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A role for set when naming Arabic numerals: How intentionality limits (putatively automatic) performance

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Processing in various skilled domains is often described as *automatic*, in the sense that functional stimulus processing is triggered by stimulus onset and cannot be interrupted. One problem is that subjects typically know what task they have to perform prior to stimulus presentation. Various effects attributed to automatic processing may, therefore, arise instead from the mental *set* that is already in place. In the present study, we investigated skilled subjects' ability to engage in processing prior to knowing what the task is. A numeral was presented, and subjects either named it or added 1 and named the result. Which task was to be performed on a trial was signaled by a tone that appeared before or at the same time as the target. If functional target processing is triggered by its presentation, the effect of low contrast should be absorbed into the time taken to decode the task cue, regardless of the task (the effect of contrast should be absent at the 0-msec stimulus onset asynchrony [SOA] and present when task information is given in advance of the target). An underadditive interaction between contrast and SOA was seen for one task, but these factors had additive effects in the other task. This pattern can be understood in terms of the hypothesis that although *encoding* can be thought of as a stage common to both tasks, it is not, in the present context, functionally independent of a subsequent stage unique to a task.

The basic processes underlying the perception and identification of well-known stimuli (e.g., single words and digits) by skilled individuals are widely viewed as *automatic*. This automatic-processing perspective holds that (1) the presentation of a stimulus initiates processes that end with the full activation of orthographic, phonological, and semantic representations and that, (2) such processes are capacity free, (3) not interruptible by other concurrent processes, (4) operate in the absence of *attention* (even spatial attention), and (5) can operate without intent (see, e.g., Brown, Gore, & Carr, 2002; Frost, 1998; Marcel, 1983; Neely & Kahan, 2001; Posner & Snyder, 1975).

We concern ourselves here with three aspects of such putatively automatic processing: the claim that it is initiated by the appearance of the stimulus, that such processing occurs without intent, and that such processing is not prevented from taking place by other mental activities. More generally, it should not matter that the subject does not know what the task is when the stimulus appears, because such processing occurs in the absence of such knowledge.

In our view, this "automatic"-processing account, although widely promulgated and accepted, is problematic precisely because it is derived from situations in which the subject knows what the task is before the stimulus is presented. That is, in the vast majority of paradigms, subjects are asked to do the same task throughout a block of trials. The subject is therefore "set" to perform that task. Consequently, the conclusion that various mental processes are automatic (as defined above) is premature, because knowing what the task is may serve to "set" the subject's mental apparatus in such a way that some (many, or even all) of these putatively automatic behaviors are a by-product of this set. A convincing demonstration that various mental processes are automatic in the senses offered above requires an experimental paradigm in which functional processing of the target occurs in the absence of knowledge about the task. We turn now to a discussion of the procedure used by Besner and Care (2003) to address this issue.

The Task Choice Procedure

Besner and Care (2003) described a paradigm in which information dictating what task is to be performed is presented either in advance of the target stimulus or at the same time. For example, a colored rectangle is presented either 750 msec before or at the same time as the target. The color of the rectangle informs the subject what task he or she must perform. In the *advance knowledge* condition, there is ample time to decode the task cue before the target appears. This condition resembles the vast majority of experiments, in that the subject knows what the task is before the target is presented. However, when the stimulus onset asynchrony (SOA) between the task cue and the target is zero, there is now an opportunity to determine

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whether the target is processed *without intention*, because subjects do not yet know what specific task they should carry out. Making a correct response requires subjects to identify what the task is. Critically, this takes time. Therefore, if subjects can identify the target without intention during the time they are decoding the task cue that dictates what to do, a straightforward prediction can be made: The effect of a manipulated factor associated with a target that is processed without intent will be absorbed into the time period associated with the delay incurred by decoding the task cue.[1]

More concretely, stimulus contrast is a factor that affects very early processing (see, e.g., Pashler & Johnston, 1989). When the task is known in advance of the target, a contrast effect is observed; bright targets are processed more quickly than dim ones. Now consider the case in which the task cue appears simultaneously with the target. If the mental work associated with processing a low-contrast stimulus can be undertaken during the time taken to decode the task cue, the effect of contrast will not be observed in overt performance, provided that this mental work takes less time than that necessary to decode the task cue. This is because the additional time taken to process a low-contrast stimulus will be absorbed into the time taken to identify the task. In the language of the psychological refractory period (PRP) paradigm, the effect of this factor will be “absorbed into slack” (see Pashler & Johnston, 1989). In contrast, if this mental work cannot be done during the time the cue is being decoded but must wait until such processing is finished, a full-blown effect of stimulus contrast will be observed. That is, it will be the same size as in the advance cue condition (i.e., stimulus contrast and SOA will have additive effects on reaction time [RT]).

Besner and Care (2003) presented subjects with a letter string on every trial and asked them to either name it aloud or decide whether it appeared in upper- or lowercase. They manipulated stimulus contrast, task, and SOA and randomly intermixed these factors within a single block of trials. One of the critical findings was that contrast and SOA had additive effects on RT for both tasks. Besner and Care interpreted these results as evidence that subjects are not able to carry out the mental work necessary to deal with the effect of low contrast at the same time as decoding the task cue. Instead, these processes are serially organized.[2] The functional computations underlying letter identification in the service of reading aloud are not simply triggered by the appearance of the stimulus. In other words, Besner and Care argued that the subject does no *functional* work on the stimulus until the specific task has been identified.

The Present Experiment

How general are Besner and Care’s (2003) conclusions? At least three concerns can be raised. One is that their experiment utilized a visual task cue and a visually presented target. It is possible that processing of the (visual) task cue interferes with (visual) target processing on zero SOA trials. The additive effects of contrast and SOA might, therefore, reflect a strategy that subjects implement to avoid peripheral interference, rather than an effect that reflects some more basic (structural?) limitation. The present study therefore combines an auditory tone as the task cue with a visually presented target. If peripheral interference was a limiting factor in the Besner and Care study, an underadditive interaction between contrast and SOA should be seen here for both tasks.

A second issue concerns Besner and Care’s (2003) use of nonwords as stimuli. Certainly, it is a widespread belief that sublexical spelling-to-sound translation is an automatic process (e.g., Frost 1998, 2003; see also a number of chapters in the book edited by Kinoshita & Lupker, 2003). Nonetheless, we would like to know whether Besner and Care’s conclusions generalize to other kind of stimuli that are simple and highly overlearned and that use a mapping from symbol to sound that is better characterized as *lexical*, rather than sublexical. The present experiment therefore used the digits 1 to 8, since such stimuli are well known to university students.

Finally, the tasks used by Besner and Care (2003) likely required subjects to engage a mental set that was unique to each task. For example, when asked to name the letter string, the subjects needed to identify each letter of the letter string. For case decisions, however, the subjects needed only to determine whether a single letter was in upper- or lowercase. This may have been accomplished without identifying the letter (e.g., by some simple physical discrimination). Besner and Care raised the issue of whether different combinations of tasks might affect *how* early processing unfolds. In particular, they raised the question of whether using pairs of tasks that appear to call for the same encoding operations would allow processing to begin with stimulus onset in the absence of any intent. To this end, the subjects in the present experiment had either to name the digit or to add 1 and then name the result (*N* and *N*+1 naming). These two tasks have a common front end, in that subjects must first *identify* the digit. According to Sternberg (1969), the extra stage of adding 1 on *N*+1 trials takes place after such identification has occurred.

Three outcomes are considered here (without implying that this exhausts the set of possible outcomes). One is that the effect of low contrast is considerably smaller at the zero than at the long SOA for *both* tasks. Such a result could be explained by appealing to the idea that such encoding is unintentional, in the standard sense of being automatic, or that subjects adopt an intentional experiment-wide mental set that allows them to encode the target while decoding the task cue. A second outcome is that additive effects of contrast and SOA are observed for *both* tasks. This outcome would be inconsistent with the idea that functional encoding unfolds automatically (i.e., without intent) and inconsistent with the idea that subjects can establish an experiment-wide set that allows them to encode the target during the time taken to decode the cue at the zero SOA. A third outcome is that there is a smaller effect of contrast at the zero than at the long SOA for one task but additive effects of contrast and SOA for the other task. This outcome would again be inconsistent with the idea that functional encoding unfolds automatically (i.e., without intent) and inconsistent with the idea that subjects can establish an experiment-wide set applicable to both tasks that allows them to encode the target during the time taken to decode the task cue. However, such a result could arise if the set held by the subject serves to bind the early encoding stage to a subsequent stage (e.g., add 1). The consequence is that components of both tasks cannot be held in a state of readiness for a zero SOA trial and, hence, functional encoding in aid of the other task cannot be accomplished.

To preview the results, there was a three-way interaction between contrast, SOA, and task. Contrast and SOA yielded an underadditive interaction for the $N+1$ task but additive effects for the N task. These results will be considered further in the Discussion section.

METHOD

Subjects

Twenty-six undergraduate students from the cognition subject pool at the University of Waterloo took part; each was paid $6 for his or her participation. All the subjects reported English as their first language and had normal or corrected-to-normal vision.

Apparatus

The experiment was conducted using Micro Experimental Lab (MEL) 2.0 software running on a Pentium IV (1800-MHz) computer. MEL 2.0 software controlled the timing and presentation of stimuli and logged RTs. The stimuli were presented to the subjects on a standard 15-in. SVGA color monitor. The subjects' vocal responses were collected using a Plantronics microphone.

Stimuli

The stimulus set consisted of the digits 1 to 8 presented in a standard MEL 2.0 font (system96.fnt) as white text on a black background. Each digit appeared equally often in all the conditions.

Design

The design consisted of a 2 × 2 × 2 factorial in which the first factor was task (naming vs. naming + 1), the second factor was SOA (0 vs. 750 msec), and the third factor was contrast (high vs. low). All the conditions were randomly intermixed within a single block of trials, and each subject received a different random sequence.

Task Cues

A tone on each trial indicated which of the two tasks was to be performed. For half the subjects, a high-frequency tone (2150 Hz) required the subjects to name the digit, and a low tone (400 Hz) required the subjects to add one to the digit and name the result. The remaining subjects were assigned to the reversed tone–task mapping.

Contrast

Half of the items appeared in high contrast, and the other half in low contrast. Each digit appeared equally often in high- and low-contrast form for each subject. High-contrast items appeared in MEL 2.0 (RGB values: 63, 63, 63), and low-contrast items appeared in MEL 2.0 (RGB values: 6, 6, 6).

Placeholder

On each trial, a rectangle that acted as a placeholder appeared in the center of the screen (RGB values: 33, 33, 33). The rectangle was 4.1 cm wide and 2.2 cm tall and subtended visual angles of 3.9° and 2.1° at a viewing distance of 60 cm. The target digit appeared in the center of the rectangle. The digits were 0.6 cm in height and 0.4 cm wide and subtended visual angles of 0.6° and 0.4°.

Procedure

The subjects were tested individually in a dimly lit room. They were seated in front of the computer monitor and were given written and verbal instructions. The subjects were told that on each trial, they would hear a tone and a digit would appear in the center of a white rectangle on the monitor. They were instructed that, depending on the tone, they would either name the digit (N task) or add one to the digit and then name the result ($N+1$ task). They were also told that some items would appear bright, whereas others would be dim, and to just ignore this. The subjects performed a practice block and then a test block. Every digit was presented once per condition in the practice block, resulting in 64 trials. In the experimental block, every digit was presented four times in each condition, for a total of 256 trials (32 observations per condition).

Each trial began with the presentation of a 100-msec duration tone (high or low) that was accompanied by the placeholder rectangle displayed in the middle of the screen. In the advance cue condition, the digit appeared 750 msec after the onset of the tone. In the 0-msec SOA condition, the digit appeared at the same time as the onset of the tone. Following a response, a blank screen was displayed until the experimenter logged the subject's response as correct or not. Once the experimenter keyed in a response, an intertrial interval of 1,000 msec ensued.

Responses were classified in three ways: (1) as a spoiled trial if the microphone did not pick up the subject's vocal response, or some external noise triggered the microphone before the subject could respond; (2) as incorrect, in which case feedback was given (during practice trials only), or (3) as a correct response.

RESULTS

Reaction Times

Spoiled (4.0%) and incorrect trials (2.6%) were discarded. The remaining RT data were submitted to a recursive outlier analysis that discarded any RTs 2.5 or more standard deviations above or below the mean for each subject in each condition. This resulted in an additional 2.1% of the data being discarded.

Correct mean RTs were then submitted to a 2 × 2 × 2 factorial ANOVA in which the factors were task, SOA, and contrast. There were significant main effects of task [shorter RTs for the N than for the $N+1$ task; $F(1,25) = 55.17$, $MS_e = 6{,}213$, $p < .001$], SOA [shorter RTs at the 750-msec SOA than at the 0-msec SOA; $F(1,25) = 406.83$, $MS_e = 7{,}196$, $p < .001$], and contrast [shorter RTs for high- than for low-contrast items; $F(1,25) = 27.17$, $MS_e = 8{,}881$, $p < .001$]. Critically, there was a three-way interaction between task, SOA, and contrast [$F(1,25) = 5.15$, $MS_e = 1{,}814$, $p < .05$]. This interaction can be seen in Figure 1. A 2 × 2 ANOVA on the RT data for the $N+1$ task confirms that the effect of contrast at the 0-msec SOA (26 msec) was significantly smaller than that at the 750-msec SOA [85 msec; $F(1,25) = 8.47$, $MS_e = 2{,}730$, $p < .05$]. In contrast, a 2 × 2 ANOVA on the RT data for the N task yielded main effects of contrast [$F(1,25) = 251.71$, $MS_e = 7{,}062$, $p < .001$] and SOA [$F(1,25) = 21.79$, $MS_e = 7{,}847$, $p < .001$] but no interaction ($F < 1$) between SOA and contrast (78 msec at the 0-msec SOA, as compared with 84 msec at the 750-msec SOA).

Errors

There was a significant main effect of task [the subjects made more errors on the $N+1$ task than on the N task;

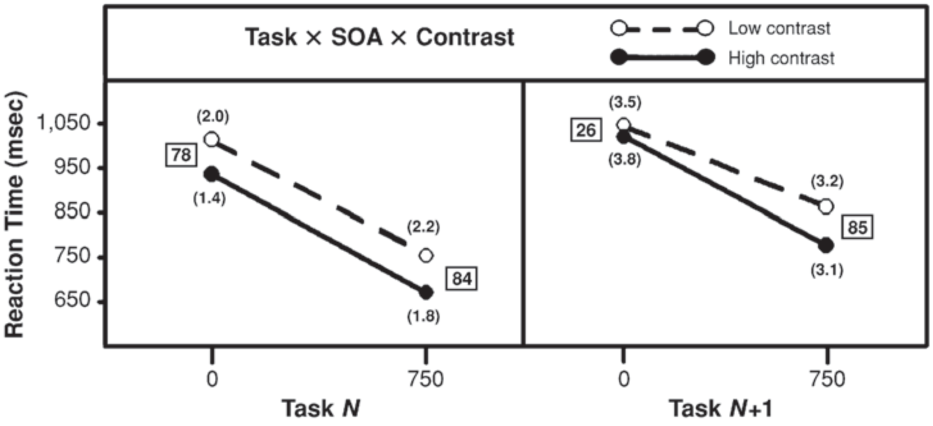

Figure 1. Mean reaction time (in milliseconds) and percentage of errors (in brackets) as a function of task, SOA, and contrast.

$F(1,25) = 13.98$, $MS_e = 9.08$, $p < .005$]. Neither SOA nor contrast yielded a main effect (Fs < 1). No interactions were significant (all Fs < 1.2).

Switch Analysis

A *switch* analysis was also conducted in order to determine whether any of the observed effects were modulated by whether or not the subject switched tasks relative to the previous trial. Correct RTs were therefore categorized as either a switch or a stay trial, relative to the previous trial (*switch*/*stay* was defined in terms of whether the task changed or not). For each subject, data from the first trial were excluded from this analysis (but not its status as type of trial with respect to the following trial).

Correct RTs were submitted to a 2 × 2 × 2 × 2 ANOVA in which the factors were switch, task, SOA, and contrast. There was a significant main effect of switch [longer RTs for switch trials than for stay trials; $F(1,25) = 41.75$, $MS_e = 5{,}754$, $p < .001$] and a significant interaction between switch and task [$F(1,25) = 17.50$, $MS_e = 6{,}074$, $p < .001$]. This interaction is displayed in Figure 2. All other interactions with the switch factor were not significant (all Fs < 1.65), except for the switch × SOA interaction, in which there was a marginally larger effect of switch at the short, as opposed to the long, SOA ($F = 2.76$, $MS_e = 8{,}210$, $p < .11$).

Errors

The error data were submitted to the same 2 × 2 × 2 × 2 ANOVA. The main effect of switch was marginal; the subjects made more errors on switch trials than on stay trials [$F(1,25) = 2.78$, $MS_e = 18.9$, $p = .108$]. There were no significant interactions between switch and any of the other three factors (all Fs < 1.97).

DISCUSSION

There are two central findings of this experiment. One is that contrast and SOA yielded an underadditive interaction between contrast and SOA in the $N+1$ task, so that the effect of low contrast was smaller at the 0-msec SOA than at the 750-msec SOA. The second is that these same factors had additive effects on RT when the task was to simply name the presented numeral (the three-way interaction of contrast × SOA × task was significant).

These results are inconsistent with the idea that subjects can engage in functional identification of the target in the absence of knowing what the specific task is, because this should have yielded an underadditive interaction between contrast and SOA for *both* tasks. More specifically, these data are not consistent with functional automatic encoding initiated by the stimulus. These results are also inconsistent with the idea that a functional experiment-wide set can be intentionally instituted on the basis of the assumption that there is an identification stage common to both tasks, because again, this should have led to an underadditive interaction between contrast and SOA for both tasks (i.e., a two-way interaction, but no three way interaction with task).

How then are these data to be explained? Our tentative account is that subjects intentionally hold a set that prepares them to do the $N+1$ task, in the sense that, regardless of whether processing is discrete or cascaded, encoding of the stimulus (identification) *enables* a subsequent stage in which 1 is added. Functional encoding can, therefore, go on while the task cue is being decoded. However, when the task cue dictates that the stimulus be named without adding 1, the latter operation is not enabled (either subjects experience difficulty holding two different enabling conditions simultaneously or may not be able to), and the subject starts processing anew once the task cue is decoded; hence, additive effects of contrast and SOA are produced. In the N task, then, no functional encoding occurs while the task cue is decoded. It remains to be seen whether this account still holds when there is extensive practice at the two tasks. It may also be possible to reverse the three-way interaction, so that contrast and SOA are now underadditive for the N task and additive for the $N+1$ task, merely by having the N task be more probable.

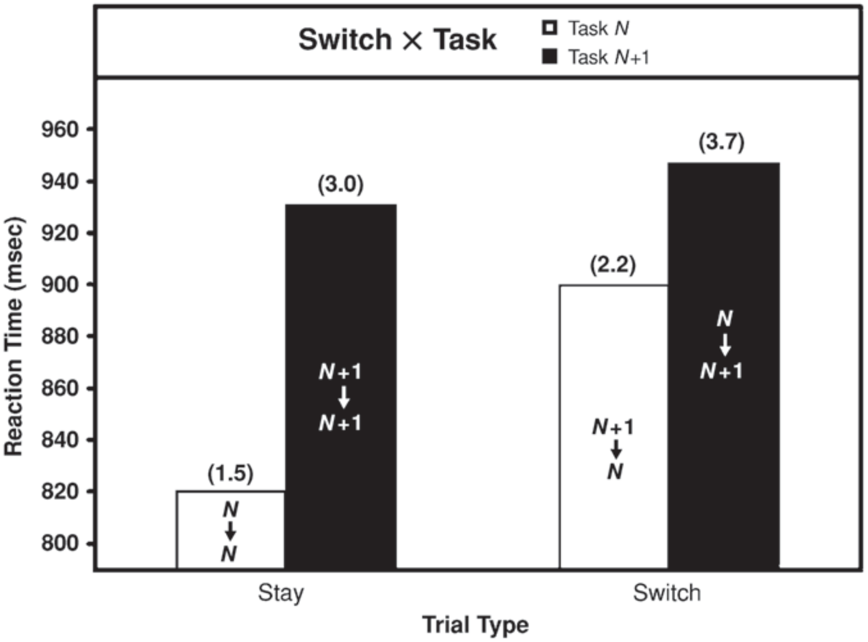

Figure 2. Mean reaction time (in milliseconds) and percentage of errors (in brackets) as a function of the task and the task on the preceding trial.

The Effect of Switching

The less practiced *N*+1 task was performed considerably more slowly than the *N* task overall, but as Figure 2 shows, there was a *larger* RT cost associated with switching from *N*+1 to *N* than from *N* to *N*+1. This finding is probably best situated in the context of the ongoing debate between the view that the cost of shifting between tasks reflects, in large part, a central *switch* cost associated with mental reconfiguration appropriate to the task (e.g., Rogers & Monsell, 1995) and the view that such costs reflect proactive interference, rather than central processing (e.g., Allport, Styles, & Hsieh, 1994; Waszak, Hommel, & Allport, 2004). This debate is ongoing, and the present results do not allow us to distinguish between these accounts. Nonetheless, it is intriguing that switching from the *N*+1 to the *N* task is more difficult than vice versa and, on its face, consistent with the hypothesis that the *N*+1 task is the default set.

Relation to Other Paradigms

The present results can also be understood in a wider context. Two examples are briefly noted. First, as Besner and Care (2003) noted, additivity of stimulus quality and SOA on RT in the present paradigm contrasts starkly with the underadditivity of these same two factors on RT that is seen in the PRP paradigm (e.g., Pashler & Johnston, 1989). Arguably, the critical difference is that in the PRP paradigm, the subjects always know what task to do before the target appears, whereas in the task choice paradigm, they do not. The absence of this knowledge in the latter case at the short SOA limits the processing that can go on in parallel between "tasks." (It should be noted that this limitation cannot be explained in terms of competition for peripheral resources, given that the task cue and the target appeared in different modalities here.)

Second, this limitation to parallel processing across tasks (tone identification and naming) extends (although not completely) to even simpler variants of the task choice paradigm. Besner and Risko (2005) had subjects detect the onset of a small disk that appeared either left or right of a vertical bar by pressing a key ipsilateral to the disk. The disk was either bright or dim, and a tone appearing at the same time as the disk or well in advance of it signaled whether to make an overt response or withhold a response. Additive effects of contrast and SOA were observed on *go* trials, provided that the previous trial was a *no-go* trial, in accord with the idea that when a new action has to be taken, functional processing of even a simple visual event is interrupted.

Importantly, however, when the prior trial was also a go trial, contrast was underadditive with SOA. This interaction between switch/stay, contrast, and SOA stands in marked contrast with the fact that there is no evidence of such a three-way interaction either here or in Besner and Care (2003). An obvious question to pursue concerns what it is that is responsible for the different patterns seen across these different kinds of tasks. For example, is it the use of a go/no-go procedure, or is it that one task requires *lexical* identification and the other spatial localization? This question could be addressed by crossing lexical identification with the go/no-go procedure (name the digit or withhold a response, depending on the cue). An underadditive interaction between contrast and SOA that holds across switch/stay would suggest that the kind of *identification* (lexical vs. spatial) that is required plays a role.

Conclusions

The fact that contrast and SOA are additive for the *N* task in the context of also seeing an underadditive interaction for these same factors in the *N*+1 task suggests that, even for skilled subjects in quite simple domains, the role of mental set is quite pervasive and can trump putatively automatic processing. The mind does not always engage in functional stimulus processing while deciding what task to perform.

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NOTES

1. Complete absorption is expected when the effect size (in RT) associated with the manipulated factor is smaller than the effect size associated with cue decoding time.

2. Besner and Care (2003) discussed why the data do not support the possibility that initial processing takes place before cue decoding, rather than vice versa.

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