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Effects of monetary reward and punishment on information checking behaviour: An eye-tracking study

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ABSTRACT

The aim of the present study was to investigate the effect of error consequence, as reward or punishment, on individuals' checking behaviour following data entry. This study comprised two eye-tracking experiments that replicate and extend the investigation of Li et al. (2016) into the effect of monetary reward and punishment on data-entry performance. The first experiment adopted the same experimental setup as Li et al. (2016) but additionally used an eye tracker. The experiment validated Li et al. (2016) finding that, when compared to no error consequence, both reward and punishment led to improved data-entry performance in terms of reducing errors, and that no performance difference was found between reward and punishment. The second experiment extended the earlier study by associating error consequence to each individual trial by providing immediate performance feedback to participants. It was found that gradual increment (i.e. reward feedback) also led to significantly more accurate performance than no error consequence. It is unclear whether gradual increment is more effective than gradual decrement because of the small sample size tested. However, this study reasserts the effectiveness of reward on data-entry performance.

1. Introduction

The ability to detect and correct one's errors is an important aspect of human performance. This ability becomes especially important in work contexts that are mission or safety critical. For example, in healthcare, a widely cited report estimated that about 44,000 to 98,000 hospital deaths each year are results of various kinds of medical errors (Kohn et al., 2000). Moreover, safety-critical errors can often happen in routine tasks such as data-entry, which has been ranked as the fourth-leading cause of medication errors by the U.S. Pharmacopeia in 2003 ("Data entry is a top cause of medication errors," 2005).

Traditional research on error detection has focused on whether or not errors are detected, and whether certain error types (e.g. slips vs mistakes) are easier to be detected than others (Sellen, 1994; Zapf et al., 1994). A number of theoretical models of error detection have been proposed. For example, Reason (1990) described three main ways in which errors get detected: (1) by monitoring one's own performance; (2) by cues or feedback provided in the environment; and (3) by other people. Sellen (1994) proposed a similar framework and suggested that error detection can occur via (1) the incorrect actions themselves; (2) consequences from the incorrect actions; (3) external constraints in the environment; and (4) other people. More recently, Blavier et al. (2005) proposed a model of error detection based on prospective memory and emphasised the importance of intention formation and retention when detecting errors. Despite their different theoretical orientation, these error detection models share a common idea that regular checking of one's own performance forms an important part of the detection process. This is supported by empirical evidence from laboratory (e.g. Allwood, 1984) and observational studies (e.g. Nyssen and Blavier, 2006).

Human-computer interaction (HCI) researchers have also investigated data-entry performance. A number of studies have examined the effectiveness of various data-entry methods by comparing double entry (same set of data entered twice), read aloud (data checked while another person reads them out loud), and visual checking (data checked by sight) (Barchard and Pace, 2011; Barchard and Verenikina, 2013); consistently, double entry has been found to result in the most accurate performance. However, whilst Barchard and colleagues' studies provide answers to the research questions they set, the findings do not address what motivates checking in the first place.

As previous research has implicated the essential role of checking in error detection, in this paper, we carried out two eye-tracking

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experiments to investigate how checking might be motivated to enhance error detection. The questions we ask are: can one motivate checking behaviour in terms of monetary reward and punishment? If so, can checking enhance data-entry performance?

The role of motivation has long been recognised in theoretical discussions of human error (e.g. Lourens, 1990) and it may take many different forms. For example, accountability can be a form of motivation, which determines whether or not one is held accountable for one's errors; and this can have implications for an organisation's safety culture and its workers' attitudes towards errors (Dekker, 2009; Woods et al., 2010). Error consequences in terms of reward and punishment are another form of motivation. It was found that punishment that did not have any direct consequence was ineffective in reducing errors (Back et al., 2007). However, when it had an actual cost on participants' performances, punishment resulted in fewer errors in procedural task performance (Brumby et al., 2013).

Li et al. (2016) carried out a study on data-entry, focusing on how to motivate checking behaviour by imposing error consequences in terms of monetary reward and punishment. They designed a computer-based data-entry task in which there were two panels, each with eight information fields, on the computer screen. Participants were required to transcribe textual or numerical information from the left panel to the right panel. Each information field on the left panel was covered by a grey box, and when the participants wanted to look at the to-be-transcribed information, they had to hover the mouse over the grey box to reveal the information. This paradigm allowed Li et al. to measure the number and duration of uncovering actions made by the participants; these measurements were used to quantify their checking behaviour. Error consequences were manipulated such that in the Reward condition, participants were informed that if they correctly transcribed all the trials, they would receive extra payment; in the Punishment condition, if the participants made even one error in any of the trials, they would receive a reduced payment; participants in the Control condition were paid a fixed amount for completing all the transcription trials. One of the main findings was that reward and punishment resulted in more accurate performance than no consequence; however, reward and punishment did not lead to different performance levels (see Table 1). The other finding of the study was that monetary reward and punishment motivated participants to engage in more frequent and longer checking behaviour than no consequence at all.

In order to further investigate the effects of reward and punishment on checking behaviour in terms of eye-movement data, we employed an eye tracker and an experimental task similar to that used in Li et al. (2016). The experimental task was modified so that there were no grey boxes on the left panel of the computer screen; this way, participants could check the to-be-transcribed information by eye gazes only rather than mouse movement as in Li et al. By adopting an eye tracker, our first experiment is designed to examine the effect of reward and punishment under more ecologically valid checking conditions. Research on interaction behaviour suggests that people are sensitive to information access cost. Gray and Fu (2004) found that, when given a choice, people consistently opt for an interaction strategy that involves the least cognitive and physical effort even when the strategy might lead to suboptimal task performance. As our current experimental paradigm imposed less checking effort (visual) than Li et al. (manual mouse movement), we expect there would be an overall increase of checking behaviour in our first experiment relative to Li et al.

Table 1
Data reproduced from Li et al.'s (2016) Experiment 1.

Error Consequence conditions[a]	No. of errors[b]	Error rate[c] *M (SD)*	No. of checks *M (SD)*	Duration of checks (ms) *M (SD)*
Control	173	1.8 (1.9)	4.2 (2.6)	1486.3 (512.0)
Reward	94	0.92 (1.2)	7.1 (3.6)	2108.7 (831.4)
Punishment	88	0.98 (1.1)	8.2 (4.0)	2140.7 (978.2)

[a] For each condition, $n = 30$.

[b] No. of error opportunities for each condition = 9600.

[c] Error rate is a percentage calculated as a ratio of no. of errors to the no. of error opportunities.

In terms of theoretical formulation in our study, it is worth noting that we did not adopt a framework such as the Tversky and Kahneman (1991) work on gain/loss framing because that is applied to decision-making tasks and our domain of interest is not decision making but data entry, which is a procedural activity. While the effect of loss aversion can be found in decision making under uncertainties, we do not see it as a suitable theoretical framework for our data-entry task. Therefore, we appeal to empirical findings from other domains in the following.

Findings from neuroscience suggest that a neural signal called error-related negativity (ERN) is sensitive to monetary gains (Stürmer et al., 2011) and losses (Potts, 2011) and that different neural circuits are responsible for reward and punishment (Wrase et al., 2007; Yeung and Sanfey, 2004). Moreover, recent evidence suggests that reward is more effective than punishment in improving motor memory (Abe et al., 2011). Reward has also been found to improve creativity (Eisenberger and Cameron, 1996; Eisenberger and Rhoades, 2001) and motivation (Eisenberger et al., 1999; Hendijani et al., 2016). Although none of the outlined studies directly compared rewards to punishments (e.g. Eisenberger et al., 1999; Hendijani et al., 2016) or investigated the effect on data-entry performance (Abe et al., 2011), these studies suggest that reward is better than punishment at improving human performance in a number of domains. One of the novelties of our study is the investigation of motivation (in terms of reward and punishment) on data-entry performance, and, to the best of our knowledge, there are no existing studies in HCI that can provide us with direct predictions. Therefore, it is necessary to look for theoretical support from studies in other domains and test whether their findings can be generalised to ours. We examined the effect of reward and punishment in the first experiment and predicted that reward consequence would result in better data-entry performance than punishment consequence.

In the second experiment, we manipulated error consequences so that they were associated with each individual trial and that immediate performance feedback, in terms of payment increment (i.e. reward) or decrement (i.e. punishment), was also provided to the participants. Therefore, in the second experiment, we predicted that reward, in the form of gradual increment, would result in more accurate data-entry performance and more rigorous checking behaviour than punishment in the form of gradual decrement.

2. Experiment 1

This experiment was designed to examine the effect of reward and punishment on checking behaviour by using an eye tracker. Checking behaviour was quantified in terms of eye fixations and fixation duration. In Li et al. (2016), the experimental task involved the, previously mentioned, grey-box paradigm and checking was carried out by the participants through mouse movement. Therefore, checking, as performed in the current task paradigm, was less effortful when compared to Li et al. (2016).

Three hypotheses were tested in the current experiment: first, based on the effect of information access cost (Gray and Fu, 2004), we predicted an overall increase in the number of checks and a decrease in check duration when compared to Li et al. (2016). Because when checking is easier (as in the current experiment), participants might check more often but each check is shorter in duration due to the ease of information access. Second, the current experiment was expected to partially reproduce Li et al.'s results, namely that reward and punishment result in more accurate data-entry performance and more rigorous checking than no error consequences at all. Third, based on various empirical studies in the literature (Abe et al., 2011; Eisenberger and Cameron, 1996; Eisenberger and Rhoades, 2001; Eisenberger et al.,