

Cognitive load at encoding hurts memory selectivity



Mirela Dubravac^{id} and Beat Meier^{id}

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Abstract

People remember more task-relevant information than task-irrelevant information, and this difference can be conceptualised as memory selectivity. Selectively attending and remembering relevant information is a key ability for goal-directed behaviour and is thus critical for leading an autonomous life. In the present study, we tested the influence of cognitive load on memory selectivity. Specifically, we investigated the effects of task switching, stimulus presentation duration, and preparation time during incidental learning in five experiments ($N=351$). For the study phase, we used two established task switching paradigms (cued and alternating runs). Participants were presented with picture–word pairs on which they performed one of two classification tasks. Depending on the task, participants had to attend to the picture or to the word. In a subsequent surprise recognition test, we assessed how well they remembered the targets and distractors. After 1 day or 1 week, a second recognition test assessed the longevity of the effects. Results showed that task switches (vs task repetitions), short (vs until response) stimulus duration, and short (vs long) preparation time reduced memory selectivity. The effect of preparation time was significant only in cued task switching but not in the alternating runs paradigm, highlighting the importance of advance cues for preparation effects on memory. With longer retention intervals, the effects washed out. In conclusion, higher cognitive load leads to lower selective attention and, consequently, to lower memory selectivity. The present study provides links between theories of attention, cognitive control, and memory.

Keywords

Memory; attention; cognitive control; task switching; cognitive load

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Memory and attention are inextricably linked (Chun & Johnson, 2011; Chun & Turk-Browne, 2007; Logan, 2002). Previous experiences guide attention allocation, and attention, in turn, controls the contents of working memory and long-term memory. While pursuing our goals, we switch between different tasks many times a day and shield the current task-set by directing our attention selectively towards task-relevant information. This results in better memory for relevant over irrelevant information, that is, memory selectivity (Richter & Yeung, 2012, 2015, 2016). Richter and Yeung (2012) discussed memory selectivity in the context of the load theory of selective attention (Lavie, 2005) and resource-sharing accounts (Liefvooghe et al., 2008). As task switching affected only the identity, not the amount, of information encoded into long-term memory, task switching does not reduce general encoding resources (Richter & Yeung, 2012). Rather, task switching reduces the selectivity of encoding. This suggests that task

switching and selective encoding share cognitive control resources. To test this interpretation, we assessed the interactive effects of different cognitive load manipulations.

The load theory of selective attention combines early and late selection processes in a hybrid model for attention and distinguishes between perceptual and cognitive load (Lavie, 2000, 2005, 2010). Perceptual processing has capacity limits and operates automatically (Lavie, 1995). When perceptual load is low, task-irrelevant distractors are automatically processed. When perceptual load is high, however, the processing capacity is exhausted by the processing of task-relevant targets, and thus distractors are not

Institute of Psychology, University of Bern, Bern, Switzerland

Corresponding author:

Mirela Dubravac, Institute of Psychology, University of Bern, 3012 Bern, Switzerland.

Email: dubravac.mirela@hotmail.com

processed. Several studies support this theory by showing that various manipulations of perceptual load in a target task affect the processing of distractors (Brand-D'Abrescia & Lavie, 2007; Forster & Lavie, 2008; Lavie, 1995; Lavie & Cox, 1997; Lavie et al., 2003). Further studies showed that perceptual load reduced subsequent distractor memory (Jenkins et al., 2005; Lavie et al., 2009). In other words, perceptual load *enhances* selective encoding (see also Middlebrooks & Castel, 2018).

When perceptual load is low, a second, higher-order control mechanism that actively inhibits attention to irrelevant distractors comes into play (Lavie, 2000). The efficiency of this control mechanism depends on the *cognitive* load associated with the target task (Lavie et al., 2004). When cognitive load is low, there is enough cognitive control capacity to inhibit distractor interference. When cognitive load is high, however, control functions are already absorbed by the target task, and thus there is not enough capacity to inhibit distractor interference. Switching between different tasks and actively maintaining contents in working memory require cognitive control functions (Lavie, 2010). Supporting studies showed that cognitive load increased distractor interference (Lavie & De Fockert, 2005; Lavie et al., 2004). Although not explicitly framed within this theory, later studies found that cognitive load associated with task switching and response inhibition reduced target memory and enhanced distractor memory (Chiu & Egner, 2015a, 2015b, 2016; Muhmenthaler & Meier, 2019a, 2019b; Reynolds et al., 2004; Richter & Yeung, 2012, 2015). In other words, cognitive load *impairs* selective encoding.

According to the “time-based resource-sharing model,” cognitive load results from concurrent attention-demanding activities competing for limited cognitive control resources (Barrouillet et al., 2004, 2007). For example, task switching loads cognitive control because it involves an attention-demanding and time-consuming task-set reconfiguration process diverting attentional resources from selective stimulus processing (Liefoghe et al., 2008; Vandierendonck et al., 2010). Accordingly, we operationalised cognitive load as a function of the proportion of time during which concurrent cognitive processing captures attention (Barrouillet et al., 2007). Processes that load cognitive control concurrently should therefore divert attentional resources needed for selective encoding. Specifically, we tested the independent and interactive effects of task switching, stimulus presentation duration, and the time for advance task preparation on subsequent memory selectivity. Presenting task-relevant stimuli only for a short amount of time increases cognitive load because the stimuli need to be actively maintained in working memory. In contrast, preponing task-related processes, however, alleviates cognitive load through the sequencing of cognitive operations. Before introducing our own study, we briefly review similar studies that held the perceptual

load low (thus allowing for distractor processing) and varied the cognitive load by using a task switching paradigm to investigate the influence on memory.

As task switching loads cognitive control, selective attention is impaired on switch compared with repeat trials (Lavie, 2010; Liefoghe et al., 2008). The impaired selective attention on switch trials is mirrored in lower memory for to-be-attended target stimuli presented on switch compared with repeat trials (Muhmenthaler & Meier, 2019b; Reynolds et al., 2004). Moreover, task switching has an opposite effect on to-be-ignored distractor stimuli. For example, Richter and Yeung (2012) used a cued task switching paradigm with picture–word compounds as stimuli to investigate subsequent memory for the pictures and words. Depending on the cue signalling the task to be performed (picture vs word classification), participants either attended to the picture or the word. Task switching impaired recognition memory for targets, but actually improved memory for distractors. This finding suggests that task switching impairs selective attention at encoding resulting in lower memory selectivity at retrieval. A follow-up study replicated the switch cost on memory selectivity and investigated the impact of preparation time, voluntary task switching, and motivation (Richter & Yeung, 2015). Most relevant for the present study, a shorter (vs longer) cue-to-stimulus interval (CSI) reduced memory selectivity. This finding suggests that limiting the time for advance task preparation loads cognitive control at the time of stimulus presentation, which impairs selective encoding resulting in lower memory selectivity.

The cost of task switching on memory selectivity is also evident in predictable task switches. Muhmenthaler and Meier (2019b) presented participants pictures of animals and objects on which they had to perform two classification tasks in alternating runs. In a subsequent recognition test, participants recognised more pictures from repeat than switch trials, and this effect was larger for bivalent (i.e., relevant for two tasks) than univalent (i.e., relevant for only one task) stimuli (Muhmenthaler & Meier, 2019b). A follow-up study confirmed the finding of switch costs in the alternating runs task switching paradigm with words and a free recall memory test (Muhmenthaler & Meier, 2019a). The findings suggest that task switching impairs encoding of task-relevant information by withdrawing attention from target encoding in order to enable operations on the task level. Due to the lack of an exogenous cue signalling the upcoming task, the alternating runs paradigm requires keeping track of the task sequence, which may pose a further cognitive load.

In contrast to the cued task switching paradigm, the role of task preparation has not been investigated in the alternating runs paradigm, and one goal of the present study was to fill this gap. As an exogenous task cue triggers top-down preparation processes that activate the appropriate task-set in advance, we suggest that a short CSI impairs

selective encoding because the preparation processes are not yet completed at stimulus presentation (Koch, 2003; Koch & Allport, 2006; Meiran, 1996; Monsell, 2003; Rubin & Koch, 2006). In other words, if preparation time is too short, selective encoding is impaired. In the alternating runs paradigm, however, there is no exogenous cue triggering preparatory processes, questioning an effect of the response-to-stimulus interval (RSI) on encoding. Furthermore, the studies of Richter and Yeung (2012, 2015) and Muhmenthaler and Meier (2019a, 2019b) differ in respect of stimulus presentation duration, which may also affect selective encoding. A shorter stimulus presentation duration can pose cognitive load because a stimulus representation needs to be actively maintained in working memory, which is not the case if the stimulus is presented until response.

The present study

We present five experiments in which we investigated the interactive effects of different cognitive load manipulations on subsequent memory selectivity. Specifically, we manipulated task switching, preparation time, and stimulus presentation duration. We used the same stimulus materials and tasks in both the cued and the alternating runs task switching paradigms in order to compare the effects across paradigms. Furthermore, we were interested in whether the effects would change with longer retention intervals. Therefore, we also included retention intervals of 1 day and 1 week. As the stimuli are encoded in the context of increased cognitive load (i.e., on switch trials), it could be that consolidation strengthens the stimulus-context association. After 1 day, the effect on memory selectivity may become even stronger. Alternatively, the memory selectivity effect may wash out after a longer retention interval. In addition, we used the remember/know procedure to assess the contribution of recollection and familiarity to recognition memory performance (Dubravac & Meier, 2021; Gardiner & Java, 1991; Meier et al., 2013; Muhmenthaler & Meier, 2019b; Tulving, 1985; Yonelinas, 2002). Typically, the proportion of remember-responses to know-responses declines with longer retention intervals indicating a weakening of the memory traces over time (Meier et al., 2013; Yonelinas, 2002). Experiment 1 tested whether recollection would contribute to the switch-related reduction of target memory (Muhmenthaler & Meier, 2019b). Conversely, we predicted that familiarity would contribute to the switch-related increase in distractor memory.

As cognitive load impairs selective attention (Lavie, 2010), we suggest that cognitive load at encoding determines what is later remembered (i.e., memory selectivity). According to the time-based resource-sharing model, cognitive load results from concurrent activities that compete for limited cognitive control resources (Barrouillet et al.,

2004, 2007). As processes required for selective encoding and processes required for task switching (e.g., task-set reconfiguration) compete for limited cognitive control resources (Liefoghe et al., 2008; Vandierendonck et al., 2010), we hypothesised that task switching impairs selective encoding (Richter & Yeung, 2012, 2015). As task preparation is a time-consuming process that also relies on cognitive control resources (Kiesel et al., 2010), we hypothesised that a short preparation time impairs selective encoding (Richter & Yeung, 2015). As the stimulus representation needs to be actively maintained in working memory while solving a task (i.e., picture/word categorization), we hypothesised that a short stimulus presentation duration impairs selective encoding (Cattapan-Ludewig et al., 2005; see also Middlebrooks et al., 2016).

Specifically, we predicted that task switching (vs task repetition), short (vs long) preparation time, and short (vs until response) stimulus presentation duration reduce subsequent memory selectivity. These predictions are derived from the “shared resource hypothesis,” whereby cognitive load at encoding diverts cognitive control resources shared by encoding processes (Chiu & Egner, 2015a; Rissman et al., 2009). Increased cognitive load should therefore reduce selective attention and selective encoding. The main question concerns possible interactions between the manipulations of cognitive load. The time-based resource-sharing model would predict interacting effects when the manipulations draw concurrently on the same resources and independent effects when the manipulations draw asynchronously on the same resources. As advance task preparation consumes most resources *before* stimulus presentation, interactions with task switching or stimulus presentation duration are not expected. However, an interaction between task switching and stimulus presentation duration is expected because these manipulations consume resources concurrently *during* stimulus presentation.

General method

Table 1 (left part) gives an overview of the five experiments. The experiments involved two phases: a study phase and a subsequent test phase. The study phase consisted of a task switching procedure using either the cued task switching paradigm (Figure 1) or the alternating runs paradigm (Figure 2). The test phase consisted of an immediate and a delayed surprise recognition test.

Participants

In a power analysis, we computed the sample size as a function of effect sizes (η_p^2) reported by Richter and Yeung (2015), a significance level of .05, and .90 as power level. For the interaction between task switching and attention ($\eta_p^2 = .788$), we calculated a sample size of seven participants. For the interaction between preparation time and

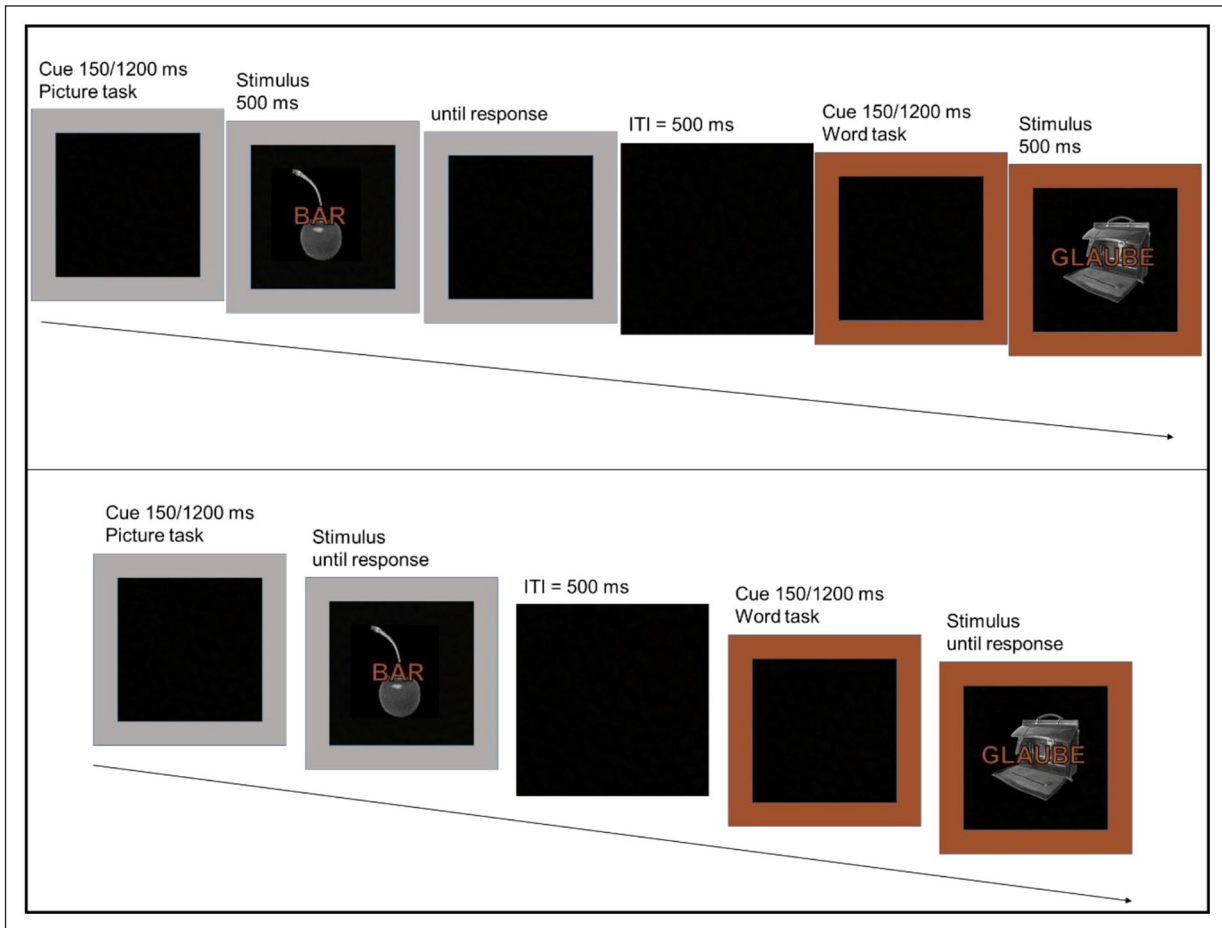


Figure 1. Trial sequence of the cued task switching procedure. ITI: inter-trial interval. Top: Stimulus duration = 500 ms. Bottom: Stimulus duration until response.

attention ($\eta_p^2 = .409$), we calculated a sample size of 18 participants. To account for between-subjects variables, we recruited 20 participants per condition. Table 1 (right part) presents the demographic characteristics of the sample of each experiment. Participants were recruited and tested by undergraduate students. All participants gave written consent. The local ethics committee of the University of Bern approved the study.

Stimuli

We adopted the stimuli from Richter and Yeung (2012). The set consisted of 288 words and 288 pictures. The words (Poldrack et al., 1999) were abstract and concrete nouns translated into German and one to four syllables long. The pictures were monochrome photographs of natural and human-made objects on a black background (Hemera Photo Objects, Hull, Quebec, Canada). Words were printed in brown Arial font and superimposed over the pictures. Pictures and words were paired pseudo-randomly to ensure an equal number of the four category combinations (abstract noun + human-made object,

abstract noun + natural object, concrete noun + human-made object, concrete noun + natural object). The picture–word associations were held constant. The pairs were counterbalanced across participants. The stimuli were presented using E-prime 2.0 software (Psychology Software Tools, Inc., Pittsburgh, PA, USA).

Procedure

Study phase. Participants were tested individually. They were seated in front of a laptop screen at approximately arm length distance to the keyboard. They were instructed to categorise pictures as human-made or natural objects and words as abstract or concrete nouns as fast and correctly as possible. Participants gave their responses by keypress with their left middle and index fingers for the word task (x-key for abstract and c-key for concrete nouns) and the right middle and index fingers for the picture task (n-key for natural and m-key for human-made objects).

The study phase consisted of 192 experimental trials comprising two-thirds of the words and pictures. The other third was reserved for the test phase. Participants practised

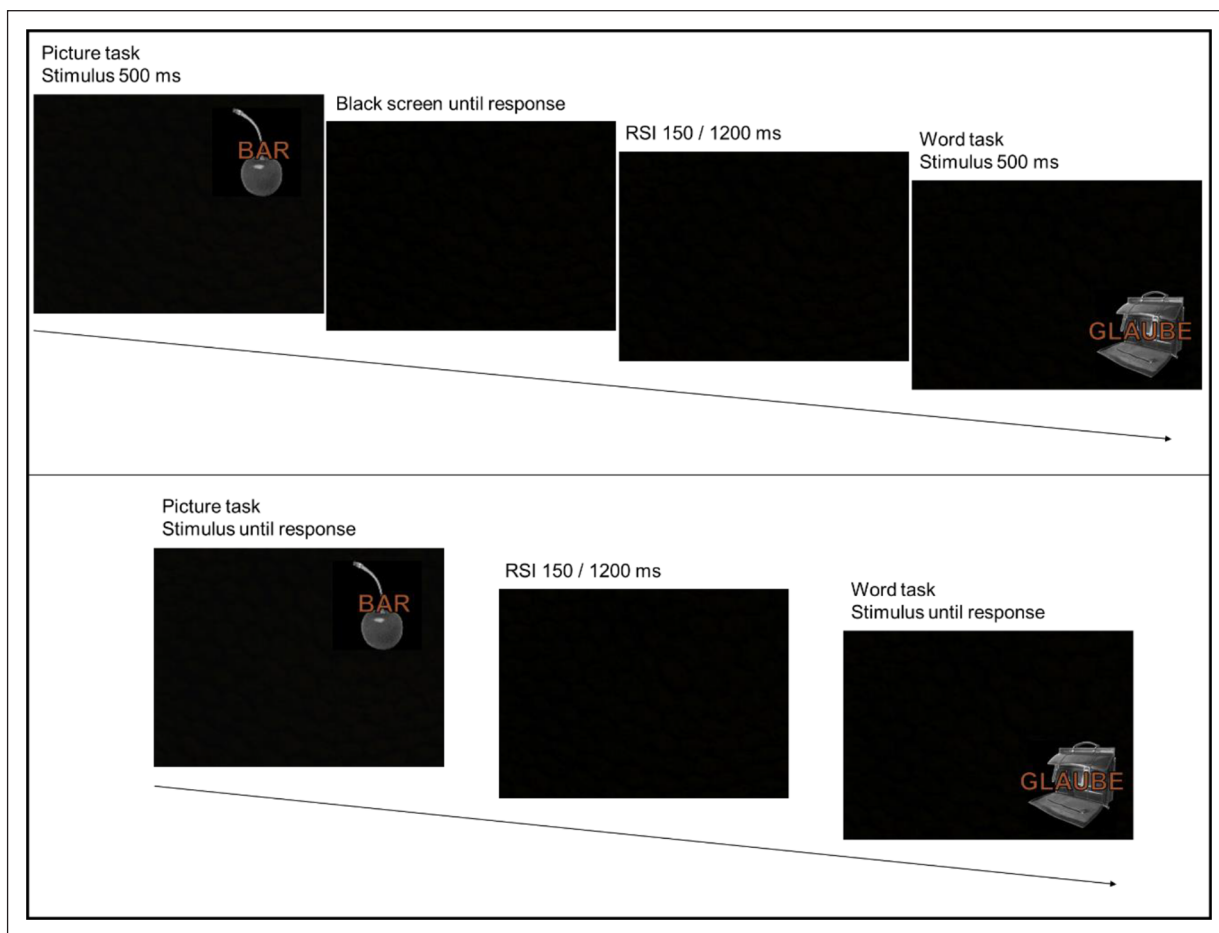


Figure 2. Trial sequence of the alternating runs task switching procedure. RSI: response-to-stimulus interval. Top: Stimulus duration = 500 ms. Bottom: Stimulus duration until response.

Table 1. Overview of the experiments and characteristics of the sample.

Exp.	Manipulations				Sample		
	Task cue	Preparation time	Stimulus duration	Retention interval	N	Men/women	M age (SD)
1	Advance cue	150 ms CSI	500 ms	Immediate/after 1 week	39	20/19	23 (3)
2	Advance cue	150/1,200 ms CSI	500 ms/until response	Immediate/after 1 day	78	30/48	26 (7)
3	Advance cue	150/1,200 ms CSI	500 ms/until response	Immediate/after 1 week	77	13/64	21 (3)
4	Stimulus position	150/1,200 ms RSI	500 ms/until response	Immediate/after 1 day	78	26/52	22 (4)
5	Stimulus position	150/1,200 ms RSI	500 ms/until response	Immediate/after 1 week	79	30/49	23 (4)

CSI: cue-to-stimulus interval; RSI: response-to-stimulus interval.

In cued task switching experiments (Exps 1–3), the task was cued by a coloured frame before stimulus onset. In alternating runs task switching experiments (Exps 4 and 5), the task was cued by the position of the stimulus on the screen.

the task in 20 trials. The practice block repeated until the participant reached a minimum of 80% correct answers. After ensuring participant’s comprehension of the task, the experimental block started with four warm-up trials that were discarded from analysis. In total, the study phase lasted for approximately 10 min. Participants were not informed about the test phase and therefore were not instructed to memorise the items presented during task

switching. In the following sections, we describe the trial sequences separately for the cued and alternating runs task switching paradigms.

Cued task switching. A coloured frame around the picture–word pair cued the task (Richter & Yeung, 2015). A brown frame cued the word task, and a grey frame cued the picture task. Cue presentation lasted until participant’s

response. With this procedure, task order was not predictable. Depending on the preparation time condition, the CSI was either 150 or 1,200 ms. Depending on the stimulus presentation duration condition, the stimuli lasted either for 500 ms (Figure 1, upper panel) or until response (Figure 1, lower panel). After the response and an inter-trial interval of 500 ms followed the next cue, starting a new trial. The two tasks alternated in a pseudorandom order.

Alternating runs. The position of the picture–word pair on the screen cued the task (Dubravac & Meier, 2021; Muhmenthaler & Meier, 2019b; Rogers & Monsell, 1995). If the pair appeared in the upper half of the screen, participants had to solve the picture task, and if it appeared in the lower half, they had to solve the word task. Participants were informed that the stimuli would appear successively in adjacent quadrants, in continuous, clockwise rotation: top-left, top-right, bottom-right, bottom-left, top-left, and so on. As the tasks alternated every second trial, task order was predictable. The predictable task order was emphasised, and participants were asked to use this information to prepare for the upcoming task. Depending on the preparation time condition, the RSI was either 150 or 1,200 ms (Rogers & Monsell, 1995; Steenbergen et al., 2015). Depending on the stimulus presentation duration condition, the stimuli lasted either for 500 ms (Figure 2, upper panel) or until response (Figure 2, lower panel).

Test phase. Participants were instructed to identify *all* the items of the study phase in a forced-choice recognition test. They were asked to press the b-key for old and the n-key for new items. The stimulus was presented in the middle of the screen until a key was pressed. After every “old” response, a remember/know judgement was assessed (Dubravac & Meier, 2021; Meier et al., 2013; Muhmenthaler & Meier, 2019b; Tulving, 1985). Participants had to press “1” if they were sure they remembered the item (recollection) and “2” if they had a feeling of knowing (familiarity). Words and pictures were tested in separate blocks. Two short practice blocks with four trials each were administered before the experimental blocks. To attenuate the picture-superiority-effect (Standing, 1973), the word block was always administered before the picture block.

All participants completed the first test phase immediately after the study phase. Because at least 3 min elapsed between the end of the study phase and the start of the first experimental block of the test phase (with instructions and practice blocks in between), we were sure not to be measuring short-term memory. We administered two recognition tests. During the first test phase (immediate recognition test), one-half of the old items (96 pictures and 96 words) were presented randomly intermixed with 48 new pictures and 48 new words. During the second test phase (delayed recognition test), the other half of the old items were presented randomly intermixed with 48 other new items. The

assignment of old and new items to one of the two test phases was counterbalanced across participants. We chose a 2:1 ratio of old and new items in the test phase because only one-half of the old items were attended during the encoding phase (targets), and the other half was not attended (distractors). A 1:1 ratio of old and new items could lead to response bias (cf. Richter & Yeung, 2012, 2015). Time of day effects were minimised by testing the participants at roughly the same time across sessions. After completion of the final test phase, participants were debriefed, thanked, and dismissed.

Analyses

To assess recognition memory performance, we computed the mean proportion of correctly recognised old items (hits) per participant and separately for target and distractor stimuli. As it was not possible to assign the false alarm rates to the experimental conditions, we used hit rates to assess memory performance (Muhmenthaler & Meier, 2019b). To assess task switching performance, we computed mean accuracy rates and median reaction times of correctly answered switch and repeat trials per participant. The results of the study phase are reported in Supplementary Material 1.

The design varied slightly across experiments. The full design is specified in the “design” section of the respective experiment. In a first step, we performed analyses of variance (ANOVA) on recognition memory performance, remember-responses, and know-responses (the results are presented in Tables 2–6). In a second step, we computed the memory selectivity score by subtracting the hit rate of the distractors from the hit rate of the targets. More hits for targets and fewer hits for distractors means that selectively more targets over distractors are remembered. The bigger the difference between targets and distractors, the higher the score, and the higher the score, the higher memory selectivity (Richter & Yeung, 2012). Thus, for example, an interaction between transition (switch vs repeat trial) and attention (target vs distractor) on absolute recognition performance would be reflected in a main effect of transition on memory selectivity.

An alpha level of .05 was used for all statistical tests. Effect sizes are expressed as η_p^2 . Reported *t*-tests were two-sided. For better interpretability of the results, we also conducted Bayesian *t*-tests. For Bayesian *t*-tests, the alternative hypothesis of a true difference between two means is compared against the null hypothesis (no difference). When comparing two means, we thus report Bayes factors (BF_{10}) indicating how much more likely the data are under the alternative hypothesis. A BF_{10} above 1 favours the alternative hypothesis, while a BF_{10} below 1 favours the null hypothesis. The higher the BF_{10} , the more evidence is found for the alternative hypothesis (Wagenmakers et al., 2018). One convention is that a $BF_{10} > 3$ can be interpreted

as substantial evidence for the alternative hypothesis (Wetzels et al., 2011).

The data and analysis scripts can be accessed on OSF (<https://osf.io/f4w68/>).

Experiment 1

The aims of Experiment 1 were to extend the findings of Richter and Yeung (2012, 2015) to a longer retention interval and to assess the contribution of recollection and familiarity to the effects of attention modulation during task switching on subsequent memory (Muhmenthaler & Meier, 2019b). Preparation time (150 ms CSI) and stimulus presentation duration (500 ms) were held constant in a cued task switching procedure (Figure 1). The first recognition test followed immediately after the study phase and the second test followed after 1 week.

The first goal of Experiment 1 was to replicate the finding of lower memory selectivity for switch compared with repeat trials (Richter & Yeung, 2012, 2015). This would be evident in an interaction between attention and transition. The second goal was to examine further the contribution of recollection and familiarity to this effect. Based on a previous study, we expected that the memory benefit for targets from repeat trials would be mainly expressed in remember-responses (Muhmenthaler & Meier, 2019b). Assuming that on switch trials attention is directed towards distractors unintentionally, we predicted that the memory benefit for distractors from switch trials would be mainly expressed in know-responses. As recollection-based memory is more prone to long-term forgetting than familiarity-based memory, we further hypothesised that the proportion of remember-responses to know-responses would decline with a longer retention interval due to a reduction in remember-responses (Meier et al., 2013; Yonelinas, 2002). The third goal was to investigate the role of retention interval on memory selectivity. A change in memory selectivity would be evident in an interaction between attention and retention interval. As the memory benefit for targets is mainly expressed in remember-responses and remember-responses decline with a longer retention interval (Meier et al., 2013), we should find a decline in memory selectivity with a longer retention interval.

Design and participants

The design consisted of the within-subject factors *attention* (target vs distractor), *transition* (switch vs repeat trial), and *retention interval* (immediate vs delayed test). After data screening, we excluded data of one participant with an error rate > 30% in the study phase (Muhmenthaler & Meier, 2019a, 2019b). The final sample consisted of 39 participants (see right part of Table 1 for demographic characteristics of the sample).

Results and discussion

Overall, recognition performance was higher in the immediate test ($M=0.521$, $SE=0.019$) than in the delayed test ($M=0.333$, $SE=0.029$), $t(38)=7.92$, $p<.001$, $BF_{10}>100$. The false alarm rate was slightly lower in the immediate test ($M=0.194$, $SE=0.021$) than in the delayed test ($M=0.247$, $SE=0.031$), $t(38)=2.28$, $p=.028$, $BF_{10}=1.72$. Table 2 presents the results of three separate $2 \times 2 \times 2$ ANOVAs on hit rates for overall recognition, recollection-based recognition (remember-responses), and familiarity-based recognition (know-responses). Figure 3 depicts recognition memory performance and the proportion of remember-responses and know-responses for each condition.

As shown in Table 2, the main effects of attention and retention interval were significant in all three analyses. The main effect of attention represents the memory benefit for attended, task-relevant targets over unattended, task-irrelevant distractors and replicates previous research (Richter & Yeung, 2012, 2015, 2016). The main effect of retention interval represents forgetting over 1 week. The significant interaction between attention and transition is in line with previous studies and represents the effect of task switching on memory selectivity: switching tasks reduce memory selectivity (Dubravac & Meier, 2021; Richter & Yeung, 2012, 2015). The interaction between retention interval and attention was also significant in all three analyses. Comparing the effect sizes (η_p^2) between remember-responses and know-responses indicates stronger effects for remember-responses. This is in line with the notion that recollection-based memory is more susceptible to attention manipulations and forgetting than familiarity-based memory (Gardiner & Java, 1991; Meier et al., 2013; Yonelinas, 2002). Due to a significant three-way interaction (see Table 2), we conducted follow-up ANOVAs separately for the immediate and delayed tests.

Immediate test. Participants recognised more targets ($M=0.694$, $SE=0.021$) than distractors ($M=0.348$, $SE=0.024$) and gave more remember-responses to old targets ($M=0.498$, $SE=0.026$) than old distractors ($M=0.165$, $SE=0.023$). This main effect of attention was significant for overall recognition performance, $F(1, 38)=241.49$, $p<.001$, $\eta_p^2=.86$, as well as for recollection, $F(1, 38)=285.78$, $p<.001$, $\eta_p^2=.88$, but not for familiarity, $F(1, 38)=0.79$, $p=.380$, $\eta_p^2=.02$. The main effect of transition had opposing effects on remember-responses and know-responses. On one hand, participants gave less remember-responses to old items from switch trials ($M=0.321$, $SE=0.024$) than from repeat trials ($M=0.342$, $SE=0.022$), $F(1, 38)=6.30$, $p=.016$, $\eta_p^2=.14$. On the other hand, participants gave more know-responses to old items from switch trials ($M=0.203$, $SE=0.013$) than from repeat trials ($M=0.176$, $SE=0.012$), $F(1, 38)=11.00$, $p=.002$, $\eta_p^2=.22$. The main effect of transition was not

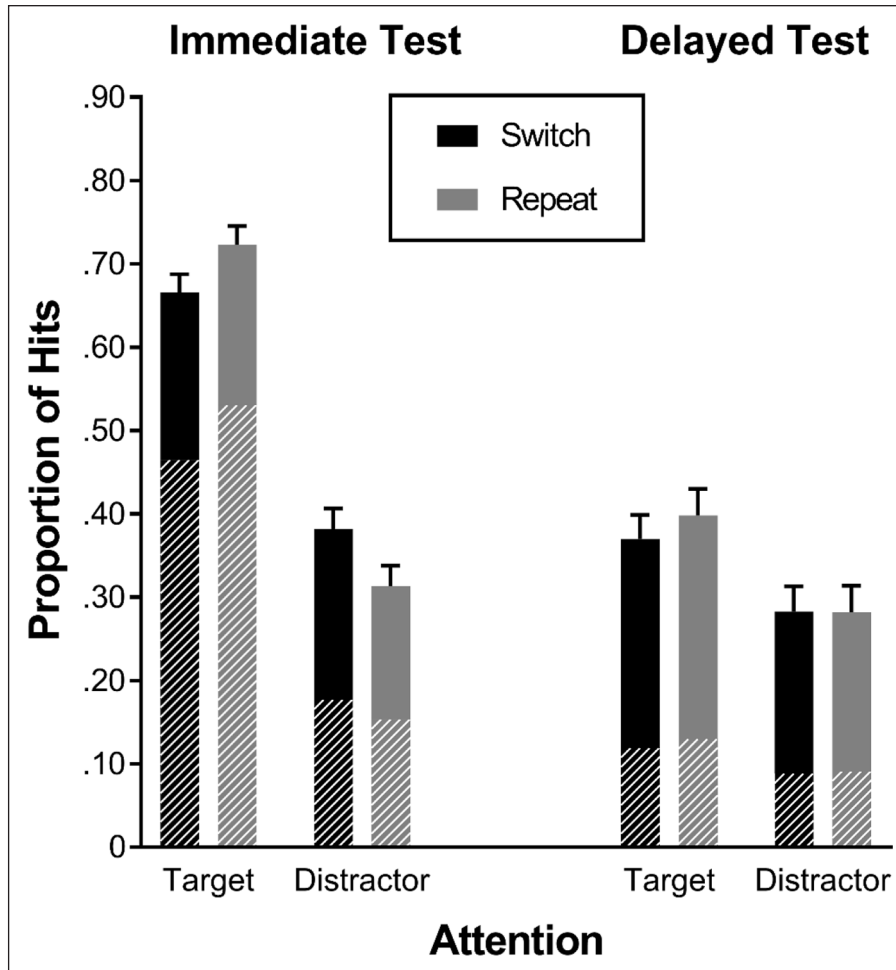


Figure 3. Experiment 1: Mean proportion of correctly recognised old items (hits) as a function of attention (target vs distractor), transition (switch vs repeat trial), and retention interval (immediate vs delayed test) with the proportions of remember-responses and know-responses. The immediate test (left part) was administered after the incidental study phase. The delayed test was administered after 1 week (right part). The shaded areas reflect remember-; the solid areas represent know-responses. Error bars represent standard errors.

Table 2. Experiment 1: Inference results for recognition performance, remember-responses, and know-responses.

Experiment 1	Recognition			Remember			Know		
	<i>F</i> (1, 38)	<i>p</i>	η_p^2	<i>F</i> (1, 38)	<i>p</i>	η_p^2	<i>F</i> (1, 38)	<i>p</i>	η_p^2
Attention	178.98	<.001	.82	316.23	<.001	.89	11.57	.002	.23
Transition	0.41	.527	.01	8.87	.005	.19	3.08	.087	.07
Retention interval	62.68	<.001	.62	148.68	<.001	.80	6.32	.016	.14
Attention × transition	25.25	<.001	.40	20.47	<.001	.35	4.40	.043	.10
Attention × retention interval	212.50	<.001	.85	212.67	<.001	.85	8.42	.006	.18
Transition × retention interval	3.97	.054	.09	1.89	.178	.05	12.74	.001	.25
Attention × transition × retention interval	10.61	.002	.22	15.93	<.001	.30	0.38	.541	.01

Mean proportion of hits was analysed by means of a 2 (attention: target vs distractor) × 2 (transition: switch vs repeat trial) × 2 (retention interval: immediate vs delayed test) repeated-measures analysis of variance (ANOVA). The immediate test took place immediately after the incidental study phase. The delayed test took place after 1 week. The same ANOVA was conducted for the proportion of remember-responses and know-responses. Effects of interest are printed in bold. η_p^2 indicates partial eta-squared.

significant for overall recognition performance, $F(1, 38) = 0.54$, $p = .469$, $\eta_p^2 = .01$. Notably, transition was involved in a highly significant interaction with attention, $F(1, 38) = 29.88$, $p < .001$, $\eta_p^2 = .44$. This interaction was

based on recollection because the pattern was mirrored in a highly significant interaction for remember-responses, $F(1, 38) = 22.24$, $p < .001$, $\eta_p^2 = .37$, but not for know-responses, $F(1, 38) = 3.29$, $p = .077$, $\eta_p^2 = .08$. Participants

recognised less targets of switch ($M = 0.666$, $SE = 0.022$) than repeat trials ($M = 0.723$, $SE = 0.023$), $t(38) = -3.59$, $p < .001$, $BF_{10} = 32.40$, but more distractors of switch ($M = 0.382$, $SE = 0.024$) than repeat trials ($M = 0.314$, $SE = 0.024$), $t(38) = 6.07$, $p < .001$, $BF_{10} > 100$. Participants' remember-responses indicated that they remembered less targets from switch ($M = 0.465$, $SE = 0.028$) than repeat trials ($M = 0.530$, $SE = 0.026$), $t(38) = -4.55$, $p < .001$, $BF_{10} > 100$, but slightly more distractors from switch ($M = 0.177$, $SE = 0.024$) than repeat trials ($M = 0.153$, $SE = 0.024$), $t(38) = 2.23$, $p = .032$, $BF_{10} = 1.55$. Together, this pattern of results suggests that task switching has no overall effect on memory. Thus, task switching does not affect general encoding capacities. Rather, task switching affects the *selectivity* of memories.

Delayed test. After 1 week, the main effect of attention remained significant for overall recognition performance, $F(1, 38) = 50.33$, $p < .001$, $\eta_p^2 = .57$, remember-responses, $F(1, 38) = 35.20$, $p < .001$, $\eta_p^2 = .48$, and know-responses, $F(1, 38) = 22.15$, $p < .001$, $\eta_p^2 = .37$. This pattern suggests that after 1 week, participants still recognised more targets ($M = 0.384$, $SE = 0.030$) than distractors ($M = 0.282$, $SE = 0.031$) and that this effect was driven by both recollection and familiarity. Neither the main effect of transition nor the interaction was significant for overall recognition performance, $F(1, 38) = 2.63$, $p = .113$, $\eta_p^2 = .06$, and $F(1, 38) = 2.16$, $p = .150$, $\eta_p^2 = .05$, respectively. The same applied to remember-responses, $F(1, 38) = 1.59$, $p = .215$, $\eta_p^2 = .04$, and $F(1, 38) = 0.80$, $p = .376$, $\eta_p^2 = .02$, respectively, as well as for know-responses, $F(1, 38) = 1.24$, $p = .273$, $\eta_p^2 = .03$, and $F(1, 38) = 1.52$, $p = .226$, $\eta_p^2 = .04$, respectively.

To summarise, Experiment 1 replicated the finding of Richter and Yeung (2012) that task switching reduces memory selectivity (Dubravac & Meier, 2021; Richter & Yeung, 2015). The effect was mainly driven by recollection (Muhmenthaler & Meier, 2019b) and vanished after 1 week. Our findings are consistent with the idea that the cognitive load associated with task switching reduces memory selectivity. Thus, beyond the well-documented task switching costs on immediate performance (Monsell, 2003), there is also a task switching cost for memory selectivity. Notably, switch costs on memory emerged even after excluding stimuli from error trials in the study phase (see Supplementary Material 2). This suggests that the effect is not solely a consequence of participants failing to switch the task-set on some trials and hence attending to the wrong stimulus in the study phase. The fact that the effect was stable even when we included only stimuli from correct trials, rather supports the interpretation that task-set reconfiguration draws on limited cognitive control resources shared with selective encoding.

In Experiment 1, preparation time and stimulus presentation duration were held constant. In the task switching

literature, preparation (operationalised as preparation time or task predictability) is found to reduce switch costs, but the effect is not specific to switch trials, as preparation improves performance on both switch and repeat trials (Kiesel et al., 2010). This raises the question of whether varying preparation time and the stimulus presentation duration may modulate memory selectivity. Moreover, we were interested in whether preparation time and stimulus presentation duration interact with task switching. Based on the time-based resource-sharing model (Barrouillet et al., 2004, 2007), we predicted task switching to interact with stimulus presentation duration but not with preparation time, as preparation takes place *before* stimulus presentation and thus the manipulation of preparation time is asynchronous to the other two manipulations while task-set reconfiguration and working-memory maintenance take place concurrently. This was tested in the following experiments.

Experiment 2

In Experiment 2, we further investigated the impact of cognitive load at encoding on subsequent memory. We extended Experiment 1 by introducing two new manipulations of cognitive load: preparation time and stimulus presentation duration. As in Experiment 1, a cued task switching procedure was used in the study phase (Figure 1). Preparation time was varied by using a CSI of 150 or 1,200 ms. Stimulus duration was varied by presenting stimuli either for 500 ms or until response of the participants. The first recognition test followed immediately after the study phase and the second test followed after 1 day. In Experiment 1, the cost of task switching for memory selectivity vanished after 1 week. It could be that we would still find a switch cost on memory selectivity after a shorter interval. Thus, we shortened the retention interval for the delayed test from 1 week to 1 day.

On task switching trials, load is increased compared with task repetition trials because the task-set reconfiguration process is cognitively demanding (Liefoghe et al., 2008). With a shorter CSI, advance task preparation is limited and cognitive load is increased at stimulus presentation compared with a longer CSI when task-related processes (e.g., task-set reconfiguration) are completed before stimulus presentation (Barrouillet et al., 2004, 2007; Koch, 2003; Liefoghe et al., 2008). As advance task preparation reduces cognitive load on repeat trials as well as on switch trials, no interaction between CSI and transition type is expected. When the stimuli are presented for a short time, cognitive load is also increased because a representation of the picture and word needs to be kept in working memory, while this is not the case when the stimuli are presented until response. We explored the possibility of an interaction between stimulus duration and transition type expressed as a multiplication of load on switch trials. Here, the time-based resource-sharing model (Barrouillet et al., 2004, 2007) would predict an interaction as task-set reconfiguration and

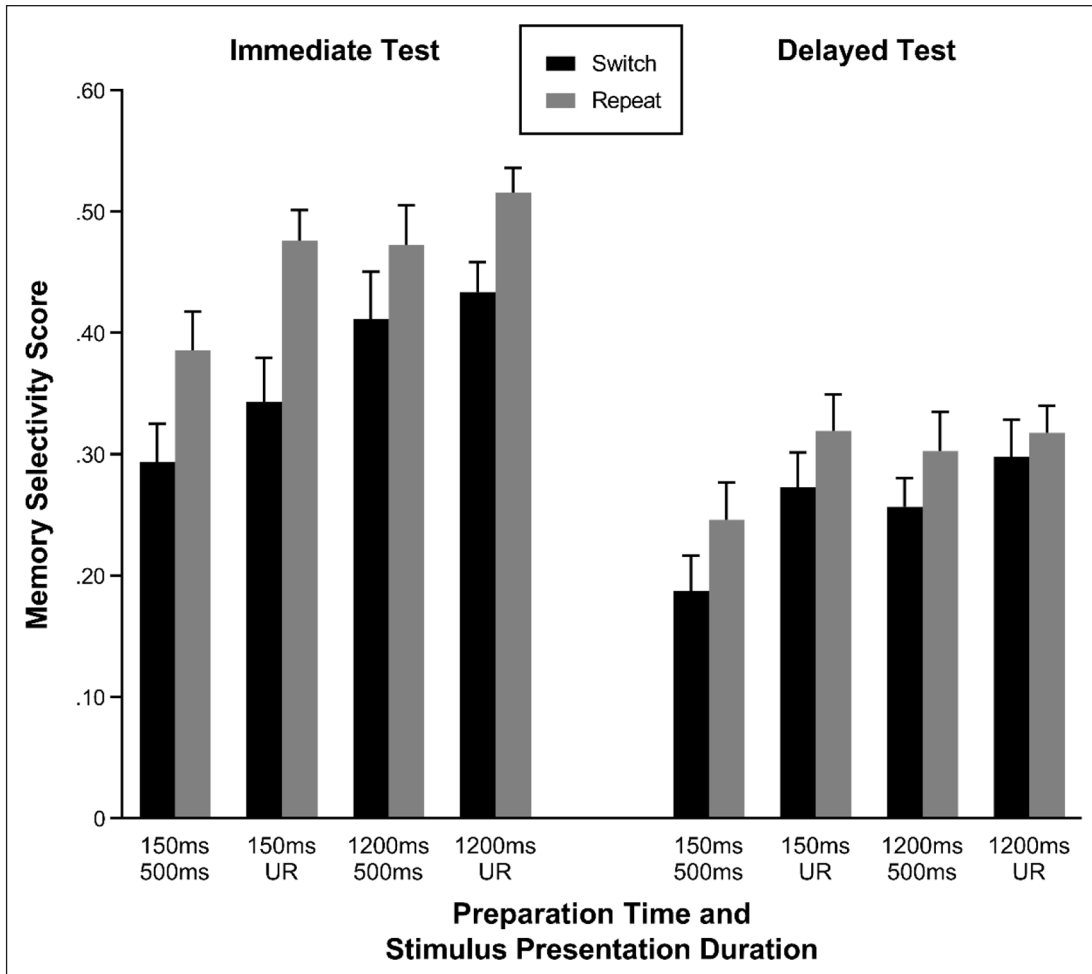


Figure 4. Experiment 2: Memory selectivity (hits targets—hits distractors) as a function of transition (switch vs repeat trial), preparation time (150 vs 1,200 ms cue-to-stimulus interval), stimulus presentation duration (500 ms vs until response [UR]), and retention interval (immediate vs delayed test). The immediate test (left part) was administered after the incidental study phase. The delayed test was administered after 1 day (right part). Error bars represent standard errors.

stimulus maintenance take place concurrently and thus compete for limited cognitive control resources. As cognitive load impairs selective attention (Lavie et al., 2004), we hypothesised that cognitive load impairs target encoding and enhances distractor encoding (i.e., impairs selective encoding). Together, task switching (vs task repetition), short (vs long) CSI, and short (vs until response) stimulus duration should reduce memory selectivity.

Design and participants

The design consisted of the within-subject factors *attention* (target vs distractor), *transition* (switch vs repeat trial), and *retention interval* (immediate vs delayed test), as well as the between-subjects factors *CSI* (150 vs 1,200 ms) and *stimulus duration* (500 ms vs until response). Participants were randomly assigned to the four between-subjects conditions

(1=150 ms-CSI and 500 ms-stimulus-duration, 2=150 ms-CSI and until-response-stimulus-duration, 3=1,200 ms-CSI and 500 ms-stimulus-duration, 4=1,200 ms-CSI and until-response-stimulus-duration). The exclusion criteria were similar to Experiment 1, resulting in two exclusions due to high error rates (conditions 2 and 3) and one exclusion from the remember/know analyses because occasionally pressing key “3” instead of “1” or “2” for the remember/know judgments (condition 1). The final sample consisted of 78 participants (see right part of Table 1 for demographic characteristics of the sample).

Results and discussion

Overall recognition performance was higher in the immediate test ($M=0.533$, $SE=0.012$) than in the delayed test ($M=0.416$, $SE=0.014$), $t(77)=13.14$, $p<.001$, $BF_{10}>100$. The false alarm rates were lower in the immediate

Table 3. Experiment 2: Inference results for recognition performance, remember-responses, and know-responses.

Experiment 2 Effect	Recognition			Remember			Know		
	<i>F</i> (1, 74)	<i>p</i>	η_p^2	<i>F</i> (1, 73)	<i>p</i>	η_p^2	<i>F</i> (1, 73)	<i>p</i>	η_p^2
CSI	0.22	.644	<.01	0.97	.328	.01	0.58	.448	.01
Stimulus duration	1.44	.234	.02	0.17	.680	<.01	1.10	.297	.01
Attention	951.36	<.001	.93	561.38	<.001	.88	31.66	<.001	.30
Transition	0.06	.806	<.01	0.20	.659	<.01	0.37	.547	<.01
Retention interval	177.42	<.001	.71	434.43	<.001	.86	51.86	<.001	.42
CSI × stimulus duration	0.14	.707	<.01	0.03	.857	<.01	0.61	.438	.01
CSI × attention	7.28	.009	.09	7.97	.006	.10	0.39	.534	.01
Stimulus duration × attention	5.49	.022	.07	2.04	.157	.03	0.95	.333	.01
CSI × transition	3.08	.084	.04	0.57	.455	.01	1.14	.290	.02
Stimulus duration × transition	0.27	.608	<.01	2.57	.113	.03	0.95	.333	.01
CSI × retention interval	4.94	.029	.06	1.57	.214	.02	1.30	.258	.02
Stimulus duration × retention interval	0.32	.573	<.01	3.81	.055	.05	2.05	.157	.03
Attention × transition	38.68	<.001	.34	20.57	<.001	.22	6.67	.012	.08
Attention × retention interval	127.03	<.001	.63	350.05	<.001	.83	50.57	<.001	.41
Transition × retention interval	0.11	.740	<.01	0.41	.523	.01	0.19	.668	<.01
CSI × stimulus duration × attention	0.98	.327	.01	0.48	.488	.01	0.07	.789	<.01
CSI × stimulus duration × transition	1.41	.239	.02	0.70	.406	.01	0.41	.523	.01
CSI × stimulus duration × retention interval	0.01	.904	<.01	0.11	.740	<.01	0.04	.833	<.01
CSI × attention × transition	1.90	.173	.02	1.42	.237	.02	0.31	.580	<.01
Stimulus duration × attention × transition	0.07	.788	<.01	0.06	.804	<.01	0.17	.677	<.01
CSI × attention × retention interval	3.40	.069	.04	1.33	.252	.02	0.93	.338	.01
Stimulus duration × attention × retention interval	0.01	.920	<.01	0.42	.520	.01	0.38	.542	.01
CSI × transition × retention interval	0.59	.444	.01	0.10	.758	<.01	0.53	.468	.01
Stimulus duration × transition × retention interval	0.45	.505	.01	1.17	.284	.02	0.23	.636	<.01
Attention × transition × retention interval	6.07	.016	.08	7.54	.008	.09	0.14	.706	<.01
CSI × stimulus duration × attention × transition	0.16	.695	<.01	1.25	.268	.02	1.94	.168	.03
CSI × stimulus duration × attention × retention interval	0.08	.784	<.01	1.73	.193	.02	2.20	.143	.03
CSI × stimulus duration × transition × retention interval	0.28	.597	<.01	0.20	.657	<.01	0.12	.731	<.01
CSI × attention × transition × retention interval	0.27	.602	<.01	1.01	.318	.01	0.05	.828	<.01
Stimulus duration × attention × transition × retention interval	1.56	.215	.02	1.01	.318	.01	5.30	.024	.07
CSI × stimulus duration × attention × transition × retention interval	0.01	.939	<.01	<0.01	.982	<.01	<0.01	.980	<.01

CSI: cue-to-stimulus interval.

Mean proportion of hits was analysed by means of a 2 (CSI: 150 vs 1,200ms) × 2 (stimulus duration: 500ms vs until response) × 2 (attention: target vs distractor) × 2 (transition: switch vs repeat trial) × 2 (retention interval: immediate vs delayed test) analysis of variance (ANOVA). The immediate test took place immediately after the incidental study phase. The delayed test took place after 1 day. The same ANOVA was conducted for the proportion of remember-responses and know-responses. Effects of interest are printed in bold. η_p^2 indicates partial eta-squared. Descriptive statistics are presented in the online Supplementary Material 3.

recognition test ($M=0.182$, $SE=0.011$), compared with the delayed recognition test ($M=0.209$, $SE=0.013$), $t(77)=2.63$, $p=.010$, $BF_{10}=3.07$. For completeness reasons, results of the remember-know analyses are provided in the tables but will not be discussed in detail hereafter. Table 3 presents the results of the 2 × 2 × 2 × 2 × 2 ANOVAs on hit rates for overall recognition,

recollection-based recognition (remember-responses), and familiarity-based recognition (know-responses). The means of the hit rates for each condition are presented in Supplementary Material 3. Consistent with Experiment 1, the interaction between attention and transition was significant. The interactions between attention and CSI and between attention and stimulus duration were also

significant (at least for overall recognition performance). Because retention interval modulated several effects (see Table 3), we analysed the immediate and delayed tests separately. To further enhance comprehensibility, we collapsed the interactions with attention by using memory selectivity as the dependent variable. To this end, we computed the memory selectivity score by subtracting the hits of the distractors from the hits of the targets. This allowed us to analyse the effects of transition, CSI, and stimulus duration on memory selectivity in a $2 \times 2 \times 2$ mixed ANOVA separately for the immediate and delayed tests. We report and discuss these results in the following sections. The results are depicted in Figure 4.

Immediate test. Memory selectivity was lower for items from switch ($M=0.370$, $SE=0.017$) than repeat trials ($M=0.462$, $SE=0.015$). This effect of transition was highly significant, $F(1, 74)=36.42$, $p < .001$, $\eta_p^2 = .33$, and is in line with Experiment 1 and previous studies (Richter & Yeung, 2012, 2015). The main effect of CSI was significant, $F(1, 74)=9.92$, $p = .002$, $\eta_p^2 = .12$. Participants in the 150 ms-CSI condition had lower memory selectivity scores ($M=0.374$, $SE=0.019$) than participants in the 1,200 ms-CSI condition ($M=0.459$, $SE=0.019$), suggesting that a shorter CSI impairs selective encoding. This is consistent with the results of Richter and Yeung (2015). The effect of stimulus duration failed to reach significance, $F(1, 74)=3.73$, $p = .057$, $\eta_p^2 = .05$. The interactions were not significant, all $F_s < 1.75$, $p_s > .190$.

Delayed test. After 1 day, the main effect of transition was still significant, $F(1, 74)=8.91$, $p = .004$, $\eta_p^2 = .11$. Memory selectivity was lower for items from switch ($M=0.253$, $SE=0.015$) than repeat trials ($M=0.296$, $SE=0.015$). The main effect of CSI was not significant anymore, $F(1, 74)=2.27$, $p = .136$, $\eta_p^2 = .03$. The main effect of stimulus duration was significant, $F(1, 74)=4.71$, $p = .033$, $\eta_p^2 = .06$. Participants in the 500 ms-stimulus-duration condition had lower memory selectivity scores ($M=0.247$, $SE=0.019$) than participants in the until-response-stimulus-duration condition ($M=0.302$, $SE=0.016$). The interactions were not significant, all $F_s < 1.07$, $p_s > .305$.

To summarise, task switching (vs task repetition) reduced subsequent memory selectivity, suggesting that task-set reconfiguration impairs selective encoding. The effect was driven mainly by recollection (cf. Table 3). Testing memory 1 day after encoding (vs testing immediately after encoding) reduced memory selectivity, suggesting that with longer retention intervals, the attentional priority given to targets at encoding loses its weight. In contrast to Experiment 1, where the switch cost on memory selectivity vanished after 1 week, the effect was still significant in Experiment 2 with a shorter retention interval of 1 day. The novel elements of Experiment 2 were the assessments of the effects of CSI and stimulus presentation duration. Short (vs long) CSI, and short (vs until response)

stimulus duration tended to reduce memory selectivity. After 1 day, the effect of CSI vanished, but the effect of stimulus presentation duration increased. Experiment 3 aimed to replicate the effects of CSI and stimulus presentation duration on immediate recognition performance and assess the effect of an even longer retention interval of 1 week.

Experiment 3

One aim of Experiment 3 was to replicate the effects of task switching, preparation time, and stimulus presentation duration on memory selectivity found in the immediate recognition test in Experiment 2. A further aim was to extend the findings of the second recognition test to a longer retention interval and assess the impact of CSI and stimulus presentation duration after 1 week.

Design and participants

The design consisted of the within-subject factors *attention* (target vs distractor), *transition* (switch vs repeat trial), and *retention interval* (immediate vs delayed test), as well as the between-subjects factors *CSI* (150 vs 1,200 ms) and *stimulus duration* (500 ms vs until response). Participants were randomly assigned to the four between-subjects conditions (1 = 150 ms-CSI and 500 ms-stimulus-duration, 2 = 150 ms-CSI and until-response-stimulus-duration, 3 = 1,200 ms-CSI and 500 ms-stimulus-duration, 4 = 1,200 ms-CSI and until-response-stimulus-duration). Exclusion criteria were the same as in Experiment 2, resulting in three exclusions due to high error rates (one in condition 1, two in condition 3) and one exclusion from the remember/know analyses (condition 2). The final sample consisted of 77 participants (see right part of Table 1 for demographic characteristics of the sample).

Results and discussion

Overall recognition performance was higher in the immediate test ($M=0.503$, $SE=0.013$) than in the delayed test ($M=0.324$, $SE=0.014$), $t(76)=13.96$, $p < .001$, $BF_{10} > 100$. The false alarm rates were lower in the immediate recognition test ($M=0.151$, $SE=0.009$), compared with the delayed recognition test ($M=0.216$, $SE=0.012$), $t(76)=6.26$, $p < .001$, $BF_{10} > 100$. Table 4 presents the results of the $2 \times 2 \times 2 \times 2 \times 2$ ANOVAs on hit rates for overall recognition, recollection-based recognition (remember-responses), and familiarity-based recognition (know-responses). The means of the hit rates for each condition are presented in Supplementary Material 3. As retention interval was again involved in several interactions, we conducted separate $2 \times 2 \times 2$ mixed ANOVAs of memory selectivity for the immediate and delayed tests. The results are depicted in Figure 5.

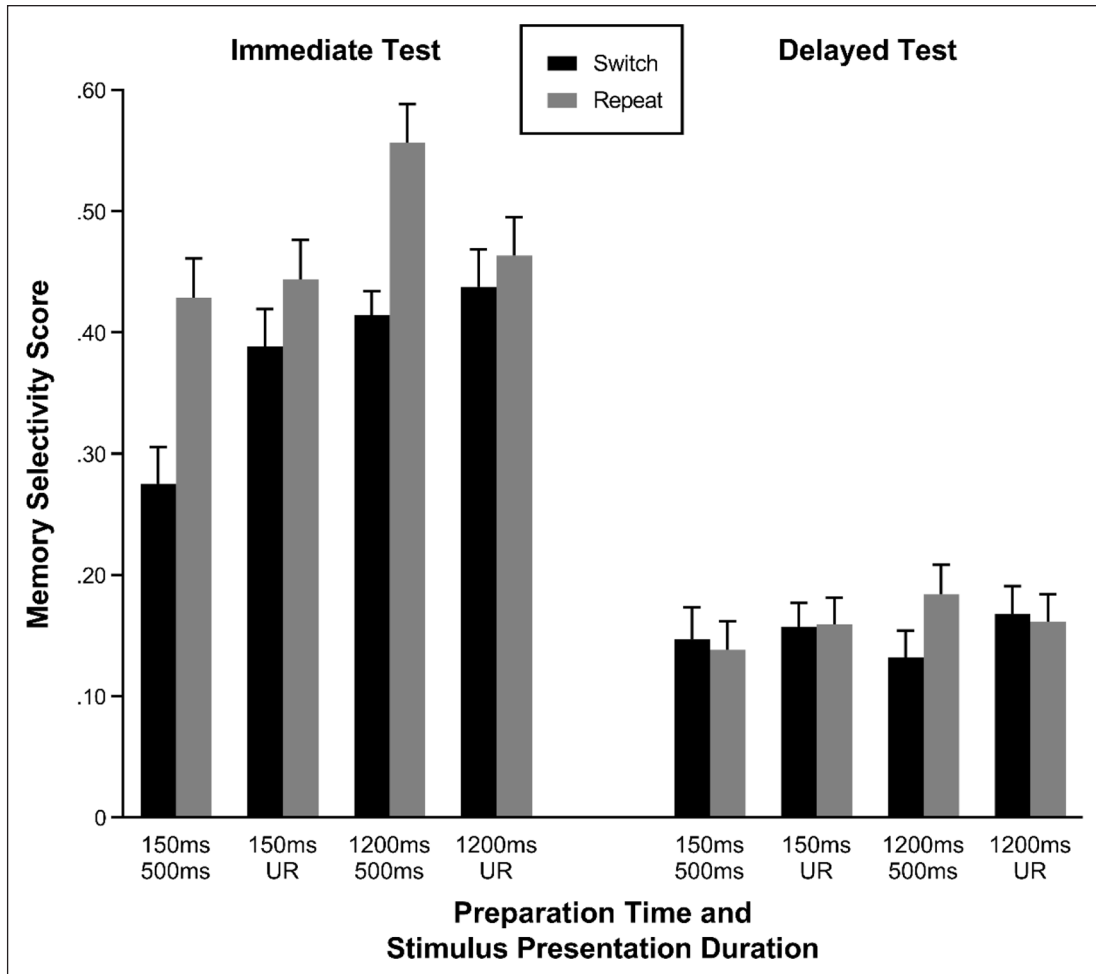


Figure 5. Experiment 3: Memory selectivity (hits targets—hits distractors) as a function of transition (switch vs repeat trial), preparation time (150 vs 1,200 ms cue-to-stimulus interval), stimulus presentation duration (500 ms vs until response [UR]), and retention interval (immediate vs delayed test). The immediate test (left part) was administered after the incidental study phase. The delayed test was administered after 1 week (right part). Error bars represent standard errors.

Immediate test. Memory selectivity was lower for items from switch ($M=0.379$, $SE=0.016$) than repeat trials ($M=0.472$, $SE=0.017$). This main effect of transition was highly significant, $F(1, 73)=40.61$, $p < .001$, $\eta_p^2 = .36$, and is in line with Experiments 1 and 2, and previous studies (Richter & Yeung, 2012, 2015). The main effect of CSI was significant, $F(1, 73)=9.97$, $p = .002$, $\eta_p^2 = .12$. Participants in the 150 ms-CSI condition had lower memory selectivity scores ($M=0.385$, $SE=0.020$) than participants in the 1,200 ms-CSI condition ($M=0.467$, $SE=0.018$). This is in line with Experiment 2 and suggests that shorter CSI impairs selective encoding (cf. Richter & Yeung, 2015). Consistent with Experiment 2, stimulus duration modulated memory selectivity. While stimulus duration had no significant main effect on memory selectivity, $F(1, 73)=0.30$, $p = .585$, $\eta_p^2 < .01$, the interaction with transition emerged highly significant, $F(1, 73)=13.15$, $p < .001$, $\eta_p^2 = .15$. For repeat trials the difference between the

500 ms-stimulus-duration condition ($M=0.491$, $SE=0.025$) and the until-response-stimulus-duration condition ($M=0.454$, $SE=0.022$) was not significant, $t(75)=1.12$, $p = .265$, $BF_{10}=0.41$. For switch trials, however, the effect of stimulus duration went in the expected direction; lower memory selectivity in the 500 ms-stimulus-duration condition ($M=0.343$, $SE=0.021$), compared with the until-response-stimulus-duration condition ($M=0.413$, $SE=0.022$), $t(75)=-2.28$, $p = .025$, $BF_{10}=2.15$. This pattern of results suggests that a short stimulus duration reduces memory selectivity in conditions of heightened cognitive load (i.e., switch trials). Other interactions were not significant, all F s < 3.48 , p s $> .066$.

Delayed test. After 1 week, no effect was significant anymore, all F s < 1.45 , p s $> .232$. This suggests that the effects found on immediate recognition wash out with time. Compared with Experiment 2, where the effect of

Table 4. Experiment 3: Inference results for recognition performance, remember-responses, and know-responses.

Experiment 3 Effect	Recognition			Remember			Know		
	F(1, 73)	p	η_p^2	F(1, 72)	p	η_p^2	F(1, 72)	p	η_p^2
CSI	0.21	.644	<.01	6.42	.013	.08	3.79	.055	.05
Stimulus duration	0.29	.589	<.01	0.64	.427	.01	<0.01	.962	<.01
Attention	1,028.95	<.001	.93	748.43	<.001	.91	61.58	<.001	.46
Transition	0.02	.899	<.01	0.27	.602	<.01	0.24	.625	<.01
Retention interval	193.28	<.001	.73	442.63	<.001	.86	43.51	<.001	.38
CSI × stimulus duration	1.20	.278	.02	0.09	.761	<.01	1.10	.299	.01
CSI × attention	6.83	.011	.09	11.83	.001	.14	0.72	.398	.01
Stimulus duration × attention	0.50	.480	.01	0.56	.456	.01	0.02	.887	<.01
CSI × transition	0.16	.694	<.01	0.53	.468	.01	0.72	.400	.01
Stimulus duration × transition	3.27	.075	.04	3.59	.062	.05	1.27	.264	.02
CSI × retention interval	1.05	.309	.01	1.55	.218	.02	0.02	.887	<.01
Stimulus duration × retention interval	1.77	.187	.02	3.77	.056	.05	0.24	.629	<.01
Attention × transition	28.76	<.001	.28	28.35	<.001	.28	0.80	.375	.01
Attention × retention interval	390.60	<.001	.84	508.60	<.001	.88	29.89	<.001	.29
Transition × retention interval	0.07	.794	<.01	2.04	.157	.03	1.23	.271	.02
CSI × stimulus duration × attention	2.23	.140	.03	0.38	.541	.01	1.28	.261	.02
CSI × stimulus duration × transition	0.66	.418	.01	0.02	.893	<.01	2.02	.159	.03
CSI × stimulus duration × retention interval	0.16	.691	<.01	0.02	.894	<.01	0.14	.711	<.01
CSI × attention × transition	0.02	.875	<.01	0.50	.480	.01	0.20	.656	<.01
Stimulus duration × attention × transition	11.40	.001	.14	5.76	.019	.07	2.60	.111	.03
CSI × attention × retention interval	7.15	.009	.09	6.83	.011	.09	0.03	.862	<.01
Stimulus duration × attention × retention interval	0.02	.902	<.01	0.53	.468	.01	0.67	.416	.01
CSI × transition × retention interval	0.09	.760	<.01	2.52	.116	.03	1.04	.311	.01
Stimulus duration × transition × retention interval	<0.01	.979	<.01	0.41	.525	.01	0.28	.598	<.01
Attention × transition × retention interval	15.09	<.001	.17	9.69	.003	.12	2.47	.120	.03
CSI × stimulus duration × attention × transition	1.26	.265	.02	1.53	.220	.02	<0.01	.991	<.01
CSI × stimulus duration × attention × retention interval	2.71	.104	.04	1.14	.288	.02	0.54	.463	.01
CSI × stimulus duration × transition × retention interval	0.55	.462	.01	0.64	.427	.01	<0.01	.974	<.01
CSI × attention × transition × retention interval	1.14	.290	.02	0.15	.701	<.01	0.64	.427	.01
Stimulus duration × attention × transition × retention interval	3.69	.059	.05	3.56	.063	.05	0.29	.592	<.01
CSI × stimulus duration × attention × transition × retention interval	0.35	.558	<.01	0.05	.827	<.01	0.72	.397	.01

CSI: cue-to-stimulus interval.

Mean proportion of hits was analysed by means of a 2 (CSI: 150 vs 1,200 ms) × 2 (stimulus duration: 500 ms vs until response) × 2 (attention: target vs distractor) × 2 (transition: switch vs repeat trial) × 2 (retention interval: immediate vs delayed test) analysis of variance (ANOVA). The immediate test took place immediately after the incidental study phase. The delayed test took place after 1 week. The same ANOVA was conducted for the proportion of remember-responses and know-responses. Effects of interest are printed in bold. η_p^2 indicates partial eta-squared. Descriptive statistics are presented in the online Supplementary Material 3.

transition was still significant after 1 day, in Experiment 3 the effect vanished after 1 week.

To summarise, Experiment 3 replicated the finding that cognitive load at encoding reduces memory selectivity at

retrieval. As effect sizes were consistently larger for remember-responses than know-responses (cf. Table 4), we conclude that these effects were based mainly on recollection. Task switching and short CSI reliably reduced memory

Table 5. Experiment 4: Inference results for recognition performance, remember-responses, and know-responses.

Experiment 4 Effect	Recognition			Remember			Know		
	<i>F</i> (1,74)	<i>p</i>	η_p^2	<i>F</i> (1,70)	<i>p</i>	η_p^2	<i>F</i> (1,70)	<i>p</i>	η_p^2
RSI	1.63	.206	.02	1.58	.213	.02	0.01	.905	<.01
Stimulus duration	0.22	.637	<.01	0.01	.909	<.01	0.70	.405	.01
Attention	1,244.73	<.001	.94	800.89	<.001	.92	32.61	<.001	.32
Transition	0.58	.450	.01	6.12	.016	.08	7.16	.009	.09
Retention interval	194.45	<.001	.72	334.80	<.001	.83	46.05	<.001	.40
RSI × stimulus duration	1.00	.321	.01	2.69	.106	.04	0.42	.517	.01
RSI × attention	< 0.01	.969	< .01	0.60	.441	.01	0.83	.367	.01
Stimulus duration × attention	10.66	.002	.13	3.09	.083	.04	2.01	.160	.03
RSI × transition	0.27	.607	<.01	4.93	.030	.07	0.72	.401	.01
Stimulus duration × transition	0.01	.938	<.01	0.02	.885	<.01	0.03	.872	<.01
RSI × retention interval	4.02	.049	.05	1.14	.290	.02	0.70	.407	.01
Stimulus duration × retention interval	0.10	.749	<.01	0.13	.716	<.01	0.04	.836	<.01
Attention × transition	29.39	< .001	.28	31.19	< .001	.31	2.55	.115	.04
Attention × retention interval	287.50	< .001	.80	515.79	< .001	.88	52.12	< .001	.43
Transition × retention interval	3.70	.058	.05	3.17	.079	.04	0.62	.434	.01
RSI × stimulus duration × attention	0.19	.661	<.01	4.72	.033	.06	4.82	.031	.06
RSI × stimulus duration × transition	1.12	.293	.01	0.39	.532	.01	2.79	.100	.04
RSI × stimulus duration × retention interval	0.74	.393	.01	1.22	.274	.02	6.09	.016	.08
RSI × attention × transition	1.52	.222	.02	6.49	.013	.08	0.55	.459	.01
Stimulus duration × attention × transition	3.66	.060	.05	4.11	.046	.06	0.13	.719	<.01
RSI × attention × retention interval	3.26	.075	.04	0.22	.642	<.01	0.65	.424	.01
Stimulus duration × attention × retention interval	4.22	.043	.05	6.45	.013	.08	0.28	.602	<.01
RSI × transition × retention interval	3.03	.086	.04	1.74	.192	.02	0.61	.437	.01
Stimulus duration × transition × retention interval	0.04	.845	<.01	0.91	.342	.01	1.57	.214	.02
Attention × transition × retention interval	1.45	.232	.02	1.21	.275	.02	0.01	.933	< .01
RSI × stimulus duration × attention × transition	0.09	.767	<.01	1.83	.181	.03	1.18	.282	.02
RSI × stimulus duration × attention × retention interval	3.31	.073	.04	0.01	.927	<.01	2.32	.133	.03
RSI × stimulus duration × transition × retention interval	0.04	.835	<.01	0.64	.428	.01	0.20	.654	<.01
RSI × attention × transition × retention interval	0.03	.868	<.01	1.54	.218	.02	0.83	.366	.01
Stimulus duration × attention × transition × retention interval	0.96	.331	.01	4.67	.034	.06	0.57	.454	.01
RSI × stimulus duration × attention × transition × retention interval	2.93	.091	.04	2.83	.097	.04	0.24	.629	<.01

RSI: response-to-stimulus interval.

Mean proportion of hits was analysed by means of a 2 (RSI: 150 vs 1,200 ms) × 2 (stimulus duration: 500 ms vs until response) × 2 (attention: target vs distractor) × 2 (transition: switch vs repeat trial) × 2 (retention interval: immediate vs delayed test) repeated measures analysis of variance (ANOVA). The immediate test took place immediately after the incidental study phase. The delayed test took place after 1 day. The same ANOVA was conducted for the proportion of remember-responses and know-responses. Effects of interest are printed in bold. η_p^2 indicates partial eta-squared. Descriptive statistics are presented in Supplementary Material 3.

selectivity while short stimulus duration reduced memory selectivity only after a 1-day retention interval (Exp. 2) or when the stimuli were presented on switch trials (Exp. 3). It could be that stimulus presentation duration affects selective encoding mostly on switch trials because the task-set

reconfiguration process involved in task switching concurrently increases demands for shared cognitive control resources. To be convincing, though, this effect must be replicated. In Experiments 4 and 5, we extended these findings to the alternating runs task switching paradigm.

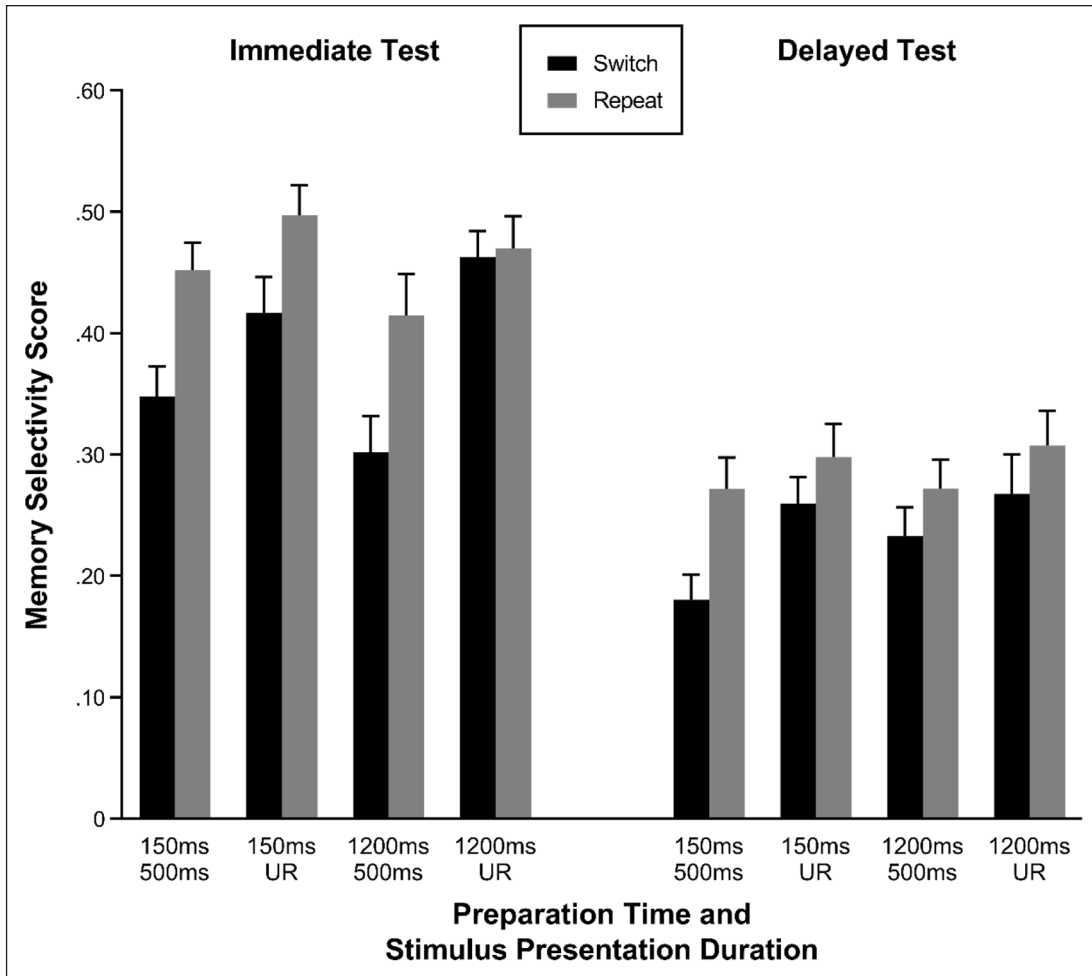


Figure 6. Experiment 4: Memory selectivity (hits targets – hits distractors) as a function of transition (switch vs repeat trial), preparation time (150 vs 1,200 ms response-to-stimulus interval), stimulus presentation duration (500 ms vs until response [UR]), and retention interval (immediate vs delayed test). The immediate test (left part) was administered after the incidental study phase. The delayed test was administered after 1 day (right part). Error bars represent standard errors.

Experiment 4

The aim of Experiment 4 was to extend the findings of Experiment 2 to the alternating runs task switching paradigm (Figure 2). Preparation time was varied by using a RSI of 150 or 1,200 ms. Stimulus duration was varied by presenting stimuli either for 500 ms or until response of the participants. The first recognition test followed immediately after the study phase and the second test followed after 1 day. Based on previous studies with this paradigm (Muhmenthaler & Meier, 2019a, 2019b) and based on the reliable effects in Experiments 1–3, we expected that task switching (vs task repetition) would reduce memory selectivity. Moreover, we tested whether the task switching paradigm modulates the effects of preparation time and stimulus presentation duration on memory selectivity.

Design and participants

The design consisted of the within-subject factors *attention* (target vs distractor), *transition* (switch vs repeat trial), and *retention interval* (immediate vs delayed test) and the between-subjects factors *RSI* (150 vs 1,200 ms) and *stimulus duration* (500 ms vs until response). Participants were randomly assigned to the four between-subjects conditions (1 = 150 ms-RSI and 500 ms-stimulus-duration, 2 = 150 ms-RSI and until-response-stimulus-duration, 3 = 1,200 ms-RSI and 500 ms-stimulus-duration, 4 = 1,200 ms-RSI and until-response-stimulus-duration). Exclusion criteria were the same as in the previous experiments, resulting in two exclusions due to high error rates (condition 3) and four exclusions from the remember/know analyses (one in condition 1, two in condition 2, and one in condition 4). In addition, one participant did not finish the second recognition test due to technical problems close to the end. Thus, recognition

data of two stimuli are missing for this participant. The final sample consisted of 78 participants (see right part of Table 1 for demographic characteristics of the sample).

Results and discussion

Overall recognition performance was higher in the immediate test ($M=0.544$, $SE=0.013$) than in the delayed test ($M=0.415$, $SE=0.017$), $t(77)=13.82$, $p<.001$, $BF_{10}>100$. The false alarm rates were lower in the immediate recognition test ($M=0.193$, $SE=0.013$), compared with the delayed recognition test ($M=0.225$, $SE=0.015$), $t(77)=3.48$, $p<.001$, $BF_{10}=28.92$. Table 5 presents the results of the $2 \times 2 \times 2 \times 2 \times 2$ ANOVA on hit rates for recognition and separately for remember-responses and know-responses. The means of the hit rates for each condition are presented in Supplementary Material 3. Consistent with our hypothesis and the results of Experiments 2 and 3, the interaction between attention and transition was significant, suggesting robust task switching costs for memory selectivity. The significant interaction between attention and stimulus duration was also consistent with the cued task switching Experiment 2. However, in contrast to Experiments 2 and 3, the interaction between attention and RSI was not significant.

As in Experiments 2 and 3, we computed the memory selectivity score by subtracting the hits of the distractors from the hits of the targets and analysed the effects of transition, RSI, and stimulus duration in a $2 \times 2 \times 2$ mixed ANOVA separately for the immediate and delayed recognition tests. The results are depicted in Figure 6.

Immediate test. Memory selectivity was lower for items from switch ($M=0.384$, $SE=0.015$) than repeat trials ($M=0.459$, $SE=0.014$). This main effect of transition was highly significant, $F(1, 74)=24.36$, $p<.001$, $\eta_p^2=.25$, and is in line with our previous experiments as well as other studies (Richter & Yeung, 2012, 2015). The main effect of RSI was not significant, $F(1, 74)=0.55$, $p=.462$, $\eta_p^2<.01$, indicating that in contrast to experiments with a cued task switching paradigm (Exps 2 and 3; Richter & Yeung, 2015, Exp. 1), varying preparation time in the alternating runs paradigm does not modulate memory selectivity. The main effect of stimulus duration was highly significant, $F(1, 74)=14.10$, $p<.001$, $\eta_p^2=.16$. Memory selectivity was lower in the 500 ms-stimulus-duration condition ($M=0.380$, $SE=0.016$) than in the until-response-stimulus-duration condition ($M=0.461$, $SE=0.015$), suggesting that shorter stimulus duration impairs selective encoding. The effect of stimulus duration was qualified by an interaction with transition, $F(1, 74)=4.38$, $p=.040$, $\eta_p^2=.06$. Consistent with Experiment 3, the effect of stimulus duration was only significant for switch, $t(76)=-4.26$, $p<.001$, $BF_{10}>100$, but not repeat trials, $t(76)=-1.82$, $p=.073$, $BF_{10}=0.97$, suggesting that stimulus duration affects selective encoding mostly on switch trials, when cognitive load is already high. Other interactions were not significant, all $F_s<1.73$, $ps>.192$.

Delayed test. After 1 day, the main effects of transition, $F(1, 74)=11.71$, $p=.001$, $\eta_p^2=.14$, and stimulus duration, $F(1, 74)=4.34$, $p=.041$, $\eta_p^2=.06$, were still significant, consistent with the results in the delayed test of Experiment 2. Memory selectivity was lower for items from switch ($M=0.235$, $SE=0.013$) than repeat trials ($M=0.288$, $SE=0.013$). Participants in the 500 ms-stimulus-duration condition had lower memory selectivity scores ($M=0.238$, $SE=0.012$) than participants in the until-response-stimulus-duration condition ($M=0.283$, $SE=0.017$). No other effects were significant, all $F_s<0.74$, $ps>.391$.

To summarise, Experiment 4 confirms and extends the finding that task switching reduces memory selectivity (cf. Exps 2 and 3; Richter & Yeung, 2012, 2015). Previous studies with the alternating runs paradigm showed a task switching cost for target memory and a task switching benefit for distractor memory (Dubravac & Meier, 2021; Muhmenthaler & Meier, 2019a, 2019b). Thus, even if task switches are predictable, they nevertheless impair selective encoding. In line with the tendency in Experiments 2 and 3, presenting the stimuli for only 500 ms (vs until response) reduced memory selectivity. As opposed to Experiments 2 and 3, RSI had no effect on memory selectivity. The effect of task switching on memory selectivity was based mainly on recollection (cf. Table 5).

Experiment 5

The aims of Experiment 5 were to extend the findings of Experiment 4 to a longer retention interval of 1 week. Moreover, it allows a comparison to Experiment 3, in which a cued task switching procedure was used. The first recognition test followed immediately after the study phase and the second test followed after 1 week. This extended retention interval should lead to a stronger decrease in memory selectivity. Based on our findings in Experiment 4, we hypothesised that task switching and short stimulus duration—but not short RSI—would reduce memory selectivity.

Design and participants

The design consisted of the within-subject factors *attention* (target vs distractor), *transition* (switch vs repeat trial), and *retention interval* (immediate vs delayed test) and the between-subjects factors *RSI* (150 vs 1,200 ms) and *stimulus duration* (500 ms vs until response). Participants were randomly assigned to the four between-subjects conditions (1=150 ms-RSI and 500 ms-stimulus-duration, 2=150 ms-RSI and until-response-stimulus-duration, 3=1,200 ms-RSI and 500 ms-stimulus-duration, 4=1,200 ms-RSI and until-response-stimulus-duration). Exclusion criteria were the same as in the previous experiments, resulting in one exclusion due to high error rate (condition 2) and four exclusions from the remember/know analyses (two in

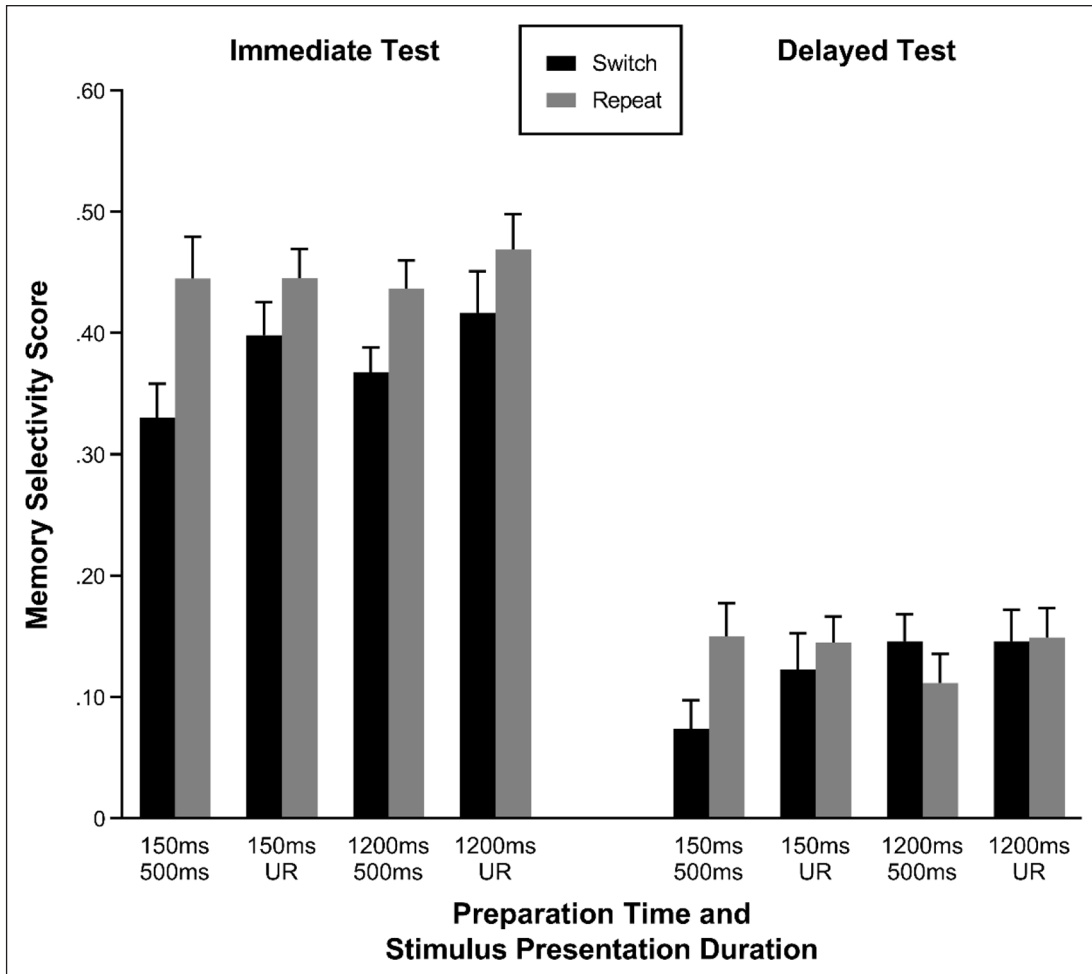


Figure 7. Experiment 5: Memory selectivity (hits targets—hits distractors) as a function of transition (switch vs repeat trial), preparation time (150 vs 1,200 ms response-to-stimulus interval), stimulus presentation duration (500 ms vs until response [UR]), and retention interval (immediate vs delayed test). The immediate test (left part) was administered after the incidental study phase. The delayed test was administered after 1 week (right part). Error bars represent standard errors.

condition 1, others in conditions 2 and 3). The final sample consisted of 79 participants (see right part of Table 1 for demographic characteristics of the sample).

Results and discussion

Overall recognition performance was higher in the immediate test ($M=0.546$, $SE=0.012$) than in the delayed test ($M=0.375$, $SE=0.013$), $t(78)=14.34$, $p<.001$, $BF_{10}>100$. The false alarm rates were lower in the immediate recognition test ($M=0.201$, $SE=0.012$), compared with the delayed recognition test ($M=0.273$, $SE=0.011$), $t(78)=6.42$, $p<.001$, $BF_{10}>100$. Table 6 presents the results of the $2 \times 2 \times 2 \times 2 \times 2$ ANOVA on hit rates for recognition and separately for remember-responses and know-responses. The means of the hit rates for each condition are presented in Supplementary Material 3. As in Experiments 2–4, we computed the memory selectivity

score by subtracting the hits of the distractors from the hits of the targets and analysed the effects of transition, RSI, and stimulus duration in a $2 \times 2 \times 2$ mixed ANOVA separately for the immediate and delayed recognition tests. The results are depicted in Figure 7.

Immediate test. Memory selectivity was lower for items from switch ($M=0.378$, $SE=0.014$) than repeat trials ($M=0.449$, $SE=0.014$). This main effect of transition was highly significant, $F(1, 75)=22.05$, $p<.001$, $\eta_p^2=.23$, and is in line with all our previous experiments as well as other studies (Richter & Yeung, 2012, 2015). As in Experiment 4, the main effect of RSI was not significant, $F(1, 75)=0.56$, $p=.456$, $\eta_p^2=.01$. The effect of stimulus duration was not significant, $F(1, 75)=2.46$, $p=.121$, $\eta_p^2=.03$, and neither was the interaction with transition, $F(1, 75)=1.95$, $p=.166$, $\eta_p^2=.03$. Other interactions were not significant, all $F_s < 0.71$, $ps > .402$.

Table 6. Experiment 5: Inference results for recognition performance, remember-responses, and know-responses.

Experiment 5 Effect	Recognition			Remember			Know		
	$F(1, 75)$	p	η_p^2	$F(1, 71)$	p	η_p^2	$F(1, 71)$	p	η_p^2
RSI	3.01	.087	.04	0.06	.810	<.01	3.53	.064	.05
Stimulus duration	0.31	.580	<.01	0.31	.580	<.01	<0.01	>.999	<.01
Attention	1,019.98	<.001	.93	950.23	<.001	.93	16.38	<.001	.19
Transition	0.57	.451	.01	0.19	.666	<.01	0.07	.790	<.01
Retention interval	200.18	<.001	.73	442.24	<.001	.86	76.98	<.001	.52
RSI \times stimulus duration	0.51	.479	.01	0.02	.879	<.01	0.74	.392	.01
RSI \times attention	0.94	.336	.01	0.98	.325	.01	0.24	.623	<.01
Stimulus duration \times attention	2.86	.095	.04	0.01	.921	<.01	4.54	.037	.06
RSI \times transition	0.02	.880	<.01	0.92	.340	.01	0.11	.741	<.01
Stimulus duration \times transition	0.09	.769	<.01	11.07	.001	.13	6.24	.015	.08
RSI \times retention interval	0.23	.636	<.01	0.03	.869	<.01	0.87	.355	.01
Stimulus duration \times retention interval	0.79	.378	.01	0.01	.914	<.01	2.15	.147	.03
Attention \times transition	15.70	<.001	.17	16.83	<.001	.19	0.28	.598	<.01
Attention \times retention interval	436.15	<.001	.85	646.66	<.001	.90	32.05	<.001	.31
Transition \times retention interval	0.98	.324	.01	2.30	.134	.03	9.39	.003	.12
RSI \times stimulus duration \times attention	<.01	.959	<.01	0.03	.864	<.01	0.11	.739	<.01
RSI \times stimulus duration \times transition	0.93	.338	.01	0.26	.610	<.01	1.48	.228	.02
RSI \times stimulus duration \times retention interval	0.07	.795	<.01	0.66	.419	.01	1.97	.165	.03
RSI \times attention \times transition	3.72	.057	.05	0.20	.660	<.01	2.78	.100	.04
Stimulus duration \times attention \times transition	1.31	.257	.02	3.12	.082	.04	0.15	.697	<.01
RSI \times attention \times retention interval	0.01	.921	<.01	0.15	.697	<.01	0.22	.642	<.01
Stimulus duration \times attention \times retention interval	0.40	.530	.01	0.56	.458	.01	1.87	.176	.03
RSI \times transition \times retention interval	1.82	.182	.02	0.80	.375	.01	0.52	.475	.01
Stimulus duration \times transition \times retention interval	3.26	.075	.04	2.27	.137	.03	0.07	.786	<.01
Attention \times transition \times retention interval	6.39	.014	.08	7.01	.010	.09	0.06	.803	<.01
RSI \times stimulus duration \times attention \times transition	2.61	.111	.03	9.30	.003	.12	0.50	.481	.01
RSI \times stimulus duration \times attention \times retention interval	0.03	.860	<.01	0.09	.768	<.01	0.01	.926	<.01
RSI \times stimulus duration \times transition \times retention interval	<.01	.980	<.01	0.26	.612	<.01	0.41	.523	.01
RSI \times attention \times transition \times retention interval	1.07	.304	.01	1.12	.294	.02	0.03	.867	<.01
Stimulus duration \times attention \times transition \times retention interval	0.62	.432	.01	2.34	.130	.03	0.37	.544	.01
RSI \times stimulus duration \times attention \times transition \times retention interval	0.23	.634	<.01	0.09	.761	<.01	0.34	.560	<.01

RSI: response-to-stimulus interval.

Note. Mean proportion of hits was analysed by means of a 2 (RSI: 150 vs 1,200 ms) \times 2 (stimulus duration: 500 ms vs until response) \times 2 (attention: target vs distractor) \times 2 (transition: switch vs repeat trial) \times 2 (retention interval: immediate vs delayed test) repeated measures analysis of variance (ANOVA). The immediate test took place immediately after the incidental study phase. The delayed test took place after 1 week. The same ANOVA was conducted for the proportion of remember-responses and know-responses. Effects of interest are printed in bold. η_p^2 indicates partial eta-squared. Descriptive statistics are presented in Supplementary Material 3.

Delayed test. After 1 week, the main effect of transition was not significant anymore, $F(1, 75)=1.14$, $p=.290$, $\eta_p^2=.01$. However, transition was involved in an interaction with RSI, $F(1, 75)=4.27$, $p=.042$, $\eta_p^2=.05$. The switch cost on memory selectivity was significant for

participants in the 150ms-RSI condition, $t(38)=-2.28$, $p=.029$, $BF_{10}=1.71$, but not for participants in the 1,200ms-RSI condition, $t(39)=0.70$, $p=.490$, $BF_{10}=0.21$. Other main effects and interactions were not significant, all $F_s < 2.15$, $p_s > .147$.

To summarise, task switching again reduced memory selectivity and this effect was driven mainly by recollection (cf. Table 6). This is in line with all our previous experiments as well as other studies (Richter & Yeung, 2012, 2015). Consistent with Experiment 4, RSI did not affect memory selectivity. The effect of preparation time was consistently found in cued task switching paradigms (Exps 2 and 3; Richter & Yeung, 2015) while it was absent in the alternating runs paradigm (Exps 4 and 5). The effect of stimulus duration was not significant in Experiment 5, while it was significant or at least involved in a significant interaction in Experiment 2 (delayed test), Experiment 3 (interaction with transition in the immediate test), and in Experiment 4 (main effect in immediate and delayed tests, interaction with transition only in immediate test). This inconclusive pattern motivated us to further explore the impact of stimulus presentation duration on memory selectivity.

As we did not have an estimate for the stimulus presentation duration effect size from previous studies, we based the sample size calculations solely on effect sizes for the effects of transition and preparation time. It is, thus, possible that the sample was too small to detect the effect of stimulus duration consistently across experiments. To overcome this power issue and to test the paradigm-specific effects of preparation time directly, we collapsed the data of the immediate tests of Experiments 2–5 and reanalysed the data including the new factor paradigm.

Analysis across Experiments 2–5

The cued task switching paradigm and the alternating runs paradigm yielded differing results regarding the influence of preparation time on memory selectivity and the effect of stimulus presentation duration was not consistently significant. To follow up on the effect of paradigm and to increase power, we reanalysed memory selectivity across Experiments 2–5. Data of the immediate tests of Experiments 2 and 3 were collapsed to one paradigm condition (cued), and the immediate tests of Experiments 4 and 5 were collapsed to another paradigm condition (alternating). A mixed 2 (*paradigm*: cued vs alternating) \times 2 (*preparation time*: short vs long) \times 2 (*stimulus duration*: 500 ms vs until response) \times 2 (*transition*: switch vs repeat trial) ANOVA was conducted.

As expected, the main effects of transition, $F(1, 304) = 117.84, p < .001, \eta_p^2 = .28$, preparation time, $F(1, 304) = 11.80, p < .001, \eta_p^2 = .04$, and stimulus duration, $F(1, 304) = 14.18, p < .001, \eta_p^2 = .04$, were highly significant. The main effect of paradigm was not significant, $F(1, 304) = 0.09, p = .760, \eta_p^2 < .01$. As expected, paradigm interacted significantly with preparation time, $F(1, 304) = 11.16, p < .001, \eta_p^2 = .04$. In line with the results of the individual experiments, memory selectivity was lower with a shorter preparation time ($M = 0.379, SE = 0.014$) compared with a longer preparation time ($M = 0.463,$

$SE = 0.013$) in the cued paradigm, $t(308) = -5.13, p < .001, BF_{10} > 100$, but not in the alternating runs paradigm, $t(312) = -0.16, p = .870, BF_{10} = 0.13$. Also, the previously reported interaction between stimulus duration and transition was confirmed, $F(1, 304) = 8.75, p = .003, \eta_p^2 = .03$. Memory selectivity was significantly lower in the 500 ms-stimulus-duration condition ($M = 0.342, SE = 0.011$) than in the until response stimulus duration condition ($M = 0.413, SE = 0.011$) for switch trials, $t(310) = -4.68, p < .001, BF_{10} > 100$, but not for repeat trials, $t(310) = -1.68, p = .095, BF_{10} = 0.48$. Other interactions were not significant, all F s $< 3.72, p$ s $> .055$.

To summarise, the main effects of transition, preparation time, and stimulus duration were all highly significant in the analysis across Experiments 2–5, suggesting that for stimulus duration a larger sample size is needed to detect the effect on memory selectivity. Alternatively, future studies could use even shorter stimulus presentation durations (e.g., 250 ms) to further increase load for participants, which might result in a stronger effect on memory. The significant interaction between stimulus duration and transition is a further hint that increasing load might strengthen the effect of stimulus duration. Resolving this interaction showed that a shorter stimulus duration reduced memory selectivity especially on switch trials when cognitive load is already high. Furthermore, the significant interaction between preparation time and paradigm suggests a paradigm specific effect of preparation time on memory selectivity. Resolving the interaction confirmed the results of the individual experiments showing that memory selectivity is reduced with shorter preparation times in the cued but not in the alternating runs task switching paradigm. The differences between the cued task switching and the alternating runs procedures are the kind of cue type and the predictability of the next task. It remains an avenue for future research to determine whether cue type, task predictability, or both represent the critical differences between paradigms.

General discussion

The load theory of attention states that cognitive load impairs selective attention (Lavie, 2000, 2005, 2010). In the present study, we tested the hypothesis that impairing selective attention through cognitive load would impair selective encoding and subsequently reduce memory selectivity. In five experiments, we showed participants pictures and words in the context of a task switching procedure and tested their memory in a subsequent recognition test. In the cued task switching paradigm, a coloured frame cued the required task. In the alternating runs paradigm, the stimulus position on the screen cued the required task. Conceptualizing cognitive load as a function of time during which concurrent attention-demanding activities compete for limited cognitive control resources (Barrouillet et al.,

2004, 2007), we manipulated selective attention through task switching, preparation time, and stimulus presentation duration and investigated the impact on memory.

In each of the five experiments, participants recognised more task-relevant targets than task-irrelevant distractors. In line with previous research, our results showed that targets encountered under high selective encoding conditions were better remembered than targets under low selective encoding conditions, while for distractors it was the other way round (Richter & Yeung, 2012, 2015, 2016). The effects were mostly based on recollection (Muhmenthaler & Meier, 2019b). With longer retention intervals of 1 day and 1 week, not only memory performance diminished but also memory selectivity, that is, the relative advantage of targets over distractors. This effect was accompanied by a relative decline in recollection and a relative increase in familiarity with time (Yonelinas, 2002). Task switching, preparation time, and stimulus presentation duration had opposing effects on targets and distractors, suggesting that they rather affected the selectivity of memories than memory in general. Next, we discuss the effects of task switching, preparation time, and stimulus presentation duration on memory selectivity.

Across all experiments, we consistently showed that task switching reduces memory selectivity. This switch cost on memory selectivity is in line with previous research using either the cued task switching paradigm or the alternating runs task switching paradigm (Brito et al., 2016; Chiu & Egner, 2016; Dubravac & Meier, 2021; Muhmenthaler & Meier, 2019a, 2019b; Reynolds et al., 2004; Richter & Yeung, 2012, 2015). As task switching is associated with increased cognitive load (Lavie, 2010), switch trials impair target encoding and enhance distractor encoding. In Experiments 2–5 we further tested the effects of preparation time and stimulus presentation duration on memory selectivity. In contrast to the consistent task switching effect, these effects were more variable across Experiments 2–5, suggesting a mediating role of paradigm and possibly a power issue due to small sample sizes in the individual experiments. We increased power by collapsing the data across experiments and analysed the role of paradigm. The analysis across experiments drew a more nuanced picture, which will be discussed in the following.

Short (vs long) preparation time led to lower memory selectivity in Experiments 2 and 3 with the cued task switching paradigm but not in Experiments 4 and 5 with the alternating runs paradigm. The analysis across Experiments 2–5 confirmed that the specific task switching paradigm mediated the impact of preparation time on memory selectivity. In the alternating runs procedure, the cue (stimulus position on screen) and the stimulus were presented *simultaneously*, and the RSI was varied. In the cued task switching procedure, however, the cue (coloured frame) was presented *before* stimulus presentation, and the CSI was varied. Our results with the cued task switching procedure

are in line with a related study by Richter and Yeung (2015, Exp. 1), who kept RSI constant while varying CSI. We propose that a short CSI impairs selective encoding because the advance cue triggers time-consuming preparation processes loading cognitive control at stimulus presentation. In the alternating runs paradigm, however, there is no advance cue triggering preparation processes. Thus, varying the RSI rather affects passive task-set decay than active task-set preparation. Advance cuing, thus, seems critical for preparation time effects on memory selectivity. Identifying the exact reasons for this difference between paradigms is an avenue for future research.

The analysis across Experiments 2–5 showed that short (vs until response) stimulus presentation duration reduced memory selectivity, especially for switch trials. Participants saw the stimuli either for 500 ms or until response. In the 500 ms condition, participants had to maintain the stimuli in working memory and simultaneously classify the targets according to the task requirements. There is converging evidence that holding information in working memory facilitates long-term memory formation (Hartshorne & Makovski, 2019). Indeed, an additional analysis of the hit rates across Experiments 2–5 revealed that the distractors were significantly better remembered in the 500 ms-stimulus-duration condition, $t(310)=2.20$, $p=.029$ (cf. Supplementary Material 3 for hit rate means). Memory for targets, however, did not differ significantly between conditions, $t(310)=-1.17$, $p=.242$. This pattern is reflected in lower memory selectivity and suggests that the gateway to long-term memory is susceptible to distractor intrusions, which might be a consequence of cognitive load impairing selective attention (Cattapan-Ludewig et al., 2005; Lavie, 2010; Lavie et al., 2004). This effect was especially pronounced for switch trials, suggesting that stimulus presentation duration affects memory selectivity mostly in conditions when cognitive load is already high (Liefvooghe et al., 2008). Task switching and short stimulus presentation duration thus seem to draw concurrently on the same limited cognitive control resources (i.e., working memory capacity) shared by encoding processes.

The importance of cues for an effect of preparation time converges with the finding that the brain activity elicited by a cue just before stimulus onset predicts whether the item will be recollected in a subsequent memory test (Otten et al., 2006, 2010; Padovani et al., 2013). Critically, this subsequent memory effect was found for switch as well as repeat trials (Otten et al., 2010). This is in line with our finding that CSI affected memory selectivity but did not interact with task switching. Instead, preparation time affected cognitive load at stimulus presentation on switch as well as repeat trials. However, stimulus presentation duration interacted with task switching, as the effect on memory selectivity emerged mostly on switch trials, when cognitive load was increased. Together, these results are in line with the time-based resource-sharing model

(Barrouillet et al., 2004, 2007), which would predict interactions when cognitive load is increased concurrently but not sequentially.

Assuming that the number of processes per time unit is limited (e.g., updating working memory and keeping track of task order), concurrent processes exceeding this limit accumulate cognitive load and reduce selective encoding at stimulus presentation. This account also explains the finding that voluntary (vs instructed) task switching reduces memory selectivity (Richter & Yeung, 2015). Richter and Yeung (2015) asked participants to indicate the cued task (instructed task switching condition) or to indicate which task they chose (voluntary task switching condition). In the voluntary task switching condition, participants were instructed to try to choose the task randomly and to try to perform roughly equal numbers of trials of each task as well as of task switches and repetitions (Richter & Yeung, 2015, Exp. 2). Updating the number of trials of each task and keeping track of task order load working memory and cognitive control (Arrington & Logan, 2004, 2005; Demanet et al., 2010). Thus, cognitive load is increased at stimulus presentation impairing selective encoding and resulting in reduced memory selectivity.

The load theory of attention proposes that perceptual load enhances selective attention (Lavie, 2010). Earlier studies already showed that perceptual load reduced subsequent distractor memory (Jenkins et al., 2005; Lavie et al., 2009). In other words, perceptual load leads to better target memory on one hand, and worse distractor memory on the other hand (i.e., higher memory selectivity). Together, this pattern of findings further supports the load theory of attention and its application for memory. The task switching paradigms are suitable to investigate the interactions between perceptual and cognitive load and the effects on memory. Manipulating the salience and timing of target and distractor presentation, for instance, would further our understanding of the dynamics of bottom-up and top-down cognitive control and its influence on encoding (Theeuwes, 2010; Theeuwes et al., 2000). To determine the most effective conditions for encoding, more research is needed on the effects and interactions of perceptual and cognitive load on memory.

Conclusion

Cognitive load during study affects selective attention and long-term memory. Our findings suggest that the load theory of attention (Lavie, 2010) can be applied to the memory domain and contributes to the comprehension of the interaction between attention and memory (Chun & Johnson, 2011; Chun & Turk-Browne, 2007; Logan, 2002). A higher cognitive load impairs cognitive control capacities needed for directing attention selectively to targets and inhibiting distractor interference. With a lower cognitive load, however, cognitive control supports

selective attention and selective encoding of targets, which is reflected in a later memory benefit for targets over distractors. Cognitive load cumulates when cognitive processes concurrently engage working memory resources manifesting in further decrements in memory selectivity. The memory selectivity effect is driven mainly by recollection, suggesting a more elaborate encoding of target events in conditions of increased selective attention. That is, selective attention leads to selective memories.

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ORCID iDs

Mirela Dubravac  <https://orcid.org/0000-0002-4096-2912>
Beat Meier  <https://orcid.org/0000-0003-3303-6854>

Data accessibility statement



The data and materials from the present experiment are publicly available at the Open Science Framework website: <https://osf.io/f4w68/>.

Supplementary material

The supplementary material is available at qjep.sagepub.com.

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