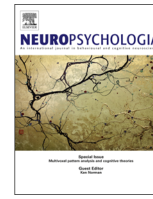
Neuropsychologia 55 (2014) 115–121

Contents lists available at ScienceDirect

Neuropsychologia

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



Our actions in my mind: Motor imagery of joint action

Cordula Vesper [a,b,*], Günther Knoblich [a,b], Natalie Sebanz [a,b]

[a] *Central European University, Department of Cognitive Science, Budapest, Hungary*
[b] *Radboud University Nijmegen, Donders Institute for Brain, Cognition and Behaviour, Nijmegen, The Netherlands*

ARTICLE INFO

Available online 7 June 2013

Keywords:
Joint action
Motor imagery
Simulation
Prediction
Interpersonal coordination

ABSTRACT

How do people imagine performing actions together? The present study investigated motor imagery of joint actions that requires integrating one's own and another's part of an action. In two experiments, individual participants imagined jumping alone or jointly next to an imagined partner. The joint condition required coordinating one's own imagined actions with an imagined partner's actions to synchronize landing times. We investigated whether the timing of participants' own imagined jumps would reflect the difference in jump distance to their imagined partner's jumps. The results showed that participants' jump imagery was indeed modulated to achieve coordination with an imagined task partner, confirming prior findings from a performance task. Moreover, when manipulating both target distance and target size, the same violation of Fitts' law reported for individual jumping was present in imagery of joint jumping. These findings link research on motor imagery and joint action, demonstrating that individuals are able to integrate simulations of different parts of a joint action.

1. Introduction

Imagining a simple action such as pouring coffee into a cup is in many respects similar to actually performing that action except that the observable motor output is lacking. Jeannerod described motor imagery as the "ability to generate a conscious image of the acting self" (Jeannerod, 2004; p. 379) and proposed that many of the principles underlying action performance also hold in action imagery (Jeannerod, 1995, 2004). This proposal has sparked a whole line of research that investigated what is common between covert (internally simulated) action and overt (actually performed) action. Similarities in neurophysiological activity when planning, performing and imagining actions indicate that these phenomena are governed by overlapping processes and brain networks (Decety & Grèzes, 2006; Dietrich, 2008; Grèzes & Decety, 2001; Rizzolatti & Sinigaglia, 2010; but see Dietrich, 2008 for a critical view). In particular, imagined and to-be-performed actions might be represented in a common motor format (Jeannerod, 1995; Prinz, 1997), thereby relying on internal forward models that predict the (imagined) outcome of an action (Grush, 2004; Blakemore & Frith, 2005; Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003).

Whereas researchers have intensively studied motor imagery of individual actions (e.g., Guillot and Collet (2005), Jeannerod (2004)), motor imagery of joint actions has not been addressed. However, investigating imagery of joint action can help us to better understand the mechanisms underlying motor simulation. The reason is that in order to imagine a coordinated joint action it is neither sufficient to simulate one's own action nor is it sufficient to simulate the other's action. Rather it is also necessary to integrate these two action simulations. This becomes clear when one considers that joint action often requires that two or more individuals adapt their actions in space and time to what the other is doing (Clark, 1996; Sebanz, Bekkering, & Knoblich, 2006). Examples for such joint actions range from carrying a heavy object with a friend to passing a basketball to a team-mate or dancing a tango together. Importantly, co-actors need to represent not only their own and a partner's part of a joint action, but also the shared goal resulting from their combined actions (Vesper, Butterfill, Knoblich, & Sebanz, 2010). For performance, it has been suggested that joint action coordination toward a shared goal is to a large extent achieved by internal simulations that allow co-actors to predict their own and their partner's actions using their own motor system (Keller, 2012; Wolpert et al., 2003). We propose that the same simulation processes that support the planning and execution of joint action also support imagery of joint action. Especially when coordinating actions with others, motor simulations of one's own and a partner's action parts need to be integrated to plan one's own action with respect to achieving the shared goal. Although there is growing evidence that different motor simulations can run in parallel (Hamilton, Wolpert, & Frith, 2004; Kourtis, Sebanz, & Knoblich, 2013), there is hardly any

* Corresponding author at: Central European University, Department of Cognitive Science, Frankel Leó út 30-34, Budapest 1023, Hungary. Tel.: +36 1 887 5146.
E-mail address: vesperc@ceu.hu (C. Vesper).

0028-3932/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.neuropsychologia.2013.05.024

evidence that motor simulations can be integrated to simulate different components of a joint action.

The current study attempted to test this assumption using motor imagery. Imagining performing actions is a pure form of motor simulation as imagery is not subject to any sensorimotor or perceptual influences that are present when movement is actually performed (cf. Schmidt and Richardson (2008)). If people were able to engage in imagery of joint action that constrained their own as well as their partner's action parts in the same way as during actual joint action planning and performance, this would provide evidence for an integration of motor simulations of one's own and others' actions.

Previous research on individual motor imagery has compared how people actually perform actions to how they imagine performing the same actions (e.g., Jeannerod (1995, 2004)). A highly consistent finding in such studies is that constraints present in performance also govern motor imagery. For example, when people imagine walking a specific distance then the time their movement takes is similar to actually walking that distance (Decety, Jeannerod, & Prablanc, 1989). Moreover, if a to-be-imagined action is more difficult reported movement times increase systematically. In one study where individual participants were asked to imagine walking through doors of varying width, their reports of the imagined movement time scaled as a function of the distance toward the door and its width (Decety & Jeannerod, 1995), thereby complying with the speed-accuracy trade-off known as Fitts' law (Fitts, 1954). Similarly, the same biomechanical constraints determining in which way people lift objects were found in their self-reports of imagining grasping the object (Johnson, 2000).

Based on these previous findings, the present study asked whether the constraints imposed by the requirement to coordinate with another person would influence imagery in the same way as when two people perform coordinated actions together. Two experiments tested whether behavioral effects previously observed in joint action coordination could be observed in a motor imagery task where participants imagined both parts of the joint action. To this end, we adapted and extended an existing joint action task (Vesper, van der Wel, Knoblich, & Sebanz, 2013) and asked participants to imagine coordinating their own action with an imagined partner. If participants' action imagery resembled actual performance this would demonstrate that participants take the same aspects of another person's task or action into account when imagining interpersonal coordination. This, in turn, would support the assumption that they can engage in an integrated motor simulation of their own and another's part of a joint action.

2. Experiment 1

Experiment 1 investigated motor imagery of joint action coordination based on a joint action task in which pairs of participants were asked to synchronize the landing times of forward jumps of varying distance (Vesper et al., 2013). In this study, co-actors knew how far they themselves had to jump and how far their partner had to jump. However, they had no perceptual information about their partner. The results demonstrated that the information received prior to jumping was sufficient for participants to adapt to the partner's jump distance so that a high degree of synchronicity in landing times was achieved. For the current study, we adapted this previous task to investigate imagery of joint action. Individual participants were asked to imagine jumping either alone (individual condition; Fig. 1a) or jointly, next to an imagined second person (joint condition; Fig. 1b). In the latter condition, they imagined coordinating their own jumping with the imagined partner's jumping such that their imagined landing would occur at exactly the same time. Participants reported their imagined jump take-off by releasing a button and their imagined landing by pressing the button again.

We predicted that participants' self-reported imagery would show the same pattern that was previously found during actual performance of individual and joint jumping (Vesper et al., 2013). More specifically, we predicted that the duration of imagined individual jumps should increase with increasing jump distance, indicating that participants succeeded in imagining jumping as a ballistic movement that is dependent on the jump distance (Juras, Slomka, & Latash, 2009). Our second prediction was that the imagined duration of a joint jump should take into account not only the jump distance that participants needed to cover but also the jump distance their imagined partner needed to cover. This should become particularly visible when the partner's jump covered a larger distance than the participant's jump. Such a finding would mirror the prior performance results where co-actors modulated the duration of both jump preparation and jump execution to achieve synchronization at landing. If the same adaptation would be observed in joint action imagery this would provide evidence that participants could integrate motor simulations of their own and an imagined person's jumping even in the absence of actual sensorimotor or perceptual feedback. On an alternative account, if individuals were only able to imagine either their own or their partner's actions, but were not able to integrate both imagined actions, then the results should not mirror those found during performance. In particular, participants' imagined jump duration should then either just reflect their own jump distance or just reflect their partner's jump distance.

2.1. Method

2.1.1. Participants

Twenty-four university students participated (17 women; mean age=21.8 years, *SD*=3.1 years; one left-handed and three left-footed). Their mean body height was 172.4 cm (*SD*=9.8 cm). On average they were 2.6 cm shorter than the experimenter. Participants were naïve to the purpose of the study, gave prior informed consent, and received monetary compensation or course credits. The experiments conformed to the standards of the Declaration of Helsinki.

2.1.2. Materials and apparatus

The experimental setup (Fig. 1) was mostly identical to that used in a previous performance study (Vesper et al., 2013). An opaque black cloth (220 cm × 400 cm) divided two jumping areas consisting of a row of five rectangles (35 cm × 50 cm) each. Next to each rectangle was a pair of red and green light-emitting diodes (LEDs) covered by a transparent matted plastic cube (edge length 4 cm). Participants pressed and released a button on a standard computer mouse to indicate the imagined point in time for take-off (release) and landing (press). Half the group of participants performed the task on the right side of the occluder, the other half on the left. Auditory information was provided via headphones. The experimental procedure was controlled by the software Presentation (Neurobehavioral Systems Inc., version 14.0) run on a standard Hewlett Packard PC (Windows Vista).

2.1.3. Procedure

Participants completed two experimental parts within one session. Part 1 was the individual condition in which participants were instructed to imagine jumping on their right leg to the target highlighted by the LED-light right next to them. In Part 2, the joint condition, participants imagined synchronizing their landing time with the landing time of an imagined person on the other side of the occluder. The experimenter always served as a reference for imagining the second person. A second light indicated the distance the imagined partner needed to cross with her jump. Detailed written instructions were given before each part.

At the beginning of a trial, participants stepped from outside the jump area into the first rectangle and simultaneously pressed the mouse button with their right index finger or thumb. The LED-lights on the ground were switched on indicating the targets for the participant's own imagined jump and the imagined partner's jump (participants were told to ignore the second LED in the individual condition). After a randomized interval of 1.7 s, 2.0 s or 2.3 s, an auditory start signal (440 Hz, 100 ms) informed participants that they should now, at their own speed, imagine jumping by releasing (time of jump take-off) and pressing (time of landing) the mouse button. At imagined landing, a short feedback tone (1320 Hz, 100 ms) was played.