



Controlling the self: The role of the dorsal frontomedian cortex in intentional inhibition



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ABSTRACT

Intentional inhibition refers to the suppression of ongoing behavior on the basis of internally-generated decisions. This ability to cancel planned actions at the last moment is thought to be critical for self-control and has been related to activation in a circumscribed region of the dorsal frontomedian cortex (dFMC). Preliminary theories of intentional inhibition were based on studies that exclusively examined the cancellation of motor responses, and consequently concluded that this region serves the suppression of motor output. Yet recent evidence suggests that the dFMC is also involved in inhibitory control over more abstract internal states such as emotions or desires that have no immediate behavioral output. In this review, we therefore wish to put forth a new integrative perspective on the role of the dFMC in human self-control. We will argue that by virtue of its anatomical location and functional connections, this area may subserve the disengagement from current urges and impulses, thus facilitating successful exertions of self-control across a wide range of contexts by overcoming a self-focused perspective. We will discuss the fit of this view of the dFMC with the existing literature, identify critical experimental determinants for engaging the dFMC in intentional inhibition, and outline promising perspectives for future research.

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1. Introduction

The ability to withhold behavioral impulses in favor of higher-order goals is central to human self-regulatory behavior (Baumeister, Vohs, and Tice, 2007). To date, this ability has been investigated in two distinct research domains, namely cognitive and social psychology. In cognitive psychology, research on inhibitory control typically employs experimental paradigms that require participants to withhold simple key presses in response to pre-instructed stop or nogo signals (henceforth referred to as externally guided inhibition, Chikazoe, Konishi, Asari, Jimura, & Miyashita, 2007; Logan & Cowan, 1984; Verbruggen & Logan, 2008, 2009). While this research has the advantage of providing maximal experimental control, the transfer to inhibition and self-control in everyday life is limited. In particular, most situations that require self-control do not provide external signals that indicate whether or not to withhold a specific behavior. By contrast, social psychological research on self-control has investigated behavioral inhibition under more complex and ecologically valid circumstances (see Hagger et al., 2010 for a review). Because of the complex experimental settings that are used, however, it is often very difficult to determine the exact neurocognitive mechanisms that are involved in these forms of self-control. Recently, the theoretical

concept of *intentional inhibition* has been introduced to combine elements of both research traditions (Brass & Haggard, 2007; Brass & Haggard, 2008; Filevich, Kühn, & Haggard, 2012). Intentional inhibition refers to the voluntary and internal decision to withhold from executing a prepotent action tendency. In this sense, the concept of intentional inhibition is much closer to social psychological conceptions of self-control.

In the current review, we will first give an overview of research in the domain of intentional inhibition. We will argue that the concept strongly relies on the assumption that intentional inhibition can be distinguished from externally guided inhibition on the basis of its functional neuroanatomy. In particular, intentional inhibition has been related to a specific part of the medial prefrontal cortex, namely the dorsal frontomedian cortex (dFMC), although the precise functional contribution of this region remains elusive. Therefore we will try to explore the role of the dFMC in the broader context of self-control. Thereafter we will argue, based on the location of this area at the intersection of brain areas involved in cognitive motor control and those involved in more complex self-reflective and social cognitive processes, that it contributes to self-control by facilitating disengagement from impulses and urges¹. On the basis of this new

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¹ We use the term 'impulse' to denote particularly sudden or spontaneous response tendencies, whereas 'urge' refers to a subjective motivation that develops over time.

conception, we will outline crucial experimental determinants for investigating intentional inhibition and sketch future perspectives in this research domain.

2. Previous findings: what do we know about intentional inhibition?

The concept of intentional inhibition is relatively young and only dates back a few years. As outlined above, it evolved as an extension of classical inhibition research in cognitive psychology, which focused primarily on externally guided inhibition. Following the logic of intentional action research, in which intentional action is usually contrasted with stimulus-guided action (e.g., [Passingham, Toni, & Rushworth, 2000](#); [Toni, Rushworth, & Passingham, 2001](#)), early paradigms tried to introduce a choice component preceding the inhibition process. From this perspective, intentional inhibition, like intentional action, is internally generated. Yet because intentional inhibition paradigms do not present a stop signal, it becomes difficult to derive chronometric measures such as stop signal reaction times (SSRTs). Thus, the only behavioral dependent measure that can be used is the proportion of inhibition trials (e.g. [Brass & Haggard, 2007](#); [Lynn, Van Dessel, & Brass, 2013](#); [Rigoni, Kühn, Gaudino, Sartori, & Brass, 2012](#)). Brain imaging techniques such as fMRI therefore provide valuable tools that permit the delineation of neural activity preceding intentional decisions to inhibit behavior.

In the first study to introduce the concept of intentional inhibition, [Brass and Haggard \(2007\)](#) employed a modified version of the method introduced by [Libet, Gleason, Wright, and Pearl \(1983\)](#), which required participants to perform self-paced button presses (i.e., action trials) and to monitor the moment in time when they felt the intention to execute the movement. In addition, participants were instructed to occasionally prepare such movements but cancel them at the very last moment prior to execution (i.e., inhibition trials). Contrasting brain activity on inhibition trials with action trials yielded increased activation in the dFMC, as well as in the left and right anterior insula, and the superior temporal sulcus. This neural signature was in striking contrast to findings resulting from externally guided response inhibition, which typically engages a neural network around the right inferior frontal gyrus, the pre-supplementary motor area (pre-SMA), and the basal ganglia (rIFG; see [Aron, Robbins, & Poldrack, 2004](#); [Aron, Robbins, & Poldrack, 2014](#) for reviews), implying that these two types of behavioral inhibition rely on largely different control mechanisms.

Importantly, a number of follow-up studies that employed quite disparate experimental procedures could replicate the involvement of the dFMC in intentional inhibition. For instance, [Kühn, Haggard, and Brass \(2009\)](#) introduced the so-called “ramp task” in which participants saw the image of a marble moving downwards on a ramp and breaking into pieces when it reached the end of the ramp. Participants could freely choose between preventing the marble from breaking via a button press, and inhibiting their urge to do so. Importantly, the shattering of the marble was associated with an aversive glass-breaking sound and a monetary loss in order to create an incentive of responses over response omissions, which ties intentional inhibition more closely to realistic scenarios of self-control in which highly prepotent behavior needs to be suppressed. As in the study by [Brass and Haggard \(2007\)](#), inhibition-related brain activity was found in the dFMC, leading to the idea that the dFMC constitutes a “veto area” that generates endogenous top-down signals in the service of the intentional cancellation of behavior. However, this interpretation of the dFMC as being involved in intentional inhibition rests on the assumption that activity in this brain area precedes the inhibition process. Given that the temporal resolution of fMRI is rather poor, this assumption requires independent proof. A recent EEG study addressed this question ([Walsh, Kühn, Brass, Wenke, & Haggard, 2010](#)) using a variant of the Libet task similar to [Brass and Haggard \(2007\)](#).

Frequency analyses of brain oscillations shortly after the experience of an intention to move revealed an increase in spectral power over frontal electrodes that was specific for trials in which the movement was then inhibited, highlighting that the neural signature of intentional inhibition has a plausible time course during motor preparation.

3. The role of the dFMC in intentional inhibition

Despite this converging evidence for the general importance of the dFMC in intentional inhibition, it is still largely unknown *how* this area exerts control over behavioral impulses. Recently, [Filevich et al. \(2012\)](#) embedded the concept of intentional inhibition in a more general model of motor control, based on internal feedback loops. This model includes an inner loop that continuously adjusts movement parameters based on a comparison between predicted and perceived sensory feedback, and an outer loop that monitors the long-term consequences of ongoing actions and compares them with general goals. Intentional inhibition is conceived as a braking mechanism that links both loops by canceling ongoing behavior when the anticipated outcome seems no longer desirable. In line with this idea, the dFMC has been shown to exhibit increased functional connectivity with the pre-SMA during intentional inhibition ([Kühn et al., 2009](#); [Kühn, Haggard, & Brass, 2013](#)). This finding is of particular interest, given that the pre-SMA is involved in action planning (e.g., [Cunnington, Windischberger, Deecke, & Moser, 2002](#); [Cunnington, Windischberger, Deecke, & Moser, 2003](#)) as well as in externally guided response inhibition (e.g., [Simmonds et al., 2008](#)). Accordingly, the pre-SMA may constitute a common pathway for the implementation of different types of motor decisions, with the dFMC directing the outcome of this decision.

Additional research has concurrently shown that the dFMC is not only involved in the inhibition of overt behavior, but also in the suppression of other psychological states such as emotions ([Kühn, Gallinat, & Brass, 2011](#); [Kühn et al., 2013](#)), cigarette cravings ([Brody et al., 2007](#); [Hanlon et al., 2013](#); [Hartwell et al., 2011](#)), or gambling desires ([Campbell-Meiklejohn, Woolrich, Passingham, & Rogers, 2008](#)). While these findings strengthen the general notion that the dFMC is a brain region crucial for the successful exertion of self-control, they also indicate that the functional contribution of this region might be more general than previously assumed, and extend beyond the suppression of motor output.

In the following, we will put forth a broader perspective of the role of the dFMC in self-control, arguing that this area allows for disengagement from one's current impulses and urges. We will first review the social psychological literature in order to highlight that such disengagement strategies are an effective functional mechanism for exerting self-control. Thereafter we will outline that the dFMC is well situated to perform this self-regulatory function because of its anatomical location and functional connections. Finally, we will illustrate that this new conception of intentional inhibition is capable of explaining seemingly inconsistent findings in the literature, and helps to further bridge the gap between cognitive and social psychological conceptions of inhibition.

4. Disengagement as a functional mechanism for self-control

Evidence for the role of disengagement in self-control dates back to the famous delay-of-gratification experiments (e.g., [Mischel, 1974](#)) in which preschoolers were able to choose between a smaller but immediately available reward, and a larger reward with a temporal delay. Successful delay strategies on the part of the children included

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