Cognition 173 (2018) 21–27

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Original Articles

# Sensory predictions during action support perception of imitative reactions across suprasecond delays

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ARTICLE INFO

*Keywords:*
Prediction
Action: social interaction
Perception
Imitation
Sensorimotor integration

ABSTRACT

Perception during action is optimized by sensory predictions about the likely consequences of our movements. Influential theories in social cognition propose that we use the same predictions during *interaction*, supporting perception of similar reactions in our social partners. However, while our own action outcomes typically occur at short, predictable delays after movement execution, the reactions of others occur at longer, variable delays in the order of seconds. To examine whether we use sensorimotor predictions to support perception of imitative reactions, we therefore investigated the temporal profile of sensory prediction during action in two psychophysical experiments. We took advantage of an influence of prediction on apparent intensity, whereby predicted visual stimuli appear brighter (more intense). Participants performed actions (e.g., index finger lift) and rated the brightness of observed outcomes congruent (index finger lift) or incongruent (middle finger lift) with their movements. Observed action outcomes could occur immediately after execution, or at longer delays likely reflective of those in natural social interaction (1800 or 3600 ms). Consistent with the previous literature, Experiment 1 revealed that congruent action outcomes were rated as brighter than incongruent outcomes. Importantly, this facilitatory perceptual effect was found irrespective of whether outcomes occurred immediately or at delay. Experiment 2 replicated this finding and demonstrated that it was not the result of response bias. These findings therefore suggest that visual predictions generated during action are sufficiently general across time to support our perception of imitative reactions in others, likely generating a range of benefits during social interaction.

## 1. Introduction

Behavioural success for humans and other animals often depends on effectively navigating the social world – on accurately anticipating and interpreting the actions of conspecifics (Happé, Cook, & Bird, 2017). An influential hypothesis in recent decades has been that we use our motor system to generate predictions about how others will behave while we observe them during interaction (Schütz-Bosbach & Prinz, 2007; Wolpert, Doya, & Kawato, 2003). Specifically, processes for anticipating the sensory consequences of our own actions during selection and execution (e.g., we predict that we will see our hand waving when we send a motor command to wave; Greenwald, 1970) are repurposed to support perception of similar reactions in others (e.g., when we wave to a friend and they return the gesture). These processes are proposed to support the perception of imitation given that the sensory consequences generated by our own movements closely resemble those generated by our imitative partner. This generalized predictive process would increase our sensitivity to imitative responses in others, promoting fluent social interactions by facilitating rapid and appropriate responses to our partner's behaviour (see Schütz-Bosbach & Prinz, 2007 for a discussion).

However, it remains unknown whether sensorimotor predictions have the temporal profile needed to support perception of imitative reactions. Typically, when we produce an action (e.g., a wave) the direct outcome of visual stimulation relating to our own action is perceived at reliable and short delays after action execution, whereas the imitative responses of others are observed across variable delays in the order of seconds. While a number of influences of sensorimotor prediction on visual processing have previously been reported with no action-outcome delays (Deschrijver, Wiersema, & Brass, 2017; Stanley & Miall, 2007; Yon & Press, 2017), no empirical work has investigated whether sensorimotor predictions operate across the suprasecond delays between action and reaction that characterize natural social interaction. In fact in contrast with theories of social interaction, it has been argued by action control researchers that sensorimotor predictions operate with subsecond precision (e.g., Frith, Blakemore, & Wolpert,

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https://doi.org/10.1016/j.cognition.2017.12.008
Received 18 July 2017; Received in revised form 9 December 2017; Accepted 10 December 2017

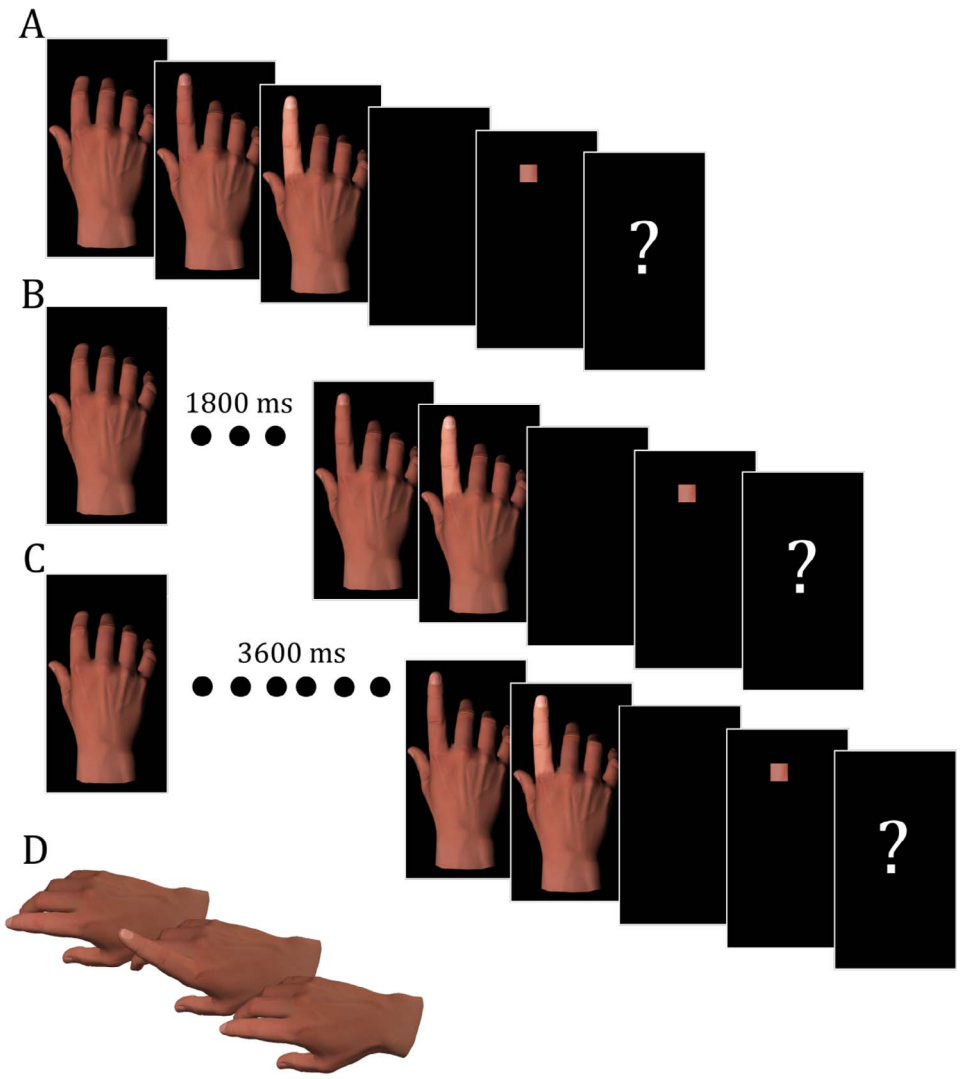


**Fig. 1.** The timecourse of stimulus presentation on a single trial in both Experiments 1 and 2. Sensory outcomes were presented at a 0 ms (A), 1800 ms (B) or 3600 ms delay (C) relative to the participant's own executed action (D). In the above figure the observed outcome (index lift) is congruent with the executed action. Note that in Experiment 1 participants were required to report which event (target or reference) was brighter, while in Experiment 2 participants were required to report whether the target and reference events were the same brightness or not. Hand stimuli were generated using Poser 7.0 (Smith Micro Software).

2000) and therefore the temporal variability with which others imitate our actions may preclude prediction.

The experiments presented here therefore considered the timecourse of visual sensorimotor prediction. To measure influences of prediction on perception of observed actions, we exploited the fact that predicted stimuli appear more intense (brighter) than unpredicted stimuli. For example, Han and VanRullen (2016) report that predictable gray shapes are perceived as brighter than the same gray hues displayed in the unpredictable context of random lines. These brightness effects are consistent with models where predictions increase the 'gain' on (or activation of) expected sensory units, enhancing the effective signal strength of predicted events (Summerfield & de Lange, 2014). Specifically, physically more intense signals are associated with increased activation in populations of sensory neurons, and therefore manipulations which increase apparent intensity are reasoned to reflect gain enhancements of underlying sensory populations (see Carrasco, Ling, & Read, 2004; Cutrone, Heeger, & Carrasco, 2014, for a discussion). These schemes are consistent with suggestions from ideomotor theory that action execution involves activating representations of anticipated sensory outcomes (Greenwald, 1970). They are argued to be an adaptive use of sensory systems given that they will bias perceptual processes towards events that are by definition more likely to occur, leading to (on average) more veridical percepts (Summerfield & de Lange, 2014; Yuille & Kersten, 2006; see General Discussion).

We have recently demonstrated these influences of expectation on apparent brightness in an action context (Yon & Press, 2017). In these previous experiments, participants executed finger movements (index or middle lifts) and observed synchronized congruent or incongruent finger movements (same or opposite finger, i.e., expected or unexpected action outcome) performed by an avatar hand. The perceived brightness of these outcomes was measured by briefly increasing the brightness of the observed avatar finger shortly after movement, and asking participants to compare its apparent brightness to a reference stimulus. Results revealed that participants perceived congruent action outcomes probed shortly after action (50 ms delay) as brighter than incongruent ones. This effect was absent for non-action control stimuli (squares) presented at equivalent locations, suggesting that the underlying predictive process is sensitive to the identity of action outcomes rather than simple spatial features.

In the present study we adapted our previous task, but varied the delay between action execution and the presentation of action outcomes. In Experiment 1, participants executed finger movements (e.g., index finger lift) and judged the brightness of resulting congruent (index lift) or incongruent (middle lift) outcomes made by an onscreen avatar. Observed actions occurred at different delays after the participant's own movement (0, 1800, 3600 ms). The suprasecond (> 1 s) delays employed in the 1800 ms and 3600 ms conditions mirror the natural delay with which our actions are likely to be imitated, given reports that prosocial effects of being imitated arise with 2–4 s delays (Bailenson & Yee, 2005; see Catmur & Heyes, 2013). If sensorimotor