back tasks could also rely on the short-term memory for serial order is somewhat speculative, as it was not examined in this context so far and was not considered as such in any previous theoretical considerations. However, to exclude the possibility that this might have masked the effects of processing-code similarity, we run a second experiment. In this experiment, we used the same primary task. However, the interruption tasks used differed only with respect to their processing code (verbal vs. spatial) but did not involve any serial-memory demand.

Experiment 2

In this experiment participants again performed the WORTKLAU task and were repeatedly interrupted between single steps. However, now the interruption task was one of two versions of a classification task. Whereas the verbal version required to classify pairs of figures as being smaller or bigger than five, the spatial one involved a comparison of three-dimensional shapes as being identical or mirror images of each other. Thus, these tasks differed with respect to the processing codes involved, but neither of them required any sort of serial-memory function. Given that the similarity of processing codes involved in maintaining primary task goals during an interruption phase and the interruption task would make a difference, we assumed that the differences between verbal and spatial conditions now would be able to emerge. That is, due to higher interference of verbal interruptions with verbal rehearsal of cues of the primary task during the interruption, it is expected that the verbal classification task would cause higher resumption costs than the spatial one.

Method

Participants

Forty-seven university students (28 female; M = 24.06 years, SD = 2.29) took part in the study for monetary compensation or a course credit. A total sample size of 32 participants was calculated using G-power sample size calculator (Faul et al., 2007, 2009) for within-subject ANOVA with two measurements, p = .05, power of .95, and η^2 = .15 for the main effect of Processing codes. The value of η^2 was chosen based on the results of Experiment 1, as we now expect to find an effect of that size or greater.

Tasks

Primary Task. The same WORTKLAU task as in Experiment 1 was used as the primary task.

Interruption Tasks. Two classification tasks were included as interruption tasks, differing in their processing code. In the verbal classification task, participants were presented with a series of pairs of figures (from the set: 3, 4, 6, 7; see examples of stimuli in Figure 7). Participants were required to respond to a pair whenever both figures were smaller or bigger than five (e.g., Figure 7, first row) but refrain from responding if only one of the numbers was smaller than five (e.g., Figure 7, second row). In the spatial classification task, a series of pairs of two differently rotated 3-D figures were presented. Subjects were required to respond if the figures were identical (see Figure 7, third row) and to refrain from responding if the figures were mirrored versions of each other (Figure 7, fourth row).

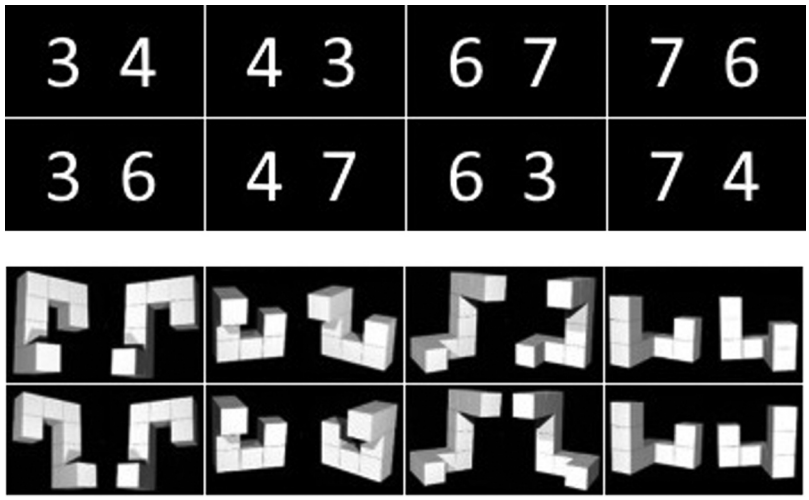
Apparatus and Stimuli

Stimulus presentation and response recording were controlled by a custom-made JAVA software running on an Intel Pentium (2.9 GHz, 8 GB RAM; Windows 7 Pro). Presentation of the stimuli and recording of the responses of the WORTKLAU task were the same as in the first experiment. For the classification tasks, white stimuli (RGB (255, 255, 255)) were presented on black background (RGB (0, 0, 0)) one at a time in the center of the screen. Size of the stimuli in interruption tasks was 92 × 63 px. Participants responded by simultaneously pressing two shift-keys on the keyboard using index fingers. During the presentation of stimuli of the interruption tasks, the view on the stimulus display of the primary WORTKLAU task was not available.

Procedure

Ethical approval for this study was obtained from the ethics committee, Intitut für Psychologie und Arbeitswissenschaften (IPA), Technische Universitaet Berlin. Participants were tested

Figure 7
Stimulus Sets Used in Experiment 2



individually in one session (approx. 90 minutes) in the Human Performance Laboratory of the Chair of Work, Engineering and Organizational Psychology at Technische Universitaet Berlin. All procedural details concerning the length and structure of familiarization, practice trials as well as experimental blocks corresponded completely to the first testing day of Experiment 1. Only three details concerning the use of tasks, the presentation of task stimuli, and the way of collecting information from the participants after the experiment (debriefing) were different. The first difference was the type of interruption task, that is, the verbal n-back task was replaced with the verbal classification task, and the spatial n-back with the spatial classification task. The second difference concerned the presentation time of stimuli and the length of the interstimulus interval (ISI) in the classification tasks. The presentation time of each pair of figures or 3D patterns was 750 ms long, followed by a 750 ms ISI. This resulted in the presentation rate of 20 stimuli over a 30 s period (one trial length), just as in the n-back tasks in the first experiment. Finally, the third difference involved using a short debriefing survey instead of an interview at the end of the experiment addressing the strategies used for performing the tasks in the experimental blocks. The survey was an adaptation of the structured debriefing interview of Experiment 1 and was used instead in order to reduce contact with participants during the COVID-19 pandemic.

Experimental Design

A one-factor (Processing code: verbal vs. spatial) within-subjects design was used. The design for investigating performance in the interruption tasks involved a 2 (Processing code: verbal vs. spatial) × 2 (Context: baseline vs. interruption) within-subjects design.

Dependent Variables

In total, four performance measures were registered. Three measures were calculated to assess the resumption performance in the primary task after an interruption (resumption time, postinterruption sequence errors, postinterruption nonsequence errors) and were defined in the same way as in the first experiment.

Performances in interruption (classification) tasks were expressed by the percentage of correct responses in the classification tasks. The percentage of correct responses was calculated using both, hits (correct key presses in response to stimuli that fulfill the classification criterion), as well as correct rejections (refrain from key press in response to stimuli that do not fulfill the classification criterion).

Results

On an individual basis, all response times faster than 500ms slower than 3 *SD* above the individual mean of the respective condition were considered as outliers and excluded from further analyses. In addition to that, all interruption trials in which low performance was measured (accuracy < 61%) were excluded from further analyses, including all response times, sequence, and nonsequence errors in the interrupted WORTKLAU task that followed that interruption task. In addition, the full data sets of four participants who reported to have used fingers as a strategy to cope with interruptions were excluded from further analyses. Finally, the data sets of two other participants had to be excluded because they did not understand the instructions of the experiment, resulting in a considerable number of missing data either in the main task or in the classification tasks. As in the previous experiment, all our participants reported using verbal rehearsal of either the last step executed before the interruption took place or the one that should take place after the interruption in order to refresh the primary task goal during the interruption task. Thus, the statistical analyses were based on 41 participants. An observed power of .87 was obtained using PANGEA software (Westfall, 2015) for 20 observations per factor level, 41 participants, who were included as a random factor, Processing Codes as a fixed factor, and for $\eta^2 = .15$ for the main effect.

Postinterruption Performance in the Primary Task

A *t*-test for paired samples did not reveal significant effect of Processing code on the resumption time, $t(41) = .83$, $p = .43$, $\eta^2 = .017$, the postinterruption sequence error rates, $t(41) = .23$, $p = .82$, $\eta^2 = .001$, or the nonsequence error rates, $t(41) = .98$, $p = .33$, $\eta^2 = .024$.

For examining this null effect further, a Bayesian paired sample t-test with a default Cauchy prior was conducted for resumption times. A two-sided analysis revealed a Bayes factor (BF01) suggesting the data were 4.27 times more likely under the null hypothesis than the alternative hypothesis median effect size of −.12. The same analysis for the postinterruption sequence errors revealed Bayes factor (BF01) suggesting the data were 5.73 times more likely under the null hypothesis than the alternative hypothesis median effect size of .03. For the postinterruption nonsequence errors similar results were obtained, that is, the data were 3.7 (BF01) times more likely under the null hypothesis than the alternative hypothesis.

Performance in the Classification Tasks

Performance in the classification task was analyzed by a 2 (Processing code: verbal vs. spatial) × 2 (Context: baseline vs. interruption) ANOVA for repeated measures. This analysis revealed a significant main effect of Context, $F(1, 41) = 19.60$, $p < .001$, $\eta^2 = .33$, that is, mean performances were somewhat better in the baseline context than in the interruption context ($M = 95.3\%$, $SE = .60$ vs. $M = 93.6\%$, $SE = .60$). However, this effect emerged independently of processing codes involved in the classification tasks. Neither the main effect of Processing code, $F(1, 41) = 3.54$, $p = .067$, $\eta^2 = .08$, nor the interaction between the factors, $F(1, 41) = .006$, $p = .94$, $\eta^2 = 0$, reached the level of significance.

Exploratory Analysis

In order to test our initial assumption that the similarity between the primary task and the interruption task in terms of sequential constraint had an impact on the postinterruption performance, the data of the two experiments were formally compared in an exploratory analysis. As the performance in 1-back tasks in Experiment 1 was comparable with the performance in classification tasks in Experiment 2 ($M = 97.5\%$, $SE = .7$ vs. $M = 94.4\%$, $SE = .5$, respectively), only the data from these experimental blocks was included in the analysis. For controlling the differences in experience with the tasks, a subgroup of 21 participants who performed the 1-back tasks on the first testing day in Experiment 1 was selected, while all 41 participants from Experiment 2 were included in the

analyses. In total, data from 62 participants were reanalyzed for the purpose of this exploratory study.

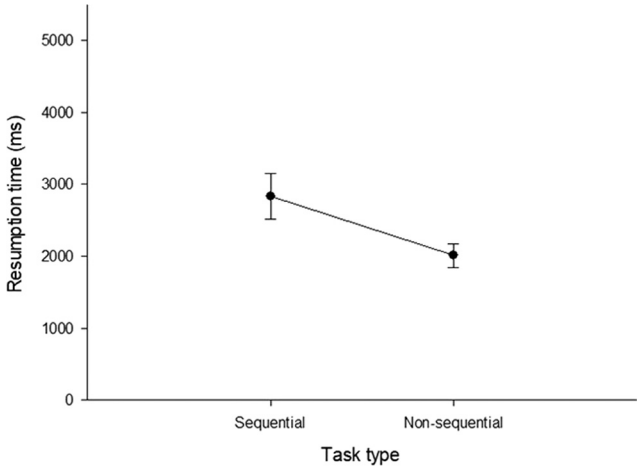
Mean resumption times for the first step after the interruption for the sequential and nonsequential interruption tasks are shown in Figure 8. Resumption times were analyzed using an independent sample t-test with Task type (sequential vs. nonsequential) as a factor. The analysis revealed a significant main effect of Task type, $t(62) = 2.52$, $p = .014$, $\eta^2 = .096$. As it becomes obvious from Figure 8, longer postinterruption resumption times emerged after the sequential interruption tasks compared to the nonsequential interruption tasks ($M = 2832$ ms, $SE = 266$ vs. $M = 2006$ ms, $SE = 190$). However, when the postinterruption sequence error rates were subjected to the same analysis, neither significant main effects nor interactions between the factors emerged, all $p > .73$. The same results were obtained in the analysis of the nonsequence error rates, all $p > .47$.

Discussion

In this experiment, we accounted for the possibility that the effects of verbal and spatial processing codes involved in the interruption tasks were not able to emerge unambiguously in Experiment 1, due to the structural similarity between the primary task and the interruption task in terms of sequential constraints. For that reason, in this experiment we administered classification tasks with simultaneous presentation of two either verbal or spatial stimuli as interruption tasks. However, the data again did not support our hypothesis. Despite all our participants reported again engaging in verbal rehearsal during the interruption task to maintain the cue needed for the resumption of the primary task, the verbal classification task did not impair the postinterruption performance more than the spatial one. This was not supported just by the finding of a nonsignificant effect but also by our additional Bayesian analysis, which revealed a null effect as much more likely than an effect of processing codes, given our data. Thus, overall, the results converge with the data from the first experiment and provide no evidence that the similarity in terms of processing codes between the primary task and the interruption task plays a role when resuming the primary task after the interruption. However, the exploratory analysis contrasting the resumption costs after the interruptions in Experiment 1 with the ones in this second experiment showed that participants needed more time to resume the primary task after an interruption, which also involved a sort of sequential constraint, that is, the 1-back task, compared to a nonsequential interruption, that is, classification task. This result confirmed our speculation about the significance of a placekeeping mechanism or a serial order memory shared by the primary task and interruption task and will be further discussed in the General Discussion.

Figure 8

Mean Resumption Times and Standard Errors Depending on the Type of Interruption Task



General Discussion

The main goal of the present study was to investigate the effects of complexity of the interruption task, the effects of similarity between the primary and the interruption task in terms of processing codes, and the interaction between these factors. In addition, an exploratory analysis comparing the two experiments hinted that an aspect of structural similarity between the primary task and the interruption task could potentially play a role in magnitude of resumption costs. To the best of our knowledge, this is the first study that has addressed these questions directly and in a systematic way.

Let us first consider the effects of complexity of the interruption task on resumption times and sequence errors at the first postinterruption step of the primary task. It was expected that the complex interruption task will lead to longer resumption times and more sequence errors compared to the simple interruption. In accordance with this hypothesis, our results revealed that complex interruptions led to greater interference when resuming the primary task compared to the simple ones in both resumption times and sequence errors. This finding is in line with the previous research (e.g., Cades et al., 2008; Hodgetts & Jones, 2006), which also has shown that resumption costs increase with higher complexity of an interruption task. The results can be interpreted within the MfG model (Altmann & Trafton, 2002) or the resource-theoretical view, which conceptualizes interruptions in terms of a prospective memory model (Dodhia & Dismukes, 2009; Einstein et al., 2003). Both theoretical perspectives predict greater resumption costs in a primary task as the complexity of an interruption task increases. The MfG model predicts higher costs in terms of additional time needed to reactivate goals of the primary task after more complex interruptions, while the prospective memory model predicts increased error rates. Both predictions were indeed confirmed in our research with 2-back interruptions compared to 1-back interruption tasks.

Taken together, the results of the present study suggest that the effects of interruption complexity can also be extended to the procedural tasks with sequential constraints as simulated by the WORTKLAU task. The finding that only postinterruption resumption times and sequence errors were affected suggests that the interruptions specifically interfered with the maintenance of goals of the primary task and did not cause a general impairment of the performance. The latter would be reflected in increased rates of postinterruption nonsequence errors, which was not the case in our study. Such specific effects of interruptions were reported previously in studies on interruption length with the UNRAVEL (Altmann et al., 2014) and the WORTKLAU tasks (Radović & Manzey, 2019).

When it comes to the effects of similarity between the primary and interruption tasks, we expected that a predominantly verbal primary task would be more negatively affected by an interruption task involving verbal stimuli, leading to longer resumption times and more sequence errors upon resumption compared to a spatial interruption task. Taken together, the results of the two experiments did not provide support for this hypothesis. This finding stands in odds with predictions of the MRT (Wickens, 2002) and working memory models (e.g., Baddeley, 1992), which would propose greater interference between verbal interruption task and verbal rehearsal necessary to reactivate the primary task. This suggests that maintaining the goals of a procedural primary task as simulated by the WORTKLAU task during an interruption depends on general memory processes, which operate largely independent of specific processing codes or specific memory subsystems. Possible mechanisms involved might be a specific placekeeping mechanism, which monitors the progress within a task by keeping track of completed and incoming steps (Burgoyne et al., 2021; Carlson & Cassenti, 2004; Hambrick & Altmann, 2015; Trafton et al., 2011) or a modality-independent serial order memory, as proposed by Depoorter and Vandierendonck (2009), and Jones and colleagues (1995). Such an assumption could also explain our finding of higher resumption costs when the WORTKLAU task was interrupted by an n-back task, which also involves keeping track of item sequences, compared to the interruption by a classification task without such demands. This suggests that the similarity between a primary and an interruption tasks in terms of such demands is more important than just a similarity of processing codes. Cooper et al. (2018) have already raised a similar suggestion concerning the similarity of a placekeeping process but, as to the best of our knowledge, the current study is one of the first to provide empirical support for such an effect.

Having provided evidence for interruption effects being independent of the similarity of processing codes involved in the primary task and interruptions task, the question remains to what extent this effect is generalizable also to nonverbal primary tasks. Although somewhat unlikely, recent results presented by Helton and Russell (2011, 2015, 2017) suggest that effects of similarity of processing codes of interruptions tasks might be different for verbal versus spatial primary tasks.[1] Specifically, they investigated how verbal and spatial tasks interfered with a primary vigilance task involving verbal (Helton & Russell, 2011) and spatial processes (Helton & Russell, 2015, 2017), respectively. The paradigms used at least resembled interruption paradigms, even though it simulated more a sort of additional load and of breaks offered as a countermeasure for the monotony of the vigilance task. In line with our results, the authors did not find any effects of the processing codes involved in the "interruption" tasks on a verbal vigilance task (Helton & Russell, 2011). However, the performance in a spatial vigilance task was somewhat more disrupted by the spatial compared to the verbal interruption tasks (Helton & Russell, 2017). Ratwani (2004) has also reported stronger disruptive effects of spatial interruption tasks compared to verbal ones on a spatial primary task. Nevertheless, the current evidence of these different effects is weak and additional load or breaks during vigilance tasks might be a different story than typical interruptions. In any case, more research would be needed to substantiate such a possible difference between verbal and spatial primary tasks.

Limitations of the current study include the typical limitations of laboratory studies. Our participants were university students, who might be an already highly selected population with respect to the level of their cognitive capabilities. However, this could imply that the effects of interruption complexity and structural similarity between the tasks would be even larger in the general population. In addition, the WORTKLAU task used in our research to simulate a procedural task with sequential constraints certainly is an abstract laboratory task, thus we just assume that the cognitive demands of this task closely resemble the ones needed in many procedural tasks in everyday environments and applied settings. Moreover, the consequences of committing errors in task execution were not quite comparable to typical tasks outside the laboratory. Thus, further research should show whether the effects found in this research can be replicated with more representative samples and more realistic tasks in relevant field settings.

To the best of our knowledge, the current study is one of the first attempts to examine both the effects of complexity of an interruption task and the effects of similarity in processing codes between a procedural primary task with sequential constraints and the interruption task on the postinterruption resumption costs. The results provide evidence for a large and consistent effect of complexity on the resumption costs through increased interference with goals of the primary task in working memory. Furthermore, the data do not provide support for a role of similarity in terms of the processing code in resumption costs in a complex primary task with sequential constraints. At the same time, the study provides preliminary evidence that the similarity between the tasks in terms of their sequential structure amplifies postinterruption resumption times, which is a novel finding in the domain of interruption research that should be consolidated in future studies.

[1] We thank one of our reviewers for making us aware of this research

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