Neuropsychologia 117 (2018) 253–260

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Your favorite number is special (to you): Evidence for item-level differences in retrieval of information from numerals

Danielle S. Dickson[a,*], Kara D. Federmeier[b,c,d]

[a] Department of Biology, University of Texas at San Antonio, 1 UTSA Circle Dr., San Antonio, TX 78249, USA
[b] Department of Psychology, University of Illinois at Urbana-Champaign, 603 E Daniel St., Champaign, IL 61820, USA
[c] Program in Neuroscience, University of Illinois at Urbana-Champaign, 405 N Mathews Ave, Urbana, IL 61801, USA
[d] Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, 405 N Mathews Ave, Urbana, IL 61801, USA

ARTICLE INFO

Keywords:
Numerical cognition
N400
ERPs
Memory
Familiarity

ABSTRACT

Arabic numerals have come to be used for many purposes beyond representing a particular quantity (e.g., as a label for an athlete on their jersey), but it remains to be determined how this type of meaningfulness is accessed and utilized by readers. Motivated by previous work showing that item-level ratings of personal familiarity can influence traditional indices of memory retrieval, we recorded ERPs while participants read double-digit Arabic numerals (e.g., "65"), presented in a list, and rated whether or not each was familiar/personally meaningful. All numbers repeated after a few intervening trials. The effect of number repetition on the N400 was not impacted by subjective judgments of familiarity, suggesting that all numbers (personally meaningful or not) make initial contact with semantics, facilitating semantic access on second exposure. However, consistent with findings from prior studies of memory for letter strings and visual patterns, there was a late positivity (LPC) on second presentation, selective to numbers rated as familiar. This is the first electrophysiological evidence that readers can use Arabic numerals to guide explicit retrieval of non-numerical information.

1. Introduction

1.1. General

We encounter Arabic numerals like "81" in many contexts: as a representation of a quantity or numerosity, as a unique identifier (e.g., credit card numbers, confirmation numbers), and as familiar labels (e.g., sports jerseys) that do not directly involve numerical quantities. Most of the literature on number reading focuses on their use as a symbolic representation of quantity information, with the aim of understanding how people link these symbols to their corresponding numerical meaning. However, the more general use of numerals as items that can contain meaning outside of the context of numerical quantities has been far less explored. In contrast, in the broader text reading literature, there has been great interest in understanding how people comprehend words with multiple possible referents, including ambiguous items like "duck", which has different meanings across a noun and verb reading, or polysemous items like "university," which can refer to a concrete place or an abstract entity (e.g., Lee and Federmeier, 2006; Pylkkänen et al., 2006). Additionally, some letter strings only hold meaning for a subset of readers (e.g., "VCR" is a meaningful acronym for young adults today, but unlikely to be meaningful to their children) (Laszlo and Federmeier, 2007). Under the assumption that subsets of Arabic numerals can also be uniquely meaningful across individuals, when and how this personalized information is accessible to and appreciated by the reader is not yet understood–indeed, few attempts have even been made to demonstrate that personalized knowledge can play a role at all in number processing (cf., a patient study by Cappelletti et al., 2008).

In order to address how people access meaning and retrieve individualized and specific memories associated with a given numeral, in the present work we ask more directly what happens when people are encouraged to process double-digit Arabic numerals for their broader (potentially non-numerical) meaning, and, in that context, how people's brain responses to numerals with which they have personalized experience differs from numerals with which they do not claim to have experience. We model our design after successful memory paradigms in the event-related potential (ERP) literature that similarly looked at the effect of familiarity on memory retrieval: critical items are repeated while participants provide ratings of familiarity (reviewed below). We then look at the effect of repetition (i.e., priming) on functionally distinct ERP components, sorted by whether or not a numeral was rated as familiar or not.

* Corresponding author.
E-mail address: danielle.dickson@utsa.edu (D.S. Dickson).

https://doi.org/10.1016/j.neuropsychologia.2018.05.018
Received 15 December 2017; Received in revised form 1 May 2018; Accepted 21 May 2018
Available online 22 May 2018
0028-3932/

1.2. N400 repetition effects

The first measure of interest will be the effect of repetition on the N400, an ERP component linked to initial and fairly automatic semantic memory access (i.e., N400 responses are elicited to potentially meaningful stimuli essentially whenever they are encountered, even when participants are unable to report having perceived the stimuli; Vogel et al., 1998). This classic ERP finding is rather simple: the brain response around 400 ms post-stimulus is less negative in response to items that were previously presented compared to when the same items were initially presented, a phenomenon collectively referred to as the N400 repetition effect (Kutas and Federmeier, 2000). The most straightforward account of N400 repetition effects is that they are due to a reduction in the amount of *new* semantic activity that occurs as a result of prior semantic long-term memory access (Kutas and Federmeier, 2011). That is, the semantic state established with the first presentation of an item persists to some degree over time because semantic features remain active or, on a recent computational model of N400 repetition effects, because the influence of inhibitory connectivity persists, making it harder to reactivate the same semantics (Laszlo and Armstrong, 2014).

In general, it is the case that more conceptually rich stimuli (e.g., words) elicit larger N400 repetition effects than do more conceptually impoverished stimuli (e.g., randomly connected lines) (Nagy and Rugg, 1989; Rugg et al., 1988; Rugg and Nagy, 1989; Rugg, 1990; Van Petten and Senkfor, 1996). In particular, such effects are small or not detectable for stimuli like unfamiliar geometric shapes as well as for unpronounceable strings of letters (e.g., "TXM") under many task contexts (Rugg and Nagy, 1987; Voss and Paller, 2009b; Voss et al., 2010b). It is possible that Arabic numerals may similarly elicit very small repetition effects. Importantly, however, even among classes of stimuli that have generally been associated with lower levels of rich conceptual information, individual ratings of item-level meaningfulness have been shown to influence the size of N400 repetition effects.

For example, if participants are simply asked to memorize abstract line drawings and shapes, or to judge them for a low-level visual feature, there is no evidence of semantic processing (i.e., no N400 repetition effects; Van Petten and Senkfor, 1996; Voss et al., 2010b; Voss and Paller, 2009b). However, sometimes these shapes can appear to be familiar (e.g., what appears to be a random "squiggle" to one person might appear to be a sketch of a jumping deer to another person), and this link to semantics has been shown to bolster the repetition effect. When individuals are encouraged to think about the shapes' possible meaningfulness by explicitly rating their familiarity, N400 repetition effects are obtained, selectively for the shapes that individuals rated as familiar (Voss et al., 2010b). Notably, when people are asked to rate letter strings for their familiarity, N400 repetition effects are significant both for meaningful acronyms like "DVD" as well as for letter strings rated as meaningless (Laszlo et al., 2012; cf., Voss et al., 2010a, with a longer retention interval and more intervening items, which led to only wordforms rated as familiar eliciting facilitation on the N400). In general, this work with semantic processing of letter strings and geometric shapes suggests a natural readiness for conceptual engagement with *any* class of stimuli–and the strength of this engagement can sometimes depend on readers' subjective judgment of their meaningfulness.

Given that numerals rated as familiar might be able to make a more resilient connection with semantic representations than numerals rated as unfamiliar, it is possible that the effect of repetition might differ across numerals as a function of a person's familiarity with them. At the same time, numerals are a common form of text, whose N400 repetition effects can sometimes be unaffected by semantic ratings. The present study constitutes the first attempt to characterize the N400 response to numerals as a class in an implicit priming context, and, as such, it will be broadly informative about the nature of semantic access for numerals.

1.3. LPC effects as a function of familiarity

Although N400 effects are perhaps the most robust ERP pattern associated with the repetition of meaningful items, there are other ERP responses that may also be affected by our manipulation. These additional effects offer the opportunity to further assess how numbers may be treated similarly or differently from other potentially meaningful stimuli. Specifically, in repetition paradigms, beyond effects on the N400, there are also frequent reports of differences on late positivities (typically an effect on what is conventionally referred to as the "late positive complex" or LPC), which are instead thought to reflect more explicit and conscious recollective processing of stimuli (e.g., Paller and Kutas, 1992; Paller et al., 1995; Voss and Paller, 2009a). In these cases, items that are rated familiar (or, in traditional memory paradigms, rated as having been recalled with confidence rather than more passively recognized) elicit more positive-going slow waves following the N400 period compared to less familiar items. The strongest evidence for a distinction between N400 and LPC repetition effects comes from patients with hippocampal damage, who have severe impairments in the ability to form and explicitly recall new memories of items and events, although they often retain the ability to learn subconsciously (e.g., there is evidence for implicit priming in amnesic patients) (Warrington and Weiskrantz, 1970, 1982; for review, see Schacter, 1987). In these hippocampal patients, repetition effects can be obtained on the N400, but LPC effects are eliminated (Olichney et al., 2000; Duzel et al., 2001). Also consistent with the interpretation of LPC effects as being dependent on intact hippocampal function and associated with declarative memory, larger LPC effects are typically associated with better behavioral performance (e.g., more successful recollection of the source of a given memory) in recognition tasks (Curran and Cleary, 2003; Duzel et al., 1997; Woodruff et al., 2006; Woroch and Gonsalves, 2010).

Interestingly, in the study showing that N400 repetition effects were observed only for shapes that had been judged to be meaningful, an LPC was also elicited selectively for shapes that were rated as meaningful (Voss, Schendan, & Paller, 2010). In the present experiment, participants are rating their own subjective familiarity with each numeral, and it seems likely that, in order to make these judgments about the personal relevance of a numeral due to prior experiences, recollective processes necessarily occur that should elicit an LPC.

On the basis of the prior literature, then, if LPC effects for numerals are obtained, we expect to see enhanced LPC responses (more positivity, beginning around 500 ms and continuing for a few hundred milliseconds) for repeated items (which are similar to "old" items in explicit memory paradigms). A key novel question is whether this potential LPC enhancement will also be selective (or at least enhanced) to numerals that were rated as subjectively familiar. Such a finding would be consistent with an interpretation that our long-term memories for the subset of Arabic numerals that are uniquely meaningful to us can be deliberately retrieved and impact our subsequent reading of them.

An additional possibility is that there could be a dissociation between the pattern of repetition effects seen on the two components, such that N400 effects do not distinguish between numerals rated familiar and unfamiliar, whereas an interaction occurs selectively on the LPC. This was the case in a study involving complex visual shapes (Voss and Paller, 2009b), in which stimuli were too conceptually impoverished to elicit facilitated N400 responses but still elicited enhanced LPCs during recognition. Therefore, failures to find evidence that Arabic numerals are processed for their distinctive amount of meaningfulness on the N400 would not necessarily mean that there is *no* additional information about aspects of their meaning (e.g., learned associations beyond numeracy) in long-term memory, only that accessing this extra meaning is not fast and obligatory.

In general, then, the pattern of N400 and LPC repetition effects for numerals rated as familiar and unfamiliar will help us better understand how people engage with the meaning and long-term memory representation of these symbols outside of their utilization as a