

METACOGNITION AND FRONTAL LOBE FUNCTIONING

Leslie Burton

Abstract

Objective: The frontal lobes have been reported to play an important role in metacognition. The present study evaluated metacognition in a group of neurological patients.

Method: Twenty-one neurological (traumatic brain injury and cerebral vascular accident) patients were administered a metacognitive test and neuropsychological tests including a well-known index of frontal lobe functioning, the Wisconsin Card Sorting Test (WCST). After each trial, the participants were asked to evaluate their own performance on a face recognition test by rating their confidence about their accuracy on a scale of 1 (not very confident) to 3 (very confident).

Results: A point biserial correlation between accuracy on each trial and confidence was calculated for each participant as a measure of metacognition, Mcog. Mcog was significantly associated with the index of executive/frontal lobe functioning, WCST number of categories. Mcog was not associated with Full Scale IQ, General Memory Quotient, or Benton Facial Recognition Test score (short form, which did not include the experimental trials).

Conclusions: These data add support to the idea that the frontal lobes have a special role in metacognition.

Key words: metacognition, frontal lobes, Wisconsin Card Sorting Test, traumatic brain injury, executive functions

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Introduction

Metacognition, or “knowing about knowing,” has received an increasing amount of attention in the last two decades. Recent volumes by Beran, Brandl, Perner and Proust (2012) and Fleming and Frith (2014) are notable compilations of works by researchers addressing metacognition. Fleming and Dolan (2014) review the history of the study of metacognition and note that this was a topic of study as early as 1885 (Peirce and Jastrow, 1885), and was heralded as a new area of inquiry by Flavell in 1979. With that said, it has only recently received significant attention.

Early work on metacognition evaluated “knowing about knowing” in terms of memory performance, or metamemory. A study by Shimamura and Squire (1986) found that “feeling of knowing” judgments about memory performance were impaired in Korsakoff’s patients but not in amnesic or healthy control patients. In this study participants were asked to evaluate how likely they would be to recognize the answers to questions or sentences they could not freely recall. Korsakoff’s disease typically involves decreased volume in the frontal lobes as well as poorer performance on tests (e.g., Wisconsin Card Sorting Test) evaluating functions of the prefrontal cortex (e.g., Janowsky, Shimamura, Kritchewsky and Squire, 1989).

Many other studies on metacognition have indicated

an important role of the frontal lobes (e.g., Dehaene, Kerszberg and Changeux, 1998; Shimamura, 2000). After traumatic brain injury (TBI), poor insight is often reported, especially in terms of self-evaluation of competency before versus after injury (e.g., Prigatano, Altman and O’Brien, 1990; Stuss, 1991). The frontal lobes are a frequent site of injury in TBI and deficits in self-evaluation are often attributed to this. In an fMRI study, Schmitz, Rowell, Kawahara and Johnson (2006) evaluated TBI patients and found more accurate self-evaluation to be related to increased activation in the prefrontal cortex.

In terms of methodology, metacognition has been measured in a variety of ways. One of the most common techniques is simply correlating accuracy with confidence about judgment, or comparing average confidence for correct versus incorrect trials. Another method involves applying signal detection techniques in which sensitivity can be separated from response bias (Maniscalco and Lau, 2012, 2014).

Fleming and Dolan (2014) suggest that metacognition in terms of prospective judgments of performance may rely on different brain structures than metacognition for retrospective judgments. Retrospective judgments would include paradigms in which the participant gives his confidence rating after making a forced choice on a given task. Prospective judgments would include paradigms in which participants are asked

about their future performance as in the Shimamura and Squire (1986) study discussed above. Fleming and Dolan (2014) provide data showing that retrospective judgments of performance rely on lateral prefrontal areas, whereas prospective judgments of performance may use more medial prefrontal areas.

A study by Fleming, Ryu, Golfinos and Blackmon (2014) evaluated performance accuracy and confidence ratings of accuracy on a memory task and a visual perceptual task in patients with lesions in the prefrontal cortex, patients with lesions in the temporal lobe, and healthy controls. Performance accuracy was similar in all three groups. The group with frontal lobe lesions had weaker metacognition (retrospective) in terms of accuracy of confidence ratings than the temporal lobe group and the control group for the visual perceptual task, but not the memory task.

Several studies have evaluated normative participants on retrospective metacognition. In an fMRI study, Lau and Passingham (2006) found that prefrontal activity correlated with confidence but not performance on a task requiring discrimination between a square and a diamond. McCurdy et al. (2013) found that volume of the frontal polar region was associated with confidence ratings on a visual task but that task performance was not.

In other normative samples, Rounis et al. (2010) reported that confidence rating accuracy decreased when transcranial magnetic stimulation was applied to the prefrontal cortex, although performance accuracy on a perceptual discrimination task was unchanged. Fleming, Weil, Nagy, Dolan and Rees (2010) found that the volume of gray matter in the prefrontal cortex was larger in subjects that had higher confidence sensitivity in terms of giving an accurate confidence rating after each trial of a visual discrimination task.

Many of the studies evaluating confidence ratings reviewed by Grimaldi, Lau and Basso (2015) suggest two separate systems for performance accuracy and confidence. One suggestion they make is that confidence information may be produced by the prefrontal cortex and then sent back to the systems responsible for performance of a given task. There are thus many issues that still need to be addressed in metacognition.

Present study

The goal of the present study was to evaluate the relationship between metacognition and frontal lobe *functioning* on a face recognition test, since face recognition is thought to primarily involve brain structures outside of the frontal lobes. Metacognition was evaluated by having each participant give a confidence rating regarding their accuracy on each item of a forced choice facial recognition test.

This study used frontal lobe *functioning* of participants as a variable (rather than classification of frontal abnormality by neurological tests). Conceptually, frontal lobe functioning was the variable of interest. Practically, neurological damage, especially in traumatic brain injury, is often diffuse rather than focal and neurological tests may not show some of the more subtle deficits. Further, most neurological samples (including this one) have more than one area of damage and it is hard to find a sample with injury limited to only the frontal lobes.

Executive/frontal lobe functioning was assessed with the Wisconsin Card Sorting Test (WCST; Heaton et al., 1993; Kongs et al., 2000). The WCST is viewed as the gold standard index of executive functions (see

Kopp, Lange, and Steinke, 2021; Rabin, Barr and Burton, 2005; Strauss, Sherman, and Spreen, 2006), and has shown strong association with dorsolateral frontal lobe functioning (e.g., Arnett et al., 1994; Milner, 1963; Stuss et al., 2000).

Alvarez and Emory (2006) review imaging studies that show that the dorsolateral prefrontal cortex is involved and activated during performance of the WCST. Several studies indicate that other brain areas are also activated during WCST performance, and Alvarez and Emory suggest that WCST performance activates a *distributed neural network* involving both frontal and non-frontal brain regions.

Several studies have not reported differences between groups with and without frontal lobe damage on the WCST (e.g., Anderson et al., 1991). With that said, there is good evidence that the WCST is a sensitive, although non-specific, measure of frontal lobe dysfunction (see Alvarez and Emory, 2006). These authors point out that there is not a one-to-one relationship between frontal lobe functioning and executive functioning, although there is overlap. Duffy and Campbell (2001) suggest that it would be better to view the frontal lobes as one aspect of an “executive system” which involves many structures. Alvarez and Emory conclude that “participation of the frontal lobes in virtually any ‘executive process’ is probably a necessary, but largely insufficient, requirement” (p. 34).

Method

Participants

Twenty-one (five female, sixteen male) neurological patients at a rehabilitation hospital were evaluated. Age ranged from 17 to 80 years, with a mean of 41.9 (SD of 19.2). Thirteen participants had traumatic brain injuries, nine from motor vehicle accidents, three from falls, and one from assault. Eight participants had cerebral vascular accidents, and in two of these cases, subsequent falls resulted in traumatic brain injury. This sample was thus very heterogeneous.

Neuropsychological testing data was available and is shown in **table 1**. These tests included the Wechsler Adult Intelligence Scale Revised (WAIS-R; Wechsler, 1981), the Wechsler Memory Scale Revised (WMS-R; Wechsler, 1987), the Benton Face Recognition Test (FRT; Benton and van Allen, 1968; Benton et al., 1994) and the Wisconsin Card Sorting Test 64 item test (WCST; Heaton et al., 1993; Kongs et al., 2000). All of these measures except the WCST have age corrected scores.

The group means of all of the cognitive scores were in the low average to average range. The mean WAIS-R Full-Scale IQ (FSIQ) and Verbal IQ (VIQ) were in the average range and the Performance IQ (PIQ) was in the low average range. The WMS-R General Memory Quotient (GMQ) was in the low average range, and the WCST number of categories was in the low average range. The mean FRT score calculated from the short form was in the normal range.

Administration of the tests was carried out in compliance with the ethical standards for research outlined in the Ethical Principles of Psychologists and Code of Conduct by the American Psychological Association.

Experimental Instruments

Wisconsin Card Sorting Test (WCST; Heaton et

Table 1. Means, standard deviations and ranges of variables

	Mean	SD	Range
Age	41.9	19.2	17-80
Full Scale IQ	91.0	12.1	72-121
Verbal IQ	96.0	11.5	79-115
Performance IQ	85.3	13.0	61-122
General Memory Quotient	83.8	21.2	53-112
FRT	43.9	5.1	34-52
WCST #categories	2.1	1.6	0-5
<i>Experimental variables</i>			
FRT-LF (#correct of 27)	17.6	2.2	14-23
Mean Confidence	2.05	.41	1.26-2.56
Mean Correct Confidence	2.14	.44	1.19-2.71
Mean Incorrect Confidence	1.87	.43	1.33-2.60
Mcog	.18	.21	-.29 to .56

al., 1993; Kongs et al., 2000). This task involves a variety of executive functions including abstracting, shifting strategy, and inhibiting impulsive responding. It involves sorting cards and abstracting categories with limited feedback.

In terms of administration, 4 cards are set in front of the participant. The cards have different visual categories. The participant is then given one card at a time, and must put the card below whichever of the 4 cards to which he thinks it corresponds. It is possible to match according to different categories. The examiner's response to the participant's choice is only to indicate whether he is correct or incorrect, and not tell him why. Once the participant makes a certain number of sorts according to a given category, the examiner only indicates correctness when the participant begins sorting according to one of the other categories. Thus, the participant's task is to abstract the rules, shift set, and sort accordingly.

The number of categories abstracted in 64 trials was the measure used as an index of frontal lobe functioning in the present study. A recent review of use of the Wisconsin Card Sort Test as a measure of executive function by Gomez-de-Regil (2020) indicated that the test was still most commonly administered by hand (vs computerized administration), and only a few of the possible scores were usually reported, most typically categories completed and perseverative errors. Gomez-de-Regil does not speculate as to why this is the case, but a likely interpretation is that these are very simple measures to score and have good face validity. The present study used the categories completed measure primarily for these reasons.

WCST performance is known to be associated with age (e.g., Axelrod and Henry, 1992) and this issue was addressed statistically.

Benton Face Recognition Test (FRT; Benton and van Allen, 1968; Benton et al., 1994). This is a forced choice task which involves viewing a target face and choosing the same person from a set of faces situated below which can vary in terms of lighting and orientation. The 27 item short form of this test was used to evaluate face recognition ability and was given immediately before the experimental long form trials described below. The FRT has been shown to be sensitive to right posterior damage (e.g., Dricker et al., 1978; Hamsher et al., 1979;

Mulder et al., 1995).

Experimental measure, Mcog. For each of the 9 long form trials of the Benton Face Recognition Test, the participant chose 3 of the 6 choice faces which were the same person as the target face above them, for a total of 27 items. After each choice, the participants were asked to rate their confidence regarding their accuracy on a scale of 1 (not very confident) to 3 (very confident).

A metacognition score (Mcog) was calculated for each participant, which was the point biserial correlation between accuracy (0,1) and confidence (1,2,3) on the 27 long form trials. The Mcog score was thus calculated from trials not used to calculate each subject's general facial recognition ability (calculated from short form FRT trials).

Results

To investigate the relationship between the metacognitive score Mcog and executive/frontal lobe functioning, a partial correlation between the WCST number of categories and the Mcog score was done, partialling out the effect of age, since WCST scores are known to vary with age, as discussed. In the present sample, there was indeed a correlation between age and WCST categories ($r = -.49$; $p = .012$). Mcog was significantly associated with this index of executive/frontal lobe functioning, WCST, as hypothesized.

Pearson correlations between Mcog and the other neuropsychological and experimental variables were done and are shown in **table 2**. There was a trend for Mcog to be associated with Performance IQ which is not surprising since they both involve visual perceptual skills.

Discussion

Metacognition for performance on a facial recognition task was correlated with an index of executive/frontal lobe functioning, as hypothesized. This is consistent with the literature reviewed earlier suggesting a critical role of the frontal lobes in metacognition.

It is of note that metacognition was not associated

Table 2. Correlations between Mcog and the neuropsychological variables

	r	p
Age	.04	ns
Full Scale IQ	.28	ns
Verbal IQ	.25	ns
Performance IQ	.31	.090
General Memory Quotient	.20	ns
FRT	.15	ns
WCST #categories	.35	.058
WCST #categories: partialling out Age	.43	.030

with overall intelligence or memory ability. This lends support to the idea suggested in other studies that metacognition is a distinct cognitive skill. The trend for an association of Mcog with Performance IQ most likely reflects the fact that they both involved assessments in the visual perceptual domain.

The present study involved facial recognition (versus facial emotion recognition). Most of the other visual perceptual studies on metacognition have involved geometric shapes, and it is thus of interest to see the pattern for socially relevant stimuli. Faces have an intrinsic emotional component due to their social/survival relevance. A simple facial recognition task should have a smaller emotional component than an actual facial emotion recognition task, but it is likely that they both activate emotion processing circuits which are more medially located in the brain. Metacognitive studies on value-based choices are discussed by Fleming and De Martino (2014). In their study, Fleming and De Martino (2014) evaluated metacognition when subjects had to choose between pairs of snack items and give a confidence rating, and found evidence that the ventromedial prefrontal cortex was involved in value comparison.

The present findings fit with the studies mentioned earlier on retrospective confidence ratings and accuracy as a measure of metacognition. The study by Fleming et al. (2014) found that the group with frontal lobe lesions had weaker metacognition (retrospective) in terms of accuracy of confidence ratings than the temporal lobe group and the control group for the visual perceptual task. Similarly, Lau and Passingham (2006) found that prefrontal activity on fMRI correlated with confidence but not performance on a visual discrimination task.

As discussed, McCurdy et al. (2013) found that volume of the frontal polar region was associated with confidence ratings on a visual task but that task performance was not, and Fleming et al. (2010) found that the volume of gray matter in the prefrontal cortex was larger in subjects that had higher confidence sensitivity in terms of giving an accurate confidence rating after each trial of a visual discrimination task. Rounis et al. (2010) found similar results in a normative study when transcranial magnetic stimulation was applied to the prefrontal cortex in terms of decreased confidence rating accuracy with unchanged performance on a visual discrimination task.

Limitations of the present study include the small sample size as well as the heterogeneity of the sample. In addition, detailed information on the lesions in the present sample was not available. Another limitation is

the lack of a control group.

It would be interesting to evaluate metacognition in a sample that was limited to patients with frontal lobe abnormality, within specific areas of the frontal lobes. Additionally, it would be interesting to do a similar study using functional neuroimaging. That would allow for precise specification of the neural circuits involved.

Why is metacognition of interest? “Thinking about thinking” is fundamental to our conscious experience. When we engage in “thinking about thinking” we are accessing our global workspace. We are observing the information we have pulled onto our desktop from our other processors and we are evaluating it. It is intuitively appealing that metacognition is associated with the frontal lobes, our most recently evolved brain structures.

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