Estimating the window of subjective simultaneity through illusions.

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Introduction

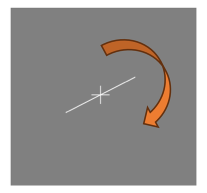
The belief that we control our body is an essential part of our conscious experience. Such a feeling is referred to as the "Sense of Agency" (SoA). (Gallagher, 2000) As an implicit measure of SoA, distortions of time perception are known (Haggard 2017) . When participants are asked to report the perceived time either of a voluntary action or of a subsequent sensory event (such as a tone), it has been reported that voluntary actions are perceived as occurring later than they actually do, while subsequent sensory events are perceived as occurring earlier than they do. These temporal shifts were observed neither in an *action only* condition nor a *sensory event only* condition. Additionally, in an involuntary condition, in which participants' finger is moved externally by transcranial magnetic stimulation, it has been reported that an externally triggered action was perceived as occurring earlier, and a subsequent sensory event as occurring later. These findings are referred to as the 'intentional binding' effect (Haggard et. al. 2002) .

These shifts in perceiving time suggest that subjective experience is not based on one-shot sensory inputs but involves some temporal width constituting one moment of subjective experience. We hypothesized the existence of such a time window and examined the validity of this view by estimating its width.

If there is a time window constituting a moment of subjective experience, the mechanism could be shared through participants' sensory perception. To investigate, we selected three well-known illusions of time perception, i.e., the flash-lag effect (Nijhawan 1994), illusory motion reversal (or the wagon wheel illusion) (Purves et al 1996), and the intentional binding (Haggard et al., 2002), and estimated the width of each participant's temporal window. Based on these estimations, we explored the consistency in the cognitive processes of time width across participants.

Methods

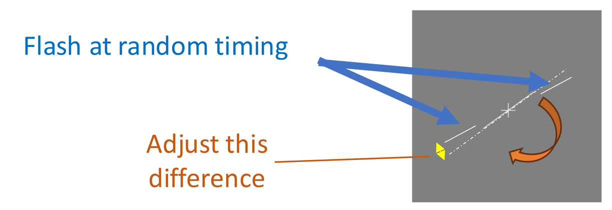
Exp.1) Illusory motion reversal (IMR)



A bar rotating clockwise at 30 RPM was initially presented. The rotation speed could be adjusted using the up/down keys. Participants were instructed to press the "up " key (to increase the rotation speed) until they perceived an apparent counterclockwise rotation.

The time width which constitutes a moment was calculated based on the half-rotation time at that point.

Exp.2) Flash-lag effect (FLE)



A rotating bar (30 RPM) was displayed at the center of the screen. A pair of lines flashed momentarily in directions that appeared to extend from both ends of the rotating bar. At first, the flashed lines were slightly offset, either in the direction of rotation or in the opposite direction. Participants were instructed to minimize this offset using the left and right keys.

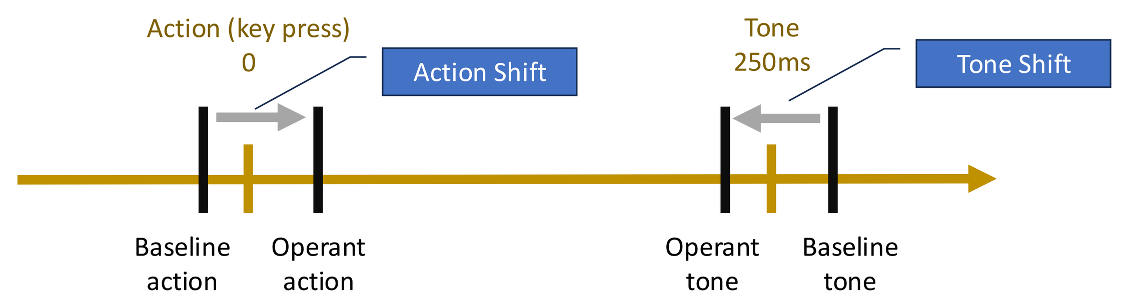
The time width which constitutes a moment was calculated based on the degree of the shifts at that point.

Exp.3-6) Intentional binding effect (IB)

Participants watched a rotating dot (completing 1 rotation every 2.56 seconds) and were instructed to press a key at their own timing, spontaneously, without prior planning. There were two conditions in response to the key press: one where a tone was played (operant condition), and one without a tone (baseline condition). Participants were asked to report the exact moment they pressed the key in one condition or when they heard the tone in the other.

Conditions	Operant	Baseline
Action	Op-action (report action)	Bs-action (Action only)
Tone	Op-tone (report tone)	Bs-tone (Tone only)

The effect of the intentional binding (I.B.) was calculated by subtracting the shift of actual timing in a baseline condition from one in an operant condition for each of the action and the tone condition.



Schematic visualization of I.B.

Result

Fig. 1: An example of experimental data from a single participant

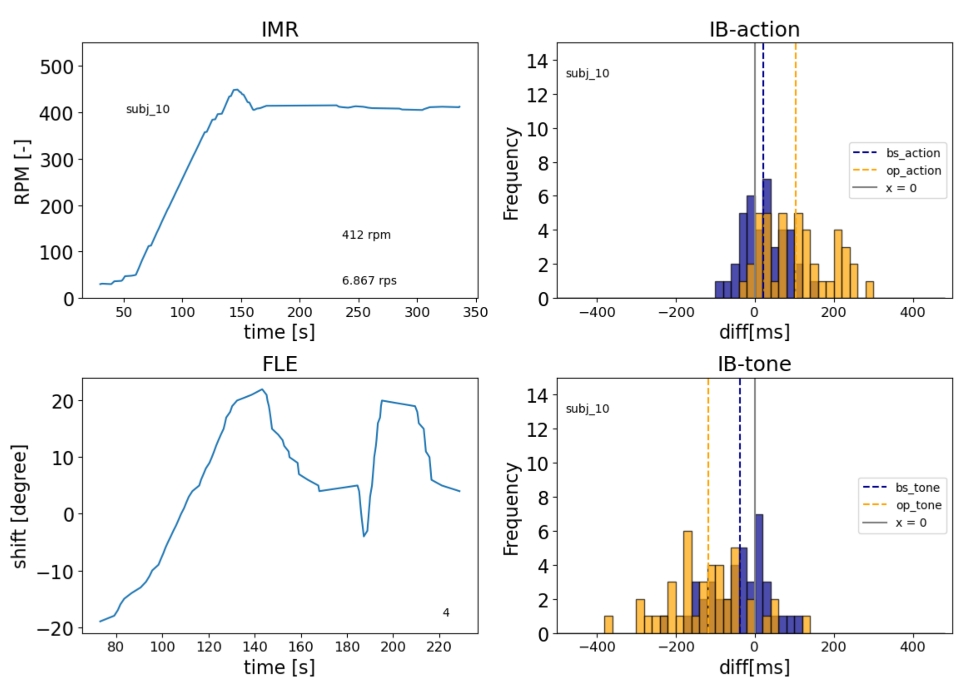
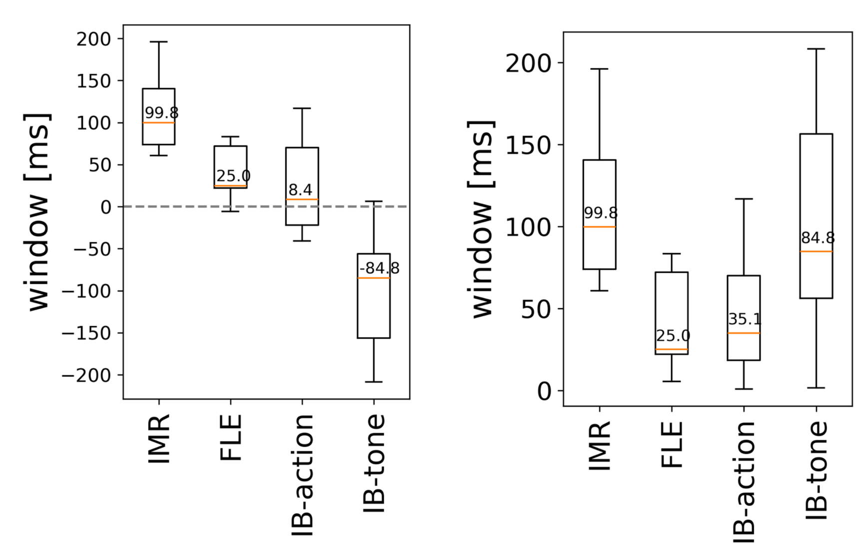


Fig. 2: Estimated time window(left) and its absolute value(right)



The orange lines are median values.

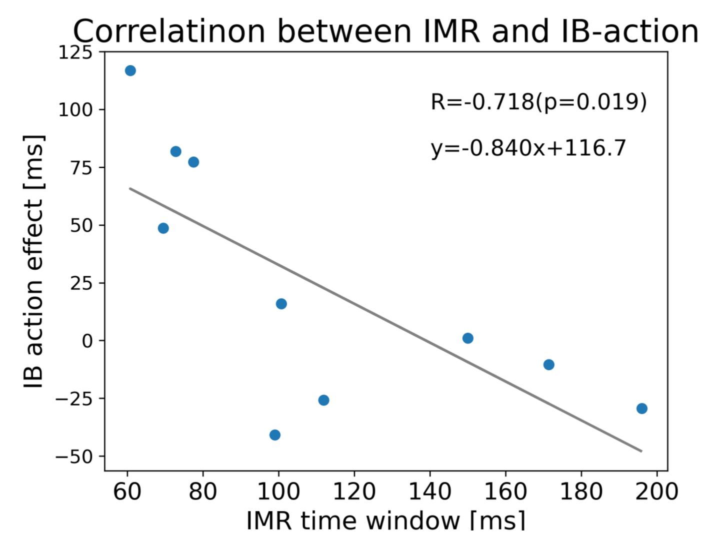
Table. 1: Correlations of four types of perceptual shifts

pair		Correlation coefficient	p-value
IMR	FLE	0.33	0.352
IMR	IB-Action	-0.72	0.019
IMR	IB-Tone	-0.12	0.740
FLE	IB-Action	-0.01	0.970
FLE	IB-Tone	-0.44	0.205
IB-Action	IB-Tone	-0.13	0.728

The correlations were calculated among participants.

There was no correlation except in the pair of IMR and IB-Action.

Fig. 3: Scatter plot of IMR and IB-Action



Material

Display-to-face distance: 42cm (A chin rest was used)

Stimulus angle: 3 degree

Display: JAPANNEXT JN-27IPS240WQHDR-HSP (Refresh rate: maximum 240Hz)

Display refresh rate: 240Hz (IMR, FLE), 120Hz(IB)

Sound: A headphone was used (audio-technica ATH-M50x)

Keyboad: CORSAIR K70 RGB TKL (polling rate 8000Hz)

Participant # : 10 (female = 4; mean age = 36.0 [SD=10.4, Range=22-54])

Condition order: Op-action, Op-tone, Bs-action. Bs-tone

Programming: PsychoPy (Psycho Tool Box module was included to generate tone)

Discussion

Replication and Analysis of IB Effects

IB was first observed as a crossover effect between voluntary and involuntary conditions. (Haggard et al., 2002) However, in subsequent studies, the IB effect was interpreted as the temporal attraction of perceived timings between actions and their outcomes (such as a tone) during voluntary movements. (Christensen et al. 2019)

Our results support this interpretation, particularly with the perceived timing of the tone shifting 84.8ms toward actions, referred to as outcome binding or effect binding. (Fig. 2, left) In contrast, the shift in perceiving action timing toward the tone, known as action binding, was only 8.4ms. (Fig. 2, left) Additionally, some participants exhibited a reverse or anti-IB reaction.

Is the time window hypothesis valid?

The estimated time window for the four types of perceptual shifts were not at the same level. The time windows for IMR and IB-tone were similar, while those for FLE and IB-action were also close.(Fig. 2, right) These results suggests that the time window hypothesis is not universally valid, as there appears to be no single shared mechanism underlying the four types of perceptual shifts. However, a partially shared mechanism may exist within shifts that have similar time windows.

The notable difference between IB-action and IB-tone was striking, indicating that distinct mechanisms may underly action perception and sensory perception. This finding is consistent with previous studies (Moore & Haggard 2010; Wolpe et al. 2013)

Correlation between IMR and IB-Action

We examined the correlation of two of the four types of perceptual shifts. No correlation was found between most pairs except for the pair of IMR and IB-Action (Fig. 3) . Interestingly, the correlation was negative value, which is difficult to interpret. If the correlation had been positive, it could have suggested that participants' precision in judging rotation direction was linked to the precision of their action timing. Instead, the negative correlation implies that the easier a participant felt the rotation reversal at low rotation speed, the later the tone is perceived. Further investigation is needed to fully understand this result.

Additionally, we note the possibility that this correlation may be a false positive, potentially due to a small sample size.

Reference

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