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Slip Errors and Cue Salience

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ABSTRACT

Motivation – Many empirical accounts of slip errors have focused on identifying causal factors. However, to what extent can avoiding slip errors be considered a cognitive skill?

Research approach – A series of experiments have shown that some actions seem to "spring to mind" for the performance of a task, whereas others do not, and that the latter are much more likely than the former to feature in erroneous actions.

Findings – The results suggest that procedural and sensory cues need to be strong enough to capture a participant's attention away from actions that "spring to mind".

Research limitations/Implications – Avoiding error can be considered a cognitive skill when a 'window of opportunity' is utilised to rehearse procedural steps or when participants are able to create their own environmental cues.

Originality/Value – The research suggests that identifying how people avoid making errors can provide us with a deeper understanding of why errors happen.

Take away message – Rehearsal and personalised cue creation is spontaneous and can be used to minimize the likelihood of error.

Keywords

Human error, attentional control, cognitive skill.

MOTIVATION

Slip errors can occur systematically even when individuals have the required 'expert' procedural knowledge to perform a task correctly. People make slip errors frequently, but do not make them every time. The frequency of errors is determined by causal factors internal and external to the cognitive system. Many empirical accounts of slip errors have focused on identifying these causal factors. For example, Byrne and Bovair (1997) showed that post-completion error (a type of omission error) is sensitive to working memory demands. An alternative approach to developing causal accounts is considered here. This paper reports on work in progress that aims to determine the extent to which avoiding slip errors is a cognitive skill.

Modelling the cognitive skill required to execute 'expert' procedural knowledge has traditionally involved the use of 'top-down' planning frameworks. However, previous research has strongly suggested that users are reliant on 'bottom-up' cues from the environment when planning future actions (Payne, 1991; Suchman, 1987). This has led to criticism of planning frameworks such as GOMS (Card, Moran, & Newell, 1983) where the successive decomposition of goals into sub-goals and operators is representative of an inherently 'top-down' model of interaction. By reviewing the findings of a series of empirical studies, this paper considers whether slip errors are caused by an inappropriate 'bottom-up' "springs to mind" response to environmental features (that correspond to known actions). For example, the appearance of a text entry box may prompt a user to start typing without initialising the box (i.e., moving the mouse cursor and clicking inside the box). Other examples include: pressing the 'start button' before setting the required wash cycle program; forgetting to attach a document to an email before clicking on the 'send' button.

RESEARCH APPROACH

While some errors appear to be stochastic, others have been shown to be systematic – i.e. there are patterns in the physical system design or user task structure that make slip errors more likely than pure chance. Error rates have been shown to be significantly influenced by working memory demands (Byrne & Bovair, 1997), interruptions (Li et al., 2006), or intrinsic load (Back et al., 2006). However even when not intentionally manipulated (e.g., in low cognitive load conditions), most slip errors remain systematic (error rate >5%). When performing a familiar interactive routine, an intention can be formulated well before the opportunity to execute the procedural steps that allow that intention to be communicated. When environmental features suggest that an intention can be communicated those features become cognitively salient. Well-designed interfaces increase the sensory salience of signals that are used to cue actions that are frequently forgotten or are performed in the wrong sequence. However, although sensory salience can be manipulated by making an indicator bigger or louder or just in time, this does not ensure that the action will be performed since the action may not be cognitively salient.

A ‘top-down’ model of interaction enforces a hierarchical control structure where the order in which actions will be attempted is largely predetermined (unless an individual is cognitively overloaded or interrupted). Chung and Byrne (2004) found that a cue has to be highly visually salient in order to ensure that a task critical step, buried deep down in the control structure, is not forgotten (leading to post-completion error). Instead of focussing on causal factors that prevent the retrieval of elements in a control structure, we speculate that many errors occur because an individual’s attention is captured by actions that “spring to mind”.

Accounts of many errors can be given in terms of how people are allocating attentional resources. An individual’s awareness of what they have to do next can be driven by cues that are internal to the cognitive system (goals and methods) or external to the cognitive system (cued in the environment). Is selecting the most appropriate cue to drive interaction a cognitive skill or is cue selection an involuntary processes directed by an off-line attentional control system?

Attentional systems are complex since they involve a range of different kinds of processing. Although allocating spatial attention to an appropriate cue within the environment does not guarantee that the cue will be processed, it increases the probability that it will be. Folk et al. (1992) argued that the allocation of spatial attention is analogous in some respect to that of, for example, a thermostat. A thermostat can automatically activate heating when the temperature falls below a certain threshold without intervention. The individual sets the threshold but the activation is off-line. Folk et al. propose that even when attention is involuntarily captured, cognitive goals determine attentional control settings in advance (off-line); the appearance of stimuli matching that setting will capture attention (on-line), with no further involvement of cognitive processes.

A series of experiments (summarised below) have shown that some actions seem to “spring to mind” for the performance of a task, whereas others do not, and that the latter are much more likely than the former to feature in erroneous actions. An individual’s attention must be captured away (or diverted) from an action that corresponds to “springs to mind” salience for an alternative course of action to be considered. The cognitive skill is to avoid performing an action that “springs to mind” if an alternative action is required.

DESIGN

An experimental paradigm was designed that manipulated the availability (and awareness) of both procedural and sensory cues that were needed to overcome performing erroneous “springs to mind” actions. We hypothesised that slip errors were more likely when the salience of cues was not sufficient to actively influence attentional control. If processes are directed by a passive (off-line) attentional control system then errors associated with performing “springs to mind” actions are more likely.

- Non-sensory cues, known as procedural cues (internal to the cognitive system), can be used to retrieve previously formulated intentions (expert procedural knowledge) enabling the next procedural step to be performed. Remembering that, and so doing, after performing x always do y if z is true is an example of following a procedural cue rule.
- Sensory cues (external to the cognitive system) can also be used to retrieve intentions (expert procedural knowledge). For example, if sensory cue p is attended to then it may indicate that q should be the next step if r is true.

A simulation of a ‘Fire Engine Dispatch Centre’ was developed. The overall objective was to send navigational information to fire engines enabling the fastest possible incident response times. When a call was processed the location of the nearest fire engine and the location of the incident were displayed automatically as waypoints on a map. Participants had three minutes to identify the best route based on information displayed on a traffic information ticker. Training trials were used to ensure that participants became familiar with the sequence of actions required. After performing two 'error free' training trials consecutively, a participant was allowed to move on to twelve experimental trials.

Two experiments using 24 participants each were run. Experiment 1 investigated the frequency of two classes of slip error under different cognitive and perceptual load scenarios (Back et al., 2007). In total there were twelve trials: half imposed a low cognitive load (less complex routes, fewer navigational waypoints to be considered) and the remaining half imposed a high cognitive load (more complex routes, more navigational waypoints) (trial order was randomized). Across all errors, high cognitive load trials provoked more errors (finding was consistent with Byrne and Bovair’s (1997) working memory theory). Experiment 2 investigated if a ‘window of opportunity’, used to rehearse procedural steps, reduced error rates. Previous research (Trafton et al., 2003) found that providing a ‘window of opportunity’ allows people to rehearse an appropriate task resumption point. Environmental cues play a potentially large role in the resumption even when candidate cues such as cursor position are removed. In Experiment 2 there were twelve trials: half allowed environmental cues to be used for rehearsal (interface was visible) and the remaining half removed all environmental cues (blank screen) (trial order was randomized). The cognitive load imposed was not manipulated and was high for all twelve trials.

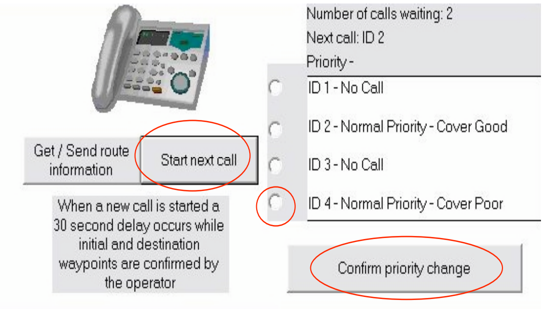
FINDINGS

Results from both of these experiments demonstrate that procedural and sensory cues need to be strong enough to capture a participant’s attention away from actions that “spring to mind”.

Initialisation Error

When commencing a new trial an individual had to decide which call to prioritize before clicking on the 'Start next call' button (*see* Figure 1). For each trial there was only one correct call prioritization selection (calls did not share the same attributes). Participants were trained to know that incidents in poor fire engine coverage areas should be selected before incidents in good coverage areas. They also knew that high priority calls took precedence over normal priority calls irrespective of fire engine coverage. The first step in the process of setting call priority involved clicking on the radio button that was located alongside the required call ID. For example, in Figure 1 a participant is required to select ID 4. Clicking on 'Confirm priority change' is the second procedural step. Participants were instructed that the 'Start next call' button should only be clicked when both the new call ID has been selected and the 'Confirm priority change' button has been clicked. The 'Confirm priority change' step can be cued by following a procedural rule (i.e., after clicking on radio button (*x*), always click on confirm (*y*) if selection (*z*) is true). The strength of this cue was high. The error rate was <1%.

Forgetting to perform the call prioritisation procedure resulted in an initialisation error (a type of omission error). The "springs to mind" salience of clicking on 'start next call' was high. Critically, no procedural cues were available since the requirement to perform call prioritisation was at the beginning of a new trial (a short interruption task was performed between trials). This led to high error rates. In Experiment 1 the mean error rate was 29% (no significant difference between high and low cognitive load conditions).


Number of calls waiting: 2
Next call: ID 2
Priority -

When a new call is started a 30 second delay occurs while initial and destination waypoints are confirmed by the operator

Figure 1: Call Prioritisation

In Experiment 2 participants were given 4 seconds to reflect on requirements before commencing a trial. During this reflection time the mouse cursor disappeared. There were two within-subjects conditions: A) call prioritisation interface always visible; B) call prioritisation interface not visible during reflection time (blank screen). In Condition A the error rate was 8%. In Condition B the error rate was 26%. Participants were significantly better able to avoid initialisation errors when they were able to reflect or rehearse task requirements (Wilcoxon Z = -2.910, $p < .005$, non-parametric two related samples test). They were able to spontaneously generate a procedural cue rule (i.e., when mouse cursor returns (*x*), remember to perform call prioritisation (*y*) before clicking start (*z*)).

Mode Error

When a participant commenced the route construction procedure (after clicking on the start button) the first requirement was to identify the most appropriate route on the map. Three suggested routes were pre-programmed: fastest (calculated using road speed limits); shortest - (calculated by distance); alternative - (avoiding roads used by both the fastest and shortest routes). Task trials were designed to ensure that the fastest route was always different to the shortest route. Participants had to select the best route based on information displayed on the traffic information ticker (i.e., they had to ensure a proposed route did not run through an accident or heavy traffic area). On average this identification process took 98 seconds.

The device provided a signal that informed participants of the required method of route construction (located above the telephone image, *see* Figure 2). This signal was available after 35-45 seconds from pressing the start button (randomised). Participants were required to attend to this signal so that they could determine what type of route information was needed. If GPS was available then the centrally located menu could be used. Clicking on this menu enabled one of the automatically generated routes to be selected. This menu "springs to mind" since the route names listed correspond to the route labels on the map. The drop-down menu located below and to the left of the automatic route selection menu was used for manual route construction (items did not correspond to memorised route labels so did not "spring to mind"). A mode error occurred when a participant used the wrong route construction method. In the majority of cases the automatic menu was selected erroneously. Cases where participants erroneously selected the manual route construction menu were rare (<5%) and are excluded from the analysis below.

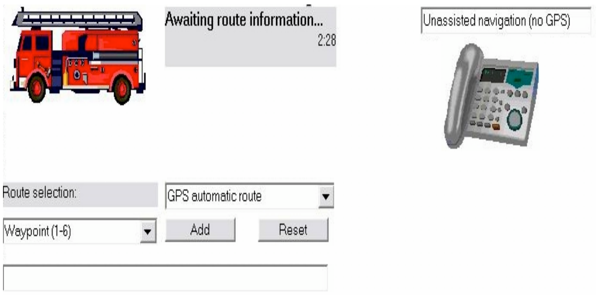

Awaiting route information...
2:28
Unassisted navigation (no GPS)
Route selection: GPS automatic route

Figure 2: Route Construction

The error rate in Experiment 1 was 16% in the high cognitive load condition and 10% in the low cognitive load condition (difference not statistically significant). In Experiment 2 Condition A, where both route selection menus were always visible, the error rate was 15%. In Experiment 2 Condition B, where route selection menus appeared after 60 seconds (after pressing the start button), the error rate was 13%. The difference between Conditions A and B was not statistically significant.

A fine-grained analysis of Experiment 1 and 2 revealed that if participants placed the mouse cursor close to the signal status display (before the signal status appeared), they were less likely to forget to attend to the display before selecting the appropriate route construction method. When the mouse cursor was placed < 2cm from the display participants were significantly less likely to make a mode error (Wilcoxon Z = -1.870, $p < .005$, non-parametric two related samples test). Positioning the mouse cursor enables the creation of a sensory cue. If cursor (p) is attended to then it may indicate that display (q) should be attended to when route identification (r) is complete.

RESEARCH IMPLICATIONS

Avoiding error can be considered a cognitive skill when a 'window of opportunity' is utilised to rehearse procedural steps or when participants are able to create their own environmental sensory cues. The findings from the experiments reported in this paper have shown that humans make use of cues in the environment when planning future actions. An opportunity to reflect on future actions is only useful when the task environment is visible. Being able to anticipate task requirements and use tools (i.e., the mouse cursor) to plan future actions make slip errors less likely. While 'top-down' models of interaction can reveal patterns in the physical system design or user task structure that make slip errors more likely than pure chance, they cannot account for the fine-grained strategies that people adopt to remain resilient against error. Dekker (2005) suggested that error classification disembodies data: it removes the context that helped to produce the behavior in its particular manifestation. "Without context, there is no way to re-establish local rationality. And without local rationality, there is no way to understand human error" (Dekker, 2005, p 60).

Performing actions that seem to "spring to mind" for the performance of a task can be avoided by 'bottom-up' planning. Although not all actions that "spring to mind" necessarily lead to error, in a safety critical environment actions should *ideally* never "spring to mind". If selecting the most appropriate cue to drive interaction is left to an off-line attentional control system then errors are more likely.

TAKE AWAY MESSAGE

Rehearsal and personalised cue creation is spontaneous and can be used to minimize the likelihood of error. System designers can modify the task environment to ensure that rehearsal and cue creation is possible. Allowing users to position markers (like 'Post-it' notes) provides support for on-line attentional control. Likewise allowing users time to rehearse procedural steps, can prevent attention being captured by potentially erroneous "springs to mind" actions.

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