newman, & Magno, 1999) reported that the W-judgment is associated with late stages of motor preparation, rather than with the initial intention and preparation for action, which is reflected by the early-RP.

Previous research revealed that weakening beliefs in self-efficacy, control and agency influence complex behaviour (Ajzen 2002; Bandura, 1982, 1989). In particular, self-efficacy beliefs – i.e. people's beliefs about their capabilities to exercise control over events that affect their lives – determine people's level of effort: the stronger the belief in their capabilities, the greater and more persistent are their efforts (Bandura, 1989). More recent research tested whether inducing disbelief in free will also affects how people behave in social situations (Vohs & Schooler, 2008; Baumeister et al., 2009). It was demonstrated that disbelief in free will led to antisocial and aggressive behaviour (Vohs & Schooler, 2008; Baumeister et al., 2009). The current study extends these findings by showing that manipulating beliefs in free will also influences low-level brain processes associated with the preparation of intentional action. Furthermore, our study shows that disbelief in free will affects intentional action at a preconscious level of motor preparation, because the effect of our belief manipulation was evident more than 1 s before participants consciously decided to act (Fig. 5.2). Currently we can only speculate about the precise mechanisms that mediate the influence of high-level beliefs on basic motor preparation. Reading such deterministic messages may induce participants to modify their high-level beliefs on free will because of insight into a rational argument. Alternatively, people may be emotionally impressed by the rhetoric or by the

message conveyed by the text. In any case, undermining the idea that we are “*the masters of our own houses*” (Freud, 1917) presumably reduces the intentional effort we put into action.

How disbelief in free will affects intentional effort is an open question. One likely possibility is that this effect is mediated by self-efficacy and perceived control (Ajzen, 2002; Bandura, 1982; 1989). However, it is crucial to note that self-efficacy and control beliefs refer to people’s beliefs about the capability to control their lives, while the anti-free will manipulation concerned a more ‘metaphysical’ idea of being in control (i.e. *We are not free because our genes and the environment determine our behavior*).

Importantly, the influence of high level beliefs on basic motor processes might also help us to understand why such beliefs lead to antisocial and irresponsible behaviour (Vohs & Schooler, 2008; Baumeister et al., 2009). Putting less effort into an action might weaken our sense of agency for these actions leading to a reduced feeling of responsibility. Thus, a reduced feeling of responsibility would very likely result in more careless and irresponsible behavior (Vohs & Schooler, 2008; Baumeister et al., 2009). One basic assumption of this explanation is that disbelief in free will influence people’s sense of agency. Interestingly, it has been shown that authorship indicators (e.g. action-effect consistency) affect self-reported agency (Ebert & Wegner, 2010). From this perspective, one could hypothesize that dismissing the idea that we can control our own actions acts as a non-authorship indicator, thereby decreasing people’s sense of authorship.

In sum, our results clearly indicate that beliefs about free will can change brain processes related to a very basic motor level, suggesting that abstract belief systems might have a much more fundamental impact than we ever thought.

## 6. Conclusive thoughts

The subjective feeling of free will is a pervasive component of human experience. We have a clear and unavoidable experience of voluntarily control a great part of our actions and we feel to be the agent of our behaviour. We therefore feel we are responsible for those actions that are performed with an intention, that is, those actions that are associated with the subjective experience that “I” decided to do so.

The present thesis describes three experiments in which ERP were recorded while participants were performing the so-called Libet’s task (Libet et al., 1983). The aim of the research was to investigate neurophysiological processes underpinning intentional actions.

Experiment 1 demonstrated that events occurring after an action is executed can influence the subjective experience of intention. In addition the Nae, an ERP component occurring 250-300 ms after feedback onset, was associated with the changes in the reported time of intention. On one hand, these findings suggest that action-monitoring processes, reflecting the evaluation of action effects, are involved in the experience of intention. This interpretation is in line with recent theories on willed behaviour that emphasize the role of inferential and reconstructive processes of intentions (Dennett & Kinsbourne, 1992; Wegner, 2002; Haggard, 2008). Intention would seem to be a perception, rather than the generator of behaviour (Hallett, 2007). On another hand, these results cast doubts on the validity of the Libet’s paradigm to study conscious intentions (Libet et al., 1983; Rigoni et al., 2010): when reporting the time of the conscious intention to perform an action, participants rely on either internal or external feedbacks signalling that a response was provided, and then infer that the intention “must have taken place” before the

response. This would not measure, neither indirectly, when the intention entered the stream of consciousness. Rather, it would reflect the subjective estimate, inferred from post-action events, of when the intention *must* have occurred. Despite this limitation however, the Libet's task still appears to be one of the few viable methods for investigating intentional actions (Haggard, 2005).

Elaborating on the issue of conscious intentions and action monitoring processes, Experiment 2 investigated neurophysiological correlates of preparation and monitoring of intentional actions. Both pre- and post- action ERP components were enhanced when participants attended to their intention (I-condition) rather than to the actual movement (M-condition). In particular, the RP, that reflects preparation for action, was larger for I-condition. This finding was interpreted as enhanced action-effect binding in intentional actions (Waszak et al., 2005; Keller et al., 2006; Haggard, 2008). The fact that also post-action components (i.e. Nae) were larger when participants attended to their intention suggest that action monitoring processes are involved in action-effect binding, a process that is crucial in the experience of intention (Haggard et al., 2002; Band et al., 2009). This result shed lights on the different contributions of preparation and monitoring processes in the experience of intention.

Experiment 3 was meant to investigate whether abstract beliefs on free will can influence neurophysiological correlates of motor preparation of intentional actions. Participants induced to disbelieve in free will showed smaller RPs' as compared to the controls. Importantly, the effect was clear already 1300 ms before actual motor response (i.e. in the early-RP), suggesting that the early stages of motor preparation are involved. This finding suggests that the decreased RP reflects less intentional involvement in the task in participants induced to disbelieve in free will. While previous studies in social psychology reported that disbelieving in free will influence

people's behaviour in social situations, leading to antisocial tendencies, here it has been shown that it has an effect on a very low motor level. A crucial question refers to what does disbelieving in free will actually mean? In the present thesis, it has been argued that free will beliefs are related to control and self-efficacy beliefs (Ajzen, 2002; Bandura, 1982; 1989), although the experimental manipulation in Experiment 3 referred to a more *metaphysical* idea of behavioural control. In any case, disbelieving in free will would refer to the idea that the person has no control over behaviour and the events that affect his or her life. This belief would in turn lead to the idea that the outcome of a person's behaviour is somehow *predetermined*, no matter how much effort he or she puts into action. As a consequence, a person would reveal a more careless and irresponsible behaviour, reflecting less intentional involvement into action.

## References

Aarts, H., Custers, R., & Wegner, D.M. (2005). On the inference of personal authorship: Enhancing experienced agency by priming effect information. *Conscious Cogn* 14 (3), 439-458.

Ajzen, I. (2002). Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *J Appl Soc Psychol*, 32, 665-683.

Band, G.P.H., van Steenbergen, H., Ridderinkhof, K.R., Falkenstein, M., & Hommel, B. (2009). Action-effect negativity: Irrelevant action effects are monitored like relevant feedback. *Biol Psychol* 82, 211-218.

Bandura, A. (1982). Self-efficacy in human agency. *American Psychologist*, 37, 122-147.

Bandura, A. (1989). Human agency in social cognitive theory. *American Psychologist*, 44, 1175- 1184.

Banks, W. P., & Isham, E. A. (2009). We infer rather than perceive the moment we decided to act. *Psychol Sci* 20 (1), 17-21.

Baumeister, R.F. (2008). Free will in scientific psychology. *Perspect Psychol Sci* 3 (1), 14-19.

Baumeister, R.F., Masicampo, E.J., & DeWall, C.N. (2009). Prosocial benefits of feeling free: disbelief in free will increases aggression and reduces helpfulness. *Pers Soc Psychol B*, 35, 260-268.

Blakemore, S.J., Frith, C.D., & Wolpert, D.M. (1999). Spatiotemporal prediction modulates the perception of self-produced stimuli. *J Cognitive Neurosci* 11, 551-559.



- Blakemore, S.J., Wolpert, D.M., & Frith, C.D. (2002). Abnormalities in the awareness of action. *Trends Cogn Sci* 6 (6), 237-242.
- Brass, M., & Haggard, P. (2008). The what, when, whether model of intentional action. *Neuroscientist* 14 (4), 319-325.
- Brass, M., & Haggard, P. (2008). The what, when, whether model of intentional action. *Neuroscientist* 14 (4), 319-325.
- Burle, B., Vidal, F., Tandonnet, C., & Hasbroucq, T. (2004). Physiological evidence for response inhibition in choice reaction time tasks. *Brain Cognition* 56(2), 153-64.
- Deiber, M., Honda, M., Ibanez, V., Sadato, N., & Hallett, M. (1999). Mesial motor areas in self-initiated versus externally triggered movements examined with fMRI: effect of movement type and rate. *J Neurophysiol* 81(6), 3065-3077.
- Eagleman, D.M. (2004). The where and when of intention. *Science* 303, 1144-1146.
- Ebert, J.P., & Wegner, D.M. (2010). Time warp: Authorship shapes the perceived timing of actions and events. *Conscious Cogn* 19, 481-489.
- Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroen Clin Neuro* 78, 447-455.
- Folstein, J.R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology* 45 (1), 152-170.
- Freud, S. (1917). *Eine Schwierigkeit der Psychoanalyse, Gesammelte Werke Band* (Fischer Verlag, Frankfurt am Main), vol. 12, p. 11.
- Gehring, W.J., Goss, B., Coles, M.G.H., Meyer, D.E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychol Sci*, 4, 385-390.

- Gomes, G. (2010). Preparing to move and deciding not to move. *Conscious Cogn* 19(1), 457-459.
- Goodale, M.A., Jacobson, L.S., Milner, A.D., Perret, D.I., Benson, P.J., & Hietanen, J.K. (1994). The nature and limits of orientation and pattern processing supporting visuomotor and control in a visual form agnostic. *J Cognitive Neurosci* 6, 46-56.
- Gratton, G., Coles, M.G.H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroen Clin Neuro*, 55, 468-484.
- Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *J Cognitive Neurosci* 15(8), 1176-94.
- Haggard, P. & Clark, S. (2003). Intentional action: Conscious experience and neural prediction. *Conscious Cogn* 12 (4), 695-707.
- Haggard, P. (2003). Intentional action: Conscious experience and neural prediction. *Conscious Cogn* 12(4), 695-707.
- Haggard, P. (2005). Conscious intention and motor cognition. *Trends Cogn Sci* 9(6), 290-295.
- Haggard, P. (2008). Human volition: towards a neuroscience of will. *Nat Rev Neurosci* 9(12), 934-46.
- Haggard, P., & Eimer, M. (1999). On the relation between brain potentials and the awareness of voluntary movements. *Exp Brain Res*, 126, 128-133.
- Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nat Neurosci* 5(4), 382-385.
- Hallett, M. (2007). Volitional control of movement: the physiology of free will. *Clin Neurophysiol* 118, 1179-1192.

- Harmon-Jones, E., & Mills, J. (1999). *Cognitive dissonance: progress on a pivotal theory in social psychology*. Washington, DC: American Psychological Association.
- Holroyd, C.B., & Coles, M.G.H. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychol Rev* 109, 679-709.
- Hommel, B. (2003). Acquisition and control of voluntary action. In S. Maasen, W. Prinz, & G. Roth (Eds.), *Voluntary Action: Brains, minds, and sociality* (pp. 34-48). Oxford: Oxford University Press.
- James, W. (1890). *Principles of psychology*. New York: Holt.
- Jenkins, I. H., Jahanshahi, M., Jueptner, M., Passingham, R. E., & Brooks, D. J. (2000). Self-initiated versus externally triggered movements. II. The effect of movement predictability on regional cerebral blood flow. *Brain* 123, 1216-1228.
- Kaiser, J., Barker, R., Haenschel, C., Baldeweg, T., & Gruzelier, J.H. (1997). Hypnosis and event-related potential correlates of error processing in a Stroop-type paradigm: A test of the frontal hypothesis. *Int J Psychophysiol* 27, 215-222.
- Kastner, S., & Ungerleider, L. G. (2000). Mechanisms of visual attention in the human cortex. *Annu Rev Neurosci* 23, 315-41.
- Keller, I., & Heckhausen, H. (1990). Readiness potentials preceding spontaneous motor acts: voluntary vs. involuntary control. *Electroen Clin Neuro* 76, 351-361.
- Keller, P., Wascher, E., Prinz, W., Waszak, F., Koch I., & Rosenbaum, D.A. (2006) Differences between intention-based and stimulus-based actions. *J Psychophysiol* 20, 9-20.
- Knight, R. (1996). Contribution of human hippocampal region to novelty detection. *Nature* 383, 256-259.

Kornhuber, H.H. (1984). Attention, readiness for action, and the stages of voluntary decision - Some electrophysiological correlates in man. *Exp Brain Res Suppl* 9, 420-429.

Kornhuber, H.H., & Deecke, L. (1965). Hirnpotentialänderungen bei Willkurbewegungen und passive Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. *Pflugers Arch* 284, 1-17.

Kriehoff, V., Brass, M., Prinz, W., & Waszak, F. (2009) Dissociating what and when of intentional actions. *Front Hum Neurosci*, 3, 1-10.

Kühn, S., & Brass, M. (2009). Retrospective construction of the judgment of free choice. *Conscious Cogn* 18, 12-21.

Lang, W. (2003). in *The Bereitschaftspotential. Movement-related cortical potentials*, eds Jahanshahi M, Hallett M (Kluwer Academic/Plenum Publishers, New York), pp 19-34.

Lau, H. C., Rogers, R. D., Haggard, P., & Passingham, R. E. (2004). Attention to intention. *Science* 303, 1208-1210.

Lau, H.C., Rogers, R.D., & Passingham, R.E. (2007). Manipulating the Experienced Onset of Intention after Action Execution. *J Cognitive Neurosci* 19, 81-90.

Leotti, L.A., Iyengar, S.S., & Ochsner, K.N. (2010). Born to choose: the origins and value of the need for control. *Trends Cogn Sci* 14, 457-463.

Libet, B., Gleason, C.A., Wright, E.W., & Pearl, D.K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act. *Brain* 106, 623-642.

Libet, B., Wright, E.W., & Gleason, C.A. (1982). Readiness potentials preceding unrestricted spontaneous pre-planned voluntary acts. *Electroen Clin Neuro*, 54, 322-

325.

Meynier, C., Burle, B., Possamaï, C., Vidal, F., & Hasbroucq, T. (2009). Neural inhibition and interhemispheric connections in two-choice reaction time: a Laplacian ERP study. *Psychophysiology* 46(4), 726-730.

Miltner, W.H.R., Braun, C.H., & Coles M.G.H. (1997). Event-related brain potentials following incorrect feedback in a time-estimation task: Evidence for a “generic” neural system for error detection. *J Cognitive Neurosci* 9(6), 788-798.

Mueller, C. M., & Dweck, C. S. (1998). Praise for intelligence can undermine children’s motivation and performance. *J Pers Soc Psychol*, 75(1), 33-52.

Näätänen, R., & Alho, K. (1997). Mismatch negativity (MMN) - The measure for central sound representation accuracy. *Audiol Neuro-Otol* 2, 341-353.

Nieuwenhuis, S., Ridderinkhof, K.R., Blom, J., Band, G.P.H., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology* 38, 752-760.

Nittono, H. (2006). Voluntary stimulus production enhances deviance processing in the brain. *Int J Psychophysiol* 59, 15-21.

Oldfield, R.C. (1997). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9, 97-113.

Oliveira, F.T.P., McDonald, J.J., & Goodman, D. (2007). Performance monitoring in the anterior cingulate is not all error related: Expectancy deviation and the representation of action-outcome associations. *J Cognitive Neurosci* 19(12), 1994-2004.

Overbeek, T.J.M., Nieuwenhuis, S., & Ridderinkhof, K.R. (2005). Dissociable components of error processing. *J Psychophysiol* 19, 319-329.

- Pockett, S., & Miller, A. (2007). The rotating spot method of timing subjective events. *Conscious Cogn* 16, 241-254.
- Prinz, W. (1987). Ideo-motor action. In H. Heuer & A.F. Sanders (Eds), *Perspectives on perception and action* (pp. 47-76). Hillsdale, NJ: Erlbaum.
- Rakos, R.F., Laurene, K.R., Skala, S., & Slane, S. (2008). Belief in free will: measurement and conceptualization innovations. *Behavior and Social Issues* 17, 20-39.
- Rigoni, D., Brass, M., & Sartori, G. (2010). Post-action determinants of the reported time of conscious intentions. *Front Hum Neurosci*, 4, 38.
- Roger, C., Bénar, C.J., Vidal, F., Hasbroucq, T., & Burle, B. (2010). Rostral Cingulate Zone and correct response monitoring: ICA and source localization evidences for the unicity of correct- and error-negativities. *NeuroImage* 51(1), 391-403.
- Roskies, A. L. (2010). How does neuroscience affect our conception of volition? *Annu Rev Neurosci* 33, 109-130.
- Searle, J.R. (1983). *Intentionality, an essay in the philosophy of mind*. Cambridge, UK: Press Syndicate of the University of Cambridge.
- Shibasaki H, & Hallett M (2006) What is the Bereitschaftspotential? *Clin Neurophysiol* 117, 2341-2356.
- Shibasaki, H, Barrett, G., Halliday, E., & Halliday, A. M. (1980). Components of the movement-related cortical potential and their scalp topography. *Electroen Clin Neuro* 49(3-4), 213-226.

- Sirigu, A., Daprati, E., Ciancia, S., Giraux, P., & Nighoghossian, N. (2004). Altered awareness of voluntary action after damage to the parietal cortex, *Nature*, 7, 80-84.
- Soon, C.S., Brass, M., Heinze, H.-J., & Haynes, J.-D. (2008). Unconscious determinants of free decisions in the human brain. *Nat Neurosci* 11, 543-545.
- Tangney, J.P., Baumeister, R.F., & Boone, A.L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *J Pers* 72, 271-322.
- Tatman, A.W., Swogger, M.T., Love, K., & Cook, M.D. (2009). Psychometric properties of the Marlowe-Crowne social desirability scale with adult male sexual offenders. *Sex Abuse-J Res Tr* 21, 21-34.
- Trevena, J., & Miller, J. (2010). Brain preparation before a voluntary action: Evidence against unconscious movement initiation. *Conscious Cogn* 19(1), 447-456.
- Tsakiris, M., & Haggard, P. (2003). Awareness of somatic events associated with a voluntary action. *Exp Brain Res* 149(4), 439-446.
- Van Boxtel, G.J.M., Geraats, L.H.D., Van den Berg-Lenssen, M.M.C., & Brunia, C.H.M. (1993). Detection of EMG onset in ERP research. *Psychophysiology* 30, 405-412.
- Vidal, F., Grapperon, J., Bonnet, M., & Hasbroucq, T. (2003). The nature of unilateral motor commands in between-hand choice tasks as revealed by surface Laplacian estimation. *Psychophysiology* 40(5), 796-805.
- Vohs, K.D., & Schooler, J.W. (2008). The value of believing in free will. Encouraging a belief in determinism increases cheating. *Psychol Sci* 19, 49-54.
- Waszak, F., & Herwig, A. (2007). Effect anticipation modulates deviance processing in the brain. *Brain Res* 1183, 74-82.

Waszak, F., Wascher, E., Keller, P., Koch, I., Aschersleben, G., Rosenbaum, D.A., & Prinz, W. (2005). Intention-based and stimulus-based mechanisms in action selection. *Exp Brain Res* 162, 346-356.

Wegner, D. (2002). *The Illusion of Conscious Will*. Cambridge, MA: MIT Press.

Wegner, D.M., & Wheatley, T. (1999). Apparent mental causation. Sources of the experience of will. *The American Psychologist* 54(7), 480-492.

Wolpert, D.M., & Ghahramani, Z. (2000). Computational principles of movement neuroscience. *Nat Neurosci* 3, 1212-1217.

Wolpert, D.M., Ghahramani, Z., & Jordan, M.I. (1995). An internal model for sensorimotor integration. *Science* 269, 1880-1882.

Yeung, N., & Sanfey, A.G. (2004). Independent coding of reward magnitude and valence in the human brain. *J Neurosci* 24, 6258-6264.



## Appendix A

### *Experiment 3 – Reading materials*

All participants were first given a Dutch translation of the following introductory paragraph:

Francis Crick is the British physicist and biochemist who collaborated with James D. Watson in the discovery of the molecular structure of DNA, for which they received the Nobel Prize in 1962. He is the author of *What Mad Pursuit*, *Life Itself*, and *Of Molecules and Men*. Dr. Crick lectures widely all over the world to both professional and lay audiences, and is a Distinguished Research Professor at The Salk Institute in La Jolla, CA. Dr. Crick's essay (below) comes from *The Astonishing Hypothesis*.

After this introductory paragraph, participants were given a text according to the condition they were assigned.

#### *No-free will group*

“You”, your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules. Who you are is nothing but a pack of neurons. Most religions hold that some kind of spirit exists that persists after one's bodily death and, to some degree, embodies the essence of that human being. Religions may not have all the same beliefs, but they do have a broad agreement that people have souls.

Yet the common belief of today has a totally different view. It is inclined to believe that the idea of a soul, distinct from the body and not subject to our known scientific laws, is a myth. It is quite understandable how this myth arose without today's scientific knowledge of nature of matter and radiation, and of biological evolution. Such myths, of having a soul, seem only too plausible. For example, four thousand years ago almost everyone believed the earth was flat. Only with modern science has it occurred to us that in fact the earth is round.

From modern science we now know that all living things, from bacteria to ourselves, are closely related at the biochemical level. We now know that many species of plants and animals have evolved over time. We can watch the basic processes of evolution happening today, both in the field and in our test tubes and therefore, there is no need for the religious concept of a soul to explain the behavior of humans and other animals. In addition to scientists, many educated people also share the belief that the soul is a metaphor and that there is no personal life either before conception or after death.

Most people take free will for granted, since they feel that usually they are free to act as they please. Three assumptions can be made about free will. The first assumption is that part of one's brain is concerned with making plans for future actions, without necessarily carrying them out. The second assumption is that one is not conscious of the “computations” done by this part of the brain but only of the “decisions” it makes -

that is, its plans, depending of course on its current inputs from other parts of the brain. The third assumption is that the decision to act on one's plan or another is also subject to the same limitations in that one has immediate recall of what is decided, but not of the computations that went into the decision.

So, although we appear to have free will, in fact, our choices have already been predetermined

for us and we cannot change that. The actual cause of the decision may be clear cut or it may be determined by chaos, that is, a very small perturbation may make a big difference to the end result. This would give the appearance of the Will being "free" since it would make the outcome essentially unpredictable. Of course, conscious activities may also influence the decision mechanism. One's self can attempt to explain why it made a certain choice. Sometimes we may reach the correct conclusion. At other times, we will either not know or, more likely, will confabulate, because there is no conscious knowledge of the 'reason' for the choice. This implies that there must be a mechanism for confabulation, meaning that given a certain amount of evidence, which may or may not be misleading, part of the brain will jump to the simplest conclusion.

### *Control group*

Psychologists have shown that common sense ideas about the working of the mind can be misleading. When psychology began as an experimental science, in the latter part of the nineteenth century, there was much interest in consciousness. It was hoped that psychology might become more scientific by refining introspection until it became a reliable technique.

Since the problem of consciousness is such a central one, and since consciousness appears so mysterious, one might have expected that psychologists and neuroscientists would now direct major efforts toward understanding it. This, however, is far from being the case. The majority of modern psychologists omit any mention of the problem, although much of what they study enters into consciousness. Most modern neuroscientists ignore it.

The American psychologist, William James, discussed consciousness in his work 'The Principles of Psychology' (1898), and described five properties of what he called "thought". Every thought, he wrote, tends to be part of personal consciousness. Thought is always changing, is sensibly continuous, and appears to deal with objects independent of itself. In addition, thought focuses on some objects to the exclusion of others. In other words, it involves attention. Of attention he wrote, "It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others."

Many psychologists believed that some processes are subliminal or subconscious. For example perception was similar in its logical structure to what we normally mean by inference, but that it was largely unconscious. Three basic ideas of consciousness were developed. Firstly, not all the operations of the brain correspond to consciousness. Secondly, consciousness involves some form of memory, probably a very short term one. Thirdly, consciousness is closely associated with attention.

Unfortunately, a movement arose in academic psychology that denied the usefulness of consciousness as a psychological concept. This was partly because experiments involving introspection (which involves thinking about what one is thinking) did not appear to be leading anywhere and partly because it was hoped that psychology could become more scientific by studying behavior that could be observed unambiguously by the experimenter. This was called the Behaviorist movement. It became taboo to

talk about mental events. All behavior had to be explained in terms of the stimulus and the response.

How can we approach the study of consciousness in a scientific manner? Consciousness takes many forms, but as I have already explained, for an initial scientific attack it usually pays to concentrate on the form that appears easiest to study. Christof Koch and I chose visual awareness rather than other forms of consciousness, such as pain or self-awareness, because humans are very visual animals and our visual input is especially vivid and rich in information. In addition, its input is often highly structured yet easy to control. For these reasons much experimental work has already been done on it.