



Action perception predicts action performance



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ABSTRACT

Everyday action impairments often are observed in demented older adults, and they are common potential barriers to functional independence. We evaluated whether the ability to segment and efficiently encode activities is related to the ability to execute activities. Further, we evaluated whether brain regions important for segmentation also were important for action performance. Cognitively healthy older adults and those with very mild or mild dementia of the Alzheimer's type watched and segmented movies of everyday activities and then completed the Naturalistic Action Test. Structural MRI was used to measure volume in the dorsolateral prefrontal cortex (DLPFC), medial temporal lobes (MTL), posterior cortex, and anterior cingulate cortex (ACC). Dementia status and the ability to segment everyday activities strongly predicted naturalistic action performance, and MTL volume largely accounted for this relationship. In addition, the current results supported the Omission-Commission Model: Different cognitive and neurological mechanisms predicted different types of action error. Segmentation, dementia severity, and MTL volume predicted everyday omission errors, DLPFC volume predicted commission errors, and ACC volume predicted action additions. These findings suggest that event segmentation may be critical for effective action production, and that the segmentation and production of activities may recruit the same event representation system.

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1. Introduction

Alzheimer's disease (AD) is associated with impairments in memory and attention. These impairments are salient and have been well studied. AD also impairs one's ability to perform everyday tasks. These impairments are less well studied but perhaps equally important. Clinicians often collect reports of instrumental activities of daily living to assess an individual's ability to live independently. The patient or caregiver answers questions about complex activities related to preparing food, housekeeping, taking medications, and managing finances (Lawton & Brody, 1969). Individuals who are unable to perform these types of instrumental activities independently meet the criteria for AD. Although these qualitative reports are important for diagnosis, they cannot distinguish the cognitive mechanisms underlying the functional deficit (Schwartz, Segal, Veramonti, Ferraro, & Buxbaum, 2002). Further, their subjective nature calls into question their accuracy, particularly in the earliest stages of dementia (see Gold, 2012 for a review).

Direct measurements of everyday action performance are a valuable complement to subjective reports, and have provided further evidence for action impairments in AD. The *Naturalistic*

Action Test (NAT) was created to simulate the complex nature of real-world activities of daily living by requiring participants to complete naturalistic actions (Schwartz et al., 2002), and performance is correlated with subjective reports of daily living (Giovannetti, Libon, Buxbaum, & Schwartz, 2002; Schwartz et al., 2002). Naturalistic actions are everyday tasks that often require using objects to complete a series of steps in order to achieve a goal. One advantage of the NAT is that it explicitly assays different types of error. Error types include omitting parts of an activity (omissions), completing parts of an activity incorrectly (commissions), and performing task-irrelevant activities (action additions). Importantly, this taxonomy of error types provides a more specific method of assessing everyday action deficits that are consistent with different neurological conditions such as traumatic brain injuries (Schwartz et al., 1998), strokes (Buxbaum, Schwartz, & Montgomery, 1998; Schwartz et al., 1999), and AD (Giovannetti et al., 2002).

In particular, older adults with varying degrees of AD demonstrate different error patterns: cognitively healthy older adults and those with mild cognitive impairment produce a higher proportion of commission than omission errors, whereas participants with AD produce a similar proportion of omission and commission errors (Giovannetti et al., 2008). This dissociation in error patterns indicates that omissions and commissions are fundamentally different measures of action performance, separable by data reduction techniques. Further, these error types are largely

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associated with different cognitive mechanisms—omissions are related to memory and global cognitive functioning (i.e., MMSE scores), whereas commissions are related to measures of executive function and working memory (Giovannetti et al., 2008, 2012; Kessler, Giovannetti, & MacMullen, 2007).

Some researchers have speculated that omission errors are due to a semantic memory deficit (Bier & Macoir, 2010; Buxbaum et al., 1998; Ochipa, Rothi, & Heilman, 1992). That is, demented participants (or any other group that demonstrates high rates of omission errors) may have insufficient task knowledge, a poor representation of the objects needed to complete the task, or both (e.g., De Renzi & Lucchelli, 1988; Hartmann, Goldenberg, Daumüller, & Hermsdorfer, 2005). Commission errors, on the other hand, could be due to age-related declines in executive control and working memory capacity (e.g., Mahurin, DeBettignies, & Pirozzolo, 1991). In other words, cognitively healthy older adults should have the appropriate task knowledge and the ability to keep the goal in mind, but working memory limitations may lead to an individual performing the task inappropriately. Giovannetti, Schwartz, and Buxbaum (2007) further evaluated the role of working memory in commission errors by assessing errors for young adults who performed actions either under full attention or divided attention conditions. Young adults produced more commission errors under divided attention (i.e., when working memory was taxed) than under full attention conditions.

Successful performance of everyday tasks requires action planning and organization, which likely depends on general cognitive abilities including working memory efficiency and semantic knowledge. Effective planning also may depend on the ability to construct an effective representation of the parts and subparts of the activity being planned. We hypothesized that some of the same event representations processing mechanisms that are used in effective action planning also are used during action perception. For example, representations (or scripts) of learned actions may help us predict what other people will do and they may guide our own preparations to perform an action (e.g., Barbey, Krueger, & Grafman, 2009). Lesions in the frontal lobes often affect the organization of these action representations, and thus action planning abilities (e.g., Sirigu et al., 1995); however, these representations may also be affected by the neuropathology associated with Alzheimer's disease. Thus, we asked whether the ability to perceive event structure when observing goal-directed activity is related to the ability to organize and execute goal-directed activity. In other words, in people at risk of disorders of action performance, is action performance related to action perception?

1.1. Segmenting continuous activity

Individuals perceive a continuous stream of activity on a daily basis; however, this activity is not stored as a continuous reel but rather as discrete events. For instance, when thinking about what happened last weekend, an individual will recount the activity in separate events (e.g., went to the gym, went grocery shopping, did laundry, went out to dinner). According to Event Segmentation Theory (EST), this process of segmenting activity into events occurs spontaneously during perception (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). EST proposes that event boundaries result from updating working memory representations in response to errors in perception prediction. Information relevant to the current event is captured by an *event model*, which is a representation of the current activity that is held active in working memory. Event models are comprised of current perceptual input as well as relevant information from episodic and semantic memory. The maintenance and manipulation of this information may be supported by medial temporal structures (Bailey et al., *in press*) and by lateral prefrontal cortex (PFC; Grafman, 1995; Zacks et al., 2007). The contents of an event

model can influence how the perceptual information is processed in posterior regions including the inferior temporal cortex (IT), the human MT complex (MT+), and posterior superior temporal sulcus (pSTS; Zacks et al., 2007). Further, information in an event model aids in accurate predictions about what will happen in the near future. For example, when watching a man set a table for dinner, individuals use episodic memories of setting a table as well as semantic memory (e.g., scripts and schemas related to preparing for a meal) to help them make predictions about what the man will do next. As the man is in the middle of one part of the activity, such as arranging the dinner plates, information in the event model remains stable and the activity is predictable. Individuals likely predict that after the man places the plate in front of the first chair, he will do the same for the next chair; thus, the predictions are fairly accurate. EST proposes that the anterior cingulate cortex (ACC) is responsible for maintaining these predictions and also for assessing their accuracy by comparing them to what actually happens. This comparison process then produces an error signal, which accumulates as the activity becomes less predictable. For instance, after all of the plates are arranged, it is more difficult to predict what the man will do next. Will he arrange the silverware? Will he arrange the glasses? Will he walk into the kitchen? Prediction error increases because information relevant to arranging the dinner plates is no longer useful, thus the event model must be updated to match the current event. If he began placing the silverware, then information relevant to the proper arrangement of silverware should now be contained in the event model. It is at these points in an activity (i.e., when prediction error spikes and event models are updated) that an event boundary is perceived.

Importantly, event boundaries help people chunk activity into meaningful events, which has consequences for later retrieval. Individuals who are better able to identify these event boundaries are better able to remember the activity at a later point (Bailey et al., *in press*; Kurby & Zacks, 2011; Sargent et al., *in preparation*; Zacks, Speer, Vettel, & Jacoby, 2006). If the ability to organize and chunk activity during perception has an effect on how that activity is remembered, could that ability be related to how well one performs everyday tasks? And if perception and action are related, which neural mechanisms mediate this relationship? We evaluated whether the integrity of several brain regions thought to be involved in event segmentation also was related to NAT performance. Finally, we examined whether cognitive variables were related to different aspects of action performance. Specifically, we examined working memory, semantic memory, and script knowledge given their relationships with action representations in individuals with Alzheimer's disease (e.g., Allain et al., 2008; Giovannetti et al., 2008; Grafman et al., 1991).

1.2. Current study

To address these questions, we asked cognitively healthy older adults and those with mild or mild AD to watch and segment three movies of everyday activities into events. Then they completed the NAT, which involved performing activities that were different from those in the movie. The participants also underwent structural MRI scans. The two main goals of the current study were to evaluate (1) whether segmenting an activity during perception is related to performing an activity and, if so, (2) which brain regions mediate the action perception and action performance relationship.

2. Method

This study was conducted as a part of a larger investigation of event segmentation in healthy older adults and those with very mild or mild AD. For data regarding the neural correlates of event segmentation and everyday memory

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