



Motor plans persist to influence subsequent actions with four or more response alternatives

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ARTICLE INFO

Article history:

Received 10 July 2013

Received in revised form 25 February 2014

Accepted 28 February 2014

Available online xxxx

PsycINFO classification:

2300

2330

2340

Keywords:

Reaction times

Choice RT

Response repetition

Information reduction paradigm

Motor system

ABSTRACT

Motor activity has the potential to persist after action and influence subsequent behaviour. A standard approach to isolating a motoric influence is to map two stimuli onto each response, so that response and stimulus repetition can be dissociated. A response-only response-repetition (RoRR) effect can then be assessed, arising if the same response made to two unrelated stimuli is nonetheless produced more rapidly. This kind of motoric behavioural influence of one response on the next has proved elusive in reaction time tasks involving choices between key presses, at least when stimuli mapped to each response are difficult to categorise together. However, such tasks have traditionally involved only a few response alternatives. We hypothesised that a larger load on the motor system might prevent participants from holding all possible action plans active throughout an experiment, and thus reveal trial-to-trial motor priming in the form of an RoRR effect. In our first experiment, increasing the number of response alternatives to four or eight yielded a reliable RoRR effect. This effect was replicated in Experiment 2, where it also proved persistent across practice and resistant to changes in response configuration. Our results are consistent with evidence of motoric perseveration in other kinds of motor task, such as reaching and grasping, and have implications for the generation of speeded decisions in a range of activities.

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1. Introduction

A classic finding in experimental psychology is that reaction time (RT) in choice tasks depends in a systematic fashion upon the previous frequencies of the different stimulus categories in the experiment (Luce, 1986). Moreover, even if the overall frequencies with which different stimuli appear are well matched, reaction time on trial N is affected by the precise pattern of stimuli experienced in immediately preceding trials (Bertelson, 1961; Hyman, 1953). Early reports highlighted the response-repetition (RR) effect. In the now well-developed language of sequential effects, this is a first-order sequential effect, where a repeated response is quicker than an alternation. First-order repetition costs (or, equivalently, alternation benefits) have also been observed, but these are less common (Kirby, 1972), particularly when more than two responses are available (Soetens, Boer, & Hueting, 1985), and generally arise only with longer response-stimulus intervals (RSIs). Many authors have also examined the higher-order influences of trials N-2, N-3 etc. on the current trial. However, effects from further back in the stimulus history appear much reduced with more than two responses (Gökaydin, Ma-Wyatt, Navarro, & Perfors, 2011). Here we

are concerned primarily with the classic first-order effect, which simplifies our presentation.

1.1. The cognitive locus of the response repetition effect

Early work on the response-repetition effect attempted to localise it within a putative serial information-processing pathway which progresses from sensory analysis, to response selection, to response preparation and execution. In a typical choice RT task, if RT on trial N is quicker when trial N-1 contained the same stimulus, this might reflect a speed-up in processing at any or all information-processing loci. To expand, we might be quicker to perceive a repeated stimulus, or quicker to translate its meaning into a response, or quicker to refresh a motor plan to send to the muscles of the body. The early literature introduced two approaches to distinguish these possibilities.

Firstly, several authors utilised the additive-factors method (Sternberg, 1969, 2001), which is a development of Donders (1868) chronometric logic. When two known RT effects are combined factorially in a single experiment, an interaction between them suggests that they arise from a common processing stage. Following this approach, the RR effect has been shown to interact with stimulus-response compatibility (Bertelson, 1963; Kornblum, 1969; Soetens et al., 1985) and with the number of response alternatives (Biederman & Stacy, 1974; Hyman, 1953; Kornblum, 1975). It does not interact with visual stimulus quality (Hansen & Well, 1984). Most recently,

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Adam & Koch (2009) have demonstrated an interaction between the RR effect and the benefit provided by partial advanced cuing of the upcoming target/response in a four-choice task. Collectively, these results seem most consistent with an RR locus at the response selection (i.e. decision-making) stage (but see Rabbitt & Vyas, 1973, for exceptions).

A second approach to identifying the locus of the RR benefit, known as the information-reduction procedure, was introduced by Bertelson (1965) and involves mapping more than one stimulus onto each possible response. This allows one to differentiate between the effects of stimulus repetition and response repetition, because a response repetition can now occur without a stimulus repetition. Bertelson (1965) mapped two even digits onto one response and two odd digits onto another response. This allowed for three possible first-order relationships, labelled “identity” (stimulus and response repetition), “equivalence” (stimulus changes, response repeats) and “difference” (stimulus and response both change). Bertelson found that participants were significantly faster on equivalence trials than on difference trials, speeding up almost to the same extent as they did in identity trials. Hereafter, we refer to RT improvements that occur when stimuli change but responses remain the same as *response-only* response-repetition (RoRR) effects. At first glance, it appears that RoRR effects can only have a motoric locus, because neither the stimulus nor the stimulus–response mapping has been repeated. They might therefore result from persistent activation in the motor system providing a head start to the subsequent response (or else perhaps some biomechanical advantage).

Bertelson's result did not, however, go unchallenged for long. Rabbitt (1968) found a much less dramatic RoRR effect prior to substantial practice, using lower versus higher-value digits as stimuli. Smith (1968) not only failed to find an RoRR benefit with a long RSI and complex stimuli (a red “1” or green “2” for one response, and vice versa for the other), she actually obtained a cost. More recently, Pashler and Baylis (1991) suggested that these contrasting results might crucially reflect the degree to which the two stimuli that were mapped onto each response could be categorised together. They argued that Bertelson's RoRR effect was simply a standard RR effect in which, although the exact stimulus had changed, the stimulus *category* was repeated, such that the stimulus–response pairing had still been primed. This was a critical insight.

Pashler and Baylis (1991) initially considered several possible accounts of the RR effect. Their perceptual speedup account predicted RR effects only when neighbouring stimuli are physically almost identical. A categorisation speedup hypothesis predicted an RR effect when a stimulus comes from the same higher-order category as its predecessor, such that the process of identifying that category is primed. The highest link hypothesis suggested transient strengthening of the S–R pathway from the stimulus category to the response, while the response-selection shortcut account suggested that a more direct link from a specific stimulus to a response (bypassing some of the intermediate stages of sensory analysis) might receive a temporary boost. Finally, Pashler and Baylis considered a response execution speedup account (essentially what we refer to here as a motor-plan persistence account) under which the response itself is facilitated whenever it repeats across trials.

With these possibilities in mind, Pashler and Baylis went on to vary the degree to which the two stimuli that were mapped to one of three possible responses shared a common category. They obtained strong RoRR effects only when the stimulus difference for a given response was trivial (i.e. two versions of the same stimulus in a different colour mapped onto a response). They found a smaller RoRR trend when stimuli changed but remained within the same easily identifiable category (e.g. having two letters mapped onto one response, two numbers mapped to a second, and two symbols mapped onto the third). Finally, they obtained no effect at all for response repetitions involving uncategorisable stimuli (by which they meant a situation in which stimulus categories existed, but were orthogonal to response mappings,

e.g. one letter and one symbol mapped to each response). Complimentary experiments showed that repeating the stimulus gave no benefit if the response changed (see also Campbell & Proctor, 1993). Hence Pashler and Baylis concluded that the locus of the first-order repetition benefit is at the stage of response selection, with repetitions producing transient links that shortcut the response selection stage.

Several groups have now manipulated whether the stimuli that are mapped onto each response can be categorised together (Campbell & Proctor, 1993; Pashler & Baylis, 1991; Soetens, 1998). Results suggest that Bertelson's (1965) RoRR effect was really just a classic RR effect masquerading as something else, because at a conceptual level the stimulus was actually still being repeated. Because RR effects were only found to be robust with stimuli that could be categorised in this way, investigating RR effects with many-to-one mappings and stimuli that could not be categorised was subsequently largely abandoned. We are aware of only one study in recent years that has shown a response-only RR effect (Notebaert & Soetens, 2003). In that case, four colours were mapped to two responses (green/yellow vs. red/blue) so it is possible that the formation of higher order categories (specifically “near chartreuse” vs. “near purple”) generated this result.

1.2. Appropriate conditions for an RoRR effect?

The preceding short review indicates that behavioural measures are in fair agreement regarding the motor system's involvement in first-order sequential effects: RoRR effects do not generally occur without stimulus category repetition, implying that motor activation representing the response on trial N-1 does not (usefully) persist through to trial N in choice RT tasks. However, while there seems little doubt that stimulus–response translation makes the largest single contribution to RR effects, there are in fact several psychophysiological findings that question the conclusion that motor persistence is irrelevant. For example, Jentzsch and Sommer (2002) reported a build up or priming of the lateralised readiness potential (LRP: an EEG component associated with the preparation and execution of a lateralised action; Coles, 1989) over multiple repetitions in a two-choice RT task. They also provided some evidence that the onset of the response-locked (R-) LRP varied with first and higher-order sequential effects. A shifted onset for the R-LRP is generally interpreted to imply a change in the duration of motor preparation, and thus that an effect is localised in the motor system (Leuthold, Sommer, & Ulrich, 2004). Note, however, that the aforementioned build up of baseline activity makes it quite difficult to assess differences in LRP onset for first-order transitions (because the pre-stimulus period used for normalisation is itself being influenced).

There is also a relevant higher-order repetition effect (the benefit-only pattern, wherein alternations at positions <N-2 increase RT regardless of the first-order transition) which can emerge as an RoRR effect when assessed with the information-reduction procedure (Jentzsch & Leuthold, 2005; Soetens, 1998). Recent behavioural and electrophysiological experiments suggest a key role for persisting motor activations in generating this effect. To be specific, the benefit-only higher-order effect appears to stem from a process triggered by response competition: Persistent activity from trial N-2 generates a competing pool of motor activation when the response alternates on trial N-1, which in turn increases the demand for resources from a conflict-monitoring process (plausibly located in anterior cingulate cortex; Jones, Cho, Nystrom, Cohen, & Braver, 2002). This conflict-monitoring process then interferes with response selection occurring on the current trial (N), slowing the response (Dudschig & Jentzsch, 2008; Jentzsch & Leuthold, 2005). For our purposes, the key point is that the whole account implies meaningful persistence of motor plans across trials. If motor activation survives the transition from trial N-2 to trial N-1 to trigger conflict monitoring, why is it not equally robust across the transition from trial N-1 to trial N?

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