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Is sequence awareness mandatory for perceptual sequence learning: An assessment using a pure perceptual sequence learning design

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ABSTRACT

We examined the role of sequence awareness in a pure perceptual sequence learning design. Participants had to react to the target's colour that changed according to a perceptual sequence. By varying the mapping of the target's colour onto the response keys, motor responses changed randomly. The effect of sequence awareness on perceptual sequence learning was determined by manipulating the learning instructions (explicit versus implicit) and assessing the amount of sequence awareness after the experiment. In the explicit instruction condition (n = 15), participants were instructed to intentionally search for the colour sequence, whereas in the implicit instruction condition (n = 15), they were left uninformed about the sequenced nature of the task. Sequence awareness after the sequence learning task was tested by means of a questionnaire and the process-dissociation-procedure. The results showed that the instruction manipulation had no effect on the amount of perceptual sequence learning. Based on their report to have actively applied their sequence knowledge during the experiment, participants were subsequently regrouped in a sequence strategy group (n = 14, of which 4 participants from the implicit instruction condition and 10 participants from the explicit instruction condition) and a no-sequence strategy group (n = 16, of which 11 participants from the implicit instruction condition and 5 participants from the explicit instruction condition). Only participants of the sequence strategy group showed reliable perceptual sequence learning and sequence awareness. These results indicate that perceptual sequence learning depends upon the continuous employment of strategic cognitive control processes on sequence knowledge. Sequence awareness is suggested to be a necessary but not sufficient condition for perceptual learning to take place.

1. Introduction

In the current study, we investigated the role of sequence awareness in perceptual sequence learning in a so-called pure perceptual sequence learning design. The effect of sequence awareness on perceptual sequence learning was determined in two ways, first by manipulating the experimental instructions during learning (explicit versus implicit) and second, by assessing the amount of sequence awareness after the experiment.

Many of our daily life activities rely on so-called implicit sequence knowledge. For instance, we incidentally learn how to execute the correct sequence of movements during walking, how to produce sequences of speech sounds during speaking, and how to produce sequences of actions during driving. Yet, this type of sequence learning occurs in the absence of any intention to learn the sequential regularities and the acquired sequence knowledge is often difficult to express (Cleeremans, Destrebecqz, & Boyer, 1998; Clegg, DiGirolamo, & Keele, 1998; but see Shanks, 2010; Shanks & St. John, 1994 for an alternative view).

Sequence learning in an experimental setting is usually investigated by means of the serial reaction time task (SRT task; Nissen & Bullemer, 1987). In a typical SRT task, a target is presented in one of four locations on a computer screen, and participants are asked to react to the target location with a spatial compatible response key. Unknown to them, the location of target changes according to a repeating sequence. It is observed that participants' reaction times (RTs) (1) decrease as training progresses, which is referred to as a general training effect, and (2) abruptly increase when the sequence is interrupted, which is called a sequence-specific learning effect.

In the SRT task, participants not only perceive the target moving from one location to the other, but also manually respond to the target location. Hence, both perceptual and motor sequence knowledge contribute to sequence learning observed in the SRT task (in addition to intermediate levels of knowledge based on stimulus-response rules, e.g. Deroost & Soetens, 2006c, and response-effect associations, e.g., Ziessler, 1998). But whereas sequence learning based on motor

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knowledge is a well-documented phenomenon (e.g., Deroost & Soetens, 2006a; Willingham, 1999; Willingham, Wells, Farrell, & Stemwedel, 2000), perceptual sequence learning has proven far more challenging to observe. Many authors have failed to obtain reliable perceptual sequence learning effects (Kelly & Burton, 2001; Nattkemper & Prinz, 1997; Rüsseler, Münte, & Rösler, 2002; Willingham, 1999), and therefore claim that perceptual sequence learning can only be observed in case of conscious awareness of the sequence. Willingham (1999, Exp. 1; see also Howard, Mutter, & Howard, 1992), for instance, found that sequence learning through observation only took place in participants who showed reliable sequence awareness. In the same line, Rüsseler and Rösler (2000) reported that 'perceptual' N200 ERP-components were only visible in learners who possessed conscious knowledge of the sequence. Based on these observations, theoretical models of sequence learning have postulated that perceptual learning relies on sequence awareness, in contrast to motor sequence learning which is suggested to occur entirely implicitly (Abrahamse, Jiménez, Verwey, & Clegg, 2010; Hikosaka et al., 1999; Willingham, 1998; Willingham et al., 2000). But contrary to this account, a number of studies have successfully observed perceptual sequence learning in the absence of sequence awareness. For instance, some authors reported perceptual sequence learning without finding any evidence for explicit knowledge in a post-experimental assessment (e.g., Gheysen, Gevers, De Schutter, Van Waelvelde, & Fias, 2009; Nemeth, Hallgató, Janacsek, Sándor, & Londe, 2009; Remillard, 2003; Song, Howard, & Howard, 2008). Others have shown that, even when explicit awareness did emerge during learning, perceptual sequence learning could also be observed in participants who remained completely unaware of the sequence (e.g., Clegg, 2005; Mayr, 1996). These latter findings thus seem to contradict the premise that sequence awareness is a necessary condition for perceptual sequence learning to take place.

However, pronouncing upon the exact role of sequence awareness in perceptual sequence learning is obscured by the fact that there is no agreement among researchers on how to properly measure perceptual sequence learning in the first place. The prototypical SRT task is essentially a motor learning task, so different methodological adjustments have been implemented to capture perceptual sequence knowledge. These come down to (a) letting participants observe the spatial sequence without making motor responses (e.g. Howard et al., 1992; Howard, Howard, Dennis, & Kelly, 2008; Song et al., 2008), (b) mapping sequenced stimuli onto randomly changing responses (e.g. Deroost, Vandenbossche, Zeischka, Coomans, & Soetens, 2012; Gheysen et al., 2009), (c) transferring participants to a new response rule while preserving the perceptual sequence (Nemeth et al., 2009; Willingham et al., 2000), or (d) imposing the spatial sequence on an additional, response-irrelevant stimulus dimension (e.g., Coomans, Deroost, Vandenbossche, Van den Bussche, & Soetens, 2012; Coomans, Deroost, Zeischka, & Soetens, 2011; Deroost & Soetens, 2006b; Mayr, 1996; Remillard, 2003). Perceptual sequence learning studies are often criticised for not tapping 'pure' perceptual sequence learning as learning could be 'contaminated' by sequential motor knowledge, especially sequential oculo-motor movements (see e.g. Coomans et al., 2012; Nemeth et al., 2009 for an extensive discussion of this topic).

Thus, to date researchers disagree (1) whether perceptual sequence learning paradigms provide a valid measure of pure perception-based sequence knowledge and (2) whether explicit awareness is required for perceptual sequence learning to take place. This means that in order to effectively determine the role of sequence awareness in perceptual sequence learning, awareness needs to be investigated in a perceptual sequence learning design that produces perception-based sequence learning effects that cannot be (partially) attributed to or confounded with motor sequence knowledge. This was the aim of the current study.

We developed a paradigm that assesses so-called 'pure' perceptual sequence learning by establishing learning of a colour sequence instead of a spatial sequence. This impedes the development of sequential oculo-motor movements. The colour sequence was kept very simple but not too obvious to allow for the development of sequence awareness in some but not all participants. The influence of sequence awareness on perceptual sequence learning was then determined in two ways. First, we manipulated the learning instructions (explicit versus implicit) and secondly, we assessed the amount of explicit knowledge after the experiment. Regarding the first manipulation, the learning instructions, one group of participants was informed about the sequential nature of the task (explicit instruction condition), while the other group performed the experiment under standard implicit learning instructions (implicit instruction condition). This manipulation of learning instructions is far less common in perceptual sequence learning (e.g. Song et al., 2008) than in motor sequence learning (e.g., Curran & Keele, 1993; Stefaniak, Willems, Adam, & Meulemans, 2008). If conscious sequence knowledge is necessary for perceptual sequence learning, we expect to observe an enhanced perceptual sequence learning effect in learners completing the explicit instruction condition as compared to the implicit instruction condition. With regard to the second manipulation, the assessment of explicit knowledge after the experiment, this was assessed in two ways: by the administration of a questionnaire and by applying the process-dissociation-procedure (PDP; Destrebecqz & Cleeremans, 2001; Jacoby, 1991). If sequence awareness is mandatory for perceptual sequence learning, we expect to observe enhanced sequence learning in participants who showed sequence knowledge in the post-experimental assessment.

2. Method

2.1. Participants

Thirty students of the Vrije Universiteit Brussel participated in the experiment in return for course credit. Fifteen participants (4 men; mean age = 20.06, *SD* = 3.30; 1 left-handed) completed the implicit instruction condition and 15 participants (4 men; mean age = 19.67, *SD* = 3.58; 2 left-handed) completed the explicit instruction condition. Participants had to possess a normal or corrected-to-normal vision and could not be colour-blind. Informed consent was obtained from all participants.

2.2. Stimuli and apparatus

The experiment was programmed in E-Prime version 2 Professional (Schneider, Eschman, & Zuccolotto, 2002) and run on Intel Core I3 personal computers with 17-inch LCD monitors. Participants completed the experiment individually in semi-darkened cubicles of the psychological laboratory of the Vrije Universiteit Brussel.

In the centre of the screen, three geometric figures (a diamond and two differently oriented pentagons), were presented in the corners of an imaginary triangle in a black rectangle (12.8 cm width × 9.4 cm height, see Fig. 1 for an example of a trial).

The figures were depicted on a grey background in Wingdings 2 point size 30 and measured 1.5 cm × 1.5 cm height (or 1.56° visual angle from a viewing distance of approximately 55 cm). Each figure appeared in a distinct colour: red, green or blue.

One and a half cm below the black rectangle, three response squares served as response bar and were presented on a horizontal row on the screen, indicating which colour corresponded to which response key (see procedure). Each response square of the response bar had a distinct colour: red, green and blue. These squares measured 2.3 cm width × 1.9 cm height.

2.3. Procedure

Participants were asked to respond as fast and as accurately as possible to the colour of the diamond target by pressing the corresponding response key. All stimuli remained on screen until a response was given. In case of an incorrect response, or when no response was