Research report

Event-related brain potentials dissociate visual working memory processes under categorial and identical comparison conditions

Stefan Berti a,*, Hans-Georg Geissler a, Thomas Lachmann a, Axel Mecklinger b

a Institut für Allgemeine Psychologie, University of Leipzig, Seeburgstr. 14-20, D-04103 Leipzig, Germany
b Max-Planck-Institute of Cognitive Neuroscience, Leipzig, Germany

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Abstract

Event-related potentials (ERPs) have been successfully employed to examine the functional and neuronal characteristics of working memory processes. In the present study, we examined the ERP waveforms in a delayed matching task to examine the cognitive processes underlying category and identity comparison and the effects of stimulus complexity. Subjects had to decide whether two visual stimuli are physically identical (identical comparison condition, IC) or b identical, irrespective of their orientation (categorial comparison condition, CC). The stimuli were structured five-point patterns, which varied in complexity. For the ERPs elicited during the 1500 ms retention interval, the following pattern of results was obtained: Stimuli in the CC-condition elicited larger P300 components than in the IC-condition. In the IC-condition, the P300 was followed by a broadly distributed negative slow wave. Moreover, complex patterns elicited a posteriorily distributed negativity at 350 ms (N350), whereas the less complex patterns gave rise to a fronto-centrally distributed slow wave that started around 500 ms. These results suggest that S1 was more elaborately processed in the CC-condition, while the more complex figures were associated with an early classification process during the retention interval. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Vision; Event-related brain potential; Working memory process; Slow wave potential; Delayed matching task

1. Introduction

Performance in visual recognition tasks depends on two main factors, the 'representational format' in which object information can be accessed in memory, and the specificity of the 'task demand', which determines both the selection and the use of information during response execution. Performance differences in visual classification tasks have been traced back to distinct principles of storing sets of objects in long-term memory, giving rise to specific modes of processing such as visual–perceptual vs. conceptual classification [24]. Similarly, investigations of the impact of task-specific response mapping, have led to models of performance for particular task demands, for example same–different matching [23] [see Ref. [8] for an overview], item-recognition [32] [cf. Ref. [33] for an overview], or naming tasks [cf., e.g., Ref. [17], Part 1]. However, until recently, both format-related and demand-related determinants of processing have been studied more or less in isolation from one another, although it is quite obvious that in order to understand complex recognition on a more general level, both types of factors have to be considered as integral parts of a processing architecture involved in task completion.

In recent years, a series of studies on feature-based classification of visual objects have been conducted in order to focus on this aspect of joint operation of representational and task-related intentional constraints [e.g., Refs. [1,4,17]; cf. also Ref. [29]]. From these studies, a rationale termed memory-guided inference (MGI) was derived, which can be summarized in three basic tenets: (i) Sets of visual objects are stored in memory via rules of a 'grammar' for the representation of perceptual structure. (ii) In classification, these rules apply only within task-induced categories, while task constraints render explication of structural relations across these categories impossible. (iii) The process of recognition comprises a first stage of task-specific encoding, implying procedures of marking the relevant information in memory and a subsequent...
search guided by category representations and their marked constituents, which can often be approximated by linear search [cf. Refs. [15,17,20]].

While the MGI approach has been successfully applied in a variety of tasks to predict the complex dependencies of reaction time (RT) on the particular item set construction [4,14,17], more recently, the approach was expanded to transformational set structures [15,16,20,29]. Here, the term 'transformational set structures' indicates that the visual stimuli employed in the experiments consist of pattern subsets, which can be turned into each other by transformations such as reflections, rotation or even systematic changes of color (the so-called equivalence sets). For stimuli of this type, it has long been known that RTs in classification tasks tend to increase as a function of the number of competing patterns belonging to an equivalence set, the equivalence set size (ESS) [e.g., Refs. [5,13]]. ESS is reciprocally related to the degree of symmetry of the patterns in a given equivalence set and thus can be considered as a measure of pattern complexity. A major outcome of the more recent investigations of Geissler et al. is that this increase can be explained via task-specific search in explicit representations of equivalence sets in memory.

The main goal of the present study was to examine the subprocesses underlying visual classification of transformational set structures by means of a combined analysis of event-related potentials (ERPs) and performance measures. Consistent with recent studies [15,16,20], a set of five-point patterns as first used by Garner and Clement [10] was chosen as the stimulus material. As illustrated in Fig. 1, these patterns exhibit a strict transformational structure, and were constructed on a 3 × 3 imaginary grid leaving no row or column empty. A major advantage of these stimuli is that their set structure is sufficiently rich to allow for a wide variation of different procedural paths, and yet the formal structure of the entire set is completely known. According to accumulated evidence, a major candidate to be checked as a determinant of performance is ESS which in the given case is 1 for two patterns, 4 for eight, and 8 for seven prototype patterns.

To examine the specificity of visual classification processes with transformational set structures, we employed the delayed matching procedure used by Posner and Mitchell [24]. Posner and Mitchell designated a task as 'physical' if subjects had to respond 'same' when two presented stimuli were physically identical (for example two identical letters l), and 'different' otherwise. Alternatively, a task was referred to as 'categorical' when subjects were to respond with 'same' if the stimuli were identical only in their conceptual denotation (for example an l and an L), but were physically different. Analogously, in the following, we will refer to 'identity comparison' (IC) when subjects are instructed to respond 'same' if two dot patterns are equal in shape and spatial orientation, and to 'categorical comparison' (CC) if the instruction requires the response 'same' when the two patterns are identical in shape, irrespective to their spatial orientation.

In a CC-task, according to these definitions, Geissler and Lachmann [15] employing the five-dot patterns of Garner and Clement found evidence of explicit search in stimulus processing. Mean RTs in positive decisions turned out to be a nearly linear function of the common ESSs of the stimuli to be compared. Since this applies even to pairs of stimuli that are identical in shape as well as orientation, the effect cannot be due to transformations such as mental rotations or reflections as part of a simple template matching of stimuli. Rather, it points to a direct role of ESS as a consequence of processing of stimuli in the format of explicit set representations. More specifically, Geissler and Lachmann [15] account for their results by assuming a first stage of processing in which representations of the equivalence sets belonging to each of the patterns become evoked. During a second stage of processing, an ordered self-terminating search for the location of the specific patterns within the evoked set is proposed. This search is assumed to start from a randomly chosen element within one of the evoked set representations and proceeds serially through all evoked sets. In this context, the term 'ordered' designates that after a match has been found for one of the two presented patterns, the search continues within the same evoked set, starting with a recheck of the element for which a match occurred. Note that, as a consequence of the rule for search, patterns that are to be judged 'same' in the categorial task, as the equivalence sets of both patterns are identical, evoke only one set representation. This safeguards that in the case of full identity immediately a second match is found and, thus, search terminates, whereas when orientations differ a second search is to be accomplished.

![Fig. 1. Stimulus material used in this experiment (right panel). The stimuli consist of five dots on an imagery 3×3-grid with no column or row left free (left panel). Using rotation or reflection as transformational rules, the stimuli could be divided into sets with one of two equivalent set sizes (ESS). Stimuli which are elements of sets with four transformational related patterns (ESS-4; right panel, upper half) and stimuli which are elements of sets with eight patterns (ESS-8; right panel, lower half).](image-url)
A weakness of behavioral indicators in checking the above mentioned general and specific assumptions is that they do not permit monitoring task-related preparation within the delay period after presentation of the first stimulus (S1) and before presentation of the second, to-be-compared stimulus (S2). Thus, questions that may be crucial for the validity of the assumptions such as whether S1-related memory processes reflect already task specificity of representation and may point to preparation for search procedures, cannot be addressed within a purely behavioral framework. In the present study therefore, we employed ERP recordings to further examine these issues. ERPs are small voltage oscillations measured at the scalp that are time-locked to the processing of external events. Differences in amplitude and latency of ERP components can be used to make inferences about the timing and nature of stimulus processing under different experimental conditions [see Ref. [18]].

Employing delayed-matching-to-sample tasks, a number of ERP studies found long-duration ERP slow waves [i.e., Refs. [21,22,26]] that index aspects of retention processes. For example, it has been shown that the amplitude and topographic distribution of ERP slow waves are correlated with the type and amount of information retained in working memory [22,27]. Given these characteristics, ERP slow waves appear as a valuable tool for monitoring the type and amount of activated representations of transformational set structures under different classification requirements.

A second ERP component, the P300, a positive deflection with a minimum peak latency of 300 ms appears to be another promising tool to examine the subprocesses underlying the classification of transformational set structures. The P300 has been associated with stimulus evaluation processes and is positively correlated with the amount of information extracted from a particular stimulus [19]. Accordingly, we expect the P300 to be associated with ESS, i.e., the amount of transformation rules inherent in a particular pattern and/or the specific task requirements (IC; CC) of the classification process.

2. Methods and materials

2.1. Subjects

Ten right-handed students (five male) of the University of Leipzig with an average age of 24.2 years (range 21–28 years) participated in the experiment. All had normal or corrected-to-normal vision and were paid DM 12/h for their participation. None of them had any prior experience with the task or the material.

2.2. Material

In this experiment, we used 24 structured five-dot patterns as used by Garner and Clement [10]. All of the stimuli may be divided by transformation rules (rotation in 90° steps and mirroring) into three equivalent-class sets (ESSs) of set size 4 (ESS-4) and three ES of size 8 (ESS-8). The equivalence sets are represented in Fig. 1 by one row each. Due to the set-specific uniqueness of their transformation rules, these ES can be considered as visual categories.

We chose at random four patterns from a set of eight ESS-8 pattern sets with one restriction: To preserve the specific ESS-8 characteristics of the reduced sets in categorical sameness judgment, it was necessary to include both transformations, rotation and mirroring. Otherwise, half of the patterns belonging to equivalence sets of this size would not have been represented. For example, without mirroring the second pattern of the last row in Fig. 1 could not be transformed into the third pattern. No such restriction holds for any ESS-4 set. Consequently, we used four elements from each set. To match both ESS-conditions for each ESS we used three sets of patterns of varying complexity, rated low, middle or high. These complexity ratings were determined in a pilot rating experiment.

2.3. Procedure

Subjects performed two S1–S2-tasks under different conditions: an identical comparison (IC) task, where subjects had to decide, whether S1 and S2 were the same patterns, and a categorical comparison (CC) task, where subjects had to decide, whether S1 and S2 are the same in form independently of their orientation. In other words, the CC-task required subjects to decide whether S1 and S2 are elements of the same ES or not.

All trials had the same timing: S1 and S2 were presented for 150 ms in the middle of the screen, separated by a 1500 ms inter-stimulus interval (ISI). To control for post-iconic storage processes during the retention interval, a black square was presented, overlapping the stimuli, as a mask. After the onset of S2, subject had 2000 ms to give their response. The inter-trial interval was 1000 ms. All trials started with a 500 ms fixation-cross in the middle of the screen followed by 300 ms of blank screen before S1 was presented.

2.4. General procedure

Subjects were seated comfortably in a dimly lit room at a distance of 60 cm from the screen. They responded using a small extra key-pad (ERTS, BeriSoft Coop.) and were instructed to use the left key to give a ‘same’-response and the right key to give a ‘different’-response. The response button to response type assignment was counterbalanced across subjects. All subjects performed an IC-session and a CC-session. Half of the subjects started with the CC-session. Subjects were instructed to respond as quickly and as
accurately as possible, and to reduce eye-movements and blinks during the stimulus presentation when possible.

Before performing the tasks with EEG-recording, subjects started with a training block to familiarize themselves with the experimental procedure. Both training blocks — for IC and CC — contained 144 trials. Training and experimental trials had the same timing. To enhance performance subjects received auditory ‘on-line’ feedback concerning response accuracy. None of the training patterns were used during the subsequent experimental testing.

Each session included eight blocks with 72 trials each, half of the trials required a ‘same’- and half a ‘different’-response. During the experiment subjects got no feedback about their performance.

Stimuli were presented on a 17-in. VGA color monitor (75 Hz) controlled by a Pentium 133 MHz computer. All stimuli were presented in blue (RGB color: 0%, 0%, 100%) against a grey background (RGB color: 65%, 65%, 65%). The mask was presented in black (RGB color: 100%, 100%, 100%). All stimuli were presented 24 times as S1 and S2 for both conditions.

2.5. Recording procedure

The EEG was recorded from 19 electrodes of the 10–20-system referenced to the left mastoid using a NeuroScan amplifier. The electrodes were mounted in an elastic cap (Electrocap Int.). Electro-occulogram (EOG) were recorded from above and below the right eye (vertical EOG) and the outer canthus of each eye (horizontal EOG). Electrode impedance was kept below 5 kΩ. Both EEG and EOG were recorded continuously with a band-pass from DC to 30 Hz and a sampling rate of 250 Hz.

ERPs were computed for the S1-interval from S1-onset to S2-onset; 1650 ms for each condition CC and IC and 1000 ms with a peak at around 350 ms N350. This N350 is most pronounced over parietal and occipital electrode sites. There is a positivity at 400 ms after S1-onset. Based on its timing and scalp distribution, this positivity will be referred to as P300.

3. Results

3.1. Behavioral data

RTs and $P_s$-values for ‘same’-responses are presented in Table 1. Subjects needed more time to make their decision in the CC- than in the IC-condition and for ESS-8 compared to ESS-4 patterns. Additionally, the subjects performed the task fairly accurately ($P_s$-values between 0.81 and 0.95). Repeated-measure ANOVA for RT reveal a significant effect of factor ‘judgment-condition’ ($F_1, 9 = 6.92, p < 0.05$) and ‘ES-size’ ($F_1, 9 = 21.09, p < 0.01$), and a significant interaction between these two factors ($F_1, 9 = 61.71, p < 0.0001$). Post hoc tests show, that all mean RTs are significantly different from one another (all $p$-values < 0.05), except for the difference between CC-ESS-4 and IC-ESS-4 ($p > 0.06$).

3.2. ERP-data

Fig. 2 shows the across-subject average ERPs in the S1-interval for ES-size averaged across both judgment conditions. Both, ESS-4 and ESS-8 pattern, elicited a complex of early negativities and positivities with an occipital N100 and a frontal P200. There is a positivity at the midline electrodes with a parietal maximum that is of comparable magnitude for ESS-4 and ESS-8 stimuli 400 ms after S1-onset. Based on its timing and scalp distribution, this positivity will be referred to as P300.

ESS-8 patterns elicited a negativity starting at about 250 ms with a peak at around 350 ms (N350). This N350 is most pronounced over parietal and occipital electrode sites. ESS-4 patterns gave rise to an enhanced slow negativity at 500–800, 800–1200 and 1200–1600 ms. An omnibus repeated measured ANOVA was computed with factors ‘judgment-condition’ (two levels), ‘ES-size’ (two levels), ‘electrode’ (19 levels) and ‘time’ (four levels). In case of significant interactions involving the factors ‘judgment-condition’ and ‘ES-size’, subsequent ANOVAs were performed to follow these interactions. For all effects with two or more degrees of freedom in the numerator, the Greenhouse–Geisser correction was applied [12].

<table>
<thead>
<tr>
<th>N</th>
<th>RT (ms)</th>
<th>$P_s$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC-condition</td>
<td>498 (78)</td>
<td>537 (94)</td>
</tr>
<tr>
<td>CC-condition</td>
<td>548 (164)</td>
<td>676 (202)</td>
</tr>
</tbody>
</table>

Table 1 Behavioral data of the experiment: mean (and standard deviation) of reaction time (RT) and $P_s$-value for the correct same-responses separated by instruction and ES-size.
Fig. 2. Grand average ERPs (N = 10) separated for the two ESS. ESS-8 patterns (dotted lines) elicited a negativity with a peak around 350 ms (N350; see PZ), whereas ESS-4 patterns (solid lines) elicited an enhanced slow negativity from 500 to 1200 ms (for example, at FZ and CZ).

Frontal and central sites relative to ESS-8 patterns. This difference starts at about 500 ms and lasts up to 1200 ms.

Fig. 3. Grand average ERPs (N = 10) separated for the two comparison conditions. Stimuli presented under CC-condition (solid lines) elicited a larger P300 than under IC-condition (dotted lines) (see CZ), whereas stimuli presented under IC-condition elicited an enhanced slow negativity starting around 400 ms (for example, see FZ, CZ and O2).
tions S1 elicited a P1–N1–P2 complex at occipital, and a P2–N2 complex at frontal sites. At around 400 ms both conditions elicit a P300 component with similar latency.

In the CC-condition, S1 elicited a larger P300 than in the IC-condition. Additionally, starting around 400 ms, there is a broadly distributed enhanced slow negativity for patterns presented in the IC-condition. This negativity is largest at occipital sites and extends to most recording sites during the recording interval. Additionally, in the same time interval, there is a negative slow-wave in the IC-condition at right frontal recording sites. These observations were confirmed by a series of statistical analyses.

The omnibus ANOVA with factors ‘judgment-condition’, ‘ES-size’, ‘electrode’, and ‘time’ showed a significant effect for factor ‘time’ ($F_{3, 23} = 41.19$, $p < 0.01$), and significant interactions between ‘ES-size’ and ‘electrode’ ($F_{18, 162} = 4.23$, $p < 0.01$), ‘ES-size’ and ‘time’ ($F_{3, 27} = 7.52$, $p < 0.01$), ‘judgment-condition’ and ‘electrode’ ($F_{18, 162} = 3.13$, $p < 0.01$), ‘time’ and ‘electrode’ ($F_{54, 486} = 8.78$, $p < 0.01$), ‘ES-size’, ‘judgment-condition’ and ‘time’ ($F_{3, 27} = 4.22$, $p < 0.05$), and ‘ES-size’, ‘electrode’ and ‘time’ ($F_{54, 486} = 3.55$, $p < 0.01$). To decompose the interactions that involved the ‘time’ factor separate ANOVAs were performed for each of the time windows, the results of which are summarized in Table 2.

The major result is that there are no interactions between ‘ES-size’ and ‘judgment-condition’ in any time interval, but interactions between each of these two factors with ‘electrode’. Therefore, subsequent analysis were performed to test the significance of the ERP results separately for the ‘judgment-condition’ factor and the ‘ES-size’ factor.

The larger P300 obtained in the CC- compared to the IC-condition was confirmed by a significant ‘judgment-condition’×‘electrode’ interaction in the 300 to 500 ms interval. Post hoc tests reveal larger P3-amplitude in the CC- than IC-condition at CZ ($F_{1, 9} = 11.22$, $p < 0.01$). The slow-wave effects were confirmed by significant ‘judgment-condition’×‘electrode’ interactions in the following time-windows. There was more negativity in the IC-condition in the 500 to 800 ms and 800 to 1200 ms interval at central, parietal and occipital recording sites (500–800 ms: C3: $F_{1, 9} = 5.56$; CZ: $F_{1, 9} = 8.30$; C4: $F_{1, 9} = 6.33$; P3: $F_{1, 9} = 8.06$; O1: $F_{1, 9} = 5.13$; O2: $F_{1, 9} = 8.74$; 800–1200 ms: CZ: $F_{1, 9} = 12.15$; P3: $F_{1, 9} = 10.44$; O1: $F_{1, 9} = 5.12$; all $p$-values < 0.05) and at right frontal sites until the end of the retention interval (F8: 500–800 ms: $F_{1, 9} = 14.19$; 800–1200 ms: $F_{1, 9} = 14.83$; 1200–1600 ms: $F_{1, 9} = 9.85$; all $p$-values < 0.05).

The effect of ES-size was reflected by an enhanced N350 for ESS-8 patterns compared to ESS-4 patterns. This was confirmed by a significant ‘ES-size’×‘electrode’ interaction in the 300 to 500 ms interval ($F_{18, 162} = 11.16$, $p < 0.01$). Post hoc tests showed an enhanced N350 for ESS-8 patterns at parieto-occipito recording sites (P7: $F_{1, 9} = 6.41$; P3: $F_{1, 9} = 7.84$; PZ: $F_{1, 9} = 8.26$; P4: $F_{1, 9} = 23.74$; P8: $F_{1, 9} = 28.99$; O1: $F_{1, 9} = 21.11$; O2: $F_{1, 9} = 16.73$; all $p$-values < 0.05). The effect of ES-size on slow wave component was confirmed by the significant ‘ES-size’×‘electrode’ interaction in the following time windows. Post hoc tests confirm an enhanced slow wave for ESS-4 patterns during the whole retention interval at frontal sites (F7: 300–500 ms: $F_{1, 9} = 5.69$; 500–800 ms: $F_{1, 9} = 6.91$; 600–1200 ms: $F_{1, 9} = 5.74$; F8: 800–1200 ms: $F_{1, 9} = 5.98$; 1200–1600 ms: $F_{1, 9} = 7.60$; all $p$-values < 0.05) and in the 500 to 800 ms interval at central sites (C3: $F_{1, 9} = 9.72$; CZ: $F_{1, 9} = 18.55$; C4: $F_{1, 9} = 16.87$; all $p$-values < 0.05).

In summary, the ERPs show remarkable and statistically significant differences for both, the judgment-condition and ESS: Firstly, ESS-8 patterns elicited a larger parieto-occipital N350 component, whereas ESS-4 patterns elicited a fronto-central slow negativity from about 500 to 1200 ms at central sites until the end of the S1-interval at right-frontal recording sites. Second, in the IC-condition, patterns elicited a more enhanced P300 in comparison to the CC-condition, whereas patterns under IC-condition elicited a more enhanced slow negativity that was largest at occipital sites but extended to central and frontal sites.

4. Discussion

Subjects performed a visual S1–S2-classification-task under two different conditions: a physical comparison (IC)
task where the two stimuli should be classified as ‘same’ when they are identical, and a CC-task where stimuli should be classified as ‘same’ when they were identical according to predefined spatial transformation rules. Twenty-four five-dot patterns were used as stimulus materials which could be split into six different sets of stimuli with four related categories, respectively (i.e., equivalent sets, ES). Moreover, the ES differed with respect to their size. In this study, we used ES with two different sizes (ESS): ESS-4 with four possible elements, and ESS-8 with eight possible elements. According to Garner and Clement [10] patterns that are elements of an ES with the size 8 are more complex than ESS-4 patterns. Therefore, we investigated the effect of judgment-condition and ESS on the RT and ERPs of the retention-interval.

The main result was that both, judgment-condition and complexity (as reflected by ES-size), had an effect on RTs as well as on the slow wave potential and other ERP-components. RTs were prolonged for the CC-task and for the more complex stimuli of ESS-8. For the ERP recorded in the retention interval, the following pattern of results was obtained: Stimuli in the CC-condition elicited larger P300 components at around 400 ms than in the IC-condition irrespective to set size. In the IC-condition the P300 was followed by a broadly distributed but parieto-occipitally accentuated negative slow wave that extended until the end of the S1 interval. Similar to the P300 effect, this latter effect was unaffected by the ES-size factor. Moreover patterns of ESS-8 elicited a posteriorly distributed negativity at 350 ms (N350) that was of comparable magnitude in both judgement conditions. These results shed some light on the processes preceding identity- and category-based decisions.

The RT-results are consistent with the findings of Geissler and Lachmann [15,16]. They also support the memory-guided inference (MGI) approach, that assumes that in CC-conditions the complete set is activated and decisions are made after locating the pattern in the activated set using a serial strategy. An alternative interpretation of the RT-results may be, that at a later stage of information processing between encoding S2 and response preparation there is some additional processing of the visual information for category-based decisions. As Shepard and Metzler [30] showed, decision times in matching tasks depend upon the degree of rotation between the to-be-compared stimuli. This well known phenomenon was called ‘mental rotation’ and it is conceivable that mental rotation was used in the CC-condition. Geissler and Lachmann [15,16], however, showed, that this explanation is rather unlikely on the basis of RT-results, which revealed that RTs are also slower for physical identical stimuli under CC-condition. These results are more consistent with the task dependent memory code of the stimuli as basis to a subsequent decision process. In addition to this, the reported ERP-results support the task-dependent encoding hypothesis.

In S1–S2-tasks, negative slow-waves are typical for the S1-interval. They may be correlated with preparation processes in easier tasks or with working memory processes such as retention, in more complex tasks [11,21,22,26]. In the present study, the timing and topography of the slow waves in the IC-condition gave evidence for the activation of a visual buffer [cf. Refs. [21,22]]. Its onset was immediately following elicitation of the P300 and it showed largest amplitudes at parietal and occipital electrodes. Based on this finding, it can be assumed that sensory input is directly transferred to a visual retention buffer housed by posterior cortical areas and maintained in this buffer until the end of the retention interval. The view that literal stimulus characteristics were processed and maintained in working memory in the IC- but not in the CC-condition receives indirect support from the P300 results in both judgement conditions; specifically, larger P300 amplitudes were found for the CC-condition. As assumed by Johnson [19], the P300-amplitude is influenced by the combination of three factors: (i) subjective probability of the event; (ii) the meaning of the stimulus; and (iii) the amount of information that could be extracted from the stimulus. In this study, neither the probability nor the meaning of the stimuli were varied. So the enhanced P300 amplitude evoked by S1 in the CC-condition support the view that S1 was more elaborately processed (i.e., more information was extracted for the S1 stimulus) in the demanding judgement condition. In other words, task demands affect the encoding and initial storage of visual inputs and this different processing is reflected in the different P300 and slow wave results.

ESS-8 stimuli in both judgment conditions evoked a larger posteriorly distributed negative component at around 350 ms. This component is presumably related to stimulus complexity at an early processing stage and the question is, whether this N350 should be interpreted as a delayed N200 or an early N400 component. The present results support a N200 interpretation. Ritter et al. [25] showed, that this component is affected by the difficulty of the stimulus classification, with increasing classification difficulty leading to larger N200 components. Given this finding, the classification of ESS-8 stimuli might have been more difficult in comparison to the ESS-4 stimuli, independent of the task condition and the larger N350 presumably reflects the more difficult classification of the ESS-8 stimuli. 1

Moreover, we found slow wave effects at frontal and central sites. In another study on visuo-spatial working memory processes, negative slow waves were obtained

1 It could be argued that some of the ESS-4 patterns resemble highly symmetric and familiar figures which therefore might be processed faster than ESS-8 patterns. While this is difficult to assess in detail, the closely linear dependence of RT on ESS found in our data as well as in those of Schmidt and Ackermann [29] and Geissler and Lachmann [15,16] exclude that such effects may have a substantial effect on the average trend.
within a delay interval, which were most pronounced at frontal recording sites [11]. Based upon the topography of the negative slow wave, the results presented here also suggest the involvement of frontal lobe activity during working memory. By comparison, the neuronal response in monkeys performing delayed matching tasks suggests that working memory processes are realized by a cortical network consisting of prefrontal and inferotemporal areas [9,34]. This findings in non-human primates were confirmed by a study in humans using functional magnetic resonance imaging (fMRI) [3]. In this study, activation of prefrontal and posterior parietal cortical areas could be observed during a working memory task. Accordingly, working memory as a system consisting of both, buffer and control processes [2] has been conceived of in terms of a cortically implemented network of distributed cortical systems [9]. On this basis, it is conceivable that the frontal activity in the present study reflects more general control or motor preparation processes while the parieto-occipital slow waves might reflect storage related activity [3,21,22,26,27]. The view that the fronto-central slow wave pattern in the easy to perform ESS-4 condition might be related to preparatory processes is supported by recent findings of Geffen et al. [11]. The authors used a delayed response task that imposes higher demands as motor memory and preparation and found largest negative slow wave differences between memory and preparation trials at anterior recording sites.

This view is not only compatible with our view of working memory as a system with both, buffer and control system [see Refs. [2,6]], but also with our more general view of the coordination of perception and action, and thus consistent with our description of the task dependent memory representation characterizing MGI [4,15,16]. As predicted by MGI, our findings show that encoding S1 depends on task conditions. The RT-results may be interpreted by the guided inference hypothesis as well, which assumes a task dependent perception and encoding. In addition, the P300 and slow wave results support the view that even S1 will be encoded more elaborately under the CC-condition. This cannot be explained by mental rotation or other processes which only influence processing stages after S2. Working memory is thus seen as a system realizing both, information storage and transformation as a prerequisite for other cognitive processes or motor response [6]. In addition, this system is realized in the primate cortex as a network of distributed cortical systems. This view is also supported by the findings of Samthein et al. [28] which show high coherence between anterior and posterior cortical areas during the retention period of a working memory task.

Nevertheless, although the present results shed some light on the processes of stimulus encoding under different task conditions, some questions related to stimulus complexity remain to be resolved. For instance, it is not yet clear whether the classification process is relevant for the matching task or not. It is conceivable that this process depends on the state of practice in the task or on the familiarity with the stimuli. On the other hand, complexity of equivalent sets with the same set size may differ. Since we had to pool over the ES-size to separate more and less complex-figure, effects of the equivalent sets itself may have been obscured. Taken together, the results show that the combined analysis of behavioral and ERP measure can be useful to elucidate the sub-processes underlying identity-based and category-based comparisons.

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