Published in final edited form as:

Mil Psychol. 2009 January 1; 21(1): 113–122. doi:10.1080/08995600802554755.

Rules Versus Evidence in Memory and Non-Memory Decision-Making

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Abstract

Recent research using functional magnetic resonance imaging has revealed that memory retrieval often places considerable demands on prefrontal cortex (PFC), a region known to underpin complex decision-making. Regional dissociations within PFC suggest that memory retrieval recruits several decision processes shared with complex decision making in non-memory domains. Here we briefly review data highlighting the role of dorsolateral prefrontal cortex (dlPFC) during memory and non-memory judgments, which suggest that dlPFC is sensitive to decision complexity during memory retrieval. As decision complexity increases, decision makers may be more susceptible to stress and/or fatigue with consequent failures of memory judgment.

Under many current decision models, performance is governed by two independent factors (Macmillan & Creelman, 1991). The first factor is the resolution or quality of the evidence supporting the judgment. For example, when attempting to identify which of two individuals is known (a forced-choice judgment), performance will be superior during a clear daylight encounter compared to when the pair is viewed at night or under hazy conditions because the available evidence is superior under the former compared to the latter. The second factor contributing to performance is the complexity of the decision rule required by the situation. For example, if the above task is no longer to simply identify which of two individuals is known, but to instead determine if they differ in terms of acquaintance status (e.g., one known and one unknown) the complexity of the decision is now greatly increased. This latter judgment is known as a same-different decision and the increased complexity results because the same-different judgment requires separately and independently classifying each individual as either known or unknown, and then contrasting these judgments to reach a conclusion. Whereas there is only one opportunity to fail in the forced-choice case, there are at least two separate opportunities for erroneous judgments in the same-different cases. Critically however, the increased decision complexity during same-different compared to forced-choice judgment occurs without manipulating the quality of the stimuli, it is simply a matter of the need to render more judgments regarding the pair before reaching a conclusion.

Recently, Dobbins and Han (2006) suggested that this increased decision complexity might increase recruitment of dorsolateral prefrontal cortex (dlPFC), a region we hypothesized was linked to the number of executed judgments or conclusions rendered during a trial regardless of domain (e.g., memory or perceptual). This hypothesis potentially runs counter to other frameworks that instead suggest that dlPFC recruitment reflects post-retrieval monitoring operations specific to memory evaluation (Henson et al., 2000) or operations increasingly

necessary for selection among competing stimulus representations (Rowe & Passingham, 2001). Instead, the decision complexity framework predicts that increasing the number of intermediate judgments required during a decision task will increase the recruitment of dlPFC, and this function should be dissociable from the number of relevant stimuli and the domain of judgment (i.e., memory versus perception). To further examine the decision complexity account we conducted a functional magnetic resonance imaging (fMRI) study with two related experiments (Han, Huettel, & Dobbins; in press). The goal of the study was to demonstrate that dlPFC activation tracked the number of intermediate judgments executed during a trial, independent of the number of competing stimulus representations, or cognitive task domain (memory versus perception judgments).

Method

Participants

Twelve native English-speaking volunteers were included in Experiment 1 (age range 19-27 years). An independent sample of fifteen native English speakers (age range 19-28 years) was enrolled in Experiment 2. Informed consent was obtained in a manner approved by the Institutional Review Board of Duke University Medical Center. The participants were paid \$20 for each hour of participation.

Materials and Tasks

Experiment 1 examined memory judgments for words intermixed with perceptual gender judgments for face pictures, and focused on two decision rules; forced-choice and same-different judgments (Figure 1; left and center tasks). Aside from contrasting the two decision rules, Experiment 1 also systematically altered the number of relevant stimuli during the forced-choice (2 through 4) and same-different judgments (2 and 3). In contrast, Experiment 2 used all three decision rules illustrated in Figure 1 (forced-choice; same-different; independent-classification) but restricted decisions to gender judgments for faces, and held the number of stimuli to two for all tasks.

During *forced-choice* decisions subjects were presented with an array of probes containing one target and a number of lures, and required to select the target satisfying a single criterion, for example, selecting which of three faces was a female. Regardless of the number of lures present during forced-choice, only one of the presented items satisfies the decision criterion, with the judgment postponed until the relative evidence among competitors has been compared. Thus the decision complexity is assumed relative to fairly constant during forced-choice even if the number of lures should increase, since the subject only renders one judgment during the trial. During *same-different* judgments subjects are asked to determine whether each of the members of an array arises from the same or different categories. For example, if a pair of faces contained a male face and a female face, the correct response would be “yes” in response to the query “are these different genders?” (Figure 1; middle panel). Although same-different and forced-choice tasks can be fully matched in terms of the items and motor response requirements, same-different trials require additional judgments prior to response. More specifically, observers must judge each item, hold these judgments in mind, and finally compare these rendered judgments in order to reach the conclusion “same” or “different”. Finally, we also investigated *independent-classification* decisions (Reynolds, McDermott, & Braver, 2006). During these judgments, subjects are asked to overtly and separately classify each presented item in an array. For example, if a pair of faces contained a male and a female face, the observer should separately respond “no” to the left item and then “yes” to the right item in response to the query “is each female?” Here, as with same-different judgments, both items are separately judged, although the judgments are overt during independent-classification versus covert during same-different trials. Additionally, there is no requirement to hold intermediate judgments in mind

during the independent-classification task since the judgment of the first item need not be directly contrasted with the judgment of the second item. Although the independent-classification task can be matched to the forced-choice and same-different tasks in terms of the nature and number of probe stimuli, it necessarily involves more overt motor responses.

The logic underlying the use of these specific tasks is as follows. If stimulus selection demands drive dlPFC activity, then functional imaging should demonstrate an increase in activation as the number of task relevant stimuli increase, during either forced-choice or same-different judgments. In contrast, same-different judgments require more intermediate classifications of the stimuli than forced-choice since each item must be judged separately. If the number of judgments executed during the task is the key factor driving dlPFC activation then this region should show a greater response for same-different compared to forced-choice judgments. This is the prediction of the decision complexity model, namely, that it is the nature of the decision operations and not the number or quality of stimuli that determines dlPFC recruitment. Finally, independent-classification also requires that each stimulus be independently judged, however, the judgments are rendered overtly and separately for each item. Critically, the judgments themselves do not have to be compared or maintained during independent-classification whereas during same-different tasks subjects must maintain and eventually compare the judgments in order to reach the conclusion that they are either the same or different. If it is the intermediate stimulus judgments that cause dlPFC activation, and not the special maintenance or comparison requirements of the same-different task, then activations will look similar during same-different and independent-classification tasks.

fMRI Data Acquisition

In Experiment 1, scanning was performed on a 4T, General Electric (Waukesha, Wisconsin) scanner using a standard head coil and a spiral-in pulse sequence. In Experiment 2, we used a 3T General Electric scanner using a standard head coil and functional data were acquired using a standard EPI pulse sequence.

fMRI Data Analyses

Data were preprocessed using SPM99 (Wellcome Dept. of Neurology, UK; <http://www.fil.ion.ucl.ac.uk/spm/>) in accordance with procedures outlined in Dobbins and Han (2006).

Experiment 1 Results: Task Performance

One key manipulation in the design was to increase the number of items during forced-choice judgment. During verbal recognition, linear trend analyses across the levels of forced-choice decisions demonstrated both decreasing accuracy, $F(1,11) = 205.97$, $MSE = .004$, $p < .001$, and increasing reaction time, $F(1,11) = 24.03$, $MSE = 138120$, $p < .001$, as the number of lures increased (Table 1). During gender discrimination, forced-choice accuracy did not significantly decline with increasing numbers of lures, $F(1,11) = 1.14$, $MSE = .002$, $p > .30$, however, reaction time did significantly increase, $F(1,11) = 102.91$, $MSE = 27260$, $p < .001$. Overall, the data demonstrate that performance declined as the number of lures increased during forced-choice judgment. If dlPFC activity is tied to the quality of evidence supporting judgments or the number of items from which subjects select, then these behavioral declines should correlate with increased recruitment of dlPFC. Table 1 also lists correct response rates for same-different performance. It is clear that subjects generally found same-different judgments more demanding than forced-choice when the number of stimuli in the arrays was the same. This was anticipated given current decision models of these tasks (Macmillan & Creelman, 1991). Critically however, if the complexity of the decisions governs activation, then dlPFC activation should be sensitive to the rule (same-different versus forced-choice) but not to the number of stimuli present.

Experiment 1 Results: fMRI Data

Rule-based modulation in dlPFC—The initial analysis focused on contrasting same-different and forced-choice decisions when the number of alternatives matched during both memory and perceptual judgments.

The results revealed greater activation for the same-different compared to forced-choice rule in bilateral dlPFC regions (approximate Brodmann's area [BA] 46/8/9) and medial superior frontal (~BA 6/32) regions, as well as in superior parietal (~BA 7) and extrastriate areas (~BA 17/18/19). Example time courses reconstructed from the right dlPFC region confirm that the dlPFC regions were predominantly modulated by the decision rule and not by the nature of the task domain (verbal memory or gender discrimination; Figure 2). Furthermore, the time courses showed that the response appeared to be insensitive to the number of items present in the trial. For example, in the right region, trend analysis suggested no reliable relationship between the number of stimuli and the level of activation during forced-choice responding for either perceptual gender, $F(1,11) = .001, p > .97$, or verbal memory judgments, $F(1,11) = 1.29, p > .27$. Thus, even though adding stimuli during forced choice increased the number of stimuli that must be considered and reduced subject performance, dlPFC activation remained invariant. Instead, the complexity of the decision rule appears to govern the neural response.

Experiment 2 Results: Task Performance

As with Experiment 1, the behavioral data clearly show that same-different responding is more difficult than forced-choice when the number of stimuli are matched across the two.

Experiment 2 Results: fMRI Data

To identify potentially similar responses across the complex tasks (same-different, independent-classification) we looked for regions demonstrating greater activation during two-alternative same-different (2ASD) responding compared to two-alternative forced-choice (2AFC) and greater activation during two-alternative independent-classification (2AIC) compared to 2AFC, (Figure 3). This map implicated many of the regions implicated in Experiment 1, including left dlPFC (~BA 46/10), medial premotor (~BA 6/32) regions, as well as lateral premotor and posterior extrastriate areas (~BA 18/19). In both the anterior and more posterior cluster of the left dlPFC response, the extracted time courses demonstrated virtually identical responses for the 2ASD and 2AIC tasks despite the fact that the analysis procedure required no such similarity of response. Direct comparison of the activations confirmed that dlPFC responses were equivalent regardless of whether the subjects separately and overtly classified each stimulus (2AIC) or instead decided whether they judged them to be of the same or different genders (2ASD). In both cases the activation was significantly greater than a forced-choice judgment for the two stimuli. This left dlPFC region closely corresponds to the one observed in Experiment 1, although a comparable response was not seen in the right hemisphere unless the threshold for significance was greatly reduced.

Discussion

The current findings indicate that dlPFC activation was closely tied to the number of classifications required by the decision rule (viz., decision complexity), supporting the hypothesis that the activation reflects the execution of intermediate judgments during the course of a trial (Dobbins & Han, 2006). In contrast, dlPFC activation neither tracked the number of relevant stimulus representations present, nor the behavioral difficulty of the trials (Lau, Rogers, Ramnani, & Passingham, 2004). During Experiment 1 this region was insensitive to the increasing number of competing stimuli during forced-choice responding. Furthermore, the region responded in a domain-general fashion across verbal memory and perceptual gender discrimination tasks reflecting a common amodal decision mechanism (Duncan, 2001).

Experiment 2 further demonstrated equivalent dlPFC responses for a task requiring two overtly rendered classifications (independent-classification) and one requiring two covert classifications prior to the single overt response (same-different judgment). Consistent with Experiment 1, both tasks showed greater activity than judgments requiring only one classification action (forced-choice), further suggesting that the number of intermediate judgments per se, whether overt or covert, governed regional activation.

Although these novel findings implicate dlPFC as decisions become increasingly complex, their link to stress and fatigue are necessarily speculative. It is perhaps relevant that dlPFC activity has also been linked to individual differences in problem solving ability (Unterrainer et al., 2004) and subjects with higher scores on tests that purportedly measure general intellectual ability also tend to exhibit greater dlPFC activity during demanding cognitive judgments (Gray, Chabris, & Braver, 2003). Similarly, during factor analysis, tasks that load highly on the construct of generalized intelligence evoke more dlPFC activity than those that load lowly (Duncan et al., 2000). Under the decision complexity account these differences would be explained by the ability (or requirement) to render multiple, perhaps interdependent, judgments during complex decision-making tasks of the type that are often employed during intelligence testing. Under the decision complexity account it is the tendency to more exhaustively consider the relevant problem dimensions, and hence render multiple judgments prior to responding, that may separate high versus low ability groups and task types.

Returning to the question of potential stress and fatigue effects on cognitive performance, it seems altogether possible that increasing the decision complexity of judgments would serve to exacerbate any cognitive decline observed under fatigue. This prediction arises from considering the current findings, which strongly suggest that the increasing complexity of decisions directly taxes dlPFC regions, and also stems from prior work linking intellectual ability and perhaps cognitive flexibility to the recruitment of this same region. Expanding upon this basic idea, it may well be the case that the effects of increasing decision complexity, in combination with increasing fatigue, would combine interactively to reduce performance levels or flexibility as a function of general intellectual ability. An interesting corollary of this clearly speculative prediction is that provided decision complexity was kept at a minimum (e.g., forced-choice tasks), intellectual ability may have an extremely limited role in mediating the relationship between cognitive decline and fatigue. Importantly, fMRI methodology has begun to enable researchers to tackle just these types of predictions, by combining measures of intellectual ability, tasks of different theoretical decision complexity, and methods of fatigue inducement (see Schnyer et al. this volume).

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Figure 1.

Examples of decision rules for perceptual gender judgments. Experiment 1 also used the equivalent rules for memory judgments about words.

Figure 2.
Rule modulated activity in dlPFC: Experiment 1.

3D overlay showing the overlap of 2ASD>2AFC and 2AIC>2AFC

A. Anterior PFC (BA10)

B. Posterior PFC (BA46)

Figure 3.
dlPFC activity for Experiment 2.

Table 1
Response Proportions and Reaction Times Experiment 1

			Alternatives			
Domain	Rule	Measure	Two	Three	Four	
Memory	FC	% corr	0.87 (.08)	0.57 (.10)	.49 (.12)	
		RT	2390 (336)	2965 (473)	3133 (612)	
	SD	% corr	0.57 (.13)	0.57 (.12)	N/A	
Perception	FC	RT	3396 (302)	3401 (487)	N/A	
		% corr	0.86 (.12)	0.84 (.10)	0.85 (.08)	
	SD	RT	2071 (283)	2452 (383)	2754 (403)	
		% corr	0.64 (.15)	0.75 (.16)	N/A	
		RT	2916 (324)	3419 (488)	N/A	

Note. Values in parentheses indicate standard deviations; % corr = percent correct; FC = forced-choice; SD = same-different; RT = reaction times (ms).