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Effects of intentional movement preparation on response times to symbolic and imitative cues

Katherine R. Naish[1] · Amentha Rajagobal[1] · Carl Michael Galang[1] · Luisa Sartori[2,3] · Sukhvinder S. Obhi[1]

Abstract Speeded responses to an external cue are slower when the cue interrupts preparation to perform the same or a similar action in a self-paced manner. To explore the mechanism underlying this 'cost of intention', we examined whether the size of the cost is influenced by the nature of the external cue. Specifically, we assessed whether the cost of intention is different for movements made in response to an imitative cue (an on-screen hand movement) compared to those made in response to a symbolic cue. Consistent with previous reports, externally cued responses were significantly slower on trials where participants were preparing to perform an internally driven movement later in the trial. Also as predicted, simple response times to the imitative cue were faster than those made to the symbolic cue. Critically, the cost of intention was similar for each cue type, suggesting that preparing an intentional action influenced responses cued by the symbolic and imitative cues to a similar degree. These findings suggest that the nature of the external cue does *not* influence the response time delay associated with concurrent intentional preparation. Together with previous findings, the results of the current study shed further light on the potential mechanisms underlying the cost of intention.

✉ Katherine R. Naish
naishek@mcmaster.ca

[1] Social Brain, Body and Action Lab, Department of Psychology, Neuroscience & Behaviour, McMaster University, Hamilton, ON L8S 4L8, Canada

[2] Dipartimento di Psicologia Generale, Universita di Padova, Padua, Italy

[3] Center for Cognitive Neuroscience, Universita di Padova, Padua, Italy

Introduction

Despite a lack of any prior intention to move, actions such as catching a falling object or moving to avoid a threat can be performed with impressive speed. Intuitively, we might predict that our reactions to such events should be even faster if we are already planning to perform the required movement. For example, if we are already intending to pick up an object when it unexpectedly begins to fall, will our reaction to save the falling item be faster than if we were not planning to move at all? Interestingly, laboratory-based studies suggest the opposite: preparing to make an intentional, self-paced movement *slows down* the execution of the same action made in response to an external cue. That is, when an individual is preparing to perform a movement but is interrupted by a cue prompting them to move immediately, their response to the imperative cue is slower than if they were responding to the cue alone (Astor-Jack and Haggard 2004; Hughes et al. 2011; Obhi and Haggard 2004; Obhi et al. 2009a, b). This result has been referred to as the 'reaction time cost of intention', or simply 'cost of intention' (Obhi and Haggard 2004). The existence of the cost of intention raises interesting questions about the mechanisms governing externally cued actions and intentional, self-paced actions, and about the way in which these mechanisms interact in situations where a switch from an intentional mode of action production to a reactive mode of response production is required.

While there is considerable overlap in brain activation associated with intentional and reactive movement types

(e.g. Ariani et al. 2015), the patterns of activity underlying them are not identical. It has been proposed that the slowing of externally cued responses made during internally driven motor preparation (for the same action) reflects a *switch* from an internally driven to an externally cued response mode (Obhi and Haggard 2004). While the activation associated with both response types converges on the primary motor cortex (M1), the level of input from brain regions that project to M1 seems to differ between internally driven and externally cued responses (Haggard 2008). Externally cued movements are thought to be driven predominantly by input from parietal areas, which in turn receive input from sensory brain regions that are activated by the external stimulus (Rizzolatti et al. 1998). In contrast, internally driven movements are associated with greater (or earlier: see Cunnington et al. 2002) activation of the supplementary and pre-supplementary motor areas (e.g. Deiber et al. 1999; Jenkins et al. 2000; Wiese et al. 2004), which receive input from prefrontal regions and the basal ganglia. The supplementary motor area (SMA) is thought to be the main source of the readiness potential, a negative cortical potential that is evident around 1–2 s before the onset of intentional movement (Shibasaki and Hallett 2006). Consistent with the findings of greater SMA activation associated with internally driven compared to externally cued movements, the cortical negativity that typically precedes internally driven movement is greater than that preceding externally cued movements (Jahanshahi et al. 1995; Waszak et al. 2005). The two response types can also be differentiated in terms of muscle activity (Obhi and Haggard 2004) and kinematics (Becchio et al. 2014) of the final motor output.

In experiments using the 'truncation' paradigm, participants prepare to perform a self-paced movement on each trial, but on some trials are interrupted by an external cue requiring them to execute the intended response immediately. This condition is referred to as the truncation condition, and the robust finding is that externally cued responses on such trials are slower than responses in a simple reaction time condition, where no self-paced movement is being prepared. Again, the slowing of externally cued responses when they are prompted during intentional preparation has been termed the 'cost of intention' (e.g. Astor-Jack and Haggard 2004; Obhi and Haggard 2004). The cost of intention demonstrates that activation induced by the cue does not simply augment existing intentional preparation (i.e. if this were the case, we might expect that existing preparation would facilitate the cued response).

Previous work supports the idea that the cost of intention is influenced by the level of intentional preparation at the time of the imperative cue. This is indicated by the finding that the cost is *smaller* when the cued response is the same as the movement being intentionally prepared, compared to when the two movements differ (Obhi et al. 2009a, b). One possibility is that existing (intentional) motor preparation is partially integrated into the new response, leading to relative facilitation of responses that match the prepared movement. In cases where the prepared and cued responses are different, internally generated motor preparation would contribute less (or not at all) to the new response, so the time taken to generate the new response would be greater. This hypothesis is supported by Hughes et al. (2011) finding that greater preparation associated with the intended action—indexed by a larger readiness potential—is associated with faster externally cued execution of the same movement. When the cued response was *different* to the planned movement, however, greater preparation of the planned response was associated with slower responses to the cue.

Hughes et al. (2011) findings suggest that the level of pre-existing intentional motor preparation influences the cost of intention. However, this explanation does not account for all variation in the cost of intention found in previous work. For example, Astor-Jack and Haggard (2004; Experiment 3) found *no* cost of intention on responses made in a choice reaction time (CRT) task in which participants were interrupted by one of two possible cues, compared to an SRT task in which participants were always interrupted by the same cue. This suggests that the type of external cue exerts some effect on the cost of intention [see also Hughes et al. (2011) for a similar but slightly different type of CRT experiment]. Taken together, these previous findings indicate that factors related to *both* intentional preparation and the externally cued response contribute to the cost of intention. It should be noted, however, experimental manipulations in previous studies have involved changing the relationship between the intentional response and the externally cued response, so the extent to which intentional motor preparation could contribute to the cued response has always varied between conditions. As discussed, contributions of intentional motor preparation to the cued response (Hughes et al. 2011) seem to account for at least some variation in the cost of intention, but there are likely other factors at play.

To further explore the mechanisms underlying this phenomenon, the current study investigated whether the nature of the external cue has any influence on the cost of intention. Specifically, we examined whether the cost of intention varies according to whether the externally cued response is prompted by a symbolic cue or an imitative cue (consisting of an on-screen hand movement), since previous work suggests differences in how these cue types are processed and responded to. Studies have demonstrated that movements are faster when cued by a visual depiction of the required movement (i.e. an 'imitative' cue) compared to when they are cued by a symbolic cue (Désy and Lepage

2013; Jonas et al. 2007; Kessler et al. 2006) or an incongruent movement cue (e.g. Brass et al. 2000). This response facilitation is likely due to effector-specific increases in corticospinal excitability during movement observation (e.g. Fadiga et al. 1995; Heyes 2011). Compared to symbolically cued movements, responses to imitative cues have been associated with greater activation of regions including the ventral premotor cortex, posterior parietal cortex, basal ganglia, and primary sensorimotor cortex (Kessler et al. 2006). Kessler et al. (2006) also found the response time advantage for imitatively cued versus symbolically cued responses to be correlated with synchronisation of premotor cortex activity with the posterior parietal cortex and right temporal pole.

Based on this previous work, it was predicted that externally cued responses would be faster when cued by an imitative compared to a symbolic cue. By keeping the required intentional and cued responses the same (as each other, and across trials) and randomizing the presentation of the two cue types within blocks, we ensured that the amount and relevance of intentional motor preparation was the same in both cue conditions. This design therefore allowed us to identify any differences in the cost of intention driven by the nature of the external cue specifically. It is possible that greater activation associated with an imitative cue facilitates the switch from intentional movement preparation to the cued response (i.e., leading to a smaller cost of intention). Alternatively, it is possible that imitative and symbolic cues do not differentially affect the cost of intention. Either of these results will enhance current knowledge of the factors that contribute to the cost of intention, thus moving the study of this phenomenon forward.

Methods

Participants

Twenty-four students aged 18–20 years ($M = 18.8$, $SD = .83$) took part in the experiment in exchange for course credit or monetary compensation. All participants were right-handed by self-report. The experiment was carried out in accordance with local ethics guidelines and conformed to the Declaration of Helsinki. Informed consent was obtained from all participants.

Design

Participants completed two experimental blocks: the simple response time (SRT) block and the Truncation block. In the SRT block, participants simply responded to an on-screen cue when it appeared during the trial. In the Truncation block, participants were instructed to perform a self-paced

movement at around 3 s from trial onset, unless they saw a cue, in which case they should respond as quickly as possible to the cue (rather than moving at the planned 3 s time point). The cue was presented on 50% of trials in the Truncation block. In both conditions, the cue was either a symbolic cue or an imitative movement. Each cue type was presented an equal number of times in each block, and trials were presented in a randomized order. Finally, the time at which the cue was presented varied across trials. This variation was introduced primarily to prevent predictability of the stimulus, but time of cue onset (early vs. late) was included in the analysis. Thus, the factors assessed in this experimental design were Movement Type (SRT, Truncation), Cue Type (Symbolic, Finger lift), and Cue Onset (Early, Late). The SRT block consisted of 60 trials, and the Truncation block consisted of 120 trials (with a cue appearing on 50% of these).

Stimuli

The experiment was programmed using Superlab v.4.5 (Cedrus Corporation). In both the SRT and Truncation blocks, each trial began with a fixation cross-presented on-screen for 1000 ms, which was then replaced by an image of a light-skinned hand on a blue background. On every trial in the SRT block, and on half of the trials in the Truncation block, an imitative or symbolic cue was presented at one of ten time points: 200, 525, 850, 1175, 1500, 1825, 2150, 2475, 2800, or 3000 ms from when the on-screen hand appeared. Cue onset was classified as 'Early' (200–1500 ms) or 'Late' (1825–3000 ms) to allow us to examine the effect of time delay in the analysis. For the imitative cue, the image of the static hand was replaced by an image of the same hand with the index finger lifted, to give the impression of finger movement. The symbolic cue was a filled grey circle that appeared on the index finger of the on-screen hand.

Procedure

In all conditions, subjects sat at a computer with their right index finger compressing the 'v' key of the keyboard in front of them. A box was placed over the keyboard and the participant's hand to reduce possible motor affordance effects of seeing the keyboard. In the SRT block (see Fig. 1a), participants were instructed to release the compressed 'v' key as soon as an on-screen (imitative or symbolic) cue was presented. The cue could occur at any of the ten time delays. The main SRT block was preceded by a block of six practice trials, which included three trials for each cue type. In the Truncation condition (Fig. 1b), participants were instructed to release the 'v' key at 3 s from trial onset, unless they saw the finger lift or dot appear

Fig. 1 Trial structure for trials in the SRT (**a**) and Truncation (**b**) blocks. Note that there were two types of trial within the Truncation block, with the cue being presented on only 50% of trials. The order of trial presentation was randomised. Trials on which a cue did *not* appear were not analysed
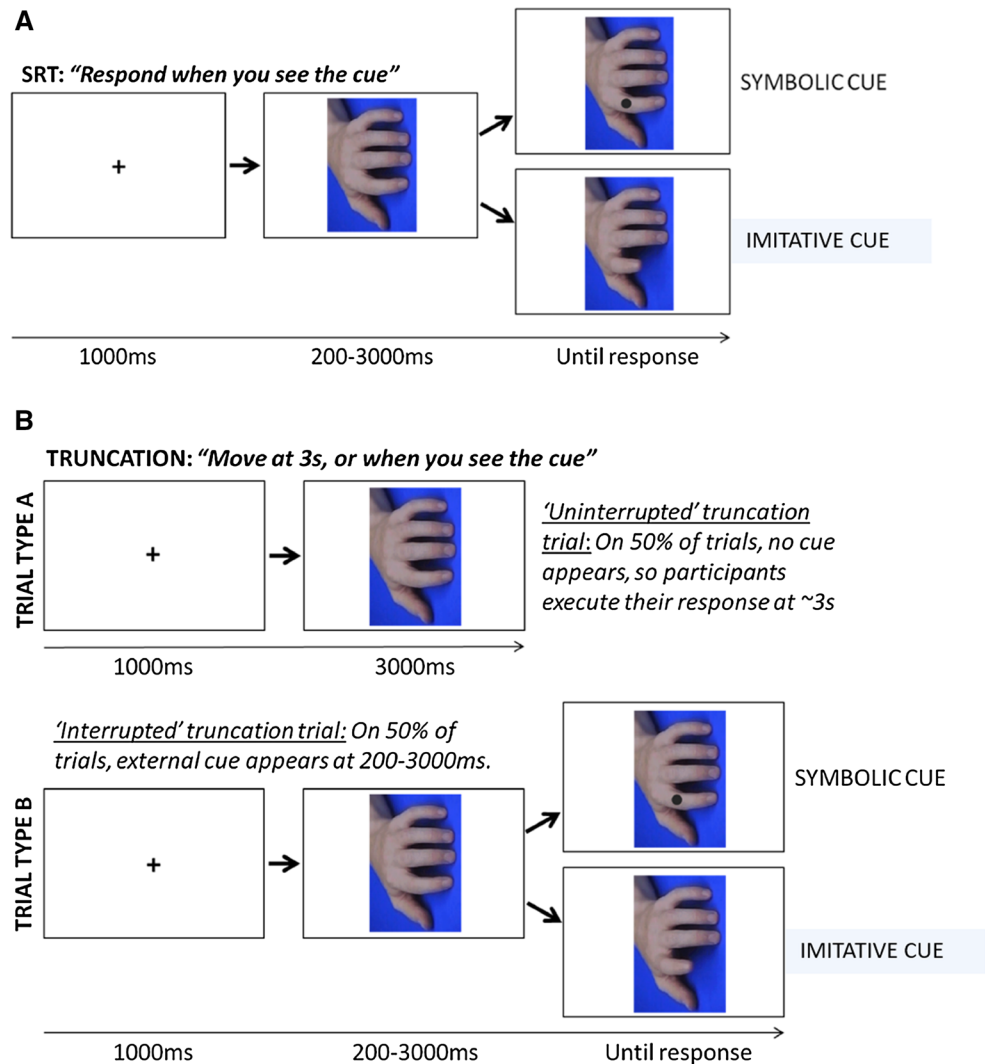
during the trial, in which case they should release the key as quickly as possible in response to the cue. The cue was presented on 50% of trials in the Truncation block, to ensure that participants prepared the self-paced movement on every trial (rather than waiting for a cue). The practice block for the Truncation condition consisted of two parts. The first five trials gave participants experience making self-paced motor actions, and required participants to plan and execute a response at 3 s after the trial started with the numbers 1–3 appearing on the screen to guide counting. This was followed by eight practice trials without the on-screen numbers; half of these were interrupted by either the symbol or the finger lift cue.

Data analysis

Since we were interested in the influence of internal preparation on cued response times, Truncation trials on which no cue was presented were not included in the main

analysis. Response times on these trials were assessed only to check that participants were indeed preparing their response as instructed. Based on previous studies using the same paradigm (e.g. Obhi et al. 2009a), responses to the cue (in both the SRT and Truncation blocks) that were faster than 75 ms or slower than 1000 ms were excluded. Response times for each condition and participant were then entered into a $2 \times 2 \times 2$ within-subject ANOVA, with Movement Type (SRT vs. Truncation), Cue Type (Imitative vs. Symbolic), and Cue Onset (Early vs. Late) as predictor variables.

Results

The average response time for self-paced trials in the truncation block (i.e. where no cue was presented) was 3260 ms (SD = 432; range = 2195–4211 ms), demonstrating that participants prepared and executed their

response as instructed at around 3 s from trial onset. Our analysis revealed a strong main effect of Movement Type ($F(1,23) = 44.7$, $p < .001$, $\eta_p^2 = .660$); responses to the cue were slower on Truncation trials ($M = 396$ ms, SD = 32.0) compared to SRT trials ($M = 329$, SD = 36.8). Additionally, a significant main effect of Cue Type ($F(1,23) = 7.69$, $p = .011$, $\eta_p^2 = .251$) showed that responses were faster to the imitative cue ($M = 353$, SD = 24.7) compared to the symbolic cue ($M = 372$, SD = 38.0). We also found a main effect of Cue Onset ($F(1,23) = 190$, $p < .001$, $\eta_p^2 = .892$), reflecting faster responses on trials where the cue was presented late compared to early in the trial.

Finally, our analysis revealed a significant interaction between Movement Type and Cue Onset ($F(1,23) = 9.59$, $p = .005$, $\eta_p^2 = .294$; Fig. 2). Paired-sample t tests comparing SRT to Truncation response times for each time delay separately showed that responses were significantly faster on SRT compared to Truncation trials for both the early ($t(23) = 7.27$, $p < .001$) and late ($t(23) = 4.40$, $p < .001$) time delays. A further t test comparing the cost of intention (i.e. Truncation-SRT) between the time delays revealed that the cost was greater for early compared to late time delays ($t(23) = 3.10$, $p = .005$). For the early time delay, the average cost of intention was 77.5 ms (SRT: M(SD) = 358(42.4); Truncation: M(SD) = 436(42.1), while for the late delay condition it was 45.9 ms (SRT: M(SD) = 301(36.7); Truncation: M(SD) = 347(40.1)). The interactions between Movement and Cue Type ($F(1,23) = 2.37$, $p = .137$, $\eta_p^2 = .093$), Cue Type and Cue Onset ($F(1,23) = .334$, $p = .569$, $\eta_p^2 = .014$), and between Movement Type, Cue Type, and Cue Onset ($F(1,23) = 2.96$, $p = .099$, $\eta_p^2 = .114$) were not significant. Figure 3 shows the average response times for each movement and cue type condition.
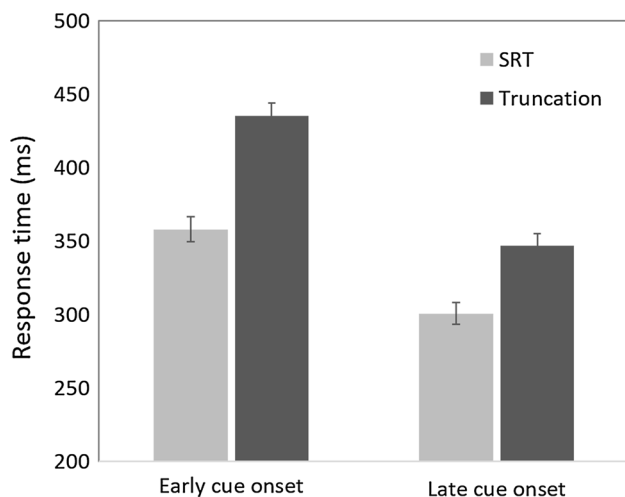

Fig. 2 Average response times (ms) of movements made to cues presented in the first half of the trial ('Early cue onset') versus the second half of the trial ('Late cue onset') on SRT trials (*light grey bars*) and Truncation trials (*dark grey bars*). Data reflect response times for movements cued by either the symbolic or imitative cue. *Error bars* represent standard error of the mean

Discussion

Previous research has shown that responses to an external cue are slower when the cue interrupts existing intentional preparation to perform the same movement, compared to situations where the cue is presented in the absence of such preparation (Astor-Jack and Haggard 2004; Hughes et al. 2011; Obhi and Haggard 2004; Obhi et al. 2009a, b). This finding has emerged from studies using the 'truncation paradigm', in which participants are asked to internally prepare to produce a particular action, but to respond immediately with the same action if a cue interrupts their preparation (see Astor-Jack and Haggard 2004). In the typical paradigm, sometimes participants make their intentional action prior to delivery of the cue, and sometimes the cue interrupts their preparation. The robust finding is that, on trials where a cue interrupts their preparation, participants are significantly slower to respond to the cue compared to when they make the same action in a simple reaction time condition. This occurs despite the fact that the prepared and cued responses are the same. Thus, it appears that reactive

Fig. 3 Average latencies (ms) of responses in the SRT and Truncation conditions, for responses cued by the symbolic cue (*left-hand plot*) and the imitative cue (*right-hand plot*). Responses were significantly slower on Truncation compared to SRT trials for both cue types. *Error bars* represent standard error of the mean
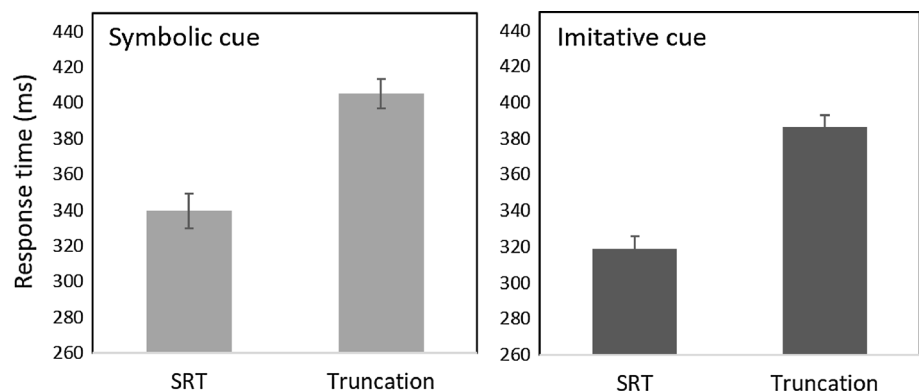
movements cannot fully harness pre-existing intentional preparation to facilitate response production. In the current study, we employed a modified truncation paradigm to investigate whether the nature of the external cue affects the magnitude of this so-called 'cost of intention'. Specifically, we measured the cost of intention when responses were cued by a symbolic visual stimulus, compared to when they were prompted by an imitative cue consisting of an on-screen hand movement (that matched the response that the participants were internally preparing). We expected simple response times to the imitative cue to be faster than those made to the symbolic cue, due to (automatic) activation of the motor system that occurs when movement is viewed.

Consistent with previous findings (Astor-Jack and Haggard 2004; Hughes et al. 2011; Obhi and Haggard 2004; Obhi et al. 2009a, b), we found that externally cued responses were significantly slower when participants were internally preparing to perform the same movement later in the trial. Previous research has found that externally cued movements are associated with different patterns of neural activation compared to intentional (i.e. non-externally cued) movements (for an overview, see Haggard 2008). It has been suggested that the cost of intention reflects the time taken to *switch* from an internally driven to an externally triggered response mode (e.g. Obhi and Haggard 2004). The notion of a switch between response modes is supported by Obhi and Haggard's (2004) finding that the muscle activity profile of truncated responses matches that characterising externally cued movements. Since internally driven and externally cued movements are characterised by distinct patterns of muscle activity, this finding suggests that participants switched from the internally driven to externally cued mode of movement production when the cue interrupted motor preparation. The time taken to complete this switch could account for the cost of intention seen in the current and previous studies.

As discussed by Obhi et al. (2009a), another (not mutually exclusive) possibility is that preparation of the intentional action is associated with concurrent inhibition in the motor system, and this inhibition must be released before the externally cued response can be initiated. Indeed, studies in both monkeys and humans have shown that preparing to perform a movement after a delay is associated with activity in the dorsal premotor cortex (PMd) during the delay period (e.g. Kroeger et al. 2010; Toni et al. 1999; Wise and Kurata 1989). The findings of Kroeger et al. (2010) suggest that PMd inhibits the primary motor cortex (M1) during the delay period preceding movement. While it is important to note that much of this work has demonstrated inhibition preceding a delayed *cued* response, Wise and Kurata (1989) showed similar motor suppression in the delay period preceding a self-paced, non-cued response. Thus, it is possible that motor activity is inhibited during the truncation trial period as participants prepare to perform the self-paced movement at the end of the trial. Such inhibition of M1 might serve to prevent premature release of the planned movement, and could account for a delay in the execution of any cued movement during the trial period.

The finding that response times were faster overall when the cue was presented later compared to earlier in the trial could be due to greater anticipation of the cue as participants neared the end of the trial period. In addition, within the truncation block, participants were closer to the time of executing their intentional action. Based on the idea that preparing and withholding a motor response involves inhibition of motor activity during the pre-movement period, it is possible that there was less inhibition at time points closer to the time of execution. The significant interaction between trial type and time delay showed that the cost of intention was smaller when cue presentation occurred in the last half of a truncation trial as opposed to the first half. This finding is consistent with Obhi et al. (2009a) finding that the cost was significantly smaller at the final two time delays before trial end. While we did not have enough trials to compare between each of the time delays in the current study, it is possible that the smaller cost on trials where the cue was presented in the second half of the trial period was driven by the final two time delays. As discussed by Obhi and colleagues, this decrease in the cost in the final portion of the trial could be due to facilitation of corticospinal excitability (or a decrease in inhibition) just prior to the planned onset of the intentional movement. Indeed, studies have shown increased corticospinal excitability around 200 ms before movement onset (e.g. Leocani et al. 2000). It is possible, therefore, that the cost of intention is reduced in the few hundred milliseconds before trial end (i.e. when participants are about to perform the self-paced movement), due to there being less inhibition associated with the internally prepared movement.

The most important new finding of the current study is that the cost of intention was *not* modulated by the nature of the external cue. Although movements prompted by the imitative cue were significantly faster than those prompted by the symbolic cue in the SRT condition, we did not find a difference in the cost of intention for the different cue types. The response time advantage for the imitative cue found here closely matches that found in previous studies, with responses to this cue being around 20 ms faster than responses to symbolic cues (Désy and Lepage 2013; Kessler et al. 2006). This main effect of cue type is likely driven by automatic activation of the motor system when biological movement is observed. Previous work has shown that activity in the corresponding muscles of the observer increases when action is passively observed (e.g. Fadiga et al. 1995). In line with this, movement execution is typically facilitated by viewing a congruent movement (e.g.

Brass et al. 2000). The fact that the cost of intention did *not* differ significantly depending on cue type suggests that differences in the speed of processing and responding to the external cue do not influence the cost of intention. Although this inference is based on a null result (i.e. the lack of interaction between cue and trial type), the possible implications of this finding deserve discussion.

The similar cost of intention for both cue types suggests that the mechanisms underlying the cost are independent of the specifics of (external) stimulus–response processing. Faster responding to the imitative compared to the symbolic cue did not have any bearing on the cost associated with intentional motor preparation. One possible explanation of variations in the cost of intention (e.g. Obhi et al. 2009a, b) discussed in the Introduction was that the cost is modulated by the level and relevance of preparation associated with the *intentional* movement. In the current study, by manipulating the nature of the cue itself rather than the type of movement required, we kept the similarity between the internally driven and externally cued response constant across all trials. In addition, our randomisation of trials ensured that the cue type on any particular trial could not be anticipated. Therefore, we are confident that there were no systematic differences in intentional preparation of the response between the two cue conditions. That is, the externally cued response should have been influenced to the same extent by existing intentional preparation in both cue type conditions. On this basis, the comparable cost of intention for each cue type fits with the notion that variations in the cost of intention found previously (e.g. Obhi et al. 2009a) are determined by variations in accumulated intentional preparation that is relevant to the cued response.

Another important finding of the current study is that the response time advantage for imitatively cued responses was preserved in the truncation condition. That is, concurrent preparation of the intentional response did not seem to affect facilitation associated with the imitative cue compared to the symbolic cue. The fact that this fundamental property of the externally cued response was preserved in the truncation condition is somewhat consistent with Obhi and Haggard's (2004) finding that cued responses on truncation trials were similar, in terms of muscle activity, to cued responses on SRT trials. This finding supports the idea that the processes underlying the cost of intention are independent of processes underlying cue-specific responding. It also bolsters the notion that actions made in response to imitative cues are automatic. That is, concurrent computations linked to intentional preparation did not affect the speed advantage for actions prompted by imitative cues (for more on the automatic nature of imitative responding see Hogeveen and Obhi 2013). It is also important to note that cognitive load and attention have been shown to modulate the effects of movement observation on response times (Chong et al.

2009; Saucedo Marquez et al. 2011; van Leeuwen et al. 2009). Thus, the fact that the SRT advantage for imitatively cued movement was preserved in the truncation condition strengthens the idea that the cost of intention is *not* driven by differences in cognitive load or attentional demands in the truncation condition compared to the SRT condition (see Astor-Jack and Haggard 2004; Obhi and Haggard 2004; Obhi et al. 2009a, b for further discussion of this).

The apparent lack of interaction between existing intentional preparation and activation associated with the imitative cue is also interesting given the putative role of the premotor cortex in motor facilitation during action observation. There is evidence that enhanced motor excitability (and consequent behavioural facilitation) might be driven by input from the premotor cortex to M1 (e.g. Avenanti et al. 2007; Catmur et al. 2011; Tai et al. 2004). If, as suggested previously, the cost of intention is partially driven by suppression of M1 by premotor regions, it is intriguing that this existing activity has no effect on facilitation of responses induced times by movement observation. Equally, it is interesting that activation of the premotor cortex during action observation would not modulate the cost of intention. Given the lack of physiological measures in our experiment, it is beyond the scope of the current paper to discuss this further; however, it will be important in future studies to combine this paradigm with measures of corticospinal excitability and intracortical inhibition to explore this further.

The current findings, together with those of Hughes et al. (2011) are also relevant to a somewhat counter-intuitive finding reported in a previous study by Obhi et al. (2009b), in which the cost of intention for single versus sequential finger movements was assessed. While sequential responses were characterised by slower SRTs compared to single movements, the cost of intention associated with sequential movements was *smaller* than that associated with single movements. One explanation for the smaller cost for sequential movements is that motor preparation associated with the intentional action was greater for sequential movements than for single-finger movements, leading to more preparatory activity that could be (partially) harnessed by the externally cued response. Indeed, sequential movements have been associated with greater activation of the SMA compared to both single (Gordon et al. 1998) and repetitive single-finger (Deiber et al. 1999) movements. Thus, although they were executed more slowly, greater preparatory activity associated with more complex movements might lead to a smaller cost of intention because this preparation contributes to execution of the new response, albeit in some complex, and as yet unspecified manner.

In summary, the current findings suggest that the cost associated with responding to an external cue when an intentional

movement is in preparation, is *not* influenced by whether the external cue is symbolic or imitative. Specifically, the speed of responding to the external cue per se (i.e. as indexed in an SRT condition) does not have any bearing on the cost of intention. Furthermore, the fact that the response time advantage for the imitative cue was preserved in the truncation condition suggests that intentional movement preparation delays, but does not modify, processing and execution of the cued response. The current study, in conjunction with previous findings, supports the idea that the cost of intention reflects the time taken to switch from intentional preparation to imposed externally cued response processing. We suggest that this time delay might reflect the release of inhibition associated with preparing to move at a later time point. We further suggest that preparation for and execution of the externally cued response (at least given the current experimental set up) does not contribute to this cost. To further examine the potential role of motor inhibition in the cost of intention, future research should track changes in corticospinal excitability and intracortical inhibition across the movement preparation period in simple reaction time and truncation conditions.

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