

Visuo-olfactory integration during action observation and execution of reach-to-grasp movements

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Observing the actions of others prompts the motor system to perform a similar action. However, visual cues are not the only source of sensory information for the motor system, which is affected by stimuli presented in all modalities even when they are irrelevant for action completion. The current experiment explored whether (and how) olfactory stimuli can influence the performance of a reach-to-grasp movement to visual objects differing in size (small and large) in the context of an automatic imitation task. Odours could match or not the size of a to-be-grasped visual target, or be nonexistent. Movement duration, an integral index of motor control, was significantly shorter when participants previously observed the same action. Addition of the odour component suggested that when the odour matched

the size of a small target, a facilitation effect was found. Results are discussed in terms of olfactory-visual integration mechanisms and how they relate to embodied cognition. *NeuroReport* 24:768–772 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

Being able to copy the actions of others is an invaluable skill supporting cognitive development and social-communicative interactions [1]. When imitation arises spontaneously, we copy an observed action without explicit intention of doing so (automatic imitation). In other words, we are temporarily sharing the same behavioural state of the agent performing the action and implicitly using that perceived behaviour as a basis for us to produce a similar action in the environment [2]. The idea of a close link between action observation and execution has been reported repeatedly in the literature from different perspectives. In behavioural terms, observing a model performing a reach-to-grasp movement implies, as an example, a reduction in movement duration (MD) [3]. Physiological evidence on motor-evoked potentials collected during action observation shows that the motor system shadows a seen action under threshold [4]. At the neural level, the ventral premotor cortex and the inferior parietal region – areas activated during action execution [5] – were also crucial during the observation of hand or arm actions [5,6]. Altogether, these findings support the existence of an early sensory-motor matching mechanism that influences movement execution and grounds the experience of higher-level social interactions [7].

Although the primary role of vision in this process is clear, the contribution of other sensory stimuli towards the automatic imitation of gestures has yet to be fully characterized. Multisensory integration research showed that the motor system receives inputs from stimuli across modalities and processes them even when they are irrelevant for completing the action [8]. Of particular interest to the foundation of social interactions are odours,

which provide relevant information for navigating the world and modulate motor behaviour [9–11]. At a behavioural level, the execution of visually guided reach-to-grasp movements can be facilitated when performed under the exposure of an olfactory stimulus that elicited a grasping pattern matching the visual object (e.g. the odour of an orange prompts a power grip, which is the grip required to grasp a fruit of similar dimensions, such as an apple). The facilitation effect becomes evident, for instance, when considering MD: it is shorter when the odour corresponds to the visual target and it is longer when it mismatches the object [11]. Such evidence indicates that although an odour might not be crucial for the execution of an action, it can be implicitly elaborated in motor terms and it modulates the motor plan established for grasping the visual target.

The present study aims to bring this evidence a step forward by investigating whether (and how) an odour matching a visual to-be-grasped object nonmatching it or at all absent influences the time it takes to perform a reach-to-grasp movement following the observation of the same action performed by a model, that is an automatic imitation task.

Methods

Participants

The study included 13 participants (seven women) between 18 and 30 years of age (women, 25.33 ± 2.73 years; men 27.50 ± 1.73 years). Two participants were excluded from the final analyses because of the detection of abnormal motor patterns (i.e. marked bradykinesia compared with the other participants). Before starting the experiment, a questionnaire was administered to all participants to ascertain previous history of nasal disease,

smoking habits and the current subjective status of olfactory functions [12]. All participants reported normal smell and taste abilities, normal or corrected-to-normal vision and no history of smell and taste dysfunction. According to the Edinburgh Handedness Inventory [13], all participants were right handed. Participants were naïve as to the purpose of the investigation and provided informed written consent to participate in the study. The experimental procedures were approved by the local Institutional Review Board and followed the principles of the Declaration of Helsinki.

Stimuli

Four visual targets were grouped on the basis of their natural size: large (apple, orange) – requiring a power grip (i.e. fingers flexed as to form a clamp against the palm) and small (almond, strawberry) – eliciting a precision grip (i.e. the opposition of the thumb with the index finger). Targets were made of plastic to maintain visual features and size consistent over the experimental period. Odour solutions of strawberry, almond, orange and apple were obtained by mixing 6000 ml of propylene glycol and 180 ml (3%), 60 ml (1%), 420 ml (7%) and 45 ml (0.75%) of the specific odorant compound, respectively. Odours were rated as equally familiar and intense on visual analogous scales by a group of 30 young adults. The combination of olfactory (matching, nonmatching, no odour) and visual stimuli (small, large) produced six variations, each of which was experienced by the participant either following the observation of an action performed by the model (action) or in the absence of preceding action observation (no action). Therefore, a total of 12 experimental conditions were tested (Fig. 1). Under matching conditions, smelling the small (or large) odour was followed by grasping the small (or large) visual target, respectively. That is, both the odour and the visual target could either be identical (e.g. almond odour, almond target) or provided size-congruent motor information (e.g. almond odour, strawberry target). Under nonmatching conditions, smelling the small (or large) odour was associated with grasping a large (or small) object, respectively. As a result, the odour provided size-incongruent information when compared with the visual information of the target. Under no-odour conditions, small and large targets were grasped following delivery of odourless air.

Apparatus

A custom-built computer-controlled olfactometer was used to deliver the olfactory stimuli [11]. Odours were contained in glass boats hit by incoming air at a flow rate of 8 l/min and were delivered to participants through Teflon tubing to a facial mask. Movements were recorded using a three-dimensional motion analysis system (SMART-D, BTS Bioengineering SPA, Milan, Italy) equipped with six-infrared cameras (frequency 140 Hz) recording the position of three markers (diameter 0.25 cm) attached using double-sided tape to the wrist, the tip of the index finger and the tip of the thumb of the model and participants' right hand.

The reconstruction of markers coordinates permitted an error of 0.2 mm for all axes (x , y , z). Data processing and analysis was carried out using the SMART-D analyser software. Vision was controlled using shutter glasses that rendered the target visually accessible by changing from opaque to clear (Plato Technologies Inc., Toronto, Canada).

Procedure

The participant and the model sat at a table in front of each other with the target aligned to both body midlines and located at a 33-cm-distance from hand starting positions, which required the participant and the model to maintain their right shoulder partially flexed, their right forearm semipronated, their wrist extended, the ulnar side of their right hand placed upon the hand starting pad and the fingertips of their index finger and thumb facing each other and almost touching. The right hand of both the participant and the model rested with the index finger and the thumb gently opposed. At the beginning of each trial, vision was occluded 500 ms before the target was positioned on the working surface. Two identical sounds indicated odour onset and offset (3 s). Following a 100 ms interval, a different tone indicated the participant vision restoration. Immediately after, the model performed the grasping movement towards the target object or sat stationary. After 3 s, the tone was presented again and participants reached towards, grasped and lifted the target object. Participants reached at a natural speed and naturally grasped the small objects between the thumb and the index finger (i.e. precision grip) and the large objects opposing the thumb with all the other fingers (i.e. power grip). An experimenter monitored each trial visually to ensure the participant's compliance with instructions. Participants performed a total of 48 trials that were presented in a randomized order within four blocks.

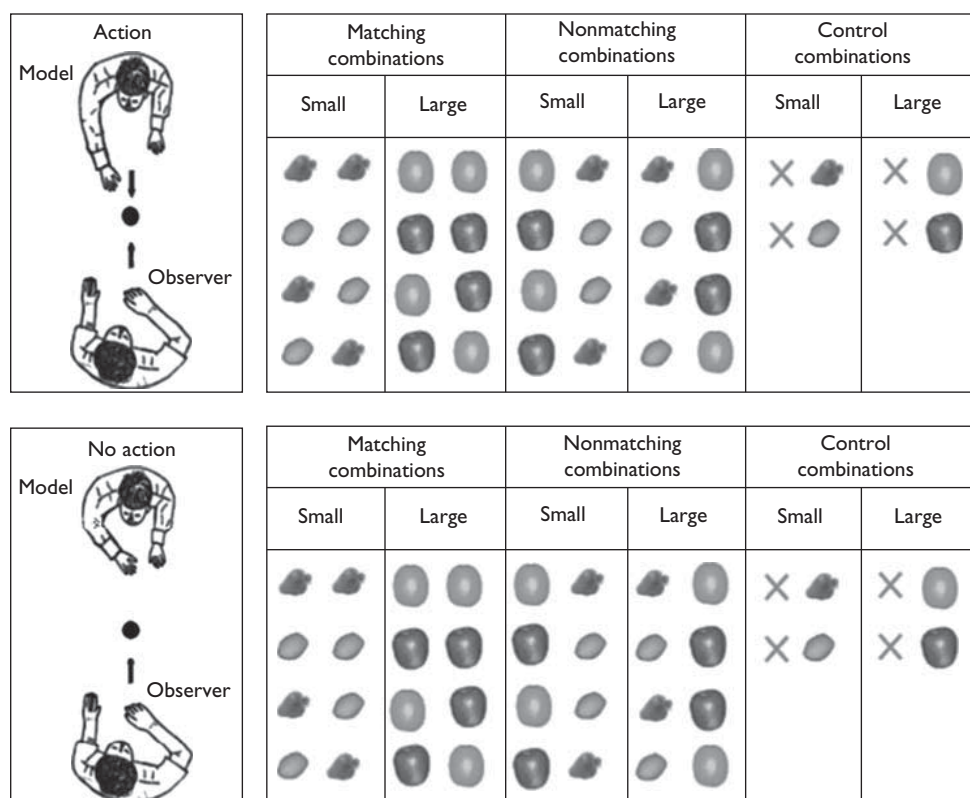
Data analysis

MD, proven to be an appropriate dependent variable for the study of automatic imitation [2], was calculated as the time elapsing from the wrist moving towards the object for two consecutive frames (20 ms) and the wrist first vertical movement following grip closure upon the object. A within-participant analysis of variance with 'odour' (matching, nonmatching and no odour), 'object dimension' (small, large) and 'observed action' (action, no action) was carried out. Bonferroni's corrections (α level: $P < 0.05$) were applied, when required.

Results

The analysis showed a significant main effect of 'observed action' [$F(1,10) = 7.66$, $P < 0.05$, $\eta_p^2 = 0.74$]. When the visual target was grasped in the absence of a preceding model's action observation, MD for the participant's movement was significantly longer than when the participant's action execution was preceded by action observation (no action vs. action condition: 1171 vs. 1125 ms, $P > 0.05$).

Fig. 1



Graphical representation of the 12 experimental conditions. The upper panel represents the conditions in which the participant acted following the observation of the model's action. The lower panel refers to conditions in which the model remained still and the participant acted without observing any action. Each column of both tables represents the combination of the type of motor plan elicited by the odour and the visual stimulus (matching, nonmatching or control) and the size of the to-be-grasped object (small or large). Within each column, the first image of every pair indicates the delivered odour ('X' corresponds to odourless air) and the second image represents the to-be-grasped object.

The present result confirms the presence of an automatic imitation effect: the observation of a model performing an action reduced the observer's MD while executing the reach-to-grasp movement. A significant main effect of 'object dimension' [$F(1,10) = 13.11$, $P < 0.01$, $\eta_p^2 = 0.90$] was also evident. MD was significantly shorter for the larger than for the smaller targets. The analysis of variance also showed a significant two-way interaction 'object dimension by odour' [$F(2,20) = 3.65$, $P < 0.05$, $\eta_p^2 = 0.60$] (Fig. 1). When considering the small object, post-hoc contrasts showed that when the participant was exposed to the matching odour condition rather than no-odour condition, a significant reduction in MD was evident (1140 vs. 1185 ms, $P < 0.05$), indicating a facilitation effect. The comparison between the nonmatching and the no-odour condition was not significant (1188 vs. 1185 ms, $P > 0.05$). When considering the large object, the results seem to suggest a difference between the exposure to an odour – independent of the congruence of the odour – and the no-odour condition. In other words, the exposure to an odour either matching or nonmatching object dimension increases MD with respect to the no-odour condition, even though this increment is not significant (1135 vs. 1108 ms, $P > 0.05$;

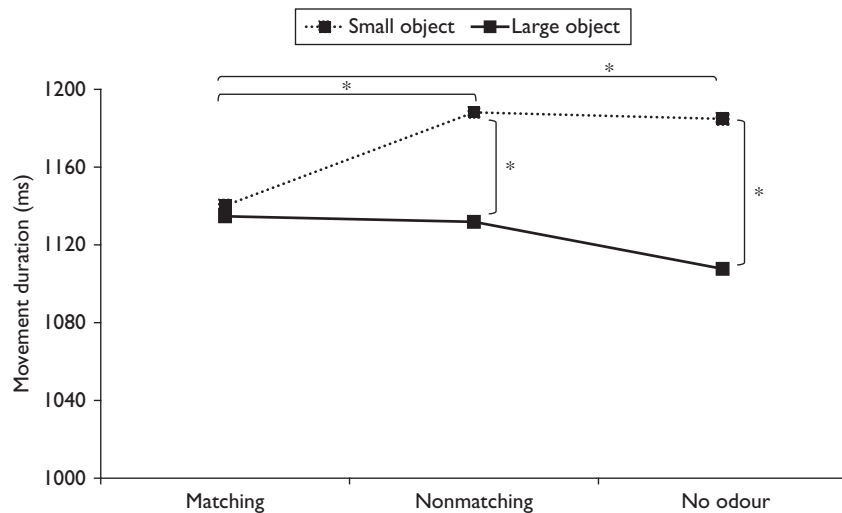
1132 vs. 1108 ms, $P > 0.05$, respectively; Fig. 2). No other significant main effect [odour, $F(2,20) = 0.35$, $P > 0.05$, $\eta_p^2 = 0.10$], two-way interactions [observed action by object dimension, $F(1,10) = 3.15$, $P > 0.05$, $\eta_p^2 = 0.36$; observed action by odour, $F(2,20) = 0.16$, $P > 0.05$, $\eta_p^2 = 0.07$] or three-way interaction [observed action by object dimension by odour, $F(2,20) = 1.98$, $P > 0.05$, $\eta_p^2 = 0.36$] were found.

Discussion

The aim of the present study was to explore the contribution of an olfactory stimulus to visually induced automatic imitation, contributing to the definition of action representations in a multimodal context.

The present findings confirm that action observation facilitates the subsequent performance of a similar movement, consolidating the idea of a direct matching between the observation of an external action and an equivalent internal motor representation in the observer [14,15]. Here, the odour manipulation proved not to be effective in modulating the appearance of automatic imitation. This finding is in line with previous evidence reporting that

Fig. 2



Representation of the 'odour by object dimension' interaction. The lines represent the means of movement duration. Dotted lines indicate small objects and solid lines indicate large objects. Vertical brackets indicate the comparison between small and large objects. Horizontal brackets indicate the comparisons across conditions with respect to the small objects. * $P < 0.05$, significant comparisons.

individuals are unaffected by the exposure to different body odours in a similar automatic imitation task [16].

The present results extend this literature, suggesting that congruent odour cues facilitate action planning and execution. To elaborate, MD of a reach-to-grasp action towards a small target under the exposure of a matching odour was faster than when the same action was performed in the nonmatching or no-odour conditions and it lasted as long as for the large target. The latter result is particularly interesting considering that MD is shorter for large targets – requiring a power grip – and longer for small objects requiring a precision grip. We suspect that this effect might be dependent on the different level of complexity underlying the planning and execution of precision and power grips. In fact, shaping the hand in a precision grip is a more demanding action than clamping the thumb against the palm in a power grip, making small targets more challenging to be grasped [17–19].

The complexity of the action is also critically influenced by the temporal integration between the visual and the olfactory stimulus. The participant smelled an odour and subsequently observed (or not) an action. During that time (~3 s), she was observing the working space and vision was collecting information on the object to act upon. Assuming that exposure to the odour activated an olfactory-driven motor plan [9,11], the time between the creation of the motor plan and the actual execution of the reach-to-grasp movement might have covered the olfactory-induced motor programming. In fact, olfactory-driven motor facilitation is found only when the participant was asked to grasp a small object, an action that requires a longer planning and execution time,

because of its intrinsic complexity [9,11,17–19]. This hypothesis is in line with the idea that the temporal coupling of inputs from different senses plays an important role in multisensory integration [20–22] and that when observers are confronted with bimodal discordant inputs (usually, auditory and visual), those inputs are often fused into a congruent multisensory percept in an appropriate temporal window [21]. However, to the best of our knowledge, no experiment has considered the temporal dimension of visuo-olfactory combinations of stimuli.

The present findings might also be explained in terms of embodied cognition [23]. Embodiment processes, namely the ways through which our body is involved in representing the external world, are extensive [24]. The body – the instrument we use to act on the world – is constantly influenced by the perceptual information that the senses provide, indicating a mutual influence [24]. The automatic conversion from visual stimuli to actions is an example of that intimate but composite link. In fact, the observation of visual stimuli directly matching the action (e.g. longer movement time required to grasp an apple) elicits spontaneous imitation. However, the action system can be activated even when the (visual) stimulus has no obvious action properties [23], such as in the case of odours. Attention plays an important role in the appearance of this effect. Selecting different stimuli or properties to attend can determine either the enhancement or the suppression of particular features that afford action. With respect to odours, they are recognized as stimuli representing the outside world and they have been proven to convert sensory stimuli into action states [9–11]. As other properties not relevant for action performance – such as colour [23] or

contextual information [25], odours might modulate the appearance of automatic imitation effects in accordance with action-affording stimulus features being in the focus of attention [23]. In other words, attention to the odour might suppress, in this specific case, the processing of action-relevant information (visual information) and harm the appearance of an automatic imitation effect beyond the temporal modulation observed above.

Conclusion

To sum up, this work confirms the presence of a direct match between action observation and execution, and suggests that odours might impact action planning and execution in an automatic imitation task. Furthermore, the effects of the odour on motor behaviour reported here point to the importance of considering temporal as well as attentional aspects that are critical for the visuo-olfactory integration resulting in embodied cognition states.

Acknowledgements

V.P. designed the experiment, analysed the data and wrote the manuscript; D.Z. collected the data; and U.C. designed the experiment and wrote the manuscript.

Conflicts of interest

There are no conflicts of interest.

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