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Coordinating the interruption of assembly workers in manufacturing

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ABSTRACT

This paper examines how interruptions from information and communications technology systems affect errors and the time to complete tasks for assembly workers. Interruptions have previously been examined in laboratory experiments and office environments, but not much work has been performed in other authentic environments. This paper contains the results of an experiment that was performed in a simulated manufacturing assembly environment, which tested the effects of interruptions on a manual assembly task. The experiment used existing interruption coordination methods as a basis, and the results showed a difference in the effect of interruptions and interruption coordination between cognitively complex laboratory tasks and manual assembly tasks in an authentic environment. Most notably, the negative effects of interruptions delivered without consideration were smaller in this experiment. Based on these findings, recommendations were developed for designing interruption systems for minimizing the costs (errors and time) imposed by interruptions during assembly tasks in manufacturing.

1. Introduction

The use of information and communications technology (ICT) has expanded greatly in recent years, having become near ubiquitous in people's personal lives and workplaces, including manufacturing facilities. This is exemplified by industrial frameworks and strategies such as Industrie 4.0 (e.g. Hermann et al., 2015), which focuses on the smart factories of the future, including both Internet of Things and Internet of Services. Smart factories inherently include extensive amounts of information flowing to and from users and one key component for successful utilisation of this information flow is the ability to know when and where information is needed as well as when and where additional information is not desirable. A key challenge in the smart manufacturing environments of today and tomorrow is to assess the current state of work and send various kinds of information to a user accordingly, as well as making a user aware of updated information that requires notifying the user that new information is available. This involves interrupting the user in some way and has been researched in many fields and domains for a long time, with the human factors advances in aviation being a prime example (e.g. Hawkins, 1993; Mirlacher et al., 2012). This has not been the case in assembly work where little research can be found on mitigating the effects of interruptions delivered by ICT systems on assembly workers. Manual assembly work on a production line often involves short and relatively simple tasks, with each workstation focusing on a minimum rational work element (Groover, 2010) as well as having an established time (takt time) in which each unit should be assembled (e.g. Womack and Jones, 2003).

Generally speaking, an interruption is anything that breaks into a user's current activity and demands a person's attention be shifted to another activity (Coraggio, 1990). It is of major importance to consider in what ways information interrupts and notifies workers in their assembly tasks in order to optimise work performance. Interruptions have been extensively investigated in several research areas (e.g. human-computer interaction (HCI), cognitive psychology, human factors) and differing domains (e.g. aviation, healthcare, office work) and potentially have large impact on work performance and output (e.g. Coraggio, 1990; Wickens, 1992; McFarlane, 2002; Iqbal and Horvitz, 2007; Iqbal and Bailey, 2008). However, it is notable that interruption research has not been applied to the manufacturing domain to any larger extent (but see Andreasson, 2014; Kolbeinsson et al., 2014), given its effect on work performance and work output. Interruptions can greatly affect workers' cognitive and mental load (e.g. Norman, 1993; Bannert, 2002) on both the primary task as well as the secondary task, depending on how and when the notification for the interruption is delivered (McFarlane and Latorella, 2002). Potential

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consequences of this include increased human errors, reductions in work output and a disregard for safety guidelines due to cognitive overload (e.g. Norman, 1993; Bannert, 2002).

The aim of this paper is to characterise the appropriate use of interruption coordination methods in manufacturing assembly and to highlight any differences from existing recommendations that have been developed using contrived and artificial tasks and environments. The main research question addressed regards what types of interruption coordination methods are suitable for use in manual assembly situations in manufacturing.

Much of previous interruption research in HCI has been carried out within controlled situations using contrived tasks and environments where the tasks are all manual, or tasks wherein the user sits in front of a stationary computer and both the primary as well as the secondary task happen on the same screen (e.g. McFarlane, 1999; Adamczyk and Bailey, 2004; Iqbal and Bailey, 2008; Grandhi and Jones, 2015). These studies also often use contrived, artificial tasks that are designed to set the difficulty, i.e. how much skill or effort is required to complete the tasks, of the primary task and interruption task high enough so that any increases in difficulty due to interruptions will result in errors being made (e.g. McFarlane, 1999; Adamczyk and Bailey, 2004; Grandhi and Jones, 2015). Iqbal and Bailey (2008) question whether results obtained using their contrived tasks can be applied directly to what they refer to as “authentic” tasks.

The contrived setups that have been described are useful for identifying fundamental interruption processes, but there is also a need for conducting applied research to complement the fundamentals in order to find a proper way to handle interruptions in other situations such as manufacturing and assembly where tasks are often simplified and optimised to avoid errors (e.g. Freivalds and Niebel, 2013; Brolin et al., 2012). Based on the research performed by McFarlane and Latorella (McFarlane, 1999, 2002; McFarlane and Latorella, 2002), where the fundamentals of interruption coordination methods were proposed and investigated, this work will elaborate on their findings and attempt to apply this on a more authentic scenario set in a simulated assembly context.

The intended contribution of this research is to identify and explore when, where and how to notify assembly workers of interruptions so as to minimise the negative consequences of interruptions. An over-arching goal for this work is more efficient management of assembly workers' cognitive load. Based on the obtained results, some recommendations for design of notification systems in manufacturing are provided that minimise increases in cognitive load due to interruptions.

2. Background

As research on interruptions has gone on for many decades within multiple fields (e.g. Coraggio, 1990; Wickens, 1992; Rubinstein et al., 2001; McFarlane, 2002; Iqbal and Horvitz, 2007; Iqbal and Bailey, 2008; Sykes, 2011; Warnock, McGee-Lennon and Brewster, 2011; Sanderson and Grundgeiger, 2015), this paper focuses on a subset of existing research, in particular on research that is relevant for work with mobile information devices used within the manufacturing domain.

Most manufacturing environments focus on the efficient mass production of products that requires supporting communications between managers, team leaders, and assembly workers (e.g. Bäckstrand, 2009). Timely dissemination of information can be vital for workers to complete their tasks, but unnecessary interruptions can have negative effects on performance and errors on the current task, and if the interruptions contain a new task to perform then interruptions at inappropriate times can also cause the interruption task to be completed with errors (e.g. Baron, 1986; Gillie and Broadbent, 1989; McFarlane, 1999; Zijlstra et al., 1999).

2.1. Interruptions and notifications

Coraggio (1990) defined an interruption as any external event that breaks into a user's current activity, the *primary task*, and demands the user's attention be shifted to another activity, the *interruption task*, or event (Coraggio, 1990). Interruptions are thus a very wide class of events, and can be anything from a random noise in the environment that causes the user to shift attention from the current task, to something that is specifically directed at a user for the purpose of diverting the user's attention through notifying that another task requires attention (Kolbeinsson et al., 2014). Interruptions may convey necessary information or superfluous information. Interruptions are referred to as *distractions* when they incur a measurable cost but do not result in a full switch from the primary task (Sanderson and Grundgeiger, 2015), which would include the example used of a random noise in the environment.

Interruptions can lead to more errors and longer time required to complete the primary task, as well as increasing stress and irritation due to increases in cognitive load (e.g. Wickens, 1992; McFarlane, 2002). These increases in cognitive load, stress, and irritation can also lead to more errors being made on both the interruption task and on the primary task (McFarlane, 1999). Directed interruptions commonly have the aim of supporting either the primary task or another task, and can thereby also be beneficial, bearing updated information so that the primary task can be completed correctly or supporting another task that must be completed. Interruptions can also be beneficial through raising cognitive load from a low state that may otherwise negatively affect performance through inducing boredom and inattention (Scerbo, 1998; Jackson et al., 2014).

The first known research on interruptions was published by Zeigarnik (1927), but research on interruptions was sparse after that until the rise of human factors research in the late 1970s (Spiekermann and Romanow, 2008). Increases in computing power and the development of more advanced computer systems then led to more complex office work and more requirements for ICT systems to interrupt workers (Speier, 1996). A consequence of this was a need for research on interruption management, which has mostly been conducted in lab environments (e.g. McFarlane, 1999, 2002; Altmann and Trafton, 2002; Iqbal and Bailey, 2008) as well as some observational studies performed to see what happens when interruptions occur in an authentic environment (e.g. Iqbal and Horvitz, 2007; Walter et al., 2015). Speier et al. (2003) found that interruptions have a larger negative effect on more complex tasks than on less complex tasks. Zijlstra et al. (1999) found that more complex interruptions result in more negative effects on the primary task, and Monk et al. (2002) showed that the difficulty of the primary task increases when the speed of the task is raised, with corresponding increases in negative effects of interruptions. The use of external cues also diminishes with increased complexity, i.e. tasks that may be more intricate and consist of a larger number of operations, or when shorter time is available to complete the task (Speier et al., 2003). This can affect the difficulty of the task and the quality of the work performed, with Speier et al. (2003) finding that participants performing tasks with a tight deadline make a trade-off in the quality of their work against performing the task in a timely fashion.

More research has been done on interruptions since, but as Brixey et al. (2007) as well as Walter et al. (2015) point out, this has mostly been carried out in laboratory experiments and may not be fully generalisable to authentic situations. Walter et al. (2015) have identified an interest in clarifying how interruptions affect occupational settings, and in particular stress the difficulty of