Applied Ergonomics 69 (2018) 120–127

Contents lists available at ScienceDirect

Applied Ergonomics

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

Cue utilisation reduces effort but increases arousal during a process control task

Mark W. Wiggins*, Edward Whincup, Jaime C. Auton

Centre for Elite Performance, Expertise, and Training, Macquarie University, Australia

ARTICLE INFO

Keywords:
Cue utilisation
Effort
Arousal
Physiology
Process-control

ABSTRACT

Process control environments are characterised by rapid changes in work demands, the successful response to which is dependent upon the availability of cognitive resources. Since high cue utilisation is associated with a reduction in cognitive load and a consequent release of residual resources, it was hypothesised that participants with high cue utilisation would experience lower subjective arousal and lower physiological effort in response to increases in the work demands associated with a simulated rail control task. A total of 41 participants completed a 10 min, low work demand period, followed by a 10 min, high work demand condition. High cue utilisation was associated with a reduction in systolic blood pressure and the maintenance of sustained, superior performance in response to high work demands. However, an increase in subjective arousal was also evident. The outcomes have implications for the selection and assessment of operators of high reliability, dynamic, process control environments.

1. Introduction

Despite increasing levels of automation and the introduction of sophisticated workload management tools, there remain work environments where operators are expected to transition from relatively low demand conditions to higher demand situations over relatively short periods of time. Examples of these environments include rail control, air traffic control, and energy transmission, where environmental and operational conditions can change quickly, imposing significantly greater levels of work demands on controllers than would normally be the case.

Coping successfully with changing demands in the workplace appears to be especially characteristic of 'expertise'. In comparison to non-experts, experts demonstrate a capacity to manage relatively greater volumes of work, while sustaining high levels of performance in other, related tasks (Cellier et al., 1997; Milton et al., 2004). This suggests that they possess cognitive strategies that enable a greater level of efficiency in identifying and responding successfully to changes in the system state.

Klein (1997) would suggest that the cognitive strategy that differentiates experts from non-experts is their capacity for situation assessment. This is a non-conscious process that involves the identification of key features in the environment, and the recognition of patterns of features through associations in memory (Wiegmann et al., 2002). These associations carry meaning that enable the interpretation of features.

The activation of features in the environment is a process that underpins recognition-driven approaches to decision-making (Kaempf et al., 1996; Macquet, 2009). Through repeated exposure, environmental features have been associated with events or objects in memory to form cues (Wiggins, 2015; Williams et al., 2002). The greater and more refined the repertoire of cues in memory, together with the consistency with which a system behaves, the more rapid, accurate, and reliable the responses (Ellis, 1996). Importantly, the efficiency with which this process occurs obviates the investment of significant cognitive resources (Small et al., 2014).

In environments where changes to a system state are unanticipated, have a rapid onset, and are cognitively demanding, there are advantages associated with the capability to assess situations rapidly and accurately, and with minimal cognitive resources. In addition to maintaining the stability of dynamic systems, it potentially enables the allocation of residual resources to other tasks, thereby ensuring that responses to changes in one part of a system do not impact the performance of other parts of the system (Xie and Salvendy, 2000). For organisations charged with the operation of dynamic, process control systems, understanding the capacity of operators to manage competing work demands successfully is critically important in ensuring the continuity of service and supply to customers.

* Corresponding author.
E-mail address: mark.wiggins@mq.edu.au (M.W. Wiggins).

https://doi.org/10.1016/j.apergo.2018.01.012
Received 21 August 2017; Received in revised form 6 January 2018; Accepted 27 January 2018

1.1. Cue utilisation

The capacity to apply feature-event/object associations in the form of cues differentiates performance across a wide range of domains, including pilots (Wiggins et al., 2014), software engineers (Loveday et al., 2014), and paediatricians (Loveday et al., 2013). Referred to as cue utilisation, it is the extent to which the behaviour observed in response to domain-related problems or events reflects the application of cue-based associations (Wiggins, 2014). For example, higher cue utilisation is normally associated with the rapid and accurate identification of key features from an array, the discrimination of relevant from less relevant features, and the acquisition of information in a prioritised sequence to enable problem resolution (Wiggins, 2015).

Cues are normally acquired through exposure to, and interaction with, task-related activities. Therefore, a relationship is typically evident between measures of cue utilisation and experience within a related domain (Loveday et al., 2013, 2014). However, while it is normally considered a domain-specific construct, there is recent evidence to suggest that a capability for cross-task cue utilisation where performance in one domain is predictive of performance in an allied domain. For example, higher cue utilisation in driving is associated with higher rates of skill acquisition during the initial stages of learning to land an aircraft, and learning to control a line-of-sight remotely piloted vehicle (Wiggins et al., 2014). Similarly, differences in cross-task cue utilisation have been established in simulated rail control environments, where higher cue utilisation in driving is associated with improved response latency to misrouted trains (Brouwers et al., 2016). Importantly, these effects are sustained despite increases in work demand (Brouwers et al., 2017).

For participants with higher cue utilisation, the capacity to sustain performance despite increases in work demands suggests that the utilisation of cues potentially releases cognitive resources. These residual resources can be directed towards the completion of secondary tasks with no loss of performance on the primary task (Brouwers et al., 2017). This effect should correspond to relatively lower increases in arousal and effort with the introduction of a secondary task.

1.2. Effort, arousal and cue utilisation

While there is a strong link between arousal and effort, the two constructs are presumed to represent different levels of cognitive processing. Arousal involves the activation of the autonomic nervous systems in response to changes in sensory stimuli (Howells et al., 2010; Posner and Petersen, 1990). However, it is often associated with the application of cognitive resources which constitutes mental effort (Westbrook and Braver, 2015). Increases in arousal and effort are evident in increases in heart rate and blood pressure, consistent with the activation of the sympathetic nervous system (Azarbarzin et al., 2014; Wulfert et al., 2005).

Changes in work demands involve changes in sensory stimuli, while an increase in demands is likely to be associated with increases in mental effort to ensure that work performance is maintained. In the present study, the work domain comprised a 20-min rail control simulation during which participants were asked to identify and correct the passage of any misrouted trains. Rail control was selected as the target domain since it involved tasks to which few participants would have been exposed, it embodied the capacity to incorporate patterns of train movements that would enable the evaluation of cue-based associations, and it could be simplified while maintaining a degree of ecological validity. It also enabled control to be exercised over the speed-accuracy trade off, since there was 7 s between the onset of a train and the point along the route at which a decision needed to be made as to whether or not the train needed to be rerouted. Finally, the work demands could be increased using a secondary task that required additional information to be recorded, thereby enabling an assessment of residual resources.

Previous research involving the rail control simulation has indicated that participants, differentiated on the basis of their cue utilisation in driving, show differences in performance within a short period following an increase in work demands (Brouwers et al., 2017). Specifically, participants with high cue utilisation record a lower mean response latency and fewer errors in comparison to participants with low cue utilisation (Brouwers et al., 2016, 2017).

Consistent with previous research, it was hypothesised that participants who demonstrate low cue utilisation would record a greater mean response latency and a greater frequency of errors with increases in work demand (Brouwers et al., 2016). However, given the role of cue utilisation in reducing the cognitive resources necessary for task performance, it was also hypothesised that a change in work demands would be associated with a greater increase in heart rate and blood pressure for participants with low cue utilisation, consistent with an increased level of arousal and the demand for greater mental effort to sustain performance.

2. Method

2.1. Participants

A total of 98 participants (64 female and 28 male[1]) were initially screened for the study, of whom the higher 21 and lower 20 performers were selected for inclusion based on their cue utilisation scores. The participants comprised first-year university students who received course credit for their participation, and they ranged in age from 17 to 23 years ($M = 18.9$, $SD = 1.89$). In addition to extreme cue utilisation scores, participants were required to have accumulated fewer than seven years of total driving experience. None of the participants reported experience in the context of rail control.

2.2. Stimuli

2.2.1. Rail control simulation

The rail control simulation was designed in-house, and consisted of a 5-min trial period, a 10-min lower workload stage followed by a 10-min period of higher work demands. The simulation comprises four tracks which run horizontally across the screen and divert at an intersection into odd and even tracks (see Fig. 1).

Trains were labelled with either an even or an odd number and travelled towards the intersection. The participants were asked to ensure that the trains travelled along their corresponding tracks so that even numbered trains travelled along the even labelled tracks, while the odd numbered trains travelled along the odd labelled tracks. A green line in advance of the train indicated the intended route of the train. Where a train was routed incorrectly (e.g., an even numbered train on the 'odd' track), participants were required to select the 'change' icon located directly above the respective track. Selecting this icon switched the intended route of the train to alternative track. Once the 'change' icon was selected, the decision could not be reversed.

Since the utilisation of cues is the principal mechanism by which participants are expected to gain residual resources, the rail control simulation embodied a pattern of movements whereby trains that were required to be re-routed were displayed only on the first and fourth tracks. Trains that travelled on the second and fourth tracks never required re-routing. This pattern of movements was tested by Brouwers et al. (2017) as part of a pilot study, during which 50% of participants successfully identified the pattern. Moreover, the identification of the pattern differentiated performance during a subsequent experimental evaluation, especially during the high workload phase of the task.

In the present study, participants were expected to divert 43 of 86 trains in the absence of any other tasks during the low work demand

[1] Six participants failed to report their sex.