Applied Ergonomics 59 (2017) 94–103

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

The effects of interruption similarity and complexity on performance in a simulated visual-manual assembly operation

Carl Pankok Jr., Maryam Zahabi, Wenjuan Zhang, Inchul Choi, Yi-Fan Liao, Chang S. Nam, David Kaber*

North Carolina State University, Raleigh, NC, USA

ARTICLE INFO

Article history:
Received 2 February 2016
Received in revised form
18 August 2016
Accepted 26 August 2016

Keywords:
Task interruptions
Manual assembly
Worker productivity

ABSTRACT

The objective of the study was to assess the effects of interruption task similarity and complexity on performance of a simulated industrial assembly operation. Eighteen participants performed a simulated industrial assembly operation, including one trial with no interruption and eight others presenting an interruption task. Interruption conditions comprised a full crossing of task similarity to the primary assembly operation (similar, dissimilar) and complexity (simple, complex) with replication for each participant. Order of condition presentation was randomized. Findings revealed greater time to return to primary visual-manual assembly performance after a similar task interruption. Results also indicated complex interruptions may promote cognitive arousal that increases productivity following assembly interruptions. The majority of results are explained in terms of the Activation-Based Memory for Goals model. Findings provide some guidance for interruption management protocol design for workers engaged in procedural visual-manual assembly operations.

1. Introduction

With increasing technology in the workplace, workers are often faced with multitasking situations and greater levels of distraction that can have negative side effects on primary task performance, such as decreased productivity or increased errors. For example, in an observational study in which operators captured and updated telephone-line data on a computer screen, Eyrolle and Cellier (2000) reported significant increases in processing time as the number of task interruptions increased. Westbrook et al. (2010) found that nurses who were interrupted while administering medications exhibited a 12–13% increase in error rate and error severity with more interruptions. In an analysis of daily work logs of 21 employees, Murray and Khan (2014) found that office workers experienced, on average, seven interruptions per day, while Gonzalez and Mark (2004) observed workers to spend less than 3 min on any task before switching to another. These studies reveal serious potential negative effects of interruptions on human performance.

1.1. Effects of interruptions on task performance

In a review of interruption literature, Li et al. (2011) categorized primary tasks used in interruption research as: procedural (e.g., Gillie and Broadbent, 1989), problem-solving (e.g., Hodgetts and Jones, 2006), and decision-making tasks (e.g., Hodgetts et al., 2014). (These three types of tasks are reviewed more in-depth in the following sections, including specific examples of each). Interruptions have been manipulated in terms of time of presentation (e.g., Monk et al., 2004), number of occurrences (e.g., Eyrolle and Cellier, 2000), complexity (e.g., Ziljstra et al., 1999), and similarity to the primary task (e.g., Ledoux and Gordon, 2006). The general objective of these studies has been to assess relative effects on primary task performance. Response measures have commonly included primary task completion time (e.g., Edwards and Gronlund, 1998), primary task error rate (e.g., Monk et al., 2008), interruption lag (defined as the time taken between acknowledging a pending interruption and beginning the interruption task; e.g., Czerwinski et al., 2000), and resumption lag (defined as the time taken to resume the primary task after completing the interruption task; e.g., Cades et al., 2008). While findings in the existing literature suggest interruptions of all types have negative effects on primary tasks of all types, the vast majority of primary tasks that have been studied are cognitive in nature, with examples

* Corresponding author. Dept. ISE, North Carolina State University, 400 Daniels Hall, Raleigh, NC 27695-7906, USA.
E-mail address: dbkaber@nscu.edu (D. Kaber).

http://dx.doi.org/10.1016/j.apergo.2016.08.022
0003-6870/

including: essay writing (Foroughi et al., 2014), aircraft radar screen monitoring for targets (Hodgetts et al., 2014), or completing a series of tasks in a video game (Gillie and Broadbent, 1989; Edwards and Gronlund, 1998).

As Wickens et al. (2013) suggest, existing literature reports conflicting results regarding the effect of similarity of an interruption to a primary task; some studies indicate similar interruptions cause interference in working memory (WM), leading to degraded performance (e.g., Lee and Duffy, 2012). However, other research claims interruptions have a negative effect on performance regardless of how similar demands may be to the primary task (e.g., Speier et al., 1999). Inconsistent findings have also been found regarding interruption complexity. Some research claims that more complex interruptions degrade primary task performance more so than simpler interruptions (Hodgetts and Jones, 2006; Cades et al., 2007). However, other research suggests there is no significant difference (e.g., Ziljstra et al., 1999). One possible explanation for these inconsistencies is the use of different experimental paradigms across studies. Another explanation might be the use of different definitions of similarity or complexity by researchers. For example, level of complexity of interruption tasks has been defined based on the nature of operations (perceptual, cognitive and motor) and operation counts as well as task time. However, task completion time is actually an outcome of complexity and does not represent a work design parameter. Related to this, task time limits represent artificial constraints that are not normally imposed in real-world assembly operations.

Given the inconsistent research findings, we conducted a review of existing literature on interruption similarity and complexity with a focus on static tasks (i.e., tasks that do not evolve during an interruption, as in assembly work) and explain results in terms of Activation-Based Memory for Goals (MFG; Altmann and Trafton, 2002) theory. MFG theory has three facets that predict cognition: (1) an interference level, the theoretical level above which a goal needs to be in order to direct behavior; (2) a strengthening constraint, which is required to make a goal higher than the theoretical interference level and consequently direct behavior; and (3) a priming constraint, which predicts the relationship between cue strength and goal encoding. MFG models the cognition involved in switching between goals, and the relative interference that multiple goals pose on each other, making it a suitable theory for explaining the effects of interruption similarity and complexity.

1.2. Similarity of interruption and primary task demands

Lee and Duffy (2012) conducted an experiment with two types of interruption tasks and two types of primary tasks, including math word problems and simple word processing, in order to assess effects of similarity of the interrupting task on primary task performance. They found combinations of similar tasks (e.g., a word problem task being interrupted by another word problem) to produce longer task completion times and higher error rates than combinations of dissimilar tasks. Similarly, Eyrolle and Cellier (2000) also demonstrated that similar interruptions degraded task completion time and increased error rates in a rule-based perception task. Regarding procedural tasks, Gillie and Broadbent (1989) and Edwards and Gronlund (1998), using a similar paradigm, found similar interruptions in a procedural "to-do list" task to degrade task completion time and increase error rates. Since similarity can be defined in multiple ways (e.g., Wickens et al., 2013), it should be noted that the studies reviewed in this section manipulated the similarity of interruption task operations, as opposed to similarity of information coding or modalities of information presentation. MFG theory suggests that when people switch from one task/goal to another, the residual goal from the previous task interferes with the new goal, leading to the negative effects demonstrated by these experiments. Coupled with memory theory (Wickens, 1992, pp. 227–228), it is possible that similarity-induced confusion of goals among tasks might lead to greater negative effects on performance than under dissimilar goal conditions.

1.3. Complexity of the interruption task

Eyrolle and Cellier (2000) defined complexity as the amount of information processed during the interruption task, and investigated the effects of interruption complexity on rule-based task performance. They reported a marginally significant effect on error rate, but no effect on task completion time. Hodgetts and Jones (2006), in an experiment utilizing a problem-solving Tower of London task, found resumption lag to be shorter following a simple interruption (completion of a "mood checklist") than following a complex interruption (a verbal reasoning task). Regarding the effects of complex interruptions on procedural tasks, Gillie and Broadbent (1989) concluded interruption complexity was an indicator of a disruptive interruption; complex interruptions were demonstrated to increase primary task completion time compared to simple interruptions. Finally, in a series of procedural VCR-programming tasks, several studies found more complex interruptions increased resumption lag (Monk et al., 2004; Cades et al., 2008) and error rate (Monk et al., 2008). However, Cades et al. (2007) found that resumption times in the complex (3-back recall) and simple (1-back recall) conditions were not statistically different, concluding that interruption complexity may not be the only reason for disruptiveness. Despite the differing results, complex tasks require greater engagement than simple tasks, possibly leading to the complex-task goal being more active than goals for simple interruptions, as explained by MFG. Being more active, the complex-interruption goal may interfere to a greater extent with the primary task goal upon return to the primary task, leading to increased resumption lag, error rate, and task completion time.

1.4. Other measures of interruption effects

Although error rates and response times have been used extensively for assessing the effects of interruptions on primary task performance, little work has reported on physiological responses to interruptions (e.g., Katidioti et al., 2014). Related to this, there is a substantial body of work on the use of physiological responses as proxy measures of workload with advantages of unobtrusiveness and high resolution. For example, Young and Stanton (2005) said that heart rate (HR) provides a simple method of monitoring of workload state without being intrusive on primary task performance. During task performance, participants expend mental effort, which has been associated with increased HR. In a review article of pilot workload assessment, Roscoe (1992) reported HR responses to be a reasonably accurate and reliable indicator of workload changes. Paxion et al. (2014) identified HR as a sensitive indicator of high- and low-complexity driving situations. A review by Scerbo et al. (2001) revealed the use of HR for measuring pilot workload in a flight simulator, automobile driver workload, and workload for electrical equipment operators conducting a visual-manual task. These studies suggest HR may be sensitive to workload associated with interruptions in various domains.

1.5. Problem statement

Existing work in the field of interruption effects has identified potential negative effects, including degradations in productivity (e.g., task completion time), increased error rates, and increased resumption lag. Furthermore, there are conflicting findings