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## Perception of temporal duration affected by automatic and controlled movements

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### ABSTRACT

Sensorimotor contingency is one of the main factors to warp time perception. Voluntary actions such as saccades and hand movements affect the subjective perception of temporal duration. Although the perceived timings of action and stimulus are affected by whether an action was automatic or controlled, its effect on the subjective perception of duration has not been studied except in the case of saccade (chronostasis), which has been shown to be unaffected by the context of action initiation. Here we investigate the effect of the context of action initiation on duration estimation in the case of finger movement. The reproduced intervals were shorter when actions were initiated by automatic manner, compared to self-timed or cognitively controlled actions. The results are compatible with an internal clock model employing variable latencies for switch closure after action.

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## 1. Introduction

The processing of temporal information is ubiquitous in cortical computation. It is important for both perception and action, serving as an essential element of how the brain constructs models of the environment.

Recently, time perception ranging from sub-second to several seconds has been extensively studied. Studies have shown that the perceived duration is influenced by the properties of stimuli (Xuan, Zhang, He, & Chen, 2007). In a successive presentation of identical stimuli, the perceived duration of an oddball stimulus is longer (oddball effect, Tse, Intriligator, Rivest, & Cavanagh, 2004). A visual onset expands the subjective time (Kanai & Watanabe, 2006). When the same stimulus is presented successively for several times, the first one is perceived as longer than the others (debut effect, Pariyadath & Eagleman, 2007). The debut effect disappeared when the stimuli were random images. These results indicate that the predictability of the stimulus affects the oddball and debut effects. Multisensory interaction (van Wassenhove, Buonomano, Shimojo, & Shams, 2008) and emotion (Droit-Volet & Meck, 2007; Doi & Shinohara, 2009) also affect the subjective duration. Thus, time perception is a highly complex cognitive process affected by various elements related to the stimuli.

One of the factors that potentially affect time perception is sensorimotor contingency. It has been suggested that the intentional state is one of the important factors affecting the sense of time (Haggard, Clark, & Kalogeras, 2002). The perceived timing of key pressing and the subsequent tone were shifted so that they were closer to each other, when the subject

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voluntarily pressed the key followed by a tone with some delay. This “temporal attraction” has been termed “intentional binding effect” (Ebert & Wegner, 2010; Engbert & Wohlschläger, 2007; Humphreys & Buehner, 2010; Moore & Haggard, 2008; Stetson, Cui, Montague, & Eagleman, 2006; Tsakiris & Haggard, 2003). In contrast, when the movement was induced by transcranial magnetic stimulation (TMS), the temporal shift occurred in the opposite direction.

The mode of initiation of an action (intrinsic or extrinsic, i.e., self-initiated (intention-based) or externally-triggered (stimulus-based), Jahanshahi et al., 1995; Waszak et al., 2005)) is one of the important contextual factors in sensorimotor contingency. In an externally-triggered condition, a subject generates a movement as a response to a sensory stimulus. A self-initiated action, in contrast, is driven internally.

It has been suggested that different mechanisms are engaged in the intrinsic and extrinsic movements (Obhi & Haggard, 2004). Welchman, Stanley, Schomers, Miall, and Bulthoff (2010) showed that the speed of action in a reactive movement was faster than in a self-timed action. Imaging studies have shown that different neural mechanisms are engaged in these movements (Herwig, Prinz, & Waszak, 2007; Jenkins, Jahanshahi, Jueptner, Passingham, & Brooks, 2000; Keller et al., 2006; Taniwaki et al., 2006). Activities in the basal ganglia (Cunnington, Windischberger, Deecke, & Moser, 2002) and dorsolateral prefrontal cortex (François-Brosseau et al., 2009; Jahanshahi et al., 1995; Wiese et al., 2004) increase in self-initiated movements compared to the externally-triggered movements. In a monkey study, the firing rate of neurons in the putamen increased faster in a self-initiated than in an externally-timed movement (Lee & Assad, 2003). A study on human subjects also showed that movement-related cortical potentials in a self-initiated movement were larger than in an externally-triggered movement (Jahanshahi et al., 1995). The onset of hemodynamic response of pre-SMA in a self-initiated movement was earlier than in an externally-triggered movement (Cunnington et al., 2002).

Some studies have suggested that externally and internally initiated movements have different effects on time perception. Haggard, Aschersleben, Gehrke, and Prinz (2002), for example, reported temporal attraction effects between action and auditory tone both in self-initiated and externally-triggered conditions. In a self-initiated condition, a subject intentionally pressed a key at his or her own timing, causing a tone after 200 ms. In an externally-triggered condition, on the other hand, the subject pressed the key as quickly as possible upon hearing tone. The temporal orders of action and tone were reversed between the two conditions. The subject reported the perceived timings of key pressing and tone. The perceived timings of action and tone became closer to each other in both conditions, indicating that the directions of the shift of the perceived timing of tone and action were reversed between the two conditions.

Studies on chronostasis have shown that actions and subjective durations are closely linked (Yarrow, Haggard, Heal, Brown, & Rothwell, 2001; Yarrow, Haggard, & Rothwell, 2004; Yarrow, Johnson, Haggard, & Rothwell, 2004). In this illusion, the visual stimulus presented immediately after the saccade was perceptually dilated (Yarrow et al., 2001). The magnitudes of the lengthening effect were similar between the controlled and automatic eye movements (Yarrow, Johnson et al., 2004), with a constant effect across various intervals, indicating that chronostasis was not affected by the magnitude of volition.

Park, Schlag-Rey, and Schlag (2003) found that not only saccades but also voluntary movements such as key press and utterance caused an overestimation of the perceived duration of its sensory feedback, extending the chronostasis studies in context. In general, there appear to be interconnections between voluntary actions and subjective durations, a point that needs to be investigated further.

Different neural mechanisms and range of intervals are involved for saccades, finger movements, and other kinds of voluntary actions (Kandel, Schwartz, & Jessell, 2000). Thus, the results obtained in the chronostasis studies do not necessarily apply to voluntary movements in general. Identifying a common mechanism for saccades and other voluntary movements will contribute to the understanding of the relation between subjective duration and voluntary movements in the general context.

The effect of chronostasis was not affected by the context of saccade initiation (Yarrow, Johnson et al., 2004), and was constant across intervals (Yarrow, Haggard et al., 2004). It is still unknown whether such is the case for other kinds of voluntary movements (e.g. key pressing). It has been shown that the perceived timings of action and effect were affected by the sensorimotor context (Haggard, Aschersleben et al., 2002). It is possible that the subjective duration in voluntary movements such as key pressing is affected by the sensorimotor context, in contrast to chronostasis. It is interesting to investigate whether the context of action initiation would affect the estimated interval.

Here we use a temporal reproduction paradigm to investigate the effect of sensorimotor context on the perception of duration. The subjects were presented with sensory stimuli of various intervals. They were instructed to estimate the intervals and reproduce them through key pressing. In order to investigate the effect of sensorimotor contexts (e.g. self-timed versus externally-timed), the timings of the key pressing were constrained in various ways.

A voluntary movement can be classified either as an automatic or a controlled process (Wegner, 2002). An automatic movement is reflex-like and fast (~500 ms), with its conscious perception occurring after the motor execution (Welchman et al., 2010). On the contrary, a controlled movement requires cognitive processes depending on attention and working memory, takes longer time (>500 ms), and is more flexible. An action initiation within 500 ms after the Go signal can be regarded as an automatically controlled movement, while an action initiated between 1 and 2 s after Go signal can be regarded as cognitively controlled movement, requiring the subject to inhibit motor output for some interval while carrying it out before the deadline. Such a movement could not be achieved without a top down control. Our experimental setup incorporated these temporal constraints.

It has been suggested that different neural mechanisms are involved in the estimation of temporal duration below and above 2–3 s (Poppel, 1997; Ulbrich, Churan, Fink, & Wittmann, 2007). Temporal processing of up to 2–3 s can be regarded

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