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Competition between automatic and controlled processes

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Abstract

We investigated the competition between automatic and controlled processes in a word stem completion task. Prime-display duration and the prime-target interval were manipulated. On each trial a masked prime was displayed briefly, followed either immediately or after a delay by a word stem. The subjects were required to complete each stem with the first word that came to mind, to report any prime they could identify, and not to give as completion any identified prime. By the assumption that automatic processes require less stimulus input and can be completed faster than consciously controlled processes we expected a stronger performance contribution from automatic processes with the shorter prime-display durations and in the immediate stems condition. The results confirmed this expectation. The findings highlight that consciously controlled processes require more time to run their course than unconscious automatic processes.

1. Introduction

Performance on a wide range of cognitive tasks is determined by the interplay of automatic and controlled processes. Automatic processes are assumed to be fast, to

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require minimal processing resources and to occur without conscious control. By contrast, controlled processes are slower, resource demanding and under direct conscious control. It is widely recognized that in the domain of memory, for example, automatic and controlled processes complement each other to facilitate performance under some test conditions whereas they oppose each other and reduce performance under other conditions (e.g., Jacoby, 1983; Mandler, 1980). To illustrate, if a test requires making old/new decisions about words, automatic processes can improve performance by providing a basis for guessing. This occurs because exposure to a word primes its processing, and as a consequence, the subsequent processing of the same word is more fluent (i.e., more automatic) and the increase in processing fluency generates a feeling of familiarity (e.g., Jacoby, 1983; Kolers, 1985; Mandler, 1980). However, the processing of a test word may be facilitated for other reasons (e.g., because the word is common in the language, or because it appeared elsewhere in an experiment). When this occurs, the feeling of familiarity that accompanies a test item might be attributed to the wrong source and thereby lead to a false alarm response on a recognition test or to an intrusion response on a recall test. In either of these cases, controlled processes must be recruited to oppose the influence of automatic processes.

In order to learn more about the interplay of controlled and automatic processes, a number of recent investigations have focused on word-stem completion test performance under various study and test conditions. In the first experiment of this kind, Forster, Booker, Schacter, and Davies (1990, Exp. 1) presented trials consisting of a masked prime word that was followed immediately by a word-stem—the first three letters of a word (e.g., app____)—with instructions to complete each stem with the first word that came to mind. The display duration of the primes was kept brief in an attempt to ensure that subjects would not be aware of them. The results showed that subjects produced the prime words as stem completions more often than expected by chance (i.e., in the absence of seeing them as primes), and this priming effect was interpreted as evidence that automatic processes influence stem-completion test performance. Although this interpretation is reasonable, the method that was used and the results do not preclude the possibility that performance was mediated by consciously controlled processes or by a combination of automatic and controlled processes.

To disentangle the contributions of automatic and controlled processes, Debner and Jacoby (1994) examined stem-completion test performance in a condition that required subjects *not to give as stem-completions* any primes they were able to identify and remember (cf., Jacoby, 1991; Jacoby & Whitehouse, 1989). They displayed masked primes either for 50 ms or for 500 ms, and the stem-completion test results showed a priming effect in the short-display condition but not in the long-display condition. Debner and Jacoby interpreted this pattern of results as evidence that the short displays were sufficient to facilitate the subsequent automatic reprocessing of the prime words, but not long enough to permit their consciously controlled processing. Thus, when instructed not to give as completions any words that had appeared as primes, subjects produced the prime words as completions only in the short-display condition where their production was facilitated by automatic processes. By contrast, in the long-display condition, subjects were able to rely on controlled processes and thus avoided giving the primes as stem completions.

In parallel to Debner and Jacoby (1994), Merikle, Joordens, and Stolz (1995) conducted an experiment that was designed to map out across a wider range of prime display durations the relative contributions made by automatic and controlled processes. They showed masked prime words for 29, 43, 57, 71, or 214 ms, and subjects were required to complete word-stems according to similar instructions as used by Debner and Jacoby (1994). The results showed no evidence of priming in the 29 and 214-ms display conditions, but there was significant priming in the 43, 57, and 71-ms conditions. Merikle and his colleagues explained this pattern of findings by focusing on the relative contributions of automatic and controlled processes. They argued that in the 29-ms condition, the primes were presented for too little time to affect either type of processing. In the 43, 57, and 71-ms conditions, the displays were sufficiently long to permit the perceptual processing of the primes but not long enough for their conscious identification. Consequently, on the stem-completion test, no consciously controlled processes were available to counteract the influence of the primed perceptual processes. Finally, the 214-ms condition permitted both the perceptual processing of the prime-words as well as their conscious identification, and thus, on the test subjects were able to rely on consciously controlled processes to avoid giving the same words as stem completions.

The interpretations offered by Debner and Jacoby (1994) and by Merikle et al. (1995) focus on the widespread assumption that automatic processes are faster than controlled processes. By this assumption, it follows that the former but not the latter would influence performance when prime-words are displayed for only a brief duration. However, this type of interpretation fails to distinguish prime-display durations that are required to initiate automatic and controlled processes from those required for these processes to run to their full course. It seems equally plausible to argue that even a very brief prime display is sufficient to initiate automatic *and* controlled processes, but because the latter are slower than the former, controlled processes can influence performance only under conditions where they are allowed to run to completion prior to the presentation of a test-item. The present study was designed to investigate this possibility.

Consistent with the foregoing assumptions about the time course of automatic and controlled processes, it would seem that the method used by Merikle et al. (1995) was biased against capturing the full influence due to consciously controlled processes. By their method, each masked prime was followed immediately by a word-stem. Thus, with a 0-ms prime-to-test-stem interval, the slower controlled processes were able to influence performance only when primes were displayed for a long time (i.e., 214 ms), even though they might have been recruited also by the much shorter prime displays (e.g., 29 or 43 ms). Based on previous investigations that required reading or naming displayed words or making lexical decisions about letter strings, it seems that several hundred ms are required for the conscious perception of a word. Thus, when the prime-to-test-stem interval is shorter, the test-stem occurs too soon, before a conscious perception has occurred. Moreover, an early test-stem may disrupt on-going controlled processes and further reduce their potential influence on performance, or it may make it difficult if not impossible for subjects to separate conscious perceptions produced by primes from those produced by test stems. Alternatively, if the display of the test-stem were delayed sufficiently, controlled processes may run their course and may influence performance under conditions with much shorter prime-displays than those estimated by Merikle et al. (1995).

To examine this possibility, the present study assessed performance on a stem-completion test under two different prime-to-test-stem interval conditions and five different prime-display durations. The basic method was similar to that used by Merikle et al. (1995), with prime display durations of 0, 16, 33, 50, and 66 ms. In one condition, the test-stem was displayed immediately after the masked prime, that is, with a 0-ms prime-to-test-stem interval. In the other condition, the prime-to-test-stem interval was 2 s, and a blank was used to fill the interval between each prime and test-stem. The latter condition is similar to that used by Debner and Jacoby's study where the prime-to-test-stem interval was filled by a 500 ms blank. However, their study cannot answer the main question that motivated the present investigation because it did not include a prime-to-test-stem interval manipulation. We anticipated that compared to the immediate-stems condition, in the delayed-stems condition consciously controlled processes would become available to reduce priming with shorter prime displays.

Our study had two additional objectives: first, to provide direct evidence that the conscious perception of words increases with prime-display duration and is augmented by the addition of a prime-to-stem delay, and second, to validate subjects' compliance with the instructions not to give prime words as stem completions. Towards these goals, we required subjects to report each prime-word that they could identify. We anticipated that subjects would identify and report a greater proportion of the primes displayed for longer durations, and that they would report more primes in the delayed-stems condition. Moreover, if subjects comply with the instruction not to give as stem completions any primes that they could identify, we expected to find a negative correlation between self-reported words and completion test performance.

2. Method

2.1. Participants

The participants were 40 student volunteers from the University of Zurich, aged 20–35 ($M = 25.8$ years). An equal number was pseudo-randomly assigned to two experimental conditions that differed by the interval between the presentation of each prime and corresponding word-stem: immediate-stems versus delayed-stems.

2.2. Materials

The materials were 140 familiar German nouns, 70 with five letters and 70 with six letters, selected from the norms by Meier and Eckstein (1998). An additional six words were selected and used for instruction and practice. The first three letters—the stem—of each word (e.g., Mus___) were unique to that word. Each stem could be completed with at least three common words (e.g., *Mus*kat, *Mus*ter, *Mus*eum). The words that were used as primes were never the most common stem-completions. According to the Meier and Eckstein norms, the critical words occur as stem completion about 12% of the time in the absence of prior study (i.e., under baseline conditions).

The critical words were arranged to form five lists each with 14 five-letter words and five lists each with 14 six-letter words. All ten lists had comparable normative baseline completion rates.

2.3. Procedure

Subjects were tested individually. They were informed about the general purpose of the experiment and about the specific events that defined each trial. As illustrated in Fig. 1, each trial started with a fixation point, a plus sign that was displayed for 500 ms. The fixation point was replaced by a 200-ms blank interval, which in turn was replaced by a 200-ms mask consisting of a random series of letters (i.e., EMXDGF), then by the display of a prime, another 200-ms random letter-mask and finally a word-stem. The display duration of the primes, which varied according to conditions, was 0, 16, 33, 50, or 66 ms, respectively. In the 0-ms prime condition, a 16-ms blank was inserted between the two masks. As depicted in Fig. 1, in the delayed-stems condition, a blank was displayed for 2 s immediately before each word-stem. In all conditions, the word-stem remained on the screen until the subject entered a completion via the keyboard or until 15 s had elapsed. Then the next trial began. All stimuli were displayed in the center of the computer screen as black characters against a white background. The first letter of each prime and stem was shown in capitals and all other letters were in lower case. The size of each character was approximately 2 cm high and 1.5 cm wide.

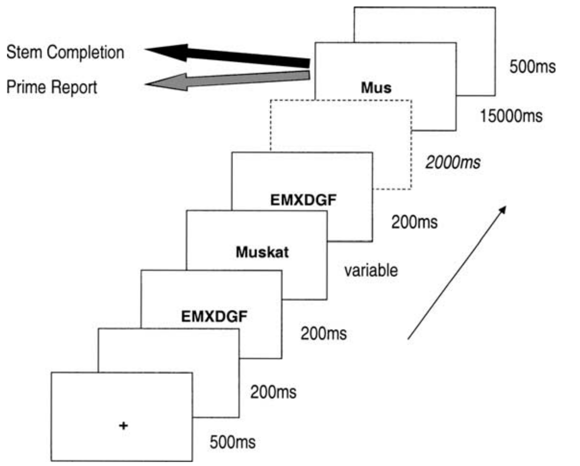

Fig. 1. The figure shows the sequence of events that occurred on each trial. The solid displays represent the events in the immediate-stems condition, and the dashed display shows the addition of the blank in the delayed-stems condition.

Subjects were instructed to complete each word-stem with the first five- or six-letter word that came to mind. They responded by entering these completions on the keyboard. In addition, they were instructed to report any prime word they were able to identify and not use this word as a stem completion. In the delayed-stems condition, subjects were also informed that a 2-s blank would be shown immediately before each word-stem. Furthermore, they were advised to report any identified primes either during this blank period or after completing the word-stem. The experimenter recorded immediately all prime words reported by subjects.

The main part of the experiment consisted of two blocks of 70 trials, with five-letter words serving as primes for one block and six-letter words for the other. The order of the blocks was counterbalanced across subjects. The two blocks were separated by a brief pause. For each subject, one of the critical word lists described in Section 2.2 was used for presentation in each prime-duration condition, and across subjects, all lists were used equally often in each prime-duration condition. The trials within each block were ordered randomly. The experiment required about 30 min.

2.4. Design and analysis

Prime-display duration (0, 16, 33, 50, and 66 ms, respectively) was manipulated within subjects and stem-delay condition (immediate-stems, delayed-stems) was manipulated between subjects. For the main data analyses, we used a two-factorial analysis of variance (ANOVA) with prime-duration and stem-delay condition as factors. In addition, we used correlations in order to examine the relationship between stem completion test performance and the frequency of reporting the primes in each condition. For all analyses, the α level was set at .05.

3. Results

The main objective of the experiment was to examine stem-completion test performance across different prime-display durations and in different prime-to-stem delay conditions. The critical results are summarized in the top panel of Fig. 2. In the 0-ms prime-display condition (i.e., in the baseline condition), the target words were produced as stem completions about 10–11% of the time. This completion rate matches the normative data by Meier and Eckstein (1998). The remaining means show evidence of priming, that is, above baseline stem completion test performance, in all other prime-display conditions. More important, in the immediate-stems condition, the amount of priming increased with longer prime displays, whereas in the delayed-stems condition, the amount of priming increased initially with longer prime displays but then declined in the longest display condition. An ANOVA with prime-display condition as a within subject factor and stem-delay condition as a between subject factor confirmed these observations. It revealed a significant main effect for prime-display duration, $F(4,152) = 25.08$, $MSe = .01$, $p < .01$ and for stem-delay, $F(1,38) = 5.86$, $MSe = .03$, $p < .05$, as well as a significant interaction between these factors, $F(4,152) = 2.83$, $MSe = .01$, $p < .05$. Follow-up t tests showed a significant difference in the amount of priming between the two stem-delay

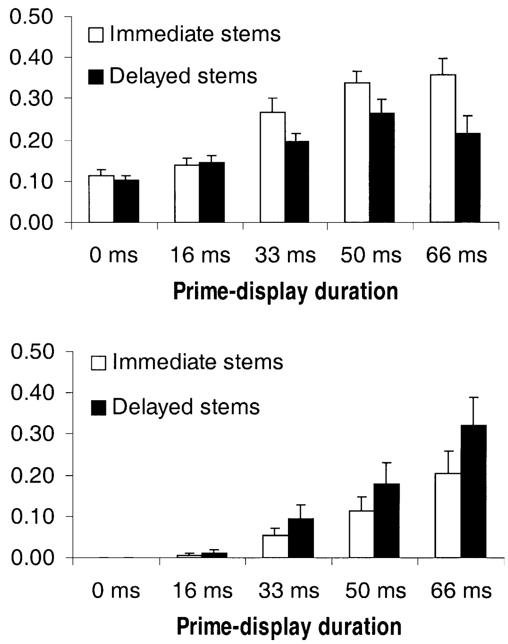

Fig. 2. The top panel shows the mean proportion of word stems completed with primes in all experimental conditions, and the bottom panel shows the mean proportion of primes that were consciously identified and reported in each experimental condition. Bars represent standard errors.

conditions with a 66-ms prime-display duration, $t(38) = 2.4, p < .02$, but not for any other prime-display duration.

The second objective of the present study was to obtain direct evidence that the conscious perception of words increases with prime-display duration and is augmented by the addition of a prime-to-stem delay. The relevant results are summarized in the bottom panel of Fig. 2. The means show that subjects were able to identify primes displayed for as little as 33 ms, that prime identification increased in parallel with prime-display duration, and that this increase was steeper in the delayed-stems condition. We used an ANOVA to compare prime identification in the three prime-display conditions where performance was significantly above zero (i.e., >16 ms). The results showed a significant effect due to prime displays, $F(2, 76) = 34.3$, $MSe = .01$, $p < .01$. No other effects reached significance.

In a final analysis, we examined the relationship between prime identifications and stem completions in the same three prime-display conditions. The results, summarized in a series of scatterplots in Fig. 3, show a small positive correlation ($r = .21$) between prime identification and stem completion performance in the 33-ms prime display immediate-stems condition, and an even weaker positive correlation ($r = .04$) in the corresponding delayed-stems condition. As expected, these correlations became negative and stronger with longer prime displays. With the 50-ms prime displays, the correlations were $-.22$ ($p = .36$) and $-.5$ ($p < .05$) in the immediate- and

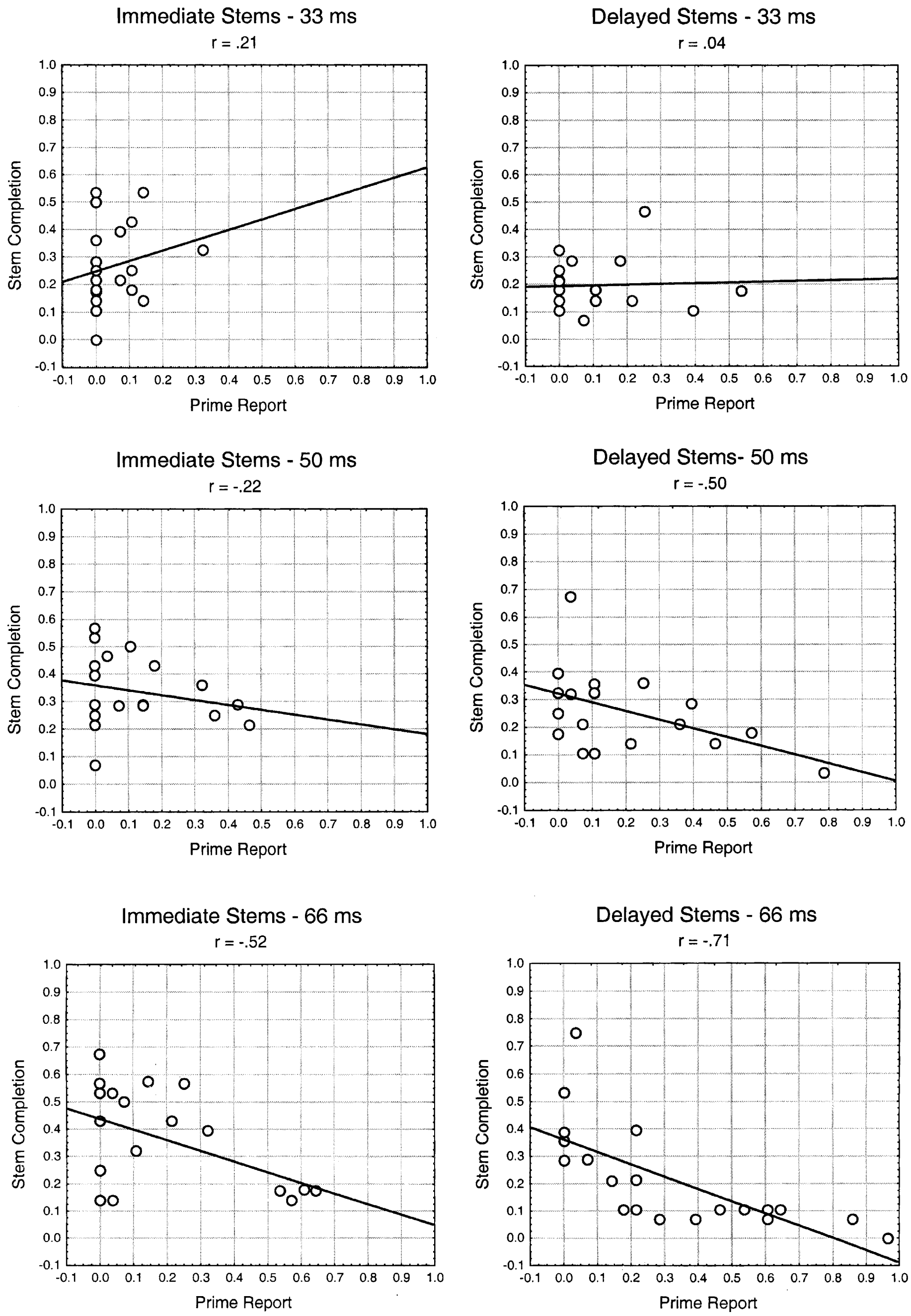

Fig. 3. Scatterplots of the relationship between consciously reported primes and stem completion performance. Each data point represents an individual participant.

delayed-stems condition, respectively, and with the 66-ms primes, they were −.52 ($p < .05$) and −.71 ($p < .05$), respectively.[1]

4. Discussion

The primary objective of this study was to learn more about the interplay of automatic and controlled processes under conditions that were suspected to facilitate or hinder performance contributions due to slow-acting consciously controlled processes. The results in Fig. 2 are most directly relevant to this issue. They show that the size of priming effects increased with prime-display duration, and that this increase was steeper and extended even to the longest prime displays in the immediate—but not in the delayed-stems condition. By contrast, although conscious identification of primes also increased with prime-display duration, this increase tended to be consistently steeper in the delayed-stems than immediate-stems condition.

The pattern of priming effects suggests that even the shortest prime displays (e.g., 16 and 33 ms) were occasionally sufficient to trigger automatic perceptual processes (however, in these display durations, performance was not significantly different from baseline). This conclusion builds on the assumption that priming effects reveal influences due to automatic perceptual processes when subjects are explicitly instructed not to give consciously identified prime-words as stem completions. The prime report data in the bottom panel of Fig. 2 show that the same brief prime displays were only sufficient to initiate a limited degree of consciously controlled processing.

The influence of both types of processing grew with longer prime displays. Based on our data and previous findings (i.e., Merikle et al., 1995), it seems that the amount of priming reached an asymptotic level with displays of about 66 ms in the immediate-stems condition, thus suggesting that prime displays of 50–66 ms are sufficient to capture the full contribution of automatic perceptual processes (i.e., about 20% priming). This notion is consistent with the finding that priming effects on stem completion tests are rarely larger than 20% (see Graf & Masson, 1993). A similar claim cannot be made about consciously controlled processes however. These processes appear to unfold more slowly as evidenced by the finding that in the 50 and 66-ms conditions, less than half of all primes were successfully identified and stem completion performance still showed significant priming effects. The priming effects

[1] To further investigate the relationships between automatic and controlled influences we compared stem completion performance of those subjects, who reported at least one item and those who did not report any item at all. No differences were significant in the immediate-stems condition. However, in the delayed-stems condition two effects are noteworthy. First, with the 16-ms prime displays, those four subjects who reported at least one prime word completed significantly more stems ($M = .21$) with primed words than those who did not report any primes ($M = .13$), $t(18) = 2.30$, $p < .05$. Second, with the 66-ms prime displays, the 16 subjects who reported at least one prime completed significantly fewer stems with primed words ($M = .17$) than those who did not report any primes ($M = .39$), $t(18) = 2.27$, $p < .05$.

would have disappeared with substantially longer display durations [e.g., 214 ms, as in the study by Merikle et al. (1995)] that permit the full conscious identification of all primes.

The prime report data show that conscious perception of words grows with prime display durations, but more importantly, it is also affected by the opportunity for post prime processing (i.e., by a non-zero prime-to-stem interval). If the prime-to-stem interval is too short, controlled processes cannot unfold their full influence. As a consequence their potential influence on performance is underestimated. Therefore, we must ensure not only that both types of processing can be initiated but also that both types of processing have time to run their course. Because there was no opportunity for post-prime processing, it appears that the method used by Merikle et al. (1995) restricted the potential performance contribution of controlled processes (a similar claim was made by Haase & Fisk, 2001).

A recent study by Visser and Merikle (1999) provides further insight into how post-prime processing might be influencing conscious identification of primes. They used the basic method from Merikle et al. (1995) together with a monetary incentive to motivate subjects not to offer prime-words as stem completions, and the results showed less priming in the motivated than non-motivated subject group. Visser and Merikle interpreted this outcome as reflecting a difference in attention to the task, raising the possibility that motivated subjects responded more cautiously. It may be that the delayed-stems condition in the present study had the same effect as the incentive used by Visser and Merikle; it gave subjects an opportunity to weigh more carefully the evidence obtained from the primes and to respond more cautiously on the stem completion test.

The notion that a subjectively controlled response criterion modulates conscious identification of primes, and thus stem-completion test performance, reveals a close operational link between the prime-display manipulation and the stem-delay manipulation used in the present study. We assumed that the prime-display manipulation would influence the amount, and perhaps the type, of information that is processed about each prime. Thus, with longer prime-displays and more information, subjects would be able either to meet the response criterion more quickly or to meet a higher response criterion. The prime report data from the present study do not permit us to distinguish between these alternatives.

Finally, the prime report data from the present study are novel, and to our knowledge the first direct validation of subjects' compliance with the "exclusion" instructions. As expected, the findings in Fig. 3 show the different relationships between priming and conscious prime-word identification, and more interestingly, they highlight the changing and strengthening of these relationships across the prime-duration and stems-delay conditions. One possibility is that this outcome is artificial, perhaps a consequence of the floor effect in reporting primes in the shorter prime-display conditions. A more interesting possibility is that this finding occurs because the prime-display manipulation and the stem-delay manipulation trigger a change in subjects' response criterion. With a low criterion, we expect only a minimal or no connection between prime reports and stem completion test performance, whereas with a high criterion, we expect that subjects would not complete any word stem with a primed word under conditions where it can be consciously identified.

To summarize, our findings do not rule out that both, automatic and controlled processes are initiated similarly. However, they highlight that consciously controlled processes take longer to complete than automatic processes to complete. This result has important implications for the assessment of automatic and controlled performance contributions.

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