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Goal neglect and inhibitory limitations: dissociable causes of interference effects in conflict situations

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Abstract

Interference effects on task performance in conflict situations might reflect real limitations in inhibitory capabilities or failures to fully or consistently utilize such capabilities in executive control of task performance. We propose that useful clues regarding the actual cause of interference effects may be obtained from examination of their robustness within and between experimental conditions. We illustrate this approach for two major types of interference effects that have commonly been attributed to fundamental inhibitory limitations: Stroop-type interference and residual switch costs. We present results that indicate that these effects may not be unavoidable consequences of fundamental inhibitory limitations but may stem from goal neglect, i.e., failures to fully or effectively deploy inhibitory capabilities. These results indicate that, in addition to mean performance levels, variability of task performance may provide a valuable source of evidence regarding the actual cause of performance limitations or deficits in conflict situations. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The human brain is capable of an enormous range of tasks. Yet, people are limited in the number of tasks they can perform concurrently, and usually they seem

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to be devoted to just one task at any moment. Two fundamental questions to be addressed by any theory of executive control of thought and action are why this serial constriction of external activities exists and how the processing system becomes temporarily committed to one activity rather than another. In this paper, we will be primarily concerned with the second of these questions, but the first one requires some consideration. An important insight, eloquently expressed by Simon (1994), is that a serial organisation of external activities should perhaps not be viewed as the result of resource scarcity prohibiting a presumably more efficient parallel organisation, but as an efficient solution to the problem of how to get a powerful parallel processing device, such as the human brain, to support coherent behavior in complex environments that offer multiple affordances for action. As stated by Simon:

> Because of the dispersion of need-satisfying situations in the environment, most needs can be satisfied only after extensive activity involving collaboration of sense and motor organs in pursuit of a specific goal... An effective division of labor is not achieved by segmenting the organism into components that each work toward satisfying one of these goals. It is much more efficient to divide labor by time segments-the resources of the entire organism being devoted, in turn, to satisfying successive goals, the priorities being established by the signaling and attention control mechanisms (1994, p. 7–8).

Similar views have been expressed by other theorists (Allport, 1987; Neumann, 1987). While acknowledging the high degree of parallel functioning observable in the sensory organs and in the control of internal processes, this view thus holds that the serial constriction of external activities is "... a response to the structure of the environment and of the organs that sense and act on it" (Simon, 1994, p. 8).

These considerations suggest a preliminary answer to the question of how a specific activity or task is selected: voluntary behavior is directed by goals and setting a goal temporarily commits the processing system to the task of attaining it. In this paper, we will focus on the case of well-trained speeded response tasks that can be performed in a second or so. Performance of such tasks may be viewed as being governed by a mental set or *task set* that, following Woodworth (1918), can be defined as an assembly of elementary processes, or processing modules, configured to deal with a specific task. Implementation of a task set involves the configuration of relevant processing modules for computing required input-output transformations and the selective enabling or disabling of inter-module connections in order to ensure a proper flow of information (Allport, 1989; Monsell, 1996). Setting the task goal triggers retrieval of an abstract representation of the associated task set from procedural memory and the subsequent implementation of that set. When these control processes have finished, the processing system is committed to or *prepared for* that task, and subsequent task performance can be aptly described as a 'prepared reflex' (Woodworth, 1918).

The schema control theory (Norman & Shallice, 1986) provides a convenient framework to expand upon these theoretical notions. Schemas are routine programs, one for each basic type of action or thought operation. For present purposes, a schema may be regarded as an abstract representation of a task set, and selection of a schema as corresponding to the retrieval and implementation of its associated task set. Schemas can be activated by sensory inputs, by other schemas, or by a general executive system, labeled the Supervisory Attentional System (SAS). Schemas compete for the control of thought and action by means of a contention-scheduling process that is probably mediated by lateral inhibition between activated schemas. Ideally, the most strongly activated schema would win this competition and suppress all other schemas. For routine actions in familiar contexts, contention scheduling will generally be sufficient to guarantee selection of the appropriate schema. In other circumstances, as discussed below, the SAS will be needed to bias or modulate the outcome of the contention scheduling process, by providing top-down activation or inhibition of schemas (Norman & Shallice, 1986).

These concepts can be made more concrete by considering the situation where subjects are instructed to prepare for a familiar reaction time (RT) task with an arbitrary stimulus-response mapping. Because the task is familiar, a well-integrated schema for the task has presumably already been acquired. The problem then is to select this schema and implement the associated task set. In order to do so, the appropriate task goal must be set. This goal then provides the drive for the SAS to activate the goal-relevant schema. In many cases, this top-down activation, followed by contention scheduling, will suffice to ensure selection of the relevant schema and adequate suppression of all other potentially applicable schemas. In other cases, further intervention of the SAS will be needed. Two such cases are of particular interest for present purposes. One is where the stimuli of the task are more strongly or naturally associated with other tasks; a familiar example is the Stroop task where naming the word is a more strongly automatic response than naming the color of the ink in which the word is printed. The other is where the stimuli of the task were recently encountered in a different task and there is residual activation of the schema for that task (Allport, Styles & Hsieh, 1994). Even if the competing schemas could be at least partially suppressed through contention scheduling, as only the relevant schema receives top-down activation from the SAS, they may subsequently be strongly triggered by the stimulus, in which case the task set would be corrupted and task performance hampered. Top-down inhibition by the SAS would then be needed to achieve effective and lasting suppression of competing schemas (Stuss, Shallice & Picton, 1995).

We will focus in this paper on the conceptual and empirical distinction between two major potential causes of interference effects in conflict situations where, as in the Stroop paradigm, task-relevant inputs may also trigger other, more highly practiced or recently activated, schemas. First, when attention is not tightly focused on the relevant task, the resulting weakened goal drive might be insufficient to enable goal-to-schema translation mechanisms to produce a strong and fully configured task set, even when such mechanisms would, in principle, be capable of effective suppression of competing schemas. Second, goal-schema translation mechanisms might be inherently incapable of achieving selective activation of the relevant task schema and effective inhibition of competing schemas, even when they are provided with an optimal goal drive. This conceptual distinction between real limitations in inhibitory capabilities versus failures to fully or consistently utilize such capabilities as potential causes of interference effects would appear to be a rather elementary one. The empirical distinction between these two possible causes, however, turns out to be rather less straightforward.

In this paper we will explore the possibility that the robustness of interference effects may offer important clues as to their fundamental cause. Our reasoning is simple. Real limitations of goal-schema translation mechanisms should give rise to interference effects that are unavoidable and robust in the sense that such effects should be present even when attention is tightly focused on the instructed task and the associated task goal fully activated. Conversely, interference effects that can be shown to be largely eliminated in conditions that promote appropriate focussing on the relevant task goal, should be attributed to failures of focused attention. We will discuss two major examples of interference effects that have been characterized in the literature as stemming from fundamental inhibitory limitations but that, upon closer examination with suitable experimental and analytical techniques, appear to reflect failures of focused attention. We propose that such interference effects should be attributed to *goal neglect*, defined by Duncan (1995) as disregard of a task requirement even if it has been understood, resulting in a mismatch between what is known of task requirements and what is actually attempted in behavior. We will develop and refine this proposal in the remainder of this paper.

2. Goal neglect and inhibitory limitations in stroop-type interference

In the classical Stroop task, subjects are instructed to name the color of the ink in which a word is printed, and to ignore the meaning of the word. On congruent trials, the word and the ink color correspond, as when the word *red* is printed in red. On incongruent trials, the word and the ink color do not correspond, as when the word *red* is printed in blue. Responses are usually slower and less accurate on incongruent as compared to congruent trials (MacLeod, 1991). The Stroop effect is commonly interpreted as an involuntary consequence of a fundamental inability to effectively inhibit the processing of the meaning of the word or, in terms of the selection-for-action view of selective attention (Allport, 1987; Neumann, 1987), to effectively decouple word meaning from control of action.

This modal interpretation may be questioned, however. Even if subjects were, in principle, able to completely prevent word meaning from influencing task performance, they might not always fully exploit this ability. Indeed, the magnitude and direction of Stroop interference has been found to be sensitive to the relative frequency of congruent and incongruent trials, a result that suggests the critical importance of strategical factors (Gratton, Coles & Donchin, 1992; Logan & Zbrodoff, 1979). As suggested by Yantis and Johnston (1990, p. 146): "Effective focused attention may be carried out only when task demands make it desirable and visual conditions make it possible." A rationale for a conservative bias in employing focused attention has been provided by Simon (1994), who noted that a processing system that is fully absorbed in some task, runs the risk of not noticing threatening events that require immediate action or information that would be useful for the attainment of other, currently latent goals. These considerations suggest that the possibility should be taken seriously that the processing demands of the standard Stroop task may not induce or force subjects to fully bring to bear their ability to prevent formally irrelevant information from influencing task performance.

The first experiment was designed to address this issue. It used a self-paced spatial version of the Stroop task, either with a rather long response-stimulus interval (RSI = 2000 ms), representative of many Stroop-type experiments, or with a short RSI (200 ms). We reasoned that a fast pace might induce or help subjects to remain well focused on the instructed task and too effectively inhibit any influence of word meaning. A slow pace, on the other hand, might give rise to sizable fluctuations in attentional state across trials and consequent failures to fully employ one's ability to inhibit the processing of word meaning.

3. Experiment 1

Subjects. Twenty-four undergraduates at the University of Groningen participated in return for payment. One half participated in the "slow pace" condition of the experiment, and the other half in the "fast pace" condition.

Apparatus and stimuli. Subjects sat at a viewing distance of approximately 70 cm in front of a VGA color monitor of an IBM compatible PC (equipped with VGA graphics, providing a resolution of 640 × 480 pixels). Stimuli consisted of a string of four plus signs, presented at the center of the display, and one of the words LAAG or HOOG (Dutch for LOW and HIGH, respectively) that was presented 0.25° above or below the string. The words and strings subtended visual angles of 1.7 × 0.7°, and all characters were displayed in an uppercase sansserif font. The response keys were the *Z* and question mark keys on the computer keyboard, operated by the left and right index fingers.

Design and procedure. A trial began with the presentation of a stimulus that remained on the screen until a response was registered. The word and its vertical position were randomly chosen on every trial. After a response was registered and the stimulus extinguished, the next stimulus appeared after a response-stimulus interval (RSI) of 2000 ms for the slow pace condition and 200 ms for the fast pace condition.

Participants received written instructions that explained the procedure and instructed them to minimize RT while keeping errors to a minimum. They were told to respond on the basis of the position (above or below) of the word relative to that of the string of plus signs, and to ignore the meaning of the word. The assignment of the "below" and "above" responses to the two hands was balanced across subjects for each condition. Subjects were instructed to respond more accurately when they made more than 10% errors in the first trial block; no other feedback was provided during the experiment.

Each subject performed a total of 10 trial blocks, with each block consisting of 100 trials. A short break was allowed between blocks. The first block was considered practice and excluded from analysis. Also excluded from analysis were trials immediately following an error.

4. Results and discussion

Trials on which the word and its relatively position corresponded (e.g., the word HOOG presented above the row of plus signs), are called congruent trials; those on which the word and its position did not correspond, are called incongruent trials. In the slow-pace condition, mean correct RT on congruent trials was 526 ms and on incongruent trials 573 ms, with error rates of 1.2% and 3.8%, respectively. In the fast-pace condition, mean congruent RT was 489 ms and mean incongruent RT 500 ms, with error rates of 2.3% and 3.8%, respectively. An analysis of variance with condition (fast vs. slow pace) as a between-subject factor and congruency as a within-subject factor yielded for RT significant main effects of condition, $F(1,22)=7.9$, $p<0.01$, and congruency, $F(1,22)=33.7$, $p<0.001$, and a significant interaction between these factors, $F(1,22)=12.5$, $p<0.002$. For error rate, only the main effect of congruency reached significance, $F(1,22)=14.2$, $p<0.001$.

Increasing the pace of trials resulted in more proficient task performance, with faster responses at no significant costs in accuracy. This is consistent with the idea that a faster pace forced or helped subjects to remain consistently focused on the instructed task. Increasing the pace also resulted in a quite dramatic decrease in the size of the Stroop effect, from 47 ms in the slow-pace condition to a non-significant 11 ms in the fast-pace condition. This latter result cannot be easily reconciled with the notion that Stroop interference is an unavoidable consequence of a fundamental inability to prevent word meaning from affecting task performance. Rather, it would seem to indicate that subjects are quite capable of effective inhibition of word reading, but that they failed to fully or consistently employ this ability in the slow-pace condition.

In a further analysis of these data, we divided the rank-ordered RTs for each subject into deciles (10% bins) and computed mean RTs for each bin, separately for congruent and incongruent trials. Averaging these values across subjects, we obtained averaged cumulative distribution functions (CDF), for congruent and incongruent trials in each of the two experimental conditions. These functions, called distributional plots, are shown in Fig. 1. For the fast-pace condition, the Stroop effect can be seen to remain small throughout the entire RT range. For the slow-pace condition, in contrast, the Stroop effect varied markedly as a function of relative response speed, assuming small values for relatively fast responses and large values for relatively slow responses. Confirming these observations, an ANOVA with condition (fast vs. slow pace) as a between-subject factor and congruency and RT bin as within-subject factors yielded as new results a significant main effect of bin, $F(9,198)=547.3$, $p<0.001$, a significant interaction between condition and RT bin, $F(9,198)=17.1$, $p<0.001$, and a significant condition x congruency x RT bin interaction, $F(9,198)=8.1$, $p<0.001$. Results similar to those in the slow-pace condition have been reported for the standard color-word version of the Stroop task (Heathcote, Popiel & Mewhort, 1991; Hommel, 1997).

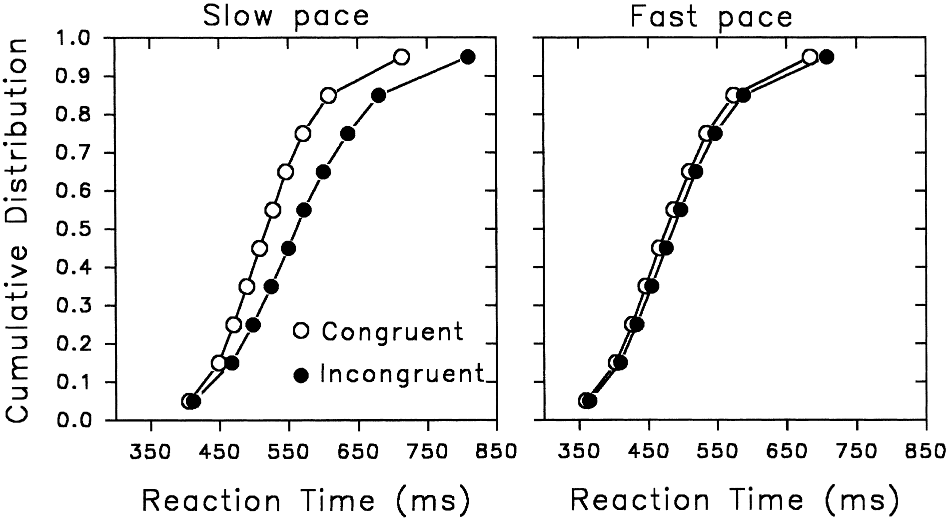

Fig. 1. Vincentized cumulative distribution functions as a function of position-word congruence. Left panel: Slow-pace condition; right panel: Fast-pace condition.

There are several possible interpretations of the dependency of the Stroop effect on relative response speed that was found in the slow-pace condition (for a full and technical exposition, see De Jong, submitted). One is that it reflects the effect of trial-to-trial fluctuations in attentional state. When attention is sharply focused on the instructed task, responses are relatively fast and any influence of word meaning will be effectively inhibited. When attention is only loosely focused, responses are slow and inhibitory control of word reading will be weakened, allowing the Stroop effect to emerge. According to this interpretation, then, these distributional plots would also indicate that subjects were in fact able to completely prevent word meaning from affecting performance and that, in the slow-pace condition, a Stroop effect emerged because they failed to consistently utilize this ability. However, other interpretations cannot be excluded. Hommel (1997) proposed that a dependency of the Stroop effect on relative response speed might be understood in terms of a horse race between the processing of relevant and irrelevant information. When the relevant information is translated into a response before word meaning is encoded, congruence cannot affect RT; such cases would be represented by the faster range of responses. According to a third interpretation, congruence might be assumed to affect the rate of information accumulation, with a higher rate for congruent stimuli, towards a response criterion that varies randomly from trial to trial (e.g., Grice, 1968). For fast, low-criterion responses, the difference in accumulated information between congruent and incongruent trials, and thus the size of the Stroop effect, would then be expected to be smaller than that for slow, high-criterion responses. [1] Because

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[1] This possibility was suggested by Gordon Logan.

these two latter alternative accounts of the distributional plots for the slow-pace condition are consistent with the notion that Stroop interference reflects a fundamental inhibitory limitation, these plots would not seem to provide any convincing and direct evidence for the alternative notion that we wish to advocate here. However, as we will discuss next, the distributional results provide important supporting evidence on this issue.

The horse-race and variable-criterion models predict that manipulations that directly affect speed of responding would, in most cases, indirectly also affect the size of Stroop interference. Thus, the smaller Stroop effect in the fast-pace condition might be a consequence of the enhanced response speed in that condition instead of a direct consequence of superior employment of inhibitory capabilities. This alternative interpretation can be rejected because it implies that, contrary to what is evident from the distributional plots of Fig. 1, the magnitude of Stroop interference should be very similar for the slow-pace and the fast-pace condition across common RT intervals.

The distributional results thus reinforce our initial conclusion that the virtual elimination of the Stroop effect in the fast-pace condition can be primarily attributed to a highly effective employment of inhibitory capabilities that prevents, in terms of the horse-race model, the processing of word meaning from entering the race or, in terms of the variable-criterion model, the rate of information accumulation from being influenced by stimulus congruence. We therefore suggest that the present results provide ample reason to take seriously the possibility that Stroop interference may be attributable, at least in large part, to a failure to fully or consistently employ available inhibitory capabilities. Put differently, these results suggest that Stroop interference may not be an inevitable result of fundamental inhibitory limitations but may be attributable to goal neglect. An important caveat concerns the fact that the Stroop task used here involved only stimulus congruence whereas in the standard color-word Stroop task both stimulus congruence and overlap between relevant and irrelevant stimulus dimensions and the response set are involved (Kornblum, Hasbroucq & Osman, 1990). However, the fact that very similar distributional results were reported by Hommel (1997) for the standard Stroop task provides reason to believe that the present results and their implications, pertain to Stroop-type interference in general.

To illustrate the broader implications of these results, we will consider the effects of normal aging on Stroop-type interference. Several studies have found that old adults produce larger Stroop effects than do young adults, and these findings have been taken to reflect a diminished capacity for inhibitory control in the elderly (Hartley, 1992). According to the previous discussion, this interpretation, though not necessarily incorrect, should be considered premature. Older adults might not be any less capable than young adults of inhibiting irrelevant information, but they might less fully or less consistently utilize their capacity for inhibitory control in the Stroop task. Our present results point to ways in which this ambiguity might be resolved. One major way would be to manipulate the degree to which tasks induce or demand consistent and full employment of subjects' capacity for inhibitory control of irrelevant information. According to the inhibitory-deficit hypothesis, tasks that strongly impose such demands should be expected to exacerbate age-related differences in

Stroop interference. According to the goal-neglect hypothesis, in contrast, such differences should be markedly reduced in such tasks. Interesting in this regard is preliminary evidence, seemingly in favor of the goal-neglect hypothesis, that old adults exhibit inhibition-based negative priming, similar to that exhibited by young adults, only in conditions where selection of task-relevant information is difficult and requires attention to be sharply focused on the relevant task (Kramer, Humphrey, Larish, Logan & Strayer, 1994).

Spieler, Balota and Faust (1996) found that disproportionate age-related increases in Stroop interference were primarily due to a strong increase in the slow tail of the RT distribution for incongruent stimuli. This finding led them to suggest that older adults might be more likely than younger adults to experience attentional lapses, resulting in decreased performance on a proportion of trials. That suggestion is well in line with the goal-neglect hypothesis. Echoing the main theme of the present paper, these authors also proposed that "An important issue that will need to be pursued in the future is the extent to which apparent breakdowns in inhibition reflect real breakdowns in inhibitory processing or reflect a general degradation in the supporting structures that drive task-relevant and appropriate processing pathways" (Spieler et al., 1996, p. 477). We propose that systematic manipulation of task demands along the lines discussed above, in conjunction with distributional RT analyses, provides a promising approach for clarifying the actual causes of age-related differences in Stroop-type interference and related phenomena.

5. Goal neglect and inhibitory limitations in task switching

Natural environments impose different processing requirements at different times, necessitating occasional shifts between different sets of cognitive operations or tasks. The *task-switching paradigm* provides a suitable laboratory situation for systematic study of people's ability to flexibly switch between tasks.

In the task-switching paradigm, the task to be performed on each trial is selected from a set of alternative tasks, usually choice RT tasks. In the standard version of the paradigm, a trial begins with the presentation of an instruction signal, or cue, that signals which of the alternative tasks is to be performed. The instruction signal is followed after a fixed or random delay, called the preparation interval (PI), by the presentation of the imperative stimulus that requires a speeded response. At short PIs, the stimulus is assumed to arrive at a time when preparation, i.e., the selection and implementation of the relevant task set, is still underway. In such cases, the response can be expected to be slow or inaccurate, either because preparation needs to be completed before task performance can proceed or because performance is hampered by a weak or incomplete task set. As the PI is prolonged, providing more time for preparation, responses are expected to become progressively faster and more accurate, perhaps approaching the speed and accuracy of responses in control fixed-task conditions. Thus, switch costs, evaluated relative to a fixed-task baseline, are expected to gradually diminish as the PI is prolonged. The study of switch costs as a function of PI duration might thus provide valuable information regarding the operation of preparatory processes in switching from one task to another (for reviews of earlier results, see (Allport et al., 1994; Rogers & Monsell, 1995).

In the experiment to be reviewed in this section (De Jong, Emans, Eenshuistra, Wagenmakers, submitted, Experiment 2), stimuli were character pairs consisting of a letter and a digit that were displayed close together. One task required a discriminative manual response based on the letter (vowel vs. consonant) and the alternative task a manual response based on the digit (odd vs. even). There were two conditions that differed only in the way in which the required task on each trial was cued. In the implicit-cue condition, the display consisted of a 2×2 grid of four squares. On each trial, a stimulus was displayed in one of the squares, and on successive trials the stimulus was presented in the next square clockwise. Subjects, all college students, were instructed to perform one task when the stimulus appeared in one of the two top squares, and the other task when it appeared in one of the two bottom squares. Because stimulus position cycled in a clockwise fashion, the task changed predictably on every second trial, according to an AABBAABB... scheme. The interval between the recording of a response and the onset of the next stimulus (RSI) served as the PI and was one of three equiprobable values (100, 600, or 1500 ms). In the explicit-cue condition, a trial began with the presentation of a cue, consisting of a square that, on each trial, was located with equal probability either above or below a central reference point. After the PI had elapsed, the stimulus was presented in the square. The assignment of tasks to vertical stimulus position and the possible values for the PI were the same in both conditions. Subjects were instructed to try to use the PI to prepare in advance for the upcoming task, in order to minimize RT.

Note that in both conditions, subjects had to switch tasks on half of the trials, called switch trials, and on the other half, called non-switch trials, they performed the same task as that on the previous trial. The cost of switching tasks can be estimated simply by subtracting RT on non-switch trials from RT on switch trials.

Fig. 2 shows the mean RTs obtained for switch and non-switch trials, as a function of PI and type of cue. RT on non-switch trials exhibited virtually no effects of PI and cue type, consistent with the fact that no switch of task was required on these trials. Very sizable switch costs were obtained at the shortest PI and these initial switch costs were very similar for implicit and explicit cues. Switch costs decreased as the PI was prolonged, more strongly so for explicit cues, indicating that subjects did use the PI to prepare for a change of task. Note, however, that even at the longest PI, that should have provided ample time to finish preparation before the stimulus was presented, sizable switch costs remained, especially so for implicit cues. We will use the term *residual switch costs* to refer to this latter phenomenon.

At first sight, residual switch costs would seem to demonstrate a clear limitation in people's ability to switch from one task set to another by fully endogenous means. Indeed, Allport et al. (1994) attributed residual switch costs to an inability to inhibit recently adopted, but now irrelevant task sets, allowing such sets to interfere with the application of the relevant task set. They proposed that a recently activated task set remains primed involuntarily, and that this priming decays only slowly and passively during prolonged performance of other tasks. Rogers and Monsell (1995) explained residual switch costs in terms of a distinction between an endogenous and an

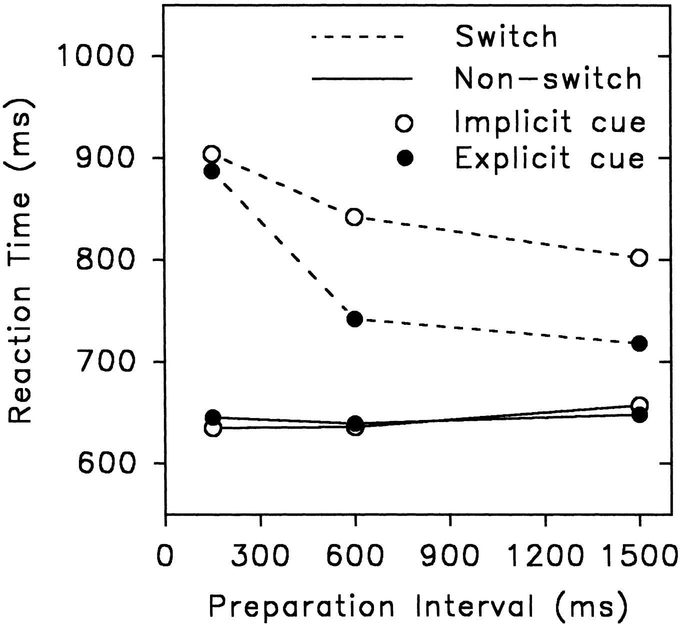

Fig. 2. Mean reaction time in the letter-number switch task, as a function of trial type, cue type, and preparation interval.

exogenous component of task-set reconfiguration. According to their proposal, the endogenous component, which can be carried out during the PI and may be identified with the top-down activation and inhibition by the SAS, is not able to fully settle the competition between the two task schemas and can bring about only a partial reconfiguration of the task set. The exogenous component, which is triggered by the task-relevant stimulus, is thought to settle the competition between schemas, allowing task set configuration to be completed. Though these two accounts differ in important respects, both of them attribute residual switch costs to fundamental restrictions to the quality of the task set that can be attained by fully endogenous means.

An alternative account of residual switch costs in terms of goal neglect is possible, however. Specifically, we have suggested the possibility that such costs may be due to occasional failures to engage in advance preparation during the PI, that, when engaged in, is capable of attaining a complete reconfiguration of task set (De Jong, in press; De Jong et al., submitted). We referred to this possibility as the failure-to-engage (FTE) account and contrasted it with what we will call here the preparatory-limitations (PL) account. Because mean RT results cannot discriminate between these alternative accounts, we turned to distributional analyses for more conclusive evidence on this issue.

CDFs, based on subdividing rank-ordered RTs into quintiles (20% bins), are shown in Fig. 3 as a function of cue type, trial type, and PI (results for the intermediate PI were left out to avoid clutter). Two features of these functions are

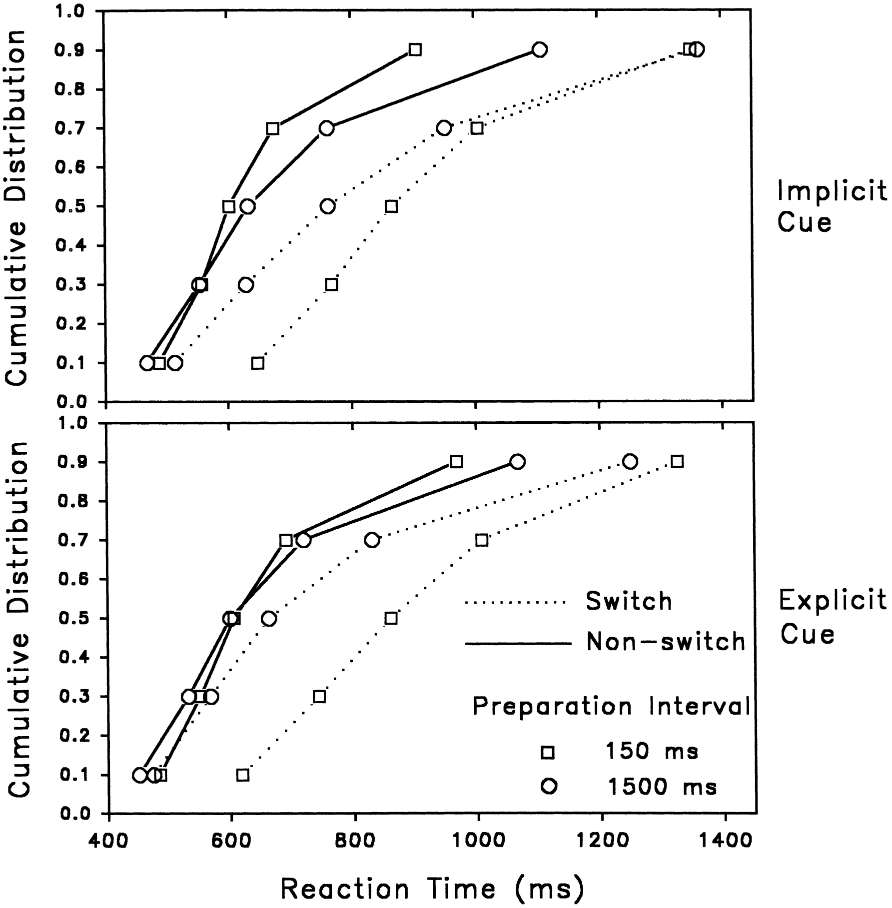

Fig. 3. Vincentized cumulative distribution functions in the letter-number switch task for implicit cues (upper panel) and explicit cues (lower panel), as a function of trial type and preparation interval.

particularly noteworthy. First, for non-switch trials, the longer PI holds a slight advantage over the short PI at the fast end of the functions, but this advantage turns into a pronounced disadvantage toward the slow end. This latter disadvantage may be attributed to frequent failures to actively maintain the still appropriate task set during the PI on non-switch trials; obviously, a longer PI provides more time for the task set to deteriorate when it is not actively maintained. Note that this suggests that task sets can deteriorate markedly within a second or so. Also note that this supports our earlier assumption that a high trial pace (i.e., a short RSI) may help subjects to stay focused on the relevant task in the Stroop paradigm.

The other important feature of Fig. 3 concerns the function for switch trials at the longest PI, the condition that yielded large residual switch costs. The fastest responses in this condition can be seen to be about as fast as the fastest responses on non-switch trials, whereas the slowest responses were about as slow as the slowest responses on switch trials at the shortest PI. The former feature poses obvious problems for the PL hypothesis, because it suggests that subjects were often able to attain completely reconfigured task sets during the PI on switch trials. The latter feature suggests that subjects quite frequently failed to take any advantage of the PI as an opportunity to prepare in advance for a change of task. Taken together, these two features would seem to be exactly in line with the FTE account of residual switch costs.

We have developed a theoretical model and an associated analytical method to put these as yet qualitative ideas to a rigorous quantitative test (for technical details, see De Jong, in press; De Jong et al., submitted). The model is based on the notion that the PL and FTE accounts represent the extremes of a theoretical continuum along which variable proportions of residual switch costs are assigned to fundamental preparatory limitations and failures to engage in advance preparation. The analytical method is used to determine which specific combination of these two factors provides the best fit of the CDFs for the various experimental conditions. For the present experiment, the best-fitting model for both implicit and explicit cues turned out to be the pure FTE model that assumes no fundamental preparatory limitations and attributes residual switch costs solely to failures to engage in advance preparation. The probability of such failures averaged 46% for implicit cues and 25% for explicit cues.

An intention-activation account of failures to engage in anticipatory preparation was proposed by one of us (De Jong, in press). According to this account, effective use of opportunities for advance preparation requires an explicit goal or intention to engage in such preparatory activities to be added to the basic goal structure that governs performance in the task-switching paradigm, and retrieval and the carrying out of this intention at the proper time, that is, at the start of the PI. Success in intention retrieval is assumed to depend on the joint influence of two factors: the activation level of the intention and the characteristics of the retrieval cue. Thus, frequent failures to engage in advance preparation are due primarily to low levels of intention activation and, in that sense, reflect goal neglect. However, low levels of intention activation can be compensated for by strong environmental support in the form of strong retrieval cues. From this perspective, the fact that failures to engage in advance preparation occurred much less frequently with explicit cues can easily be understood by noting that explicit cues, unlike implicit ones, constitute strong retrieval cues, serving much like external commands "Now do this".

To summarize, we have discussed a new approach that focuses on variability of performance across trials in order to assess the relative contributions of goal neglect and limitations of goal-schema translation (i.e., task set reconfiguration by fully endogenous means) to performance limitations in a paradigm that captures an essential aspect of cognitive flexibility in daily life, the anticipation of and preparation for an upcoming change of activity. In contrast to previous accounts that attributed residual switch costs to fundamental limitations of goal-schema translation, the present approach shows that such costs can be attributed almost exclusively to goal neglect.

6. Conclusions

Interference effects might reflect real limitations in inhibitory capabilities, failures to fully or consistently utilize such capabilities, or some combination of these factors. We proposed that important clues as to the fundamental cause or causes of interference effects may be obtained from examination of their relative robustness against variations in the degree to which attention is focused on the instructed task. Such variations can be induced by explicit manipulation of task requirements or instructions or take the form of random fluctuations in attentional state during task performance. Convergent evidence may be obtained by conjoint examination of the effects of both systematic and random variations in attentional focus.

We have illustrated this approach for two major types of interference effects that have commonly been attributed to fundamental inhibitory limitations: Stroop-type interference and residual switch costs. We presented results that indicate that both types of effects can often be attributed to failures to fully or consistently exploit inhibitory capabilities in the executive control of task performance, i.e., to goal neglect, rather than, or in addition to, real inhibitory limitations. These initial results provide promising indications of the potential of the present approach. Though the general inferential logic of the approach requires further development, we hope that the present results will encourage other investigators to pay due attention to variability in task performance, both within and between experimental conditions, as a potentially valuable source of evidence for distinguishing between various possible reasons for performance limitations or deficits in conflict situations.

We have attributed incomplete or inconsistent employment of inhibitory capabilities to goal neglect. Though goal neglect might sometimes be caused by a lack of motivation or lack of cooperation, we believe that the general case is more complex and far more interesting. As one example, goal neglect of the sort that we found in the Stroop task need not be considered maladaptive. From a general perspective, relatively small and manageable interference effects may be deemed a small price to pay for preserving the ability to monitor the environment for other potentially important or useful information (Simon, 1994). This purported bias against strict focusing of attention might only be overcome when such focusing is necessary in order to attain and maintain adequate performance (Yantis & Johnston, 1990). As another example, we have identified a variety of factors that can markedly influence the incidence of preparatory failures in the task-switching paradigm, i.e. the extent of goal neglect.

Such factors include the length of trial blocks, time on task, speed-accuracy instructions, motivational manipulations, and individual characteristics such as intelligence and age (De Jong, in press; De Jong, Schellekens & Meyman, in preparation). The diversity of these factors, and of the interactions between them, pose a challenge to attempts to formulate explicit accounts of goal activation mechanisms, even in the restricted domain of task switching. On the positive side, however, we believe that the detailed information regarding the nature and role of goal activation in task performance that may be uncovered by the approach proposed here, in conjunction with neurobiological evidence (Duncan, 1995), will be instrumental in future attempts to develop broad theoretical concepts such as goal activation and goal neglect into true explanatory constructs.

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