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Title：Movements of avatar in virtual reality can elicit sense of agency

Outline：As an important component of self-awareness, sense of agency (SOA) refers to experiencing oneself as the author of one's action. Studies on rubber hand illusion and its virtual-reality (VR) variants demonstrate that body ownership, another part of self-awareness, can be transferred to external objects or virtual effectors (Matthew Botvinick & Jonathan Cohen, 1998; Ehrsson, 2004; Olaf Blanke et al., 2007). However, whether sense of agency can be similarly attributed to avatar in VR has never been rigorously examined (Ke Ma et al., 2015). Here we use intentional binding, a well-established implicit measure of SOA, to study whether movements of an avatar can trigger SOA after sensorimotor experience in VR.

Participants wore a head-mounted display (HMD, Rift DK2, Oculus) and a data glove (Perception Neuron, Noitom), which measured their upper arm movements. They were immersed in a virtual environment with a first-person perspective and a gender-matched virtual body. The experiment consisted of a pretest, an exposure phase and a posttest. In the pretest and posttest, we measured intentional binding with a Libet's clock (Haggard, 2002). When a voluntary action is followed by a delayed action outcome, people's estimate of the outcome timing is biased towards the action. In our experiment, participants observed their avatar's right hand press a lever and received a vibrotactile stimulus delivered to their own left hand 250ms later. They were asked to report the time of the stimulus. The bias was computed by comparing this estimate to the estimate from a baseline condition without the avatar's action. During the 25-min exposure phase, participants (n=18; Test group) perform two aiming tasks by moving their upper limb while the avatar arm matched the real arm continuously and simultaneously. Another participant group (n=18; VR-Control group) went through the same procedures except that the avatar was not shown during exposure. We recruited a third group (n=11; Reality-Control group) performed the intentional binding task with their real hand and without HMD.

We found that intentional binding was stronger after exposure in Test group. This exposure

effect was absent in VR-Control group as no significant difference was detected before and after exposure. Interestingly, the size of the intentional binding in Test group was comparable to that of Reality-Control group. Hence, similar to bodily ownership, SOA can also be attributed to virtual identities after a short period of immersive VR experience. Our novel behavioral paradigm offers an opportunity to further elucidate the cognitive and neural mechanisms of self-consciousness. As VR is extensively used in motor control studies as a surrogate of real environment, our findings intriguingly suggest that virtual body or virtual representation of the body might dynamically affect SOA and its related sensorimotor control processes.