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Time course of colour-word contingency learning: Practice curves, pre-exposure benefits, unlearning, and relearning

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ABSTRACT

In performance-based measures of implicit contingency learning, learning effects have been observed very early in the task (e.g., within a few trials) and remain stable throughout the experiment. This has been taken to suggest that the contingency knowledge underlying the learning effects is formed almost instantly and does not develop further across trials. One potential concern with the available evidence is that response times are overall much slower early on in an experiment and speed up over practice in a decelerating function. If learning effects scale with overall response time, then learning effects observed early on in an experiment might be artificially inflated. In the current report with the colour-word contingency learning paradigm, participants were given an extended practice phase before introducing predictive stimuli (words). Thus, learning could be assessed after the large practice speedup in performance had already occurred. In one experiment, the contingency learning effect was found to again be fairly stable, but with a hint of an increasing effect with time. In a second experiment, words were pre-exposed in a neutral hue before being coloured. This increased the magnitude of the learning effect, suggesting a preparation time benefit. More importantly, the contingency learning effect was observed to increase over time. In a third experiment, we assessed unlearning rates when the contingency was removed, and relearning when the contingencies were reintroduced. The results revealed a cumulative effect of contingencies acquired across multiple blocks. In sum, the evidence reported in this paper shows that, contrary to previous claims, implicit contingency learning is cumulative.

1. Introduction

In the study of implicit contingency learning, performance (i.e., response time) paradigms are very useful for assessing learning. For instance, in the colour-word contingency learning paradigm, participants respond to the print colour of neutral (colour-unrelated) words (Atalay & Misirlisoy, 2012; Hazeltine & Mordkoff, 2014; Levin & Tzelgov, 2016; Schmidt & Besner, 2008; Schmidt & De Houwer, 2012a, 2012d, 2016; Schmidt, Crump, Cheesman, & Besner, 2007; Schmidt, De Houwer, & Besner, 2010; see also, Musen & Squire, 1993). Each word is presented most often in one colour (e.g., "choose" most often in purple, "drive" most often in orange, etc.). Learning can be assessed by comparing *high contingency* trials, where the word is presented in the expected colour (e.g., "choose" in purple), to *low contingency* trials, where the word is presented in an unexpected colour (e.g., "choose" in orange). This produces a highly-robust learning effect: high contingency trials

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are responded to faster (and more accurately) than low contingency trials. A similar paradigm is the flanker contingency paradigm, in which flanking letters are predictive of a centrally-presented target letter (Carlson & Flowers, 1996; Miller, 1987). Other performance paradigms include the serial response time task (Nissen & Bullemer, 1987) and hidden covariation detection (Lewicki, 1985, 1986; Lewicki, Hill, & Czyzewska, 1992).

One interesting finding with such performance paradigms is that the learning effect appears *very* early on in the experiment (i.e., within a few trials). In the most dramatic instance of this, a learning effect was observed after a single presentation of a stimulus by Lewicki (1985) in the hidden covariation paradigm. Similarly, contingency effects have been observed early on in sequence learning (Nissen & Bullemer, 1987). Also in the colour-word contingency learning paradigm, contingency effects emerge in the very first block of trials, with blocks as small as 18 trials. After this, the magnitude of the learning effect remains relatively stable (e.g., Schmidt & De Houwer, 2012b, 2012d, 2016; Schmidt et al., 2007, 2010). That is, the learning effect does not seem to increase in any notable way. Results such as this have been taken to indicate that the learning rate is extremely high. In other words, the contingencies are learned very rapidly and there is little more to learn thereafter.

First, it is important to note the distinction between the *learning effect* and the *underlying learning mechanism*. The learning effect (e.g., the difference in response speed to high vs. low contingency trials) is a behavioural observation. Of course, some underlying learning mechanism (i.e., acquisition of contingency knowledge) must be assumed to explain the learning effect. However, the learning effect is not a pure measure of the underlying knowledge. In addition to general error in estimates of high contingency RT, low contingency RT, and thus the difference between the two (Kaufman et al., 2010), the size of the contingency effect is also partially determined by the *expression of the underlying knowledge*. That is, the observed contingency effect is not a pure measure of how much is *known* about the contingency, but is also determined by how effectively this contingency knowledge is being retrieved from memory and by the processes via which it influences performance. In the present report, we assess the potential role of two other factors on the magnitude of the learning effect, which may also have major implications for inferences about the learning rate in performance paradigms: practice and stimulus pre-exposure.

It is well known that overall performance in any response time experiment improves with practice. Indeed, this occurs in a consistent enough manner that it is often described as a law of behaviour (e.g., Logan, 1988; Newell & Rosenbloom, 1981). Specifically, response times at the beginning of an experiment tend to be very slow. As the experiment progresses, response times rapidly improve early on. The improvements continue throughout the experiment, but at an ever-diminishing rate. That is, response times decrease in a decelerating function. In blocked analyses, this practice improvement can be represented with a power function: $RT = a + bN^{-c}$. In this formula, a is the minimum RT that performance improves toward, b is the difference between a and Trial 1 performance, N is the trial number, and c is the learning rate (normally ≥ 0). In more refined, trial-by-trial analyses on the data of an individual participant an exponential function is more appropriate (Heathcote, Brown, & Mewhort, 2000; Myung, Kim, & Pitt, 2000). In either case, performance approaches a theoretical asymptote over trials, with larger absolute changes in the earlier relative to later trials. The ever-decreasing rate of improvement with further practice is easily explained by the fact that the closer the current response speed is to asymptote (i.e., the fastest responding physically possible) the less room there is for further improvements. In an extreme example, if response time started out at 1400 ms per trial and has already improved to 400 ms per trial (1000 ms speedup), it is obviously impossible to improve another 1000 ms faster (i.e., to −600 ms) no matter how much one practices.

As we will shortly describe, these practice benefits might have implications for assessments of the acquisition of contingency knowledge. This is because response times do not merely decrease with practice; response time *effects* also seem, at least in some notable cases, to decrease with practice. For instance, in Stroop experiments the congruency effect is observed to decrease with practice (Dulaney & Rogers, 1994; Ellis & Dulaney, 1991; MacLeod, 1998; Simon, Craft, & Webster, 1973). This decrease in the congruency effect over time can be due to scaling with mean response time (Schmidt, 2016). That is, as mean response time decreases over practice, the congruency effect shrinks with it. Stated a different way, incongruent trials start out much slower than congruent trials, so they will gain more from practice. In yet other words, participants will get increasingly better at identifying the colour and executing the appropriate response over practice, giving the word less and less time to interfere.

Given these considerations, scaling of effects with practice can also be a concern for performance-based contingency effects. That is, overall learning effects might be larger when overall responding is slower (Stevens et al., 2002; Urry, Burns, & Baetu, 2015). In the initial blocks of learning, the contingency effect might be inflated simply because overall responding is slower early in the experiment. Thus, even if the amount of contingency *knowledge* acquired is relatively minimal, the contingency *effect* might nevertheless appear large due to response time scaling. Indeed, if we assume that: (a) contingency effects *do* scale with overall RT and (b) learning does reach peak very early on, then we should actually expect *much larger* contingency effects in the first (slower) blocks than in later (faster) blocks. This is illustrated in Panel A of Fig. 1. In particular, the response time contingency effect would be very large early on (due to the overall slow response times), and as participants become faster and faster at responding to the colour with practice, the absolute difference between high and low contingency trials would diminish. This is unlike what we have observed in the past.

Two alternative possibilities are illustrated in Panels B and C of Fig. 1, both of which produce a seemingly flat acquisition slope. In Panel B, we see a situation where: (a) true acquisition of contingency knowledge is extremely rapid, but (b) the contingency effect does *not* scale with mean RT. In Panel C, we see the exactly opposite situation, where: (a) the true contingency knowledge is still developing early on, but (b) the contingency effect *does* scale with mean RT. As such, the absolute contingency effect in response times might nevertheless already be large in the initial blocks of learning given that overall response speed is slow. As practice progresses, the contingency effect both (a) increases due to better contingency