

# Own-body representation in children: the effects of movement and corporeality for virtual hands

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What drives our sense of self? Previous research using the rubber-hand illusion (RHI: Botvinick & Cohen, 1998) has demonstrated that adults and children are susceptible to an illusion of ownership over a rubber hand (Cowie et al., 2013; 2016; 2018). The illusion is present when visual and tactile sensory cues are synchronous (i.e. congruent) rather than asynchronous, and strongest when the rubber hand represents a congruent form (appearance) to the one expected (Tsakiris, Carpenter, James & Fotopoulou, 2010). The illusion is often broken once the participant moves their own hand, yet VR research has now demonstrated that moving a virtual hand contributes to a stronger sense of body ownership (Slater et al., 2009).

Children, however, have revealed dissociable pathways in body-representation compared to adults. For example, children aged 4-9 years display three times as much drift in perceived hand location and children aged 6-7 years accept a misoriented hand as their own (Cowie et al., 2013; 2016; Gottwald, submitted). Thus, we explored the effects and constraints of movement, touch and hand corporeality (form) cues on children's sense of ownership over virtual hands.

In Experiment 1, 117 children aged 4-14 years completed a bubble popping game where a virtual hand moved synchronously or asynchronously with their own hand movements. Participants also felt a haptic touch either synchronously, asynchronously or not at all while popping each bubble. The strength of embodiment for the virtual hand was quantified via ratings (questions relating to agency and ownership) and proprioceptive drift. Findings revealed significantly greater embodiment (higher agency and ownership ratings) for the virtual hand in synchronous compared to asynchronous movement. No reliable differences in proprioceptive drift or haptic touch were observed. Age negatively correlated with Agency ratings during asynchronous movement only. That is, as age increased, the sense of agency during asynchronous movement decreased.

In Experiment 2, 80 children aged 5-14 years completed a modified version of Experiment 1, where participants used a virtual hand or block to complete the task. The hand and block moved synchronously or asynchronously with the participant's own movements, and embodiment was quantified via ratings (questions relating to ownership, agency, location and tool use) and proprioceptive drift. Findings revealed significantly greater embodiment during synchronous relative to asynchronous movement for both the hand and block. No effects of proprioceptive drift were observed. For most questions, no differences were observed between the hand and block forms, irrespective of movement synchrony. However, the virtual hand was rated significantly more like a hand (and less like a mouse / controller) in synchronous compared to asynchronous movement and was rated more like a hand compared to the block, but only during synchronous movement. The block was rated like a mouse / controller equivalently during synchronous and asynchronous movement. Age negatively correlated with embodiment ratings during asynchronous movement only, suggesting that as age increased, embodiment ratings decreased.

Collectively, findings highlight the importance of movement synchrony for ownership and embodiment of virtual limbs and suggest that children may display dissociable processes for temporally incongruent sensory information.