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The Effects of Interruption Similarity and Complexity on Assembly Operation Performance

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Abstract

Industrial and service workers are often faced with distractions that can have negative effects on primary task performance, including decreased productivity and increased errors. Findings in the existing literature primarily focus on interruption consequences for cognitive tasks, with little work assessing the effects of interruptions on visual-manual tasks, such as in industrial assembly operations. Furthermore, contradictory results have been reported on effects of interruption similarity and complexity. The objective of this study was to evaluate interruption task similarity and complexity manipulations on performance in a mock industrial assembly operation. Eighteen participants completed nine trials of the assembly operation, including one baseline and eight interruption trials with a full crossing of task similarity (to the primary assembly operation; similar and dissimilar) and complexity (simple and complex) with replication. Results revealed enhanced productivity after interruptions compared to the baseline condition and after complex vs. simple interruptions. Primary task resumption lag increased significantly after similar interruptions compared to dissimilar. These findings are applicable to worker performance of procedural visual-manual assembly operations and support job design for increasing productivity.

Keywords
Interruptions, assembly operations, task similarity, task complexity, manual performance

1. Introduction
With increasing use of technology in the workplace, modern-day workers are often faced with multitasking situations and greater levels of distraction than in previous generations. Multitasking and task distractions can have negative side effects for primary task performance, such as decreased productivity. For example, in an observational study where operators captured and updated telephone-line data on a computer screen, it was found that processing time increased significantly as the number of interruptions increased [1]. In another study, it was found that nurses who were interrupted while preparing and administering medications exhibited a 12-13% increase in error rate per interruption, and that the severity of errors also increased significantly as the number of interruptions increased [2]. Related to this, in an analysis of daily work logs of 21 employees, it was found that office workers experienced, on average, seven interruptions per day [3], while in another study, workers were observed to spend less than 3 minutes on any task before switching to another [4]. These studies reveal serious potential negative effects of interruptions on human performance.

While research findings indicate interruptions have negative effects on primary tasks, there are contradictory findings regarding the manipulation of interruption similarity. Some research indicates interruptions similar to the primary task cause interference in working memory (WM), leading to degraded performance [5-8]. However, other research claims interruptions have a negative effect on performance regardless of how similar demands may be to the primary task [1,9]. Conflicting findings have also been found regarding interruption complexity. Some research claims that more complex interruptions degrade primary task performance more so than less complex interruptions [10-12]. However, other research suggests there is no significant difference [1,13].

1.1. Motivation
Several studies on interruption effects have identified negative effects, including degradations in productivity (e.g., task completion time), and increased resumption lag, defined as the time it takes to return to a primary task after completing the interruption task (secondary task). Furthermore, there are conflicting findings regarding the effects of

complexity and similarity of interruption tasks on primary task performance. Most research in the field focuses on cognitive tasks with little work having investigated the effects of interruptions on procedural visual-manual tasks, such as worker assembly of products in a manufacturing environment. On this basis, the objective of this study was to analyze effects of similar interruptions and complex interruptions on performance of a mock industrial assembly operation. The study was aimed at addressing real production supervisor questions such as “What types of tasks can be administered to assembly workers during work shifts?” and “What types of tasks should be delayed to the end of an assembly shift?”

2. Method

2.1. Participants

Eighteen participants (11 male, 7 female) between 19 and 32 years of age (mean=22.6 years, SD=3.42 years) were required for participation in this study. All participants self-reported normal or corrected 20/20 vision, no color vision impairment, or upper extremity disability. Participants were compensated at a rate of $15 per hour for their time. The North Carolina State University Institutional Review Board approved the experiment procedure.

2.2. Apparatus

The experiment setup consisted of two desktop computers presenting instructions for a primary LEGO assembly task and similar (LEGO assembly) interruption tasks. The dissimilar (arithmetic problem) interruption tasks were presented on paper. Two tables oriented perpendicular to each other were used to administer the primary and interruption tasks separately (see Figure 1). Unique types of LEGO pieces were placed in separate part bins on each table. Bins were located at a distance of 548 mm from participants, which was calculated based on the 5^{th} percentile of zone of convenience reach for the U.S. population [14].

Figure 1: Experiment setup

2.3. Independent Variables and Experiment Design

The independent variables in the study included complexity (simple vs. complex) and similarity (similar vs. dissimilar) of the interruption task to the primary assembly operation. The primary task was a 36-layer LEGO assembly operation administered via a procedural, step-by-step manual. The similar interruption task required participants to perform a LEGO assembly operation while the dissimilar interruption task involved a series of pencil-and-paper math problems, unrelated to the primary LEGO assembly operation. The simple-similar interruption task was a 12-layer LEGO assembly operation, requiring just one type of LEGO brick (2X4 size) for assembly, and was also presented with a procedural, step-by-step manual. The complex-similar level was a five-layer assembly operation containing a variety of LEGO shapes with the assembly reference being a one-page static “3D” computer image, requiring participants to mentally rotate the assembly in order to correctly complete layers. The description of interruption tasks is shown in Table 1. Selection of simple and complex arithmetic problems was justified based on the literature [15] and pilot testing to verify that the complex tasks required significantly more time ($p<0.05$) to complete than simple tasks. In addition, the maximum number of working memory (WM) chunks required for task performance at any given time was estimated by using the Goals, Operators, Methods, and Selection (GOMS) rules modeling technique to justify the complexity level for all interruption tasks [16]. A WM chunk is defined as a single meaningful unit of information [17] maintained in temporary memory. Previous studies have shown that cognitive overload may occur when more than five chunks of information must be maintained in WM at any given time [18]. The results showed that the complex tasks imposed greater WM loads than the simple tasks (WM chunk counts are reported in Table 1). This approach has been used previously to justify complexity levels of interruption tasks [19].

Table 1: Description of interruption tasks and the maximum number of WM chunk counts

Complexity Level	Similarity to Primary Task	Description	WM Chunk Counts
Simple	Similar	Assembly operation with LEGOs of the same shape (i.e., 2*4) and a step-by-step manual	4
	Dissimilar	Addition problems; A+B where 1<A<9, 1<B<9, and A*B<25	3
Complex	Similar	Assembly operation with LEGOs of different shapes and static 3D instructions.	7
	Dissimilar	Multiplication problems which require carrying over a digit to the hundredths place; A*B where A<99, B>9, and A!=B	6

The experiment followed a 2x2 within-subjects design representing a full crossing of the levels of interruption complexity and similarity. Each condition was replicated for each participant. Participants also completed a baseline trial that included no interruptions, resulting in nine total trials per participant. The order of administration of the nine trials was randomized in order to mitigate potential order effects.

2.4. Dependent Variables

The two dependent variables included post-interruption time per layer and resumption lag time. Post-interruption time per layer was defined as the average time to complete the remaining layers of the primary assembly after interruption task performance. To assess the effect of interruptions (i.e., not complexity or similarity of interruptions), analysis was performed on the time per layer (after the interruption) in the treatment tasks minus the equivalent time per layer in the baseline task. It is important to note that higher productivity is equivalent to a smaller time per layer. Resumption lag was defined as the time to resume the primary task after interruption, measured as the time between the end of the interruption task and participant placing a first LEGO on the primary assembly operation.

2.5. Hypotheses

Based on the literature review, it was expected that the post-interruption productivity under interruption conditions would decrease in comparison to the non-interruption condition (Hypothesis 1 (H(1)), decrease in complex interruptions compared to simple interruptions (H2), and decrease in similar interruptions compared to dissimilar interruptions (H3). In addition, it was expected that the resumption lag in complex interruptions would be longer compared to simple interruptions (H4), and would be longer in similar interruptions compared to dissimilar interruptions (H5).

2.6. Procedure

Prior to the scheduled experiment time, potential participants were asked to complete a demographic questionnaire to disclose any color vision impairment, upper extremity disability, and prior experience with LEGOs. Participants who indicated recent and frequent LEGO use were excluded from the study in order to promote a uniform set of participants in terms of LEGO assembly skills. Upon arrival at the laboratory, participants read and signed an informed consent form. They were then given an overview of the experiment with explanation of the primary and interruption tasks. A training session was provided to familiarize the participants with the LEGO assembly operation. For trials with interruption, participants heard an automated bell, indicating that they had to stop the primary task immediately and turn to the other table and complete the interruption task. The interruption occurred at a randomly generated time between 3 and 5 minutes after the start of the primary task. Once the interruption task was complete, participants were asked to immediately return to the primary task. Once participants finished the primary assembly operation, they were given a break before proceeding to the next trial. During this break, the part bins containing specific types of LEGOs were repositioned to prevent participants from learning part locations. This procedure was repeated eight times for each participant with the entire experiment lasting approximately 2.5 hours per participant.

2.7. Data Analysis

A paired t-test was used to analyze the effect of interruptions on post-interruption time per layer (productivity) while Analysis of Variance (ANOVA) was used to analyze the effect of similarity and complexity of interruptions on the dependent variables. Constant variance and residual normality were assessed to ensure all ANOVA assumptions were met. If there was evidence of any assumption violation, either a square-root transform was applied to the raw responses or the responses were ranked in order to conduct a nonparametric ANOVA.

3. Results

3.1. Post-Interruption Time per Layer

A paired t-test revealed a significant effect of interruptions ($t(98)=-4.353$, $p<0.001$, $d=0.101$) on mean time per assembly layer. Mean time per layer decreased significantly (i.e., productivity increased) after an interruption ($\mu=10.290$ s, $\sigma=2.476$ s), as compared to the baseline trial ($\mu=11.154$ s, $\sigma=2.986$ s). An ANOVA was performed on the square-root-transform of mean time per post-interruption layer in order to assess the effect of different types of interruptions. Results revealed a significant effect of complexity ($F(1,91)=4.2903$, $p=0.041$), but no effect of similarity ($F(1,91)=1.5508$, $p=0.216$) or any interaction effect ($F(1,91)=0.326$, $p=0.570$). Complex interruptions significantly decreased time per layer (i.e., increased productivity) after the interruption, as compared to simple interruptions. Table 2 shows descriptive statistics for post-interruption time per layer.

Table 2: Descriptive statistics for post-interruption time per layer

Condition	Mean (s)	Standard Deviation (s)
Difference between Interruption and Baseline	-0.864	1.973
Similar-Simple	10.002	5.095
Similar- Complex	10.915	2.800
Dissimilar-Simple	10.600	2.155
Dissimilar-Complex	10.339	2.611

(Note: The negative mean value in the first row indicates the post-interruption layer time was, on average, less than the layer completion times under the baseline condition. The mean values in all other rows are the actual post-interruption layer completion times under the various interruption conditions.)

3.2. Resumption Lag

An ANOVA was performed on normalized resumption lag (i.e., z-scores) revealing a significant effect of similarity ($F(1,114)=7.4546$, $p=0.007$), but no significant effect of complexity ($F(1,114)=0.2030$, $p=0.653$) or an interaction effect ($F(1,114)=0.0006$, $p=0.981$). Resumption lag was significantly longer when the interruption task was similar to the main assembly operation vs. being dissimilar (Figure 2).

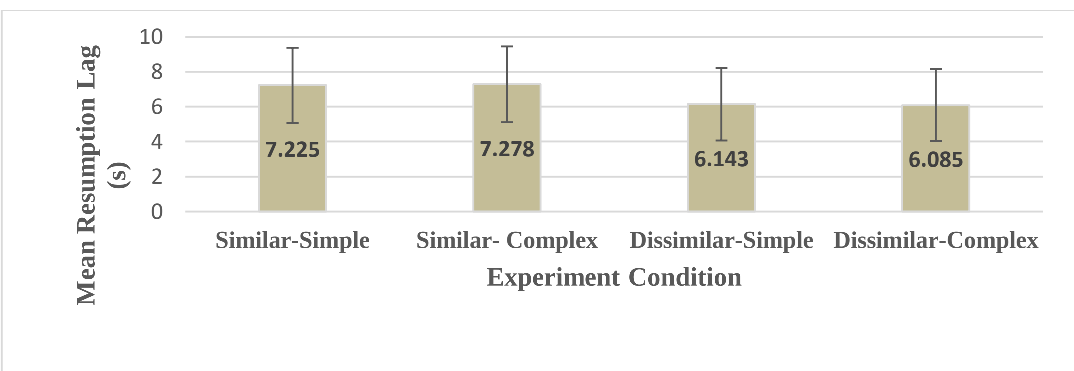

Figure 2: The effect of experiment condition on resumption lag

4. Discussion

Our results showed that post-interruption productivity in the primary task increased after an interruption, which was contrary to expectation (H1). We also expected that complex and similar interruptions would degrade post-interruption productivity (H2 and H3). However, neither of these hypotheses was supported by the results. There was a significant effect of complexity, but productivity increased after the interruption. It is possible that the complex interruption tasks, which required more information processing than the simple tasks, increased participant arousal more so than the simple interruptions, and this arousal carried over into the post-interruption stage of assembly. The results might also be due to boredom in performing the tasks. Although each assembly lasted only 8-10 min in total, repeated assemblies may have led to participant boredom, increasing the arousal when participants were signaled to perform the interruption task. In addition, it is possible that increased complexity led to greater participant engagement. Once participants completed the complex interruption task, they may have anticipated being close to completion of the experiment, leading to increased arousal and higher post-interruption productivity. A similar result was reported in a procedural, visual-manual text-editing task [13].

There was no significant resumption lag difference between simple/complex interruption tasks (rejecting H4), but resumption lag was significantly greater when a similar interruption was administered (supporting H5). The second finding suggests that there may be interference in WM between the interruption task and the primary task in the 3-8 s it took to transition back to the primary assembly operation. Similar interruptions may have led to a higher rate of decay for the primary task goal [12] than dissimilar interruptions, providing enough interference with the primary task goal to increase delay return to the primary task.

5. Conclusion

The objective of this study was to analyze effects of similar interruptions and complex interruptions on performance in a mock industrial assembly operation. Results indicate that complex interruptions may cause arousal that increases productivity in a primary assembly operation following an interruption. Similar interruptions increased the time required to resume the primary assembly operation following an interruption. Related to the broader research questions we identified in the motivation section, our results suggest that while it is not ideal to interrupt a worker during an assembly operation, it may be better to interrupt a worker to ask for a status update or to perform mental calculations, while assembly reworks or repairs may be better saved for the end of a workshift or an ongoing assembly operation.

5.1. Limitations

One limitation of our study was that the assembly task we designed was completely manual and no tools were required in the operation. This scenario might not be representative of some industrial jobs. Another limitation was that participants were interrupted by an automated bell, which may not be a realistic representation of a real-world job environment, where interruptions could come in the form of requests for information by other employees or supervisors.

5.2. Future Work

Future work should examine the use of more complex assemblies potentially including tool use. It could also involve a paradigm in which participants choose when to stop the primary task and begin the interruption task rather than requiring them to immediately address the interruption.

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References

1. Eyrolle, H. & Cellier, J. M., 2000, “The effect of interruptions in work activity: field and laboratory results,” Applied Ergonomics, 31, 537-543. http://dx.doi.org/ 10.1016/S0003-6870(00)00019-3
2. Westbrook, J. I., Woods, A., Rob, M. I., Dunsmuir, W. T. M., & Day, R. O., 2010, “Association of interruptions with an increased risk and severity of medication administration errors,” Archives of Internal Medicine, 170(8), 683-690. http://dx.doi.org/10.1001/archinternmed.2010.65
3. Murray, S. L. & Khan, Z., 2014, “Impact of interruptions on white collar workers,” Engineering Management Journal, 26(4), 23-28. Retrieved from http://search.proquest.com/docview/1630248496?accountid=12725

4. Gonzalez, V. M. & Mark, G., 2004, "Constant, constant multi-tasking craziness: Managing multiple working spheres," In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 113-120). New York, NY: ACM.
5. Gillie, T. & Broadbent, D., 1989, "What makes interruptions disruptive? A study of length, similarity, and complexity," Psychological Research, 50, 243-250. http://dx.doi.org/10.1007/BF00309260
6. Edwards, M., & Gronlund, S. D., 1998, "Task interruption and its effects on memory," Memory, 6(6), 665-687. http://dx.doi.org/10.1080/741943375
7. Ledoux, K., & Gordon, P. C., 2006, "Interruption-similarity effects during discourse processing," Memory, 14(7), 789-803. http://dx.doi.org/10.1080/09658210600679915
8. Lee, B. C. & Duffy, V. G., 2012, "The effects of task interruption on human performance: A study of the systematic classification of human behavior and interruption frequency," Human Factors and Ergonomics in Manufacturing & Service Industries, 25(2), 137-152. http://dx.doi.org/10.1002/hfm.20603
9. Speier, C., Valacich, J. S., & Vessey, I., 1999, "The influence of task interruption on individual decision making: An information overload perspective," Decision Sciences, 30(2), 337-360. http://dx.doi.org/10.1111/j.1540-5915.1999.tb01613.x
10. Hodgetts, H. M. & Jones, D. M., 2006, "Interruption of the tower of london task: Support for a goal-activation approach," Journal of Experimental Psychology: General, 135(1), 103-115. http://dx.doi.org/10.1037/0096-3445.135.1.103
11. Cades, D., Davis, D., Trafton, J., & Monk, C., 2007, "Does the difficulty of an interruption affect our ability to resume?" In Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting (pp. 234-238). Santa Monica, CA: Human Factors and Ergonomics Society. http://dx.doi.org/10.1177/154193120705100419
12. Monk, C. A., Trafton, J. G., & Boehm-Davis, D. A., 2008, "The effect of interruption duration and demand on resuming suspended goals," Journal of Experimental Psychology: Applied, 14(4), 299-313. http://dx.doi.org/10.1037/a0014402
13. Ziljstra, F. R. H., Roe, R. A., Leonora, A. B., & Krediet, I., 1999, "Temporal factors in mental work: Effects of interrupted activities," Journal of Occupational and Organizational Psychology, 72, 163-185. http://dx.doi.org/10.1348/096317999166581
14. Bridger, R., 2008, "Introduction to ergonomics," Boca Raton, FL: CRC Press.
15. Geary, D. C., Widaman, K. F., & Little, T. D., 1986, "Cognitive addition and multiplication: Evidence for a single memory network," Memory & Cognition, 14(6), 478-487. http://dx.doi.org/10.3758/BF03202519
16. Kieras, D. E., 1997, "A Guide to GOMS model usability evaluation using NGOMSL," In M. Helander, T. Landauer, & P. Prabhu (Eds.), Handbook of Human-Computer Interaction. (pp. 733-766). Amsterdam: North-Holland
17. Wickens, C. D., 1992, "Engineering psychology and human performance," (2nd edn.), New York: Harper Collins.
18. Kieras, D.E., Meyer, D.E., Mueller, S., & Seymour, T., 1999, "Insights into working memory from the perspective of the EPIC architecture for modeling skilled perceptual-motor and cognitive human performance," In A. Miyake and P. Shah (Eds.), Models of Working Memory: Mechanisms of Active Maintenance and Executive Control. New York: Cambridge University Press. 183-223.
19. Magrabi, F., Li, S. Y., Day, R. O., & Coiera, E., 2010, "Errors and electronic prescribing: a controlled laboratory study to examine task complexity and interruption effects," Journal of the American Medical Informatics Association, 17(5), 575-583.