



# Evidence for pain attenuation by the motor system-based judgment of agency

N. Karsh<sup>a,b,\*</sup>, O. Goldstein<sup>a</sup>, B. Eitam<sup>a,\*</sup>

<sup>a</sup> Department of Psychology, University of Haifa, Mount Carmel, Haifa 31905, Israel

<sup>b</sup> Department of Psychology, Tel-Hai Academic College, Qiryat Shemona, Israel

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## ABSTRACT

Pain is an integral part of our lives. Although the effect of ‘control’ on sensed pain has been extensively studied and discussed, recent findings seem to be at odds with the substantial evidence for a robust motor-based sensory attenuation effect – an indirect marker for one’s sense of agency. The goal of the current study was to re-examine whether there is evidence for such an effect in the context of pain. In three experiments, human participants were aversively stimulated and the sensitivity of self-reported pain to factors previously shown to modulate the sensory attenuation effect was tested (control over parameters of the stimulation; temporal contiguity and predictability, and stimulation intensity). Two of three experiments found some evidence that objective control attenuates pain, but only when the painful stimulation immediately follows the motor response. We discuss the complex relations between having objective control, feeling helpless, predictability and sensed pain.

## 1. Introduction

The phenomenal experience of pain that usually accompanies physical traumas is an integral part of our lives. In many such situations, we have at best minimal control over the painful stimulation. It is not surprising then that humans developed mental and behavioral strategies in order to reduce and cope with pain as well as ones that increase their sense of control over the situation. For example, self-administration of a painful procedure, holding the epidural dispenser’s button during delivery, closing our eyes at the dentist and a nurse-led distraction prior to vaccination, are all common strategies for reducing the subjective experience of pain and/or our feelings of fear and helplessness.

The relationship between such various operations of ‘control’ and sensed pain have been extensively studied and discussed (e.g., Averill, 1973; Ball & Vogler, 1971; Carlsson et al., 2006; D’Amato and Gumenik, 1960; Jensen & Karoly, 1991; Mohr, Binkofski, Erdmann, Buchel, & Helmchen, 2005; Müller & Netter, 2000; Oka et al., 2010; Pervin, 1963; Staub, Tursky, & Schwartz, 1971; Thompson, 1981). For instance, it was repeatedly shown that objective control (i.e., self-administration compared to an external administration of an aversive stimulation) and the predictability (of the temporal occurrence or the intensity of the stimulation) modulates both sensed pain and pain-related neural activation (D’Amato and Gumenik, 1960; Beck, di Costa, & Haggard, 2017; Crombez, Baeyens, & Eelen, 1994; Mohr et al., 2005; Oka et al., 2010; Pervin, 1963; Ploghaus et al., 2001; Wang, Wang, & Luo, 2011). Still, other studies failed to show such direct influence of objective control on sensed pain (Staub et al., 1971, Experiment 1; Müller & Netter, 2000). Possible reasons underlying such failures are the relatively strong influence of top-down attributional processes regarding one’s perceived control over sensed pain (Averill, 1973; Jensen & Karoly, 1991; Pervin, 1963; Salomons, Johnstone,

\* Corresponding authors at: Department of Psychology, University of Haifa, Mount Carmel, Haifa 31905, Israel (N. Karsh).

E-mail address: [noamkarsh@gmail.com](mailto:noamkarsh@gmail.com) (N. Karsh).

Backonja, & Davidson, 2004; Thompson, 1981), the relatively large personal differences in control related feelings (e.g., feeling of helplessness; Müller, 2012; Müller & Netter, 2000) and various operations of ‘control’ that are sometimes confounded (e.g., objective control and predictability). Such apparent inconsistency regarding the influence of ‘control’ on sensed pain is theoretically important as it is also seemingly inconsistent with recent work and theorizing on the ‘sense of agency’.

Research performed in the last two decades has led to substantial progress in understanding the mechanism behind one’s sense of agency; specifically, much of this work has identified and explored the involvement of the motor system in the judgment or feeling of being in control over external events - and the parameters that this judgement is sensitive to (e.g., Blakemore, Frith, & Wolpert, 1999). In this study we utilize some of this knowledge to test whether and when ‘control’ directly modulates sensed pain and as stated above, to test whether painful stimulation is unique in that it does not show the well-established motor-based sensory attenuation effect. In addition, to connect with previous work that found strong relationships between people’s judgements and feelings of control, we directly measured relevant subjective judgment and feeling (feelings of helplessness) of control.

### 1.1. Sensory attenuation and the sense of agency

The mechanism behind one’s sense of agency is (at least partially) grounded in a system whose key function is motor control (The ‘Comparator model’; Blakemore et al., 1999; Haggard, 2005; Haggard & Eitam, 2015). According to this account of the sense of agency, an efference (outgoing) copy of the motor command generates a forward model (the best prediction of the perceptual state of affairs once the motor command is performed); the forward model is ultimately contrasted with the actual (‘reafferent’) sensory feedback and a lack of discrepancy (no error signal) is taken as a positive judgement of agency.

As is the case with much of the workings of the system(s) for motor control system, this process is also considered to operate outside one’s conscious awareness (Haggard, 2005; Jeannerod, 2006; Karsh & Eitam, 2015; Karsh, Eitam, Mark, & Higgins, 2016; Synofzik, Vosgerau, & Newen, 2008). Importantly, the comparator’s determination of agency (the contrasting of the predicted and the actual sensory feedback) was found to be responsible for attenuating the sensory perception of self-produced sensation—the sensory attenuation effect.

In an influential study, Blakemore et al. (1999) found that the intensity of the haptic sensation that immediately follows and is spatially compatible with what would be predicted given the motor command is attenuated compared to temporally lagged and spatially incompatible sensation. The authors were ones of the first to link between sensory attenuation and the motor-based judgement of agency (see also, Blakemore, Wolpert, & Frith, 1998; Wolpert & Flanagan, 2001; Blakemore, Wolpert, & Frith, 2000). As other studies have shown that the sensory attenuation effect occurs in other modalities (vision; Gentsch & Schütz-Bosbach, 2011; audition; Weiss, Herwig, & Schütz-Bosbach, 2011)—sensory attenuation is today considered to be a marker of the motor-based computation of agency that occurs for sensory events that are contingent, spatially congruent and temporally contiguous with one’s voluntary action.<sup>1</sup>

### 1.2. The influence of subjective feeling of helplessness and judgment of agency on sensed pain

Notwithstanding the above, the sensory attenuation effect is not ‘process pure’ and was also found to be influenced by top-down factors (i.e., assumingly, independently of the output of the motor-system based-judgement of agency) such as one’s control beliefs, when those were manipulated by the experimenter (Desantis, Weiss, Schütz-Bosbach, & Waszak, 2012). Similarly, the ‘explicit’ sense of agency (agency judgements) may be generated through processes other than the motor system (Synofzik et al., 2008; e.g., attributional processes). Importantly, and differing from the indirect measures of agency (e.g., the sensory attenuation effect), people’s direct judgement of agency was found to be less sensitive to subtle lags (< 450 ms) inserted between a voluntary action and its preceding effect (Karsh et al., 2016).

Returning to pain, it is widely accepted that sensed pain is sensitive to top-down attributional processes that modulate one’s perceived control and feeling of helplessness (Averill, 1973; Jensen & Karoly, 1991; Müller, 2012; Müller & Netter, 2000; Salomons et al., 2004). For instance, recently, Müller and Netter (2000) found that feeling helpless (possibly, the “hot” aspect or the outcome of a motor-based ‘negative’ judgment of agency in an aversive situation) was positively correlated with sensed pain levels across conditions. Another, more recent study by Müller (2012) used two conditions in which objective control was manipulated (self-administration compared to an externally administered random stimulation). His study showed that the influence of objective control on sensed pain was fully statistically mediated by participants’ feeling of helplessness.

### 1.3. The present study

The current study aimed to test whether, as has been repeatedly demonstrated for non-painful stimulation (i.e. the sensory attenuation effect) there is a motor system-based attenuation effect for sensed pain. Accordingly, if such a modulation exists it should also be sensitive to parameters previously shown to modulate other indirect markers for one’s sense of agency (e.g., the temporal

<sup>1</sup> Two other effects were shown to be sensitive to the same parameters—Temporal binding (the perceived temporal attraction of actions and their consequent effects; Haggard, Clark, & Kalogeras, 2002) and our own Motivation from control effects (facilitation of selection of control effective actions; Eitam, Kennedy, & Higgins, 2013; Karsh & Eitam, 2015; Hemed, Karsh, Mark, & Eitam, unpublished manuscript; Karsh et al., 2016) and are also considered to be ‘implicit’ (actually, indirect) measures of the motor-based judgment of agency.

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