

I feel it in my fingers! Sense of agency with mid-air haptics

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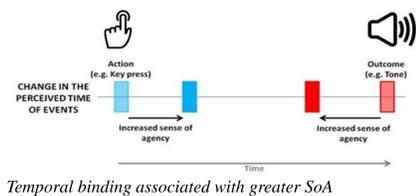
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Introduction

- Sense of agency (SoA) = the feeling of controlling external events through one's actions [4]
- Intentional binding is a widely used implicit measure of SoA [5]
- SoA in human-computer interaction (HCI) [2] - user's experience of control is of primary importance in HCI design [6]
- Touchless technology allows users to interact with systems without physically touching them [3]
- Touchless interaction may impact the user's SoA in two ways:
 - Absence of tactile (haptic) feedback
 - Temporal delay between actual movement and visual representation



In the present study we address these concerns by exploring SoA during a virtual button press task by manipulating:

- mid-air haptic feedback and
- the latency of the virtual hand's movement

Method

- **Participants**
 - Recruited via email, screened for handedness [7] and no reported visual impairments
- **Tasks and measures**
 - Binding was measured using the direct interval estimation method [1] in a virtual button pressing task
 - Explicit agency was measured via Likert scales of felt control and causation respectively
- **Apparatus**
 - The programme was setup, coded and run via Unity engine (v. 2019.3.0)

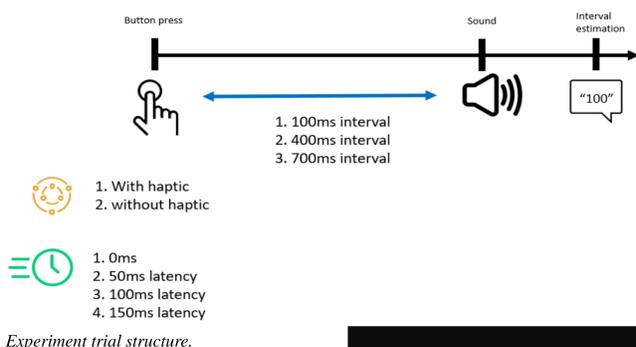


The experimental setup. The interface scene of the hand and button. The Ultraleap apparatus providing mid-air haptic feedback and hand tracking, and its setup for experimentation

Design and procedure

- 2 (haptic) x 4 (latency) x 3 (interval length) within-subjects experimental design

Trial sequence x36 per block



Every 12 trials within blocks require self-reported agency via UI.

Results

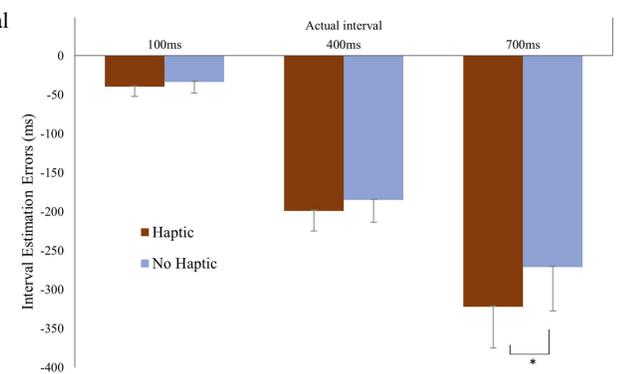
- Interval estimation error = Estimate - Actual
 - Lower scores = Greater binding.

Mean interval estimation errors (ms) for each condition with standard deviations in parentheses

Latency	Actual interval					
	100ms		400ms		700ms	
	Haptic	No Haptic	Haptic	No Haptic	Haptic	No Haptic
0ms	-48.5 (27.2)	-43.3 (50.6)	-226.6 (67.7)	-171.9 (119.6)	-347.3 (158.7)	-263.8 (192.2)
50ms	-25.8 (53.3)	-37.8 (48.0)	-176.9 (80.2)	-169.6 (98.3)	-284.2 (179.4)	-265.6 (193.7)
100ms	-48.6 (36.3)	-33.9 (39.8)	-196.1 (81.3)	-189.3 (123.0)	-342.5 (164.8)	-284.1 (175.9)
150ms	-35.5 (33.9)	-19.2 (46.9)	-195.5 (91.7)	-208.8 (102.9)	-313.8 (148.8)	-271.0 (188.1)

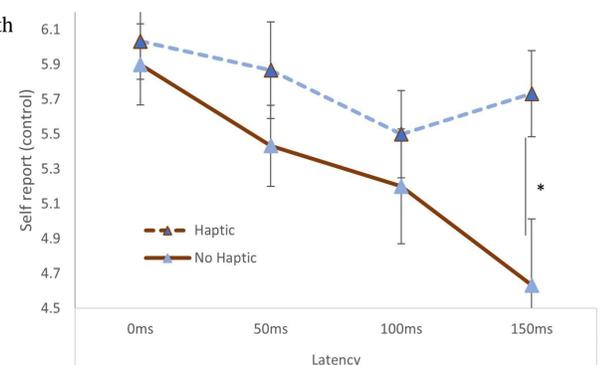
- Significant haptic x actual interval interaction ($p = .043$)

- Significant mean difference ($p = .039$) between haptic and no haptic conditions at the 700ms interval length



Estimation errors (binding) by haptic feedback, at each level of actual interval length. The error bars show SE across participants. * $p < .05$

- Significant decrease of control with latency in the no haptic feedback condition, ($p = .027$). Non-significant in the haptic feedback condition, ($p = .283$)
- Significant mean difference ($p = .038$) at 150ms latency



The linear effect of latency on self-reported control of hand modulated by haptic feedback. * $p < .05$

Discussion

- Greater implicit SoA with haptic feedback at the 700ms action-outcome intervals.
 - Visual cues may be sufficient for SoA with shorter action-outcome intervals, but longer action-outcome intervals may depend on additional haptic cues to preserve SoA
- Self-reported control of the virtual hand representation decreased as latency increased from 0ms–150ms but this effect of latency on explicit SoA was attenuated with the presence of mid-air haptic feedback
- Latency has a deleterious effect on explicit SoA but this may be mitigated by mid-air haptic feedback

In conclusion, our results showed that mid-air haptic feedback has two effects on SoA:

- promoting implicit SoA at longer action-outcome intervals, and
- protecting against latency-induced reductions in the explicit SoA

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