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The effects of cognitive load during intertrial intervals on judgements of control: The role of working memory and contextual learning

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ABSTRACT

When there is no contingency between actions and outcomes, but outcomes occur frequently, people tend to judge that they have control over those outcomes, a phenomenon known as the outcome density (OD) effect. Recent studies show that the OD effect depends on the duration of the temporal interval between action-outcome conjunctions, with longer intervals inducing stronger effects. However, under some circumstances OD effect is reduced, for example when participants are mildly depressed. We reasoned that working memory (WM) plays an important role in learning of context; with reduced WM capacity to process contextual information during intertrial intervals (ITIs) during contingency learning might lead to reduced OD effects (limited capacity hypothesis). To test this, we used a novel dual-task procedure that increases the WM load during the ITIs of an operant (e.g., action-outcome) contingency learning task to impact contextual learning. We tested our hypotheses in groups of students with zero (Experiments 1, $N = 34$), and positive contingencies (Experiment 2, $N = 34$). The findings indicated that WM load during the ITIs reduced the OD effects compared to no load conditions (Experiment 1 and 2). In Experiment 2, we observed reduced OD effects on action judgements under high load in zero and positive contingencies. However, the participants' judgements were still sensitive to the difference between zero and positive contingencies. We discuss the implications of our findings for the effects of depression and context in contingency learning.

1. Introduction

Perception of control over specific events is a subjective feeling that is thought to depend on how people perceive the objective action-outcome contingencies in the environment (Langer, 1975, also see E. A. Skinner, 1996 for various terms and measures used to describe control). Experimental studies using contingency learning paradigms have shown that perception of moderate levels of control over events, even when statistically there is none, is related to mental healthiness, with extremely high and low levels of perceived control relating to psychopathology (Alloy & Abramson, 1979, 1988; Metcalfe, Van Snellenberg, DeRosse, Balsam, & Malhotra, 2014; Reuven-Magril, Dar, & Liberman, 2008; Taylor & Brown, 1988).

In this research, we test how changes in perceived control relate to the effects of cognitive load, which might prevent learning of important contextual information relevant to contingency learning. This is relevant, as learning is believed to occur in a limited capacity device (Pearce & Hall, 1980; Wagner, 1978, 1981), and when cognitive capacity is reduced this might interfere with the learning of contextual information. Thus, our analysis will focus on cognitive and behavioural processes such as attention and memory that might play a causal role in healthy and lower levels of perceived control (Harvey, Watkins, Mansell, & Shafran, 2004). However, first, we will discuss how perception of control has been studied and the situations where individuals differ in their levels of perceived control.

1.1. Operant contingency

In operant contingency learning tasks, individuals learn the relations between their actions and the outcomes. There are two versions of the operant learning paradigms: free-operant and discrete-trial procedures. In free-operant procedures, the task is divided into time-bins, and the participants are free to act at times they would like whereas in discrete-trial procedures, the learning task is divided into trials and participant may only perform the action during this period. In discrete-trial procedures, trials are separated by a time period known as the intertrial interval (ITI) of varying durations. Experiments have tested people's perception of control over outcomes using both kinds of paradigms (e.g., Allan & Jenkins, 1983; Alloy & Abramson, 1979; Byrom, Msetfi, & Murphy, 2015; Jenkins & Ward, 1965; Msetfi, Murphy, & Simpson, 2007; Msetfi, Murphy, Simpson, & Kornbrot, 2005; Msetfi, Wade, & Murphy, 2013; Vázquez, 1987; Wasserman, Elek, Chatlosh, & Baker,

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1993). However, the advantage of discrete-trial procedures over free-operant procedures is that they include a clearly defined event structure with an objective measure of control with which judgements of control made by people can be compared to (Ackermann & DeRubeis, 1991; Clark, Beck, & Alford, 1999; Dobson & Franche, 1989). This is a measure of action-outcome contingency, denoted by the ΔP metric (Allan, 1980), which quantifies a statistical, one-way relation between binary events.

The ΔP metric is simply equivalent to the difference between the probability of an outcome occurring in the presence of an action, $P(O|A)$, and the probability of an outcome occurring in the absence of an action, $P(O|\sim A)$. This metric can vary from -1 (negative or preventative contingency) to 0 (zero contingency) to $+1$ (positive or generative contingency). For example, in a positive contingency schedule, outcomes are more likely to occur in the presence of action than in its absence, whereas in negative contingency schedule, outcomes are less likely to occur in the presence of action. From this perspective, there are four possible action-outcome conjunctions relevant to contingency all of which are given equal weighting in the ΔP calculation, and are shown in Table 1 along with exemplar conditions.

1.2. Outcome density effects and the context hypothesis

As can be seen in Table 1, in the zero contingency schedules, outcomes are equally likely to occur irrespective of the presence and absence of action. However, most studies using discrete-trial operant contingency learning paradigms indicated that healthy individuals overestimate the degree of control they have over the outcomes when the outcome density (OD) or the probability of outcome to occur, $P(O)$, is high, whereas people with mild depression tend to be less sensitive to such differences (see Moore & Fresco, 2012 for a meta-analysis). The effect that healthy people overestimate the degree of control in high OD condition is named OD bias or illusion of control, and is considered to be a deviation from ΔP. On the other hand, depressed people tend not to show this illusion, an effect known as depressive realism (Alloy & Abramson, 1979).

There are many behavioural- and cognitive-level explanations of OD and depressive realism effects, such as the response probability (Blanco, Matute, & Vadillo, 2012; Matute, 1996), response criterion (Allan, Hannah, Crump, & Siegel, 2008; Allan, Siegel, & Hannah, 2007), and context hypotheses (Msetfi, Brosnan, & Cavus, 2016; Msetfi et al., 2005, 2007, 2013). It is not possible to review all these theories in detail here. Briefly, however, Matute and colleagues suggested that illusory control might stem from high response probability, leading to more reinforced trials during the contingency learning task (Blanco et al., 2012; Matute, 1996). On the other hand, in their psychophysical analysis of contingency, Allan and colleagues (Allan et al., 2007, 2008) suggested that people perceive the normative ΔP within the constraints of memory and attention limits. However, depressed people might have a lower response criterion (e.g., a tendency to say "nay"). Given the centrally defining role of context in learning, we will particularly focus on contextual learning here.

Table 1
The standard 2 × 2 operant contingency table and zero contingency high and low outcome density conditions, assuming a response rate of 0.5.

Action	Outcome: Present (O)	Outcome: Absent (~O)	$P(O\|A)$	$P(O\|\sim A)$	$P(O)$	ΔP
Generic information						
Present (A)	a	b	a / (a + b)	c / (c + d)	(a + c) / *N*	a / (a + b) − c / (c + d)
Absent (~A)	c	d				
High OD zero contingency						
Present (A)	15	5	0.75	0.75	0.75	0
Absent (~A)	15	5				
Low OD zero contingency						
Present (A)	5	15	0.25	0.25	0.25	0
Absent (~A)	5	15				

Notes. The letters in the cells (a, b, c, and d) represent the frequency of co-occurrences and non-co-occurrences of an Action (A) and an Outcome (O). Contingency = $\Delta P = P(O|A) - P(O|\sim A)$. Outcome density (OD) is the probability of outcome to occur and is calculated as $P(O) = (a + c) / N$, where N is the total number of the event conjunctions.

Learning occurs in an environmental and associative context, and contextual effects have been studied and conceptualised in numerous ways in animal learning (e.g., Balsam & Tomie, 2014; Bouton & King, 1983; Estes, 1976; Maren, Phan, & Liberzon, 2013). Although environment represents a context, there are many other forms of contexts that define experience. Our contingency manipulations here deal with action-outcome relations that occur in a particular context, and we study how individuals learn these relations.

One of the simplest methods of testing context effects on learning is via temporal manipulations because context and time are interdependent (Msetfi et al., 2013). Along these lines, Msetfi et al. (2005, 2007) noted that most studies reporting OD effects involved long ITIs. To test the hypothesis that the ITI duration might influence judgements of control, Msetfi et al. (2005, 2007) varied ITI duration (3 s vs. 15 s), along with a standard OD manipulation (low vs. high) in two groups (depressed and non-depressed) in a zero contingency task. Msetfi and colleagues' findings indicated an OD effect in the non-depressed group when ITIs were longer (e.g., 15 s), and reduced OD effects in people with depressed mood in the same condition. On the other hand, both non-depressed and depressed groups' judgements of control did not significantly change due to OD manipulation when the ITIs were shorter (e.g., 3 s).

At the computational level, Msetfi et al. (2005) explained these findings in the light of their ITI integration hypothesis. This hypothesis adjusts the experimental contingency by accounting for extra contextual information due to long ITIs. When ITIs are integrated into the ΔP calculation as discrete events (cell 'd'), this has the effect of decreasing $P(O|\sim A)$, thus increasing ΔP in high OD conditions in particular (Msetfi et al., 2005, 2007). While non-depressed people's judgements were consistent with the ITI integrated contingency, judgements of control made by people with mild depression seemed to be less sensitive to this information.

Msetfi et al. (2005) argued that the reason ITIs are relevant to the contingency, in spite of containing no actions or outcomes, is because they occur in the same context as all the other contingency events. As depressed people's judgements seem to be insensitive to ITI duration, possibly due to depression-related cognitive processes such as rumination (Nolen-Hoeksema, 1991; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008), the findings were consistent with the idea that impaired contextual learning might underlie depressive realism effect. This hypothesis would also be compatible with the associative learning model (e.g., Rescorla & Wagner, 1972), if ITIs are considered "context only" trials (e.g., no action-no outcome). This would result in a decrease in associative strength between context and outcome, leading the action to gain associative strength (Msetfi et al., 2005).

While it is possible that contextual learning is related to reduced OD effects in depression, the exact process of how contextual learning occurs (e.g., automatic vs. controlled) remains unknown. Although, it is known that depressed people have a higher tendency to display self-referent and ruminative thinking (Nolen-Hoeksema, 1991; Nolen-Hoeksema et al., 2008), which might be related to performance-related impairments in cognitive tasks (see Whitmer & Gotlib, 2013 for a review). Based on this, we hypothesised that reduced cognitive capacity to integrate contextual information present during idle task periods (i.e, ITIs) will impact perceived control. To test this hypothesis, we manipulated the level of cognitive load during the ITIs of an operant contingency learning task.

1.3. The effects of working memory load on learning

Working memory (WM) is the ability to maintain and manipulate limited information in short periods, and is thought to play an important role in complex cognition (Baddeley, 1992, 1996; DeCaro, Thomas, &