DOES STIMULUS COMPLEXITY AFFECT CENTRAL MECHANISMS?[1]

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Abstract

Using the psychological refractory period (PRP) paradigm, we examined whether visual stimulus encoding is subject to central capacity-limited mechanisms. There is consistent empirical evidence suggesting that the stage of response selection requires central mechanisms (e.g. Pashler, 1994, Pashler & Johnston, 1989, McCann & Johnston, 1992). It is controversially discussed whether visual stimulus encoding is subject to those central capacity-limitations. We conducted an experiment in which second task difficulty was manipulated by varying the stimulus intensity and the stimulus complexity. The first task was a speeded 2 AD task consisting of pure tones. The second task was a same-different matching task consisting of patterns of different stimulus complexity and intensity. Both tasks were performed temporally overlapping at varying stimulus onset asynchronies (SOAs). Main effects for SOA, intensity and complexity, but no interaction between these factors were found. From the intensity effect it is concluded that visual stimulus encoding does require central mechanisms. Furthermore, mechanisms sensible to stimulus complexity are interpreted as to use limited capacity as well. However, it still remains unclear, whether these mechanisms belong to the encoding stage.

People's ability to perform two tasks at the same time is limited. When two stimuli are presented in rapid succession at varying stimulus onset asynchrony (SOA), with each stimulus requiring a fast and discrete response, the typical finding is a slowdown of second task performance. This slowdown is the bigger the smaller the SOA is. After a certain SOA the slowdown-effect disappears completely. According to Welford (1952) a so-called *Psychological Refractory Period (PRP)* in second task performance is responsible for this effect.

As proposed by Pashler and co-workers (Pashler, 1984, 1994; Pashler & Johnston, 1989), this *PRP*- effect is attributed to capacity-limited central mechanisms. It is assumed that some of the processing stages involved in task performance are subject to central mechanisms. These mechanisms are assumed to be limited in capacity. Therefore, only one central capacity requiring processing stage can be performed at a time. Consequently, if in a dual task situation where processing stages of both tasks require central capacity at the same

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[1] This work was supported by Grant La 1281/2 by the Deutsche Forschungsgemeinschaft (DFG) to Thomas Lachmann. Correspondence concerning this chapter should be addressed to T. Lachmann, University of Leipzig, Department of Psychology, Seeburgstr. 14/20, D-04103 Leipzig, Germany.

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time, an information processing bottleneck results, and processing for one of the tasks needs to be postponed. A waiting period or *cognitive slack* (Schweickert, 1978) arises at the stage of postponement. When the bottleneck is cleared, central capacity becomes available for the other task.

Based on a serial processing model which differentiates the stages of encoding, response selection and response preparation in a choice reaction task (Donders, 1868, cited in Lachman, Lachman and Buttlefield, 1979), most consistent empirical support has been provided for the assumption that response selection does require central mechanisms (e.g. Welford, 1952; Pashler, 1984; Pashler & Johnston; 1989; Ruthruff, Miller, Lachmann, 1995; Lachmann, 2000; McCann & Johnston, 1992, Schubert; 1996). Originally it was assumed that encoding processes do not require central capacity (e.g. Pashler, 1984). However, more recently there was a controversial discussion on whether or not, and under what conditions encoding is also subject to central mechanisms. (Posner & Boies, 1971; Pashler, 1989; Dell´Acqua & Jolicoeur, 2000, see Jolicoeur, 1999 for a review). In their model, Jolicoeur and Dell´Acqua (1998) consider the encoding stage not as a single process, but rather, they distinguish subprocesses within encoding of which the stage of short-term consolidation requires central capacity, whereas other may not. Furthermore, it was shown that the processing stages may overlap under certain conditions (Band & Miller, 1997; see also Miller, 1983, for general critique on discrete models of information processing). A last point to be considered is the role of practice. Whereas original the model assumes a practice consistent *PRP*-effect, more recent work has shown that the effect may dramatically decrease with practice (Ruthruff, Johnston, & Van Selst, 2001).

The *PRP*-paradigm proved to be a helpful tool to examine the character of processing stages and to investigate whether or not mental operations, such as memory search (Heil, Wahl, & Herbst, 1999) or mental rotation (Ruthruff, Miller, & Lachmann, 1995), require central mechanisms. The manipulation of the difficulty of the second task, e.g. the size of the memory set or the stimulus orientation, affects the duration of a specific processing stage. If this processing stage refers to central mechanisms, the manipulation of the second task's difficulty and SOA should turn out to be additive. Theoretically, every millisecond the duration of a second task processing stage is increased by, will add directly to second task reaction time (cf. Pashler, 1984). If, however, the second task difficulty factor affects a stage prior central mechanisms, there is an underadditive interaction between difficulty factor and SOA expected. The results of experiments varying the orientation or the memory size in task two appeared to be inconsistent (Van Selst & Jolicoeur, 1994, Ruthruff et al., 1995; Heil et al 1999). Therefore, it is still vague whether or not or under what conditions mental rotation and memory search require central mechanisms.

In Lachmann & Pataki (in preparation) as a second task, a visual *same-different*-matching was required. Participants had to decide whether two simultaneous presented dot-patterns, first used by Garner & Clement (1963), are the *same* or *different*. These patterns were presented with varying stimulus intensity (figure-ground contrast). The intensity of presentation is assumed to influence directly the speed of encoding (or early subprocesses of encoding). If encoding is subject to central capacity limitations additive effects should result from this manipulation. Therefore, reaction time should increase by decreasing SOAs and low stimulus intensity.

Furthermore, stimulus complexity of the patterns to be compared was varied. To measure the complexity of the patterns, the information concept of Garner (1962) was used. Patterns of five dots on an imaginary 3 × 3 grid were used, leaving no row or column empty (Garner & Clement, 1963). The total of 90 patterns falls into 17 disjunctive subsets (inferred sets) consisting of pattern elements that are equivalent in the sense that they can be transformed into each other by reflection and/or multiples of 90° of rotation (R&R

equivalence sets). These sets differ in size, depending on the symmetries of their pattern elements. Two patterns are invariant against the R&R transformations and therefore represent a set by themselves with set size 1. As members of R&R subsets, these patterns are assumed to be highly redundant, i.e. they represent a low complexity (Garner, 1962). Eight subsets consist of four elements that can be transformed into each other. Furthermore, there are seven subsets of eight equivalent pattern elements. Garner & Clement (1963) could show that the equivalence set size (ESS), as an objective measure of the degree of redundancy (or complexity) of the pattern elements, can predict the subjective goodness ratings of their participants. Therefore, it was suggested that ESS is a measure of goodness. Consequently, using the introduced pattern sets for the *same-different*-task entails a variation of complexity and thus of goodness, measured by the ESS.

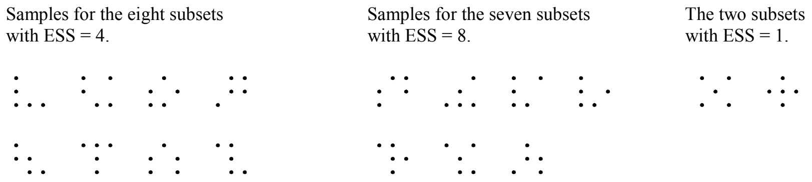

Figure 1. Pattern samples for the 17 subsets first used by Garner and Clement (1963).

Since the late 70`s, there has been a discussion in the literature, about whether or not, goodness influences the speed of encoding (Clement & Varnadoe, 1967; Checkosky & Whitlock, 1973; Hock, 1973; Garner & Sutliff, 1974; Bell & Handel, 1976; Pomerantz, 1977; Biederman, Hilton & Hummel, 1994). We conducted this experiment in order to investigate whether the variation of the stimulus complexity measured by ESS, and thus goodness, produces an additive effect and whether or not this effect occurs independently on contrast effect. Lachmann and colleagues (Geissler & Lachmann, 1996; Berti, Geissler, Lachmann, & Mecklinger, 2000; Lachmann & Geissler, 2001; Lachmann, 2000; Lachmann & van Leeuwen, 2001; Lachmann in this volume) suggested that the whole equivalence set of the patterns to be compared is internally activated and serially searched through in order to make a decision about their matching. This process was assumed to be independent of encoding (Lachmann & Geissler, 2001). As an underlying mechanism, Lachmann (2001) introduced the concept of *Symmetry Generalization*.

The Experiment

The 29 participants (17 females) took part in four sessions with 96 trials each. The first task was an auditory speeded 2 AD task of pure tones. Participants were required to decide whether the tone was high or low by pressing corresponding keys with the left hand. The second task was a visual *same-different* matching task. Two grey five-dot patterns were presented simultaneously on a black background of a computer screen. As mentioned before, in order to manipulate stimulus difficulty, stimulus intensity and complexity were varied. Low stimulus intensity led to a low contrast *C1* and high stimulus intensity to a high contrast *C2*. Stimulus complexity was varied by using three R&R subsets with ESS = 4 (low stimulus complexity) and three R&R subsets with ESS = 8 (high stimulus complexity, see Fig. 1 and 2). From the set with ESS = 8 four patterns were selected for presentation. Thus, 12 patterns of ESS = 4 and 12 patterns of ESS = 8, were used for the *same-different* task.

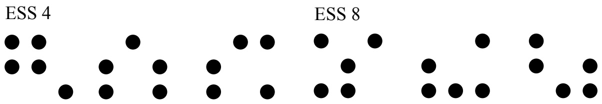

Figure 2. Samples for the sets of five-dot-patterns (cf. Garner & Clement; 1963), used in the visual *same-different* task (task 2). Patterns belonging to ESS 4 are of low complexity and those belonging to ESS 8 are of high complexity (cf. Garner, 1962).

A categorical instruction was given, i.e. participants had to judge patterns independent of their orientation. In other words, members of the same equivalent set had to be judged as *same*. Other pairs had to be responded to as *different*. Participants made *same-different* judgements by pressing corresponding keys with the right hand.

Six groups of visual stimulus combinations result from the variation of stimulus intensity and complexity (see Tab. 1). The stimulus onset-asynchrony (SOA), i.e. the interval between the onset of the auditory stimulus and the patterns to be compared, was either 50 ms, 400 ms or 650 ms. Participants were required to answer first to the tone and than to the patterns. Feedback was given for speed, accuracy, and the order of response.

Table 1. Combinations of stimulus complexity and intensity variation used in the experiment.

Stimulus complexity (SC)	**Stimulus intensity (SI)**	
	C1	**C2**
ESS 4	low SI/ low SC	high SI/ low SC
ESS 8	low SI/ high SC	high SI/ high SC
ESS different	low and high SI of different pairs	

Results and Discussion

A repeated-measures analysis of variance (ANOVA) was conducted on reaction times of the second task's (RT2) correct responses with the factors SOA, ESS (complexity) and contrast (intensity).

Significant main effects were found for all factors. Participants responded faster to patterns with ESS = 4 than to those with ESS = 8 in case of *same* as well as of *different* responses. Faster responses were given to stimuli with high contrast (C2) than to those with low contrast (C1). Reflecting the *PRP*-effect, RT2 turned out to be longer when presenting the tasks with smaller SOA (see Fig. 3a,b).

No significant interaction between contrast and ESS was found, suggesting that both ESS and contrast affect RT2 independently. Main effects were interpreted as to operate additive on RT2. From the contrast effect it was concluded that encoding of the patterns requires central mechanisms and therefore cannot start before response selection in task one has been finished.

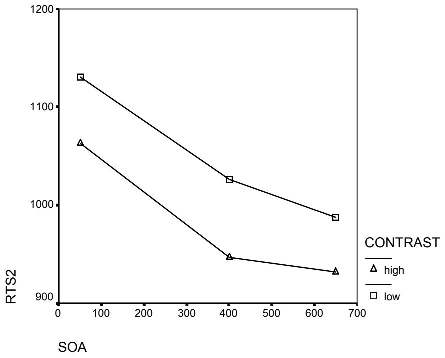

Figure 3a. Mean reaction times for the second task (RT S2) as a function of stimulus onset asynchrony (SOA) and stimulus intensity (contrast).

Furthermore, from the ESS effect it was concluded that stimulus complexity also refers to mechanisms of limited-capacity. However, from this result it cannot be decided whether or not complexity, and thus goodness measured by ESS, influence the speed of encoding. Since the ESS effect occurs independently from contrast variation, it appears likely that other mechanisms than those responsible for encoding are sensitive to stimulus complexity. In this respect, the findings are consistent with the assumption of Lachmann and colleagues (Lachmann and van Leeuwen, 2001; Geissler & Lachmann, 1996, Lachmann, 2000) that participants activate the whole equivalence set of the shown patterns and perform a serial search through that memory set. This assumption is strengthened by findings of Lachmann (2000) that when presenting patterns of different ESS in a single *same-different* task successively, the order of presentation does not affect the RT.

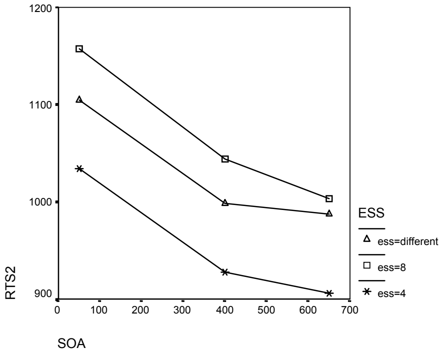

Figure 3b. Mean reaction times for the second task (RT S2) as a function of stimulus onset asynchrony (SOA) and stimulus complexity measured by ESS.

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