



Squeezing lemons in the bathroom: Contextual information modulates action recognition

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ABSTRACT

Most every day actions take place in domestic rooms that are specific for certain classes of actions. Contextual information derived from domestic settings may therefore influence the efficiency of action recognition. The present studies investigated whether action recognition is modulated by compatibility of the context an action is embedded in. To this end, subjects watched video clips of actions performed in compatible, incompatible, and neutral contexts. Recognition was significantly slower when actions took place in an incompatible as compared to a compatible or a neutral context (Experiment 1). Functional MRI revealed increased activation for incompatible context in Brodmann Areas (BA) 44, 45, and 47 of the left ventrolateral prefrontal cortex (vlPFC; Experiment 2). Results suggest that contextual information – even when task-irrelevant – informs a high processing level of action analysis. In particular, the functional profiles assigned to these prefrontal regions suggest that contextual information activates associated action representations as a function of (in-)compatibility. Thus, incompatibility effects may reflect the attempt to resolve the conflict between action and context by embedding the presented action step into an overarching action that is again compatible with the provided context.

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Introduction

Our daily activities take place in highly specialized places and rooms that are optimized for specific actions: In kitchens we prepare food, in bathrooms we engage in body care, but usually not vice versa. Since domestic settings are reminiscent of certain classes of actions, one may expect them to modulate the recognition of observed actions as well. Compatible contextual settings should constrain expectation in a facilitatory way, whereas incompatible ones should mislead expectation and thus cause interference. Its high relevance in real life notwithstanding, the influence of contextual information derived from domestic settings on action recognition has not been explored yet.

Action recognition has been defined as matching percepts of an action onto corresponding action stored in semantic memory (Jeannerod, 2006). According to Hamilton and Grafton (2007) actions can be described at three broad, hierarchically organized levels: the *muscle* level describes the pattern of muscle activity required for action execution, the *kinematic* level describes the characteristic movements of involved effectors in space and time, and the *goal* level describes the overarching desired outcome of the action. Contextual information may affect the perception–memory matching level of action recognition by activating

contextually related action memories and thereby modulating the matching process via spreading activation in the semantic network (Neely, 1977). In a similar vein, contextual information may affect higher levels of action analysis, e.g. inference of (long-term) goals and prediction of subsequent motor acts.

In the present experiments, both behavioral as well as neuroimaging methods were employed to investigate whether contextual information provided by domestic settings affects action recognition, and if so, at which level of action analysis.

In a behavioral study (Experiment 1), it was tested whether compatibility of context and action affects the speed of action recognition. We then used fMRI (Experiment 2) to identify brain regions that are modulated by contextual compatibility, and therewith to elucidate which level of action analysis is affected by contextual compatibility. We expected early steps of action analysis to be reflected in the occipitotemporal cortex (Beauchamp et al., 2002; Hamilton and Grafton, 2007; Jastorff and Orban, 2009; Jastorff et al., 2009; Kable and Chatterjee, 2006) whereas inference of (long-term) goals and prediction of forthcoming motor acts to draw on prefrontal cortex as well as premotor–parietal loops (Iacoboni et al., 2005; Johnson-Frey et al., 2003; Kilner et al., 2007; Schubotz, 2007; Van Overwalle and Baetens, 2009; van Schie et al., 2006). Moreover, visual processing of rooms and places involves especially the parahippocampal place area (PPA; Epstein and Kanwisher, 1998). In monkeys, the parahippocampal cortex is connected to ventrolateral prefrontal, parietal and occipitotemporal cortices

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(Schmahmann and Pandya, 2006; Schmahmann et al., 2007), making these regions likely candidates for the interaction of contextual and action information.

In both experiments, subjects watched video clips of context-specific everyday actions performed in domestic settings that were either compatible or incompatible with the action. In addition, we employed a neutral condition where actions were performed in settings without any interior. According to our approach, a video clip was contextually “neutral” when it did not provide a clear bias as to which room it pertains, and therefore could not serve as a cue for contextual affiliation. Importantly, the neutral condition provided a baseline for evaluating facilitatory effects of the compatible and interference effects of the incompatible condition: Compatible but neither incompatible nor neutral contexts should bias action-relevant information and thereby facilitate action recognition. Similarly, incompatible but neither compatible nor neutral contexts should activate action-irrelevant information that interferes with the observed action.

In the behavioral study (Experiment 1), subjects were instructed to observe the action videos and to interrupt them by button press as soon as they recognized the presented action. We expected differences in the speed of recognition between the incompatible, the compatible, and the neutral condition: Facilitatory effects would manifest in faster responses to the compatible condition as compared to the incompatible and neutral conditions because contextual associations of the domestic setting should *pre-activate the representation of the observed action* (Bar, 2007). In contrast, interference effects would manifest in delayed responses for the incompatible condition as compared to the compatible and to the neutral condition. In this case, action recognition is hampered by pre-activation of incompatible action information that conflicts with the observed action.

In the fMRI Experiment, we tested whether, and if so, on which level, contextual information affects the neural signatures of action perception. As elaborated above, contextual modulation of the low/perceptual level was expected to be signified by occipitotemporal activation. Modulation of the high/goal inference level was expected to be signified by prefrontal and/or premotor activation.

To this end, a different group of subjects observed the same set of actions that were presented in the behavioral study. To ensure that subjects paid attention to the videos, they occasionally had to confirm or reject an action description with respect to the preceding trial.

Influences of contextual compatibility on action observation were assessed using conjunction analyses: facilitatory effects would be signified by decreases of neural activity in the conjunction (compatible vs. neutral) $\cap$ (compatible vs. incompatible), given that context-triggered pre-activation of the target action results in neural adaptation (Bedny et al., 2008; Gold et al., 2006; Henson, 2003). Similarly, interference effects would be signified by increases of neural activity in the conjunction (incompatible vs. neutral) $\cap$ (incompatible vs. compatible) due to *activation of irrelevant, potentially conflicting information* (Bedny et al., 2008; Cardillo et al., 2004). In order to determine the functional specificity of contextual (in-)compatibility for action perception, we furthermore analyzed whether putative activation sensitive to contextual compatibility overlapped with regions sensitive to action recognition. Regions involved in action perception were identified by contrasting actions in the neutral context with a resting baseline.

Moreover, incompatibility between context and action was expected to *trigger a perceptual re-analysis of the domestic settings in a top-down manner after incompatibility of context and action has been detected*. In that case, the BOLD response should increase in scene processing regions, especially the PPA. The PPA as well as other context-specific regions (i.e. retrosplenial cortex (RSC) and transverse occipital sulcus (TOS)) was identified using a separate functional localizer for places and scenes (Epstein and Kanwisher, 1998). We also included a functional localizer for body parts to identify the extrastriate body area (Downing et al., 2001), and for objects to identify the lateral occipital complex (Grill-Spector et al., 2001). This was done because both

functional regions are located in the occipitotemporal cortex, which was part of our anatomical hypotheses (see [Methods](#) and [Supplementary material](#) for details).

All of the employed actions involved objects that were themselves also either compatible or incompatible to the context. To dissociate action-context compatibility from object-context compatibility effects, we additionally employed pantomime actions as a control. Pantomime actions used action-incompatible objects that were either context-compatible or not. Accordingly, object-context incompatible vs. object-context compatible pantomime should reveal effects of object incompatibility, if present, as well. If, in contrast, (in-)compatibility effects would be observed only for actions, but not for pantomime, these effects could not be ascribed to object-context (in-)compatibility, but unambiguously to action-context (in-)compatibility.

Methods

Behavioral experiment

Subjects

Forty-nine healthy volunteers (19–28 years, mean 23.7 years, 31 females, 2 left-handed) participated in the study. Three subjects did not enter the analysis because of poor performance (error rates higher than 2 standard deviations). All participants had normal or corrected-to-normal vision. Participants gave written consent before the experiment. Data were handled anonymously.

Stimuli

Thirty context-specific actions (e.g. using a stapler, cracking an egg, sawing a plank) were filmed in compatible, incompatible, and neutral contexts. Actions were object manipulations specific for the contexts “office”, “kitchen” and “workshop” (see appendix). Each context was specified by the background, the working surface, and 3–5 context-specific stationary objects (e.g. computer screen, coffee machine, grinding machine). The neutral context was constructed by stretching a white sheet on a table forming a uniform surface without any corners. In each context, actions were filmed from an allocentric perspective (60° to the left of the actress) providing a convenient view on the object manipulation and the contextual setting ([Fig. 1](#)). Each video had a length of 3 s, a presentation rate of 25 frames per second and a display width and height of 720 × 576 pixels.

The actions started with grasping of the objects about 680 ms after video onset. Care was taken that the three action versions were performed in exactly the same manner for each of the three experimental conditions (see [Supplementary material](#) for examples in which the three action versions are displayed simultaneously).

To ensure (1) context-specificity and (2) context-incompatibility in the incompatible condition, a pilot study was performed where an independent group of subjects delivered a judgment on a Likert rating scale from 1 (very unlikely) to 6 (very likely), indicating how likely they found the presented actions for the particular contexts. All actions scored significantly higher for compatible than for incompatible contexts. The same Likert rating was employed in a post-experiment survey following the fMRI session (see [Results](#)).

Design and procedure

Subjects were seated approximately 60 cm away from a computer screen and next to the experimenter. Trials started self-paced by pressing a target button with the right index finger, followed by a short fixation phase (500 ms blank screen, 500 ms fixation cross at the center of the screen). Videos appeared at the center of the screen (subtending approximately 13.6 × 10.5° of visual angle). Subjects were instructed to press the target button as soon as they recognized the presented action. After button press, the video was replaced by a question mark at the center of the screen, and subjects had to name the recognized action. The verbal response was recorded using a built-in program of the

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