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Running head: **Contextual locking**

The notion of contextual locking: Previously learnt items are not accessible as such when appearing in a less common context.

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Abstract

We examined the effect of context on the learning of spatial coding in four experiments. Two partially overlapping sets of stimuli, which had the very same stimulus-response spatial coding, were presented in unique contexts. Results show *contextual locking*, *i.e.*, response times to the very same item in a more common context (80%) **were** significantly shorter than in a less common context (20%). Contextual locking was obtained both when the context was more salient (Experiments 1 & 2) and less salient (Experiments 3 & 4). In addition, results were obtained even when contextualization seemed less necessary (Experiments 2 & 4). Binding of information to context is discussed in relation to chunking, transfer effects, and practical applications pertaining to professional training.

Key words: Context, Memory, Implicit, Binding

Introduction

The grouping of elementary units in collective chunks is one of the basic processes of the cognitive system and one which has been suggested to underlie numerous key psychological processes, for example working memory (e.g., Miller, 1956), the development of expert knowledge (e.g., Simon & Barenfeld, 1969), the learning of categories (e.g., Goldstone, 2000; Knowlton & Squire, 1996), and motor control (e.g., Rosenbaum, Hindorff, & Munro, 1987; Rosenbaum, Kenny, & Derr, 1983). In this paper we focus on motor chunking, where stimuli are typically presented in a fixed sequence, with one stimulus appearing after another (e.g., A,B,C,D). The type of chunking that occurs in such cases is a hierarchical process by which individual items may be initially bound to their adjacent neighbors to form sub-units (e.g., AB, CD), which eventually may be bound to form a unitized presentation comprised of the entire set (ABCD). For the entire sequences to become unitized in such cases, a fixed order is required (Perlman, Pothos, Edwards, & Tzelgov, 2010).
The current question is whether different list items can be unitized, even when these items appear in a completely random order. We propose *contextualization*, as an alternative cognitive mechanism, which can support unitization of motor responses to stimuli while not requiring a fixed sequence. Contextualization relates to the binding of randomly ordered items to a common context. As opposed to chunking where items are bound to each other in a fixed sequence, during the putative process of contextualization, list items are bound to a common context, as a result of the mere co-occurrence of the items in the context (random item sequence).

Each of these two notions (contextualization and chunking) predicts that individual items become unitized. A strong case of unitization can be shown when

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6 individual items are not responded to on the basis of their individual identity but
7 rather their unitized identity. If individual items appearing in a random order share a
8 common context, this context has the potential of binding these items to it, so that a
9 unitized contextualized representation emerges. We use the term *contextual locking*,
10 in reference to an item becoming tied (locked) to its context, to the extent that its
11 individual (context-less) identity ceases to be relevant (or at any rate is less relevant).
12 Accordingly, showing that the very same item appearing in different contexts is
13 responded to differentially would demonstrate contextual locking. Specifically, if our
14 idea of contextual locking is valid, an item presented in a more common context
15 should be responded to with a significantly shorter response time, compared to
16 responding to the very same item presented in a less common context. Such a result,
17 showing that the same item in a less common context is processed as if it were
18 another item, would provide a strong case for contextualization, over and above the
19 more researched chunking processes. Note that contextual locking is assumed to be
20 driven by an automatic process of binding which occurs in an obligatory fashion
21 (Hayes, Baena, Truong, & Cabeza, 2010) and thus should occur even if there is no
22 apparent advantage to such binding. The basic idea of contextual locking has its roots
23 in the domain of memory where the notion of context was both defined and examined.

41 Definition of context and context effects

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43 In general, context can be defined as a surrounding stimulus (Smith, 2007).
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45 There are many types of context, each with its own specific definition. Studies
46 distinguish between contexts that are explicitly encoded with their items and
47 independent contexts (Baddeley, 1982) which are encoded separately (Eich,
48 Macaulay, & Ryan, 1994; Godden & Baddeley, 1980). Moreover, an independent

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6 context may have nothing to do with its item, but rather, just happen to be in the same
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8 place at the same time (cf. background contexts). Such contexts have been termed
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10 incidental, which means that a context is not only "independent or isolated from the
11
12 target information, but also does not influence the subject's interpretation of, or
13
14 interaction with, the target material." (Bjork & Richardson-Klavehn, 1989, [p. 316](#)).

15
16 Incidental context is processed without being part of task requirement in any way.

17
18 Typically, better memory performance in the presence of an original learning
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20 context versus a *new* context has been observed, this finding has been labeled the
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22 *context effect* (Light & Carter-Sobell, 1970; Smith, 1988; Tulving & Thomson, 1973).
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24 For example, the popular butcher-on-the-bus-phenomenon (Mandler, 1980) relates to
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26 meeting your local butcher instead of in the butcher shop (original context), on a bus,
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28 in a completely new and different context. Like the butcher case, incidental context
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30 can also be processed in an analogous manner to produce context effects, as would be
31
32 the case for incidental environmental contexts (e.g., Godden & Baddeley, 1975) or
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34 incidental background contexts (e.g., Murnane & Phelps, 1995).

35
36 One final point is that context has been theoretically conceptualized in
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38 different ways leading to different predictions (cf. Hoffman & Tzelgov, 2012). While
39
40 some theories postulate that a context can function as an external retrieval cue for
41
42 item information (cf. Smith & Vela, 2001), other theories claim that a context binds to
43
44 relevant items and forms an item-context trace, compounded into a single
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46 representation (e.g., global matching theories, see Murnane, Phelps, & Malmberg,
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48 1999, see also Hayes, Nadel, & Ryan, 2007). One central difference between these
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50 positions from the current perspective is that if context functions as a cue that predicts
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52 responses, in the presence of a stronger cue, it may be outshone, i.e., its cuing power

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6 may become redundant (Smith & Vela, 2001). On the other hand, if context is
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8 automatically bound to its item, as shown for incidental contexts (Hoffman &
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10 Tzelgov, 2012), its representation should be independent of other cues, its influence
11
12 should be ubiquitous. As shown below this issue distinguishes the present studies
13
14 from previous studies addressing context in implicit paradigms.

15 16 17 Context in implicit tasks

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19 Verbal implicit memory shows typically no benefit of environmental context
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21 on performance with implicit perceptual memory tasks (e.g., Jacoby, 1983; McKone
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23 & French, 2001), where participants neither engage in intentional item memory nor is
24
25 semantic processing occurring (note, we adopt Perlman & Tzelgov's, 2006,
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27 perspective on implicit processes, tying implicitness to lack of intentionality, and not
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29 necessarily a lack of awareness). However, context effects have been shown in
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31 implicit motor sequence learning (e.g., Ruitenberg, Abrahamse, De Kleine, &
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33 Verwey, 2012a; Ruitenberg, De Kleine, Van der Lubbe, Verwey, & Abrahamse,
34
35 2012b; Wright & Shea, 1991). Yet a closer look at these studies reveals a more
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37 complex picture. Namely, in such experiments the sequence is fixed, and context
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39 functions as a cue. Accordingly, some have suggested that the first stimulus of the
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41 sequence may be a strong enough cue for loading the sequence (Ruitenberg et al.,
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43 2012a), rendering the context as a predictive cue, redundant (outshone). Thus context
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45 effects, (e.g., diminished performance in a different context) were evident only with
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47 limited practice and before the sequence was sufficiently learned (Ruitenberg et al.,
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49 2012a). When processing of the redundant context was intentional, there was no effect
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51 of contextual influences at all (Abrahamse, Van der Lubbe, Verwey, Szumska, &
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6 Jaskowski, 2012). Such a result, that a cue (e.g., context) can be outshone by a
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8 stronger cue (e.g., the sequence itself) is a central theme in the context literature
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10 (Smith & Vela, 2001). In another study, context effects were evident in motor
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12 sequence learning only when an opposite context, signaling a different sequence,
13
14 created a direct conflict, (Ruitenberg et al., 2012b).

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17 There are other considerations which also lead to a somewhat puzzling picture
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19 regarding context effects in implicit memory. In addition to color, the location of a
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21 place holder (the square in which a stimulus will appear in a serial reaction time task)
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23 also does not produce context effects; only the place holder shape, e.g., changing from
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25 square to triangle, appears to create a context effect (Abrahamse & Verwey, 2008).
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27 Finally, the learning of first order conditional sequences does not seem to benefit from
28
29 context effects either (D'Angelo, Milliken, Jiménez, & Lupiáñez, 2014).

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31 Overall, while implicit learning of motor sequences is affected in some cases
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33 by incidental context, the following points should be noted. First, in all these cases,
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35 the items did not appear in a random order, but rather in a sequence of sorts. Second,
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37 the context functioned as a cue that enabled greater prediction of the next response.

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39 Taken together, the context could have been outshone by the robust cueing of the
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41 sequence, where each previous response cues the next (with sufficient practice).

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43 Incidental contexts, however, which correspond to inherently unrelated stimuli, that
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45 do not cue a subsequent response, have been shown to be bound to their items
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47 (Hoffman & Tzelgov, 2012) in an obligatory fashion (e.g., Hayes et al., 2007). Here
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49 we address whether several items appearing in a single common context may be
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51 bound to this common context, to the extent that the items become unitized. Can the

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6 motoric response of a random sequence (which by definition cannot be chunked) be
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8 unitized via the locking of each and every stimulus to its common context?
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11 Developing and exploring this idea of contextual locking can additionally help
12 clarify two important issues in memory/learning research. First, rather than measuring
13 context effects via an old vs. novel context (e.g., Hoffman & Tzelgov, 2012), we ask
14 whether contextual effects can be observed when a more and less common context are
15 available from the start of the relevant task. Namely, would recognition of the butcher
16 on the bus be diminished, if, from the very first time she was encountered, she would
17 be seen continuously in both a more frequent (e.g., 80% in the butcher shop) and less
18 frequent context (20% on the bus). This is a strong test for contextualization, as a
19 single item is never uniquely paired with a single context; rather from the initial
20 encounter, the item of interest appears in one of two contexts. Thus if
21 contextualization does occur, it suggests that when the same item is viewed in the two
22 different contexts it appears to be different, as in each case it is bound to a different
23 context.
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37 A second issue of interest related to the idea of contextual locking is that
38 context effects have been typically tested and demonstrated as *between* item effects
39 (e.g., Godden & Baddeley, 1975; Light & Carter-Sobell, 1970; Smith & Vela, 2001),
40 so that, for example, some original items (appearing in one context) are compared to
41 *other* original items (appearing in another context). By contrast, the butcher-on-the-
42 bus phenomenon and the more general kind of contextual locking which we address,
43 focus on *same* item comparisons in different contexts. As stated, the term *contextual*
44 *locking*, is exactly meant to indicate that the very *same* item can independently be
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6 locked on to two different contexts at the same time. Obtaining such effects would
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8 suggest that context may play a role in determining an item's identity and not merely
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10 facilitate its processing.

11 The present paradigm

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15 The notion of contextual locking is examined by using a novel spatial task,
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17 which we briefly summarize below, along with considering possible outcomes and
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19 their theoretical implications. Participants are trained on two different lists (arrays)
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21 each comprising four arrows (Figure 1 a). By array, we mean a collection of four
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23 stimulus-response associations. One array appears more frequently (80%) than the
24
25 other (20%). On each trial, an item from one of the arrays appears individually in a
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27 fixed spatial location on the screen; we stress that the order of presented items in each
28
29 array was random. Participants are instructed to respond to each arrow (item) by
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31 button press, according to its (fixed) spatial position. For example in Figure 1 b, the
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33 arrow pointing down (always) appears in the second spatial position of the array and
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35 should always be responded to with the second response key, regardless of its
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37 presentation order, relative to the other items in an array, that is, regardless of whether
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39 it appears first, second etc. As addressed below, on a straightforward explicit level,
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41 the participant's sole task requirement was to indicate via button press the spatial
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43 position of each of the four items in a given array. Responding to the entire array (i.e.,
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45 making four responses to the four corresponding items in the array) constituted a
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47 single trial in the experiment.

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50 Participants knew which array they were about to see, because a blue or red
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52 rectangle, containing all four stimuli appeared prior to the beginning of each trial. The

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6 blue rectangle, containing its array of four arrows appearing in fixed screen locations,
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8 prompted the more (80%) frequent array (list) and a red rectangle, containing its array
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10 of four arrows also appearing in the same fixed screen locations, prompted the less
11
12 (20%) frequent array. To emphasize this important point, the *entire* array (i.e., the
13
14 four arrows and their locations, contained within its rectangle) was shown prior to
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16 each trial for 1000 ms. After this initial presentation (Figure 1 a), the screen went
17
18 blank. Subsequently, each of the arrows from the array that was just presented
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20 appeared individually, in a random order, in their fixed screen position. Each arrow
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22 remained on the screen until it was responded to. In Experiment 1, two out of the four
23
24 items overlapped (items 2 and 4 from the left, in Figures 1 a and b), i.e., the same
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26 items, positioned in the same location, and required the same response.

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28 We use this task to address the notion of contextual locking. Several potential
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30 outcomes can ensue from such a task, each of which reflects a specific type of
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32 processing. Three potential types of processing, along with their expected results are
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34 discussed below, followed by a fourth possibility, which specifically focuses on the
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36 overlapping stimuli, namely differences regarding the same item appearing in two
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38 different contexts.

41 Possible empirical outcomes

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43 Let us first consider ‘straw man’ possibilities for the possible underlying
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45 processes indicated by potential results in the present task. If participants only process
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47 the *stated* task requirement of responding to the spatial position of each arrow, e.g.,
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49 any item appearing in the second position is responded to with the second key etc., ~~so~~
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51 ~~that~~ there would be no effect of array frequency. Namely, there should be no
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6 difference in responding to the more or less common arrays. Because both arrays are
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8 composed of four arrows in the *same* four distinct locations, items from each array
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10 should be responded to in the same manner. Such a result is predicated on the
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12 assumption that participants only process task requirements. Based on the
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14 automaticity literature such an assumption is unlikely (see e.g., Perlman, & Telgov,
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16 2006, and as we shall shortly see, it is also inconsistent with our results). A second
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18 possibility is that participants *only* encode arrow orientation. While such an option
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20 may be implausible as participants in *contrast* to instructions to process spatial
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22 location, solely process arrow orientations without concern for spatial location, it
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24 leads to a specific profile. Namely, if participants were behaving in this way,
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26 performance would be at chance; i.e., error rates would be high, (as it turns out such
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28 an option is also inconsistent with results). A third possibility is that participants
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30 encode both spatial orientation and item identity, we would expect shorter response
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32 times to non-overlapping items in the more frequent array versus the less frequent
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34 array a finding typically observed in such paradigms (Perlman, et al., 2010; and
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36 observed in all current experiments).

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38 Finally, the hypothesized critical outcome concerns possible evidence for
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40 contextual locking, a process which relies on binding (e.g., Hayes et al., 2007;
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42 Hoffman & Tzelgov, 2012) that addresses the extent to which, each item in a given
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44 array is bound to its context. Overlapping items (the same items appearing in both
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46 arrays in the very same spatial location and requiring the very same response) should
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48 be responded to significantly faster in the more common context than in the less
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50 common context. In effect, response data for the overlapping items allows us to
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52 explore the empirical question of interest, that is, to establish whether participants are
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6 locking an item to its relevant array (this is the phenomenon of contextual locking).

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8 Such a result would indicate that an item is no longer perceived solely by its own
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10 properties, e.g., arrow orientation, but that item identity is determined by its context as
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12 well.

13 14 15 Statistical definition of contextual locking and implications

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17 Contextual locking can be operationally defined as the difference in response
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19 time between processing of the same item, in two different contexts. Contextual
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21 locking may present itself in two manners. The moderate effect occurs when there is
22
23 an overall response latency difference between the more and less frequent array, but
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25 this effect is smaller for overlapping items than for non-overlapping items.

26
27 Statistically this would be indicated by a main effect of Array frequency (80% vs.
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29 20%) and a significant interaction between Array frequency and Overlap (overlap vs.
30
31 non-overlap). A stronger effect of contextual locking would be indicated by *similar*
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33 differences between the more and less common frequencies for both the different
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35 items (non-overlapping) and same items (overlapping). Statistically, this would be
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37 indicated by a main effect of Array frequency, in the absence of an Array frequency
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39 by Overlap interaction. Such an outcome indicates that the very same item is treated
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41 as if it were a *completely* different item, when it appears in another context. To
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43 anticipate our results, we provide support for contextual locking of both types across
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45 four experiments.

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47 Another interesting analysis concerns the effect of practice on contextual
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49 locking. If the context is automatically bound with its item (Hayes, et al., 2007), then
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51 contextual locking should be evident early on, say, during the course of the first
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6 block, and it should not necessarily diminish with practice. This possibility would be
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8 consistent with contextual locking being a result of the representations, which are
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10 created when the stimuli are first perceived. Indeed, there is corresponding evidence
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12 in explicit item memory (e.g., Godden, & Baddeley, 1975; Hayes et al., 2007; 2010;
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14 Murnane, & Phelps, 1995) where a single presentation is sufficient for context effects.
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16 We addressed this issue by assessing performance across blocks. All the variables
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18 (Array, Overlap and Block) are within participant variables.

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21 We conclude the introduction by reconsidering the relevance of our research to
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23 research on learning as chunking. According to this pervasive and influential idea,
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25 learning involves a gradual recognition of co-occurring elementary units, and so the
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27 formation of corresponding chunks. Theories of chunking have been extremely
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29 influential in psychology and applied to a wide range of domains (e.g., Rosenbaum, et
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31 al., 1987; Simon & Barenfeld, 1969; also, cf. our own work, Perlman, et al., 2010). As
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33 discussed above, we stress the important point that all forms of chunking work by
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35 taking advantage of regularities in the *sequential* presentation of elementary units
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37 (e.g., symbols or elementary stimuli). In our experiments, as the sequence of items in
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39 each array presentation is *random*, there is no basis for the typical type of chunking
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41 observed in motor tasks, i.e., items can only be bound to their common context in the
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43 way we outline above. Thus, if unitized representations exist they must originate from
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45 the binding of items with the common context.

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Experiment 1

The aim of this experiment is to address the notion of contextual locking, such that putative contextual effects could be observed for the same item, in a paradigm in which participants are exposed to more and less common contexts from the outset of training. Contextual locking would be indicated by differences in processing the same item_s in the more and less frequent contexts; this should hold both for the dissimilar items (non-overlapping) and identical items (overlapping). Contextual locking would be evident by a main effect of Array frequency and depending on its strength, would appear in the absence or presence of an Array frequency by Overlap interaction.

Method

Participants

Fifteen students (five males; mean age 23.7, range 21-27) from introductory psychology courses at Ben Gurion University participated in the experiment for course credit. All participants reported normal or corrected-to-normal vision. The study was approved by the Ben Gurion ethical board and participants signed informed consent.

Apparatus

The experiment was programmed with E-prime software and run on IBM compatible Pentium III computers with 17" monitors which were placed approximately 60 cm from participants. Participants responded by using the computer

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6 keyboard. The onset of an item started the timer; the item disappeared as soon as
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8 participants responded.
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10 Stimuli and Procedure

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16 The experiment was organized in 10 training blocks, each consisting of 200
17 individual item presentations, that is, 50 array presentations. A blue or red rectangle, 6
18 centimeters wide and three centimeters tall was presented in the middle of the screen.
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20 The frequent context (blue rectangle) appeared 40 times in each block (followed by
21 the four corresponding items and responses; Figures 1 a and b) and the non-frequent
22 context (red rectangle) appeared 10 times in each block (the rectangles appeared for
23 1000 ms.). Note that the second and fourth arrows (items) were identical in both
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25 arrays.
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32 Each block began with the written message: "press any key to continue", after
33 which the screen went blank for 1000 ms. Subsequently a blue or red rectangle
34 (Figure 1), containing the four items (the arrow orientations we used are the ones
35 shown in the figures), appeared for 1000 ms. Responses were indicated by pressing
36
37 keys 1 through 4 (Figure 1 b). Participants were asked to use the index and the middle
38 fingers of both hands for responding. The current experiments used either six
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40 (Experiments 1 and 3) or seven (Experiments 2 and 4) S-R mappings. Responses
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42 triggered the onset of the next item in the array. After the last response, a response
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44 stimulus interval (RSI) of 1000 ms followed. Participants were not informed that there
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46 were two different arrays. After being instructed about the spatial coding of items
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6 (e.g., the item in the extreme left location was to be responded to with the extreme left
7 key), they were told to respond as quickly and as accurately as possible. Presentation
8 order of arrays and items within each array was randomized. Participants could rest
9 between blocks for about one minute and, on average, it took participants about 20
10 minutes to complete the experiment (the same applies to subsequent experiments).
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16 Results and Discussion

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18 Both RT and error data for all trials were recorded. While analyses on both
19 measures were similar, some effects were significant only for the RT data. There was
20 no evidence of a speed-accuracy trade-off in any experiment. Thus, here and
21 elsewhere, only RT data are presented, which are based on only correct responses.
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24 Average error rates were 2.2% for the more frequent blue array and 2.4% for the less
25 frequent red array ($p > .1$).
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31 To reduce the influence of outliers, the median and not the mean was used;
32 extreme outliers (below 200 ms. and above 2500 ms.) were removed from the
33 analyses. For each participant, the median RT for each item was calculated separately
34 for each block in each array. The mean of the median RTs is presented in Figure 2 as
35 a function of block, for each array.
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44 Figure 2
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49 In all statistical analyses, the significance level was set to .05. These mean
50 RTs were submitted to a three-way within subjects analysis of variance (ANOVA),
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6 with Array (20% vs. 80%), Block and Overlap (overlap vs. non-overlap items) as the
7 manipulated factors. The Array effect was significant, $F(1, 14)=17.97$, $MSE=10992$,
8 $\eta_p^2=0.56$, $p<.001$, indicating that response times were shorter for the more common
9 array (438 vs. 474). The Block effect was significant, $F(9, 126)=14.73$, $MSE=2368$,
10 $\eta_p^2=0.51$, $p<.001$, indicating a decrease in RT across blocks. The Overlap effect was
11 significant $F(1, 14)=14.77$, $MSE=2340$, $\eta_p^2=0.51$, $p<.01$, indicating larger RTs for the
12 non-overlapping items (449 vs. 464). The Block with Array interaction was
13 significant $F(9, 126)=2.30$, $MSE=1002$, $\eta_p^2=0.14$, $p<.05$, and this may indicate larger
14 differences between arrays at earlier blocks than later blocks (Figure 2). The Array
15 with Overlap interaction was significant $F(1, 14)=6.55$, $MSE=1232$, $\eta_p^2=0.31$, $p<.05$,
16 indicating larger differences between the frequent and non-frequent arrays for non-
17 overlap stimuli as opposed to overlap stimuli. Yet simple main effects analyses
18 revealed significant differences between responding to the more and less common
19 array for both the non-overlap items, $F(1, 14)=18.82$, $MSE=7585$, $\eta_p^2=0.57$, $p<.01$,
20 and more *importantly* for the overlap items, $F(1, 14)=13.55$, $MSE=4639$, $\eta_p^2=0.49$.
21 $p<.001$, i.e., *the very same item was responded to faster in the more common array*
22 *than in the less common array*, demonstrating contextual locking¹. No other effects
23 were significant, (F 's <1). Note that the absence of a three way interaction of Array,
24 Block and Overlap indicates that the smaller differences between arrays at later blocks
25 vs. earlier blocks was the same for both overlapping and non-overlapping items, i.e.,
26 both were affected by practice to the same extent.
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51 ¹ Both here and in the remaining experiments we examined if this pattern was evident in each
52 of the four items of each array, see the Appendix.

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6 We conducted the same analyses separately for the latter 9 blocks to address if
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8 the Block with Array interaction would remain significant, namely, whether it was
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10 dependent on the first block. Results of this interaction were not significant $F(8,$
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12 $112)=1.80$, $MSE=921$, $\eta_p^2=0.11$, $p>.08$, suggesting that the data from the first block
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14 played a critical role in this interaction. Further confirmation of the role of the first
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16 block was obtained by applying this three-way within subjects analysis to the first
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18 block, with Array, Sub-block (within the first block, there were 5 sub blocks, each
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20 comprising 40 stimuli) and Overlap as the manipulated factors. We found a
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22 significant effect for Array $F(1, 14)=18.71$, $MSE=23090$, $\eta_p^2=0.57$, $p<.001$, for Sub-
23
24 block $F(4, 56)=28.56$, $MSE=7271$, $\eta_p^2=0.67$, $p<.001$ and for Overlap $F(1, 14)=9.29$,
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26 $MSE=7271$, $\eta_p^2=0.39$, $p<.01$; the Sub-block with Array interaction was also
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28 significant $F(4, 56)=9.29$, $MSE=6719$, $\eta_p^2=0.16$, $p<.05$, indicating that participants'
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30 ability to respond faster to the more frequent Array improved over the course of the
31
32 five sub-blocks of Block 1.
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35 In summary, the main result of this experiment is that RTs were significantly
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37 shorter for the more frequent array (Figure 2). Critically, this effect persevered even
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39 when the very same overlapping items were presented. Note though that these
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41 differences were larger for the non-overlapping items than for the overlapping items,
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43 suggesting that, in Experiment 1, item identity was only partly bound to a specific and
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45 non-transferable context, i.e., item identity may have moderated the effect of context.
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47 In any event, demonstrating significant differences between the more and less
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49 frequent array for the very same overlapping items reflects contextualization.
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6 It could be the case that this anticipated pattern of results was driven by switch
7 costs (Monsell, 2003). Namely, the more common array (80%) may be responded to
8 faster, because it appears more often after itself, as opposed to the less common array,
9 which predominantly appears after the more common array. To ensure that the
10 observed results did not stem from switch costs, data from both arrays were also
11 binned into repeat and non-repeat kinds. This ‘switch factor’ was employed in our
12 statistical models, to address the possibility that switch costs partly or wholly drive a
13 difference in responding to the frequent vs. infrequent arrays. Data were subjected to
14 a three-way within subjects analysis of variance (ANOVA), with the factors Array
15 (80% vs. 20%), Overlap (overlap vs. non-overlap) and Repetition (repeat vs. switch).
16 Critically, contextual locking was not differentially affected by repeat vs. switch
17 trials, [$F(1, 14)=2.75$, $MSE=521$, $\eta_p^2=0.16$, $p > .1$]. Incidentally, Repetition was
18 neither significant as a main effect nor in any of the remaining interactions. Thus, as
19 no interactions with the Repetition factor were significant, the observed contextual
20 locking could not have been driven by putative switch costs.
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36 Note again that order of the items in each array presentation was random, thus,
37 whether the first, second, third or fourth sequential response corresponded to
38 overlapping items or not, varied from trial to trial. However, another important aspect
39 of sequencing that should be considered is that the predictive power increases with
40 each subsequent response, e.g., the first target out of 4 had lowest predictive power
41 while the last response was completely predictable. Accordingly, to make a strong
42 case for contextual locking it is important to demonstrate this effect even for the first
43 target, for which prediction is lowest. Thus we performed the same analyses as
44 presented above, but only for the first presented target, which, due to the random
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6 presentation order we employed, was different in every trial. We found similar results,
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8 notably, a significant effect for Array $F(1, 14)=39.18$, $MSE=8724$, $\eta_p^2=0.73$, $p<.001$,
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10 indicating that the more frequent Array was responded to faster than the less frequent
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12 Array, and for Block $F(9, 126)= 4.60$, $MSE=13548$, $\eta_p^2=0.24$, $p<.001$, indicating that
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14 performance improved across Blocks.
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17 Interestingly, we also found similar results for the last target, for which
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19 prediction is highest: responses to the more frequent Array were faster than responses
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21 to the less frequent Array, $F(1, 14)=27.76$, $MSE=9521$, $\eta_p^2=0.66$, $p<.001$. In addition,
22
23 performance improved across Blocks $F(9, 126)= 23.18$, $MSE=5092$, $\eta_p^2=0.62$,
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25 $p<.001$. Observing similar contextual locking for both low and high predictability
26
27 responses suggest that contextual locking is independent of sequence predictability
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29 Experiment 2

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32 The results of Experiment 1 show a significant RT difference when
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34 responding to the same items in different contexts. In Experiment 2, we ask if an
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36 effect of contextual locking holds when the overlap between the two arrays is
37
38 minimal. If we assume, as some theorists do (e.g., Diana, Yonelinas, &
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40 Ranganath, [Diana, et al., 2007](#)), that one of the main functions of context is to support
41
42 distinctive item information, contextualization should decrease with less array
43
44 overlap. Reducing array overlap renders each array more distinctive and there may be
45
46 less need to rely on context. Yet if contexts are automatically bound-to their items
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48 (Hayes, et al., 2007; Hayes, et al., 2010); contextual locking should be the same,
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50 regardless of the degree of array overlap.
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6 Method

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9 Fifteen experimentally naïve university students (6 males; mean age 22.9,
10 range 20-26) participated in this experiment. Conditions were similar to that of
11 Experiment 1, except that only one of the four items was identical between the two
12 arrays (see Figure 3).
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20 Figure 3
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25 Results and discussion

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27 Visual inspection of the mean latencies in the various conditions (Figure 4)
28 show broadly similar results to those of Experiment 1. Of particular interest is the RT
29 for the single item common to both arrays, since this informs both if contextual
30 locking occurred and to what extent.
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39 Figure 4
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44 Average error rates were 5.20% for the more frequent red array and 4.00% for
45 the less frequent blue array ($p > .1$). The mean RTs for each block of responses were
46 submitted to a three-way within subjects ANOVA with Array, Block and Overlap
47 (overlap vs. non-overlap items) as the manipulated factors. The Array effect was
48 significant $F(1, 14) = 18.82$, $MSE = 3750$, $\eta_p^2 = 0.57$, $p < .001$, indicating better
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6 performance for the more frequent array (415 vs. 438). The Block effect was also
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8 significant, $F(9, 126)=3.91$, $MSE=7453$, $\eta_p^2=0.21$, $p<.001$, indicating a decrease in RT
9
10 across blocks. The Overlap effect $F(1, 14)=14.88$, $MSE=4983$, $\eta_p^2=0.51$, $p<.01$,
11
12 (Figure 4) was significant, indicating differences in response latencies between the
13
14 overlapping and non-overlapping items (415 vs. 438). No other effects were
15
16 significant ($p>0.1$). This result pattern indicates that the observed effect (RT more-
17
18 common array < RT less-common array) was analogous for both overlap, $F(1,$
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20 $14)=5.07$, $MSE=3793$, $\eta_p^2=0.26$, $p<.05$, and non-overlap items $F(1, 14)=21.83$,
21
22 $MSE=2572$, $\eta_p^2=0.60$, $p<.001$ and was the same across all blocks, i.e., responding
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24 latencies to both overlap and non-overlap items were equally resistant to practice.
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26 Critically, to reiterate, as shown in Figure 4, the very same overlapping item was
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28 treated as if it were a different item, when it appeared in the less frequent array as
29
30 opposed to when it appeared in the more frequent array.
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33 In order to examine if these effects existed without prolonged training, we
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35 additionally analyzed data from the first block separately (breaking up the data in the
36
37 first block into five sub-blocks). Data were submitted to a three-way within
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39 participant analysis with Array, Sub-block (5 blocks within the first block) and
40
41 Overlap as the manipulated factors. We found a significant effect for Array $F(1,$
42
43 $14)=34.22$, $MSE=11478$, $\eta_p^2=0.70$, $p<.001$, indicating that the more frequent array
44
45 was responded to faster than the less frequent array, and for Sub-block $F(4,$
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47 $56)=25.73$, $MSE=13076$, $\eta_p^2=0.64$, $p<.001$, indicating that participants improved
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49 across these 5 sub-blocks.
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6 As before, in order to verify that the effects reported in Experiment 2 were
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8 not due to the more frequent array containing more repeat trials, as opposed to the less
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10 frequent array, for which there were more switch trials, we reanalyzed the data in a
11
12 three-way within subjects analysis of variance (ANOVA), with Array (80% vs. 20%),
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14 Overlap (overlap vs. non-overlap) and Repetition (repeat vs. switch) as within
15
16 participant factors. While the Repetition main effect (switch vs. repeat) was
17
18 significant, $[F(1, 14)=12.74, \text{MSE}=1115, \eta_p^2=0.47, p>.05]$, Repetition did not interact
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20 with any other factor, i.e., responses were not affected by repeat vs. switch trials, $[F(1,$
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22 $14)=1.245, \text{MSE}=8208, \eta_p^2=0.08, p>.1]$. Similar to the results of Experiment 1, these
23
24 results also indicate that contextualization effects were not driven by putative switch
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26 costs.

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28 As in Experiment 1, it is important to demonstrate if these effects were evident
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30 for the first target, for which response predictability would be lowest. Thus, we
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32 performed the same analyses as above, but only for the target presented first. We
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34 found similar results and in particular significant effects for Array $F(1, 14)=18.14,$
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36 $\text{MSE}=16375, \eta_p^2=0.56, p<.001$ and for Overlap $F(1, 14)= 51.17, \text{MSE}=8504,$
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38 $\eta_p^2=0.78, p<.001$. Results were also similar for the last target for which predictability
39
40 was highest: there was a significant effect for Array $F(1, 14)=22.87, \text{MSE}=4093,$
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42 $\eta_p^2=0.62, p<.001$ and for Block $F(9, 126)= 12.19, \text{MSE}=10829, \eta_p^2=0.46, p<.001$; the
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44 three-way interaction $F(9, 126)= 2.03, \text{MSE}=2453, \eta_p^2=0.12, p<.05$ was also
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46 significant, indicating faster RTs across blocks in the more frequent array for the
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48 overlapping target $F(1, 14)=6.28, \text{MSE}=4048, \eta_p^2=0.30, p<.05$. These results indicate
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50 that contextual locking is not dependent on predictive ability.
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6 In summary, the main result of this experiment is that RTs were significantly
7 shorter for the more frequent array and, moreover, this effect persevered even when
8 the very same overlapping item was considered. Interestingly, in this experiment, the
9 difference in responding to non-overlapping items in the more and less frequent arrays
10 was equivalent to that for the overlapping item, indicating that *the same overlapping*
11 *item in the less frequent context was treated just like any other item in the less*
12 *frequent array*. These results replicate and extend the results of Experiment 1,
13 demonstrating that contextual locking can occur, even when the arrays (contexts) are
14 more discriminable.
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24 Experiment 3

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27 In Experiments 1 and 2 we observed locking of items to context. Very
28 plausibly, the blue and red rectangles aided in distinguishing between the two arrays.
29 In other words, context was both salient and extrinsic (Godden & Baddeley, 1975). In
30 addition to any such contextual influences, processing the inter-item relations
31 (Mandler, 1980) within each array could also be a source of contextual information
32 (e.g., Sirotnin, Kimball, & Kahana, 2005), even if such information is perhaps less
33 salient vis-à-vis external stimuli (e.g., colored rectangles). In Experiments 3 and 4, the
34 rectangles were removed; context in these experiments solely referred to the
35 neighboring list items. As context effects may decrease when the context is less
36 salient (e.g., Smith & Vela, 2001), we examine whether effects of contextual locking
37 are weakened when the more salient extrinsic rectangles are not present. If, however,
38 responses in Experiments 3 and 4 do still reveal an effect of contextual locking, this
39 would provide stronger evidence for the notion that contextual locking is a ubiquitous
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6 and general process. Demonstrating contextualization in this case would show strong
7
8 support for the pervasiveness of contextual locking, as each item is bound to a general
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10 list and not individual items within a list.

11 12 13 Methods

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15 Fifteen university students (five males; mean age 23.6, range 20-25)
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17 participated in this experiment. The experiment was identical to Experiment 1, but for
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19 the fact that the colored rectangles were removed. Accordingly, there were two lists of
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21 items – response associations. As previously, participants were exposed to the (entire)
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23 item set within each array prior to responding, but without the colored rectangle.
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25 26 Results and Discussion

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28 Average error rates were 3.00% in both arrays ($p > .1$). The mean RTs for each
29
30 block of responses were submitted to a three-way within subjects ANOVA with
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32 Array, Block and Overlap (overlap vs. non-overlap items) as the manipulated factors
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34 (see Figure 5). The Array effect was significant $F(1, 14)=44.10$, $MSE=3579$,
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36 $\eta_p^2=0.75$, $p < .001$, indicating that the more common array was responded to faster
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38 (438 vs. 471). The Block effect was significant, $F(9, 126)=8.13$, $MSE=4396$,
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40 $\eta_p^2=0.37$, $p < .001$, indicating overall attenuation of differences across blocks. The
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42 Overlap effect was also significant $F(1, 14)=7.12$, $MSE=5156$, $\eta_p^2=0.33$, $p < .05$,
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44 indicating (438 vs. 471) that RT for overlapping stimuli was shorter than for non-
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46 overlapping stimuli (447 vs. 462). No other effects (including interactions) were
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48 significant, $ps > .1$.

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50 As in Experiment 2, the lack of an Array with Block interaction indicates that
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52 the contextual locking effect was practice resistant. The lack of an Overlap with Array

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6 interaction ($F < 1$) indicates that the advantage of responding to the more vs. less
7
8 frequent array which was observed for the non-overlapping items, $F(1, 14) = 20.25$,
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10 $MSE = 3762$, $\eta_p^2 = 0.59$, $p < .001$, was analogous to the very same effect observed for
11
12 overlapping items, $F(1, 14) = 22.14$, $MSE = 3688$, $\eta_p^2 = 0.61$, $p < .001$. Thus as in
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14 Experiment 2, the very same overlapping item was treated as if it were a *completely*
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16 different item, when it appeared in a different context.
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Figure 5

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32 Additionally, in order to examine the pattern of results within Block 1, the
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34 data were submitted to a three-way within participant analysis with Array, Sub-block
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36 (5 sub blocks within the first block) and Overlap as the manipulated factors. We
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38 found a significant effect for Array $F(1, 14) = 13.68$, $MSE = 12265$, $\eta_p^2 = 0.49$, $p < .01$,
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40 indicating faster performance for the more vs. the less frequent Array, and for Sub-
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42 block $F(4, 56) = 16.10$, $MSE = 11417$, $\eta_p^2 = 0.53$, $p < .001$ indicating improvement across
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44 the five sub-blocks. These results suggest, as previously observed, an overall
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46 improvement in the first block as well as revealing evidence for the key effects
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48 without practice.
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51 In order to verify that the effects reported in Experiment 3 were not due to the
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53 more frequent array containing more repeat trials, as opposed to the less frequent
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array, for which there were more switch trials, we reanalyzed the data in a three-way within subjects analysis of variance (ANOVA), with the factors Array (80% vs. 20%), Overlap (overlap vs. non-overlap) and Repetition (repeat vs. switch). While repeat trials were responded to faster than switch trials, $[F(1, 14)=9.27, MSE=326, \eta_p^2=0.39, p<.05]$, the Repetition factor (repeat vs. switch) as previously observed did not interact with any other variable, i.e. had no effect on performance, all F 's <1 . Thus contextualization effects were not driven by putative switch costs.

As in Experiments 1 and 2, it is important to demonstrate the Array effect for the first target, for which predictability is lowest. We performed the above analyses, but only for the target that was presented first. We found similar results; the main effect of Array $F(1, 14)=25.58, MSE=11076, \eta_p^2=0.64, p<.001$ was significant, as well as the main effect of Block $F(9, 126)= 2.51, MSE=7906, \eta_p^2=0.15, p<.05$. The interaction of Array with Overlap was also significant $F(1, 14)=4.82, MSE=6051, \eta_p^2=0.25, p<.05$. Data from the last target where predictive ability is highest were also similarly analyzed. There was a significant effect for Array $F(1, 14)=28.20, MSE=4636, \eta_p^2=0.66, p<.001$ and for Block $F(9, 126)= 22.01, MSE=6500, \eta_p^2=0.61, p<.001$. These results show that contextual locking is independent of predictive strength.

The present results replicate and extend the results of Experiment 1 and 2, where we also observed shorter RTs for the overlapping items in the more vs. less frequent array. These findings indicate that, even when context is neither salient nor extrinsic (red vs. blue rectangles), but rather just consists of neighboring items, the common overlapping items appearing in the less frequent context are treated as if they

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6 were different, than when they appeared in the more frequent array. In the final
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8 experiment, we ask if contextualization of an item, relative to the other items
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10 appearing in the same group, exists even when only one item overlaps between the
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12 two arrays.

13 14 Experiment 4

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17 Fifteen university students (4 males; mean age 22.9, range 21- 27),
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19 participated in this experiment which was identical to Experiment 2, where there was
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21 only one overlapping item (at location 4), with the exception that the colored
22
23 rectangles were removed. In this experiment, contextualization may be more elusive,
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25 relative to the previous experiments.
26

27 28 Results and Discussion

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30 Average error rates were 4.4% for the more frequent red array and 3.5% for
31
32 the less frequent blue array ($p > .1$). The mean RTs for each block of responses were
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34 submitted to a three-way within subjects ANOVA with Array, Block and Overlap
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36 (overlap vs. non-overlap items) as the manipulated factors. The Array effect was
37
38 significant $F(1, 14)=40.46$, $MSE=2596$, $\eta_p^2=0.76$, $p < .001$, indicating that the more
39
40 frequent array was responded to faster (456 vs. 484). The Block effect was significant,
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42 $F(9, 126)=8.76$, $MSE=4571$, $\eta_p^2=0.38$, $p < .001$, indicating that RTs decreased with
43
44 practice. The Overlap effect was significant $F(1,14)=29.83$, $MSE=11220$, $\eta_p^2=0.68$,
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46 $p < .001$, indicating that participants performed differently across conditions (442 vs.
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48 494). The Block with Overlap interaction was also significant $F(9, 126)=1.98$,
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50 $MSE=1705$, $\eta_p^2=0.12$, $p < .05$, and this may indicate that the RT decrease across blocks
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52 for overlap items was weaker than for non-overlap items (Figure 4). No other effects
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6 were significant $p > 0.1$. This pattern of results suggests that the difference between
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8 the more and less common array was the same for both overlap items $F(1, 14) = 14.16$,
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10 $MSE = 2021$, $\eta_p^2 = 0.50$, $p < .01$ and non-overlap items $F(1, 14) = 31.85$, $MSE = 3247$,
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12 $\eta_p^2 = 0.69$, $p < .001$. Namely, the very same overlapping item was treated as a
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14 *completely* different item when it appeared in the less frequent array as opposed to
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16 when it appeared in the more frequent array.
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19 As in Experiment 1, where Block interacted with Array, here we also further
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21 analyzed the Block with Overlap interaction, to examine if this effect depended on the
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23 first block. Accordingly, we conducted the above analysis only with the latter 9
24
25 blocks, which showed that the Block with Overlap interaction was no longer
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27 significant, $F(8, 112) = 1.86$, $MSE = 1656$, $\eta_p^2 = 0.11$, $p > .07$. However, there was a
28
29 significant triple interaction, $F(8, 112) = 2.04$, $MSE = 1302$, $\eta_p^2 = 0.12$, $p < .05$, indicating
30
31 that participants' shorter RTs for the more frequent Array, across Blocks was greater
32
33 for overlap vs. non-overlap stimuli.
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36 To complete the picture, the mean RTs of the responses for Block 1 were
37
38 submitted to a three-way within subjects ANOVA, with Array, Sub-block (five sub
39
40 blocks within the first block) and Overlap as the manipulated factors. We found a
41
42 significant effect for Array $F(1, 14) = 9.84$, $MSE = 15259$, $\eta_p^2 = 0.41$, $p < .01$, indicating
43
44 that participants responded faster to frequent vs. non-frequent arrays and for Sub-
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46 block $F(4, 56) = 12.66$, $MSE = 10364$, $\eta_p^2 = 0.47$, $p < .001$, indicating improvement across
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48 Sub-blocks; no other effects were significant.
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6 Figure 6
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11 Figure 6 critically shows a clear difference in the mean RTs between arrays.
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13 As noted, these RT differences between the more and less frequent arrays were the
14 same for the overlapping and non-overlapping stimuli. These results demonstrate that
15 locking of items to context occurs even without a salient context, such as the rectangle
16 and even when arrays were more distinguishable, because of a lower degree of
17 overlap. These RT differences between the more and less common arrays were
18 constant across blocks, i.e., there was no effect of practice on these RT differences,
19 $F < 1$. As shown previously, contextual locking was practice resistant in this
20 experiment as well.
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30 In order to verify that the effects reported in Experiment 4 were not due to the
31 more frequent array containing more repeat trials, as opposed to the less frequent
32 array, for which there were more switch trials, we reanalyzed the data in a three-way
33 within subjects analysis of variance (ANOVA), with the factors Array (80% vs. 20%),
34 Overlap (overlap vs. non-overlap) and Repetition (repeat vs. switch). While the more
35 frequent array was responded to faster, [$F(1, 14) = 34.79$, $MSE = 1397.0$, $\eta_p^2 = 0.71$,
36 $p < .01$], the Repetition factor did not interact with any other variable, i.e., results were
37 the same for repeat and switch trials, [$F(1, 14) = 1.34$, $MSE = 935.0$, $\eta_p^2 = 0.08$, $p > .1$].
38 Thus, contextualization effects were not driven by putative switch costs.
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48 As in Experiments 1, 2 and 3, it is important to demonstrate the key effect for
49 the first target, for which predictability was lowest. Thus, we performed the same
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6 analysis as presented above, but only for the target that was presented first. We found
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8 similar results, particularly, significant effects of Array $F(1, 14)=26.54$, $MSE=5645$,
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10 $\eta_p^2=0.65$, $p<.001$, Block $F(9, 126)= 3.35$, $MSE=9940$, $\eta_p^2=0.19$, $p<.01$ and Overlap
11
12 $F(1, 14)=24.38$, $MSE=36663$, $\eta_p^2=0.63$, $p<.001$.
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15 Similarly, for the last target we also found significant effects for Array $F(1,$
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17 $14)=28.28$, $MSE=5801$, $\eta_p^2=0.66$, $p<.001$, Block $F(9, 126)= 24.01$, $MSE=5776$,
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19 $\eta_p^2=0.63$, $p<.001$, and Overlap $F(1, 14)=16.41$, $MSE=9234$, $\eta_p^2=0.53$, $p<.01$. Both the
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21 Array with Overlap $F(1, 14)=25.42$, $MSE=1917$, $\eta_p^2=0.64$, $p<.001$, and Block with
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23 Overlap $F(9, 126)= 3.00$, $MSE=2563$, $\eta_p^2=0.17$, $p<.01$ interactions were significant.
24
25 We also found shorter RTs in the more frequent Array, for overlapping targets $F(1,$
26
27 $14)=4.78$, $MSE=3548$, $\eta_p^2=0.25$, $p<.05$. These results further confirm that the
28
29 observed effects were not a result of response predictability (which is common in
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31 sequence learning), but rather due to contextual locking.
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34 The finding of contextual locking in Experiment 4 is especially revealing as
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36 both the absence of a salient context in the form of a colored rectangle and the
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38 minimal degree of overlap between arrays might have led us to expect that the effect
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40 would be weaker. Now we turn to one final analysis conducted on data collapsed
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42 across all experiments, which addresses how context Type (with rectangle vs. without
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44 rectangle) and Similarity between arrays (one vs. two overlapping items) affected
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46 results. The mean RT for each block was submitted to a five-way mixed model
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48 ANOVA, with Array, Block and Overlap, as within subjects factors and Type
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50 (with/without rectangle) and Similarity (one/two overlapping items) as between
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52 subjects factors. The Array effect was significant, $F(1, 56)=101.16$, $MSE=5229$,
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6 $\eta_p^2=0.54$, $p<.001$, indicating that responses were faster to the more common array.
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8 The Block effect was significant, $F(9, 504)=17.73$, $MSE=4697$, $\eta_p^2=0.33$, $p<.001$,
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10 indicating a decrease in RT across blocks. The Overlap effect was also significant
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12 $F(1, 56)=14.77$, $MSE=5925$, $\eta_p^2=0.53$, $p<.001$, indicating larger RTs for the non-
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14 overlapping items. Significant interactions were Overlap with Type $F(1, 56)= 4.10$,
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16 $MSE=5925$, $\eta_p^2=0.06$, $p<.05$, Overlap with Similarity $F(1, 56)= 9.45$, $MSE=5925$,
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18 $\eta_p^2=0.14$, $p<.01$, Array with Block $F(9, 504)= 2.37$, $MSE=1124$, $\eta_p^2=0.04$, $p<.05$,
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20 Array with Overlap $F(1, 56)= 6.51$, $MSE=2599$, $\eta_p^2=0.10$, $p<.05$, Block with Overlap
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22 $F(9, 504)= 6.51$, $MSE=1741$, $\eta_p^2=0.04$, $p<.01$, and the triple interaction (Figure 7) of
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24 Array, Block and Type $F(9, 504)= 2.12$, $MSE=1124$, $\eta_p^2=0.03$, $p<.05$. Critically,
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26 neither the Type with Array interaction ($F<1$) nor the Similarity with Array
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28 interaction, $F(1, 56)= 2.50$, $MSE=5229$, $\eta_p^2=0.04$, $p>.1$) were significant, indicating
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30 that contextual locking is independent of both Context Type and degree of Similarity
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32 (i.e., the degree of overlap between arrays). Different types of context with different
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34 degrees of overlap induce the same form of unitization based on contextualized
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36 locking.

37 38 39 40 41 General Discussion

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44 The aim of this paper was to examine if items in a motor response tasks can
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46 become unitized even when they do not appear in a fixed order. Such unitization of
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48 items can only occur via their binding to a common context, which we called
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50 contextual locking, a term operationally defined as the difference in response time
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52 between processing of the same item, in two different contexts. Accordingly, we

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6 hypothesized that responding to the same stimulus, with the same response will be
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8 significantly faster in the more common context than the less common context. As
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10 distinguishing between the same overlapping item in the more and less frequent arrays
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12 was possible only via contextual factors comprised of the neighboring list items
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14 (Experiments 3 and 4) and the color of a rectangular external frame (in Experiments 1
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16 and 2), these differences between arrays for the overlapping stimuli can only have
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18 been driven by the locking of the task goal with its context. The emerging pattern of
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20 results across four experiments, in which the same item was responded to faster when
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22 it appeared in a more common context than in the less common context, is consistent
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24 with this hypothesis. There was no benefit of binding items to a common context for
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26 participants, as neither the items themselves nor the context were informative of the
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28 responses that had to be given. This evidently differs from other studies on context
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30 effects, in which actions were associated to a specific context (e.g., Ruitenberg, et al
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32 2012a.). These results were reliable across Experiments 1-4². These results were not
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34 affected by putative switch costs, i.e., by the more frequent array including more
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36 Repeat trials, as opposed to the less frequent Array, which included more Switch
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38 trials.

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40 Our results suggest that the individual items are not identified by their unique
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42 properties alone (e.g., arrow orientation), but also by their context. In effect, in each
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44 of the contexts, neither the spatial position nor the arrows' unique orientation were the

47 ² Occasionally, in particular blocks it seems that random noise caused an apparent weakening
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49 of these effects (Exp 2, block 2; Exp 3, block 4, Exp 4, blocks 1,2, and 9). Random noise is often
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51 typical in such paradigms, where an overall consistent effect may be less evident in particular blocks.

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6 main driving force underlying responses. Moreover, in three of the four experiments
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8 the difference between arrays was as great for the overlapping items as it was for the
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10 non-overlapping items. Accordingly, it seems that contextual locking can occur to the
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12 extent that items lose an individual identity in favor of a more contextual-driven
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14 representation; i.e., it is possible that an item is defined by its context. This contextual
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16 locking could only have arisen from the binding of items with their context. While
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18 such binding is more typically observed for *related* contexts that co-occur with items
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20 (e.g., butcher-in-the-butcher-shop), it has been observed for unrelated contexts too
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22 (e.g., Hayes et al., 2010; Hoffman, & Tzelgov, 2012).
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25 Evidence of contextual locking was obtained both for salient extrinsic contexts
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27 (Baddeley, 1982) and less salient contexts, involving just inter-item relations (Sirotnin,
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29 et al., 2005). Furthermore, analogous results were obtained both when the inter-item
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31 contexts across the two arrays were more similar (in which case contextualization
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33 may have played a role in facilitating item distinction) and when arrays were less
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35 similar (where distinguishing between these differentiated arrays was less necessary;
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37 Diana et al., 2007). As contextualization was evident across different levels of context
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39 salience and array distinguishability, the present results are in line with Hayes et al.'s
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41 (2007; 2010) suggestion that the binding of items with their context may be
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43 obligatory. The present results are also consistent with Perlman and Tzelgov's (2006)
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45 definition of automaticity. If indeed such binding is obligatory, it is no surprise that
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47 contextual locking is fairly ubiquitous and immediate, i.e., evident from the first
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49 block.
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6 It might be claimed that participants did not notice the overlapping items
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8 between the two contexts, especially in experiments 3 and 4, where no colored
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10 rectangle was presented. Accordingly, the difference between the overlapping stimuli
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12 in the frequent vs. the non-frequent array may simply reflect greater practice. Our
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14 results preclude this possibility. There were only four stimuli in each array presented
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16 over 1000 training trials, thus it is likely that the overlap was noticed. Furthermore,
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18 across all four experiments, the overlap stimuli were responded to significantly
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20 different than the non-overlap stimuli, further indicating that participants noticed their
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22 overlapping. Finally, had participants somehow mis-perceived the overlapping
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24 stimuli, then their performance level would have been low (e.g., high error rates), but
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26 our results indicate otherwise. What is surprising is that exactly the same stimulus is
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28 responded to differently in the frequent array vs. the infrequent one. Regardless of
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30 whether participants explicitly noticed the two contexts or not (or the fact that there
31
32 were overlapping stimuli), there is clear evidence of contextual locking.
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35 It might be claimed that the S-R mapping of overlapping and non-overlapping
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37 stimuli may have been different. For overlapping stimuli there was a 1 S-R mapping
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39 (i.e., for a given stimulus there was only one response) as opposed to non-overlapping
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41 stimuli which had a 2 S-R mapping (two different stimuli, one in the frequent array
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43 and another in the infrequent one, had the same response). This claim is of arguable
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45 relevance as it necessitates between array mapping, an unlikely assumption (both
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47 theoretically and) given the obtained results which demonstrate that mapping was
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49 conducted within array and not between array. However, even if the overlap and non-
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51 overlap stimuli do not have the same S-R mapping, it would nevertheless be
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53 compatible with our conclusions as they stem from analyses comparing between
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6 responses to the *overlapping* stimuli in frequent and infrequent arrays (for which the
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8 same S-R mapping exists).
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11 Demonstrating such contextual locking can bridge the general theory of
12 chunking with a theory of binding items with contexts. Chunking, one of the most
13 basic processes of the cognitive system (e.g., Boucher, & Dienes, 2003; Rosenbaum,
14 Hindorff, & Munro, 1987; Rosenbaum, Kenny, & Derr, 1983; Goldstone, 2000;
15 Knowlton & Squire, 1996; Miller, 1956; Simon & Barenfeld, 1969), relates to how
16 elementary units can be bound together in aggregate chunks. In sequence learning
17 (e.g., Cleeremans & McClelland, 1991), for example, the notion of chunking is central
18 and refers to a situation where adjacent stimuli in a *fixed sequence* (e.g., A and B)
19 may eventually be chunked (i.e., eventually the response to A may automatically
20 generate the B response). Perlman, et al. (2010) showed that, as chunking knowledge
21 develops, participants respond in a manner suggesting that the smaller units of a
22 chunked sequence disappear or *decay*, as larger units of representation are developed
23 (see also e.g., Perruchet, Vinter, Pacteau & Gallego, 2002; Pothos & Wolff, 2006). In
24 essence, while chunking is conceived as a hierarchical process by which items are
25 bound to each other to form sub-units, which eventually will be bound to form a
26 unitized presentation comprised of the entire set, the notion of contextual locking is a
27 lateral form of unitization, whereby different items are unitized by being bound to a
28 common context. Contextual locking of the kind observed here offers a form of
29 unitization that does not necessitate a fixed order, such that items are not bound to
30 each other, but rather to a common context. Accordingly, the aforementioned decay of
31 individual elements (e.g., Peruruchet, et al., 2002), may stem possibly from items
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6 becoming locked to their specific context, so that the other items in the array cease to
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8 exist in a non-bound, context-less manner.
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11 Following from this point, it is important to note that chunking and
12 contextualization are not mutually exclusive. There are many scenarios where
13 processing can be driven both by chunking and contextualization. For example, if one
14 is repeatedly shown a list of items in a fixed order, items may gradually be chunked to
15 each other via the formation of specific sub-units (chunking), yet items can also be
16 simultaneously bound to the general list (gist) which is common to all items,
17 irrespective of their order contextualization. Plausibly, context can extend beyond
18 contextual stimuli in a given task, to include environmental contexts e.g., underwater
19 vs. on land (Godden & Baddeley, 1975) or emotional context, e.g., happy vs. sad
20 moods (Eich, 1984). The notion of contextual locking would predict that the very
21 same daily activities, such as shaving, may be affected by the corresponding
22 environment, e.g., whether an activity is performed in the more common
23 environmental context of the dorm bathroom vs. the less common context of a public
24 bathroom. Thus, it is possible that the very *same* behavior may be performed
25 differently in different contexts. According to the simple notion of motor chunking,
26 performance of the same action will always be similar. As shaving has a fixed
27 sequence, based on previous studies we would speculate that context effects would
28 not affect shaving, as it is a highly practiced sequence of actions (Ruitenberg et al.,
29 2012a) especially as the public bathroom is not an opposite context (Ruitenberg et al.,
30 2012b). However, given the current results of contextual locking, it may very well be
31 that incidental environmental contexts are bound to the shaving behavior and unitize it
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6 – thus when for example one shaves outside the familiar environment the very same
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8 behavior might be performed slower.
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11 Another related idea concerns the transfer of learning. Transfer refers to
12 learning acquired in one context benefitting performance in another setting. Usually
13 the two settings are an original setting (e.g., as relevant to a training phase) and a new
14 setting (e.g., as relevant to a test phase). While we do not apply a new setting, our
15 results do relate to the notion of transfer, since the two arrays in the experimental
16 tasks represent two different contexts. In terms of transfer, our research question
17 concerns whether enhanced performance acquired in a frequent context can transfer to
18 a less frequent context. In many cases, skill learning remains specific, such as in
19 perceptual (e.g., Karni & Sagi, 1991) or motor tasks (e.g., Pashler & Baylis, 1991). In
20 other instances, however, learning does transfer, such as in the cases of pilots
21 benefiting from a simulation of a flight experience (Gopher, Weil & Bareket, 1994).
22 Transfer of learning has been a central theme in both cognitive psychology and
23 practical daily training courses. One factor that has been suggested to account for
24 these disparate results is the extent to which the learning procedure is varied (e.g.,
25 Green & Bavelier, 2008). When the learning procedure is varied, transfer of learning
26 from one situation to another is usually enhanced. This observation is compatible with
27 the present results, as under varied learning conditions, i.e., an item appearing in a
28 different context every presentation, contextualization may not occur, in which case
29 the behavior will not be locked to its context.
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49 Our main finding, showing that the very *same* item was responded to
50 significantly faster in the more vs. less common context, when implicitly processing
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6 the item information, extends the known incidental context effects to implicit tasks.
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8 By implicit, we do not mean that participants were unaware of the two different
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10 arrays, but that they were learning something they were not instructed to learn
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12 (Perlman & Tzelgov, 2006). Hitherto context effects were typically shown to occur in
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14 explicit semantic tasks where items appearing in an original context are processed
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16 better than different items appearing in a *new* context (e.g., Godden & Baddeley,
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18 1975; Light & Carter-Sobell, 1970; Smith, 1988; Smith & Vela, 2001; Tulving &
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20 Thomson, 1973). In implicit tasks context effects were either not obtained (e.g.,
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22 Jacoby, 1983; McKone & French, 2001; also see Mulligan, 2011) or limited (e.g.,
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24 Ruitenberg et al., 2012a; 2012b, see above). Applying incidental context to
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26 demonstrate contextual locking we show that the effect of context on item processing
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28 is more pervasive than originally conceived; this effect also appears to be (fairly)
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30 ubiquitous, in the sense that it is not linked to a certain type of test (e.g., explicit) or
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32 the available information about context. The notion of contextual locking is highly
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34 ecological, since one can speculate that many daily activities involve the kind of
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36 implicit, perhaps even procedural learning, which our task was meant to engage, such
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38 as shaving in the dorm vs. a public bathroom.

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40 In summary, we showed that contextual locking is robust. It was observed for
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42 different degrees of array overlap (both for 50% overlap and 25% overlap) and with
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44 and without an extrinsic context. The results demonstrate that the impact of context on
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46 learning extends beyond its typically assumed impact on explicit memory processes
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48 and can be strong to the extent that stimulus identity is altered across different
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50 contexts. The notion of contextual locking opens a new line of research, concerning
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52 the performance of the *same* act, in more vs. less common contexts. It also relates to

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6 key theoretical questions in cognitive psychology, such as those relating to chunking
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8 and the transfer of learning to novel situations.
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Appendix

In all experiments the data were analyzed by comparing performance on overlap vs. non-overlap items. To ensure that results also were evident for responses to all locations, additional simple main effects were conducted. This pattern of results revealed faster responses to stimuli in the more common array and was evident across all responses in all experiments; Experiment 1: location 1 [F(1, 14)=10.62, MSE=8865.59, $\eta_p^2=0.43$, $p<.01$], location 2 [F(1, 14)=14.31, MSE=5020, $\eta_p^2=0.50$, $p<.01$], location 3, [F(1, 14)=23.73, MSE=8488.2, $\eta_p^2=0.62$, $p<.001$] and location 4 [F(1, 14)=9.06, MSE=4857, $\eta_p^2=0.39$, $p<.01$]; Experiment 2: (aside from the non-overlapping item at the first location which was faster but not significantly so, [F(1, 14)=1.68, MSE=4737.70, $\eta_p^2=0.10$, $p>.1$], response latencies were faster in the more vs. the less common arrays; location 2 [F(1, 14)= 20.50, MSE=5483.20, $\eta_p^2=0.59$, $p<.001$] location 3, [F(1, 14)= 24.21, MSE=3391.87, $\eta_p^2=0.63$, $p<.001$] and for the critical overlapping stimulus at location 4, [F(1, 14)= 5.07, MSE=3793.59, $\eta_p^2=0.26$, $p<.05$]; Experiment 3: location 1, [F(1, 14)= 6.13, MSE=6415.80, $\eta_p^2=0.30$, $p<.05$], location 2, [overlap, F(1, 14)= 12.74, MSE=7705.90, $\eta_p^2=0.47$, $p<.01$], location 3, [F(1, 14)= 14.92, MSE=8380.20, $\eta_p^2=0.51$, $p<.01$], and location 4 [overlap, F(1, 14)= 26.02, MSE=3832.06, $\eta_p^2=0.65$, $p<.001$]; and in Experiment 4: location 1 [F(1, 14)=10.60, MSE=5694.79, $\eta_p^2=0.43$, $p<.01$], location 2 [F(1, 14)=23.28, MSE=5209.9, $\eta_p^2=0.62$, $p<.001$], location 3 [F(1, 14)=14.37, MSE=9557.4, $\eta_p^2=0.50$, $p<.01$] and for the overlapping item at location 4 [F(1, 14)=14.16, MSE=2021.67, $\eta_p^2=0.50$, $p<.01$]. Thus as shown, response **times** to items at all four locations, across all four experiments, were shorter in the more vs. the less frequent array.

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11 Figure Captions
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14 *Figure 1.* a Stimuli presented in Experiment 1. b An example of how the item
15 arrays (with their context) were presented in Experiment 1 (note that individual items
16 in each array would appear each time in a different order). c An example of how the
17 item arrays (with their context) were presented in Experiment 1.
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22 *Figure 2.* Mean of the median response times to overlap and non-overlap
23 items as a function of Array and Block in Experiment 1.
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27 *Figure 3.* The stimuli presented in Experiment 2.
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30 *Figure 4.* Mean of the median response times to overlap and non-overlap
31 items as a function of Array and Block in Experiment 2.
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35 *Figure 5.* Mean of the median response times to overlap and non-overlap
36 items as a function of Array and Block in Experiment 3.
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39 *Figure 6.* Mean of the median response times to overlap and non-overlap
40 items as a function of Array and Block in Experiment 4.
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44 *Figure 7.* Mean of the median response times as a function of Array, Block,
45 Type and Similarity across all experiments.
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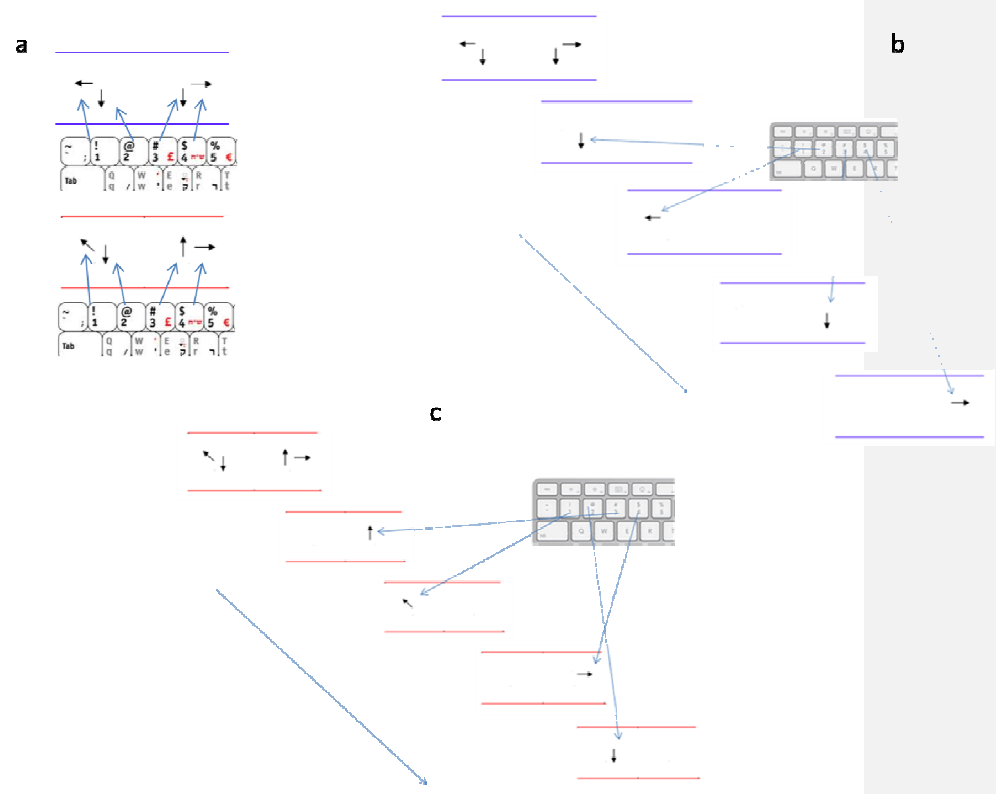


Figure 1

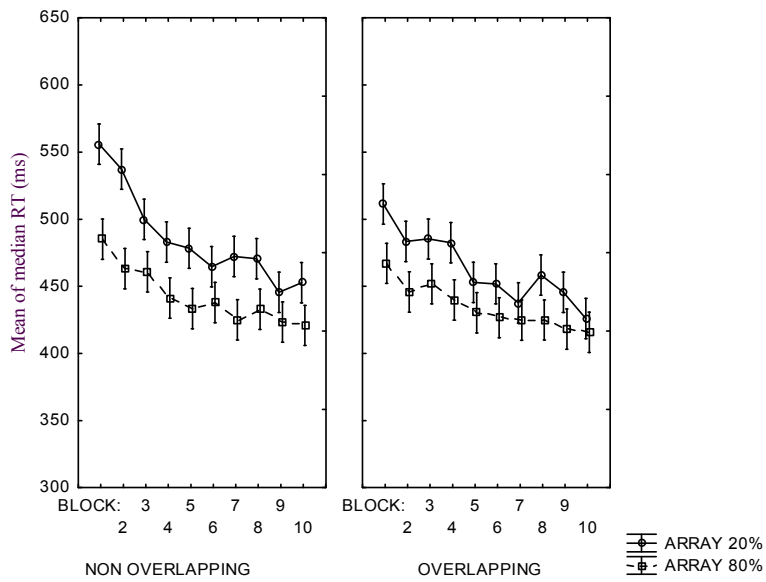


Figure 2

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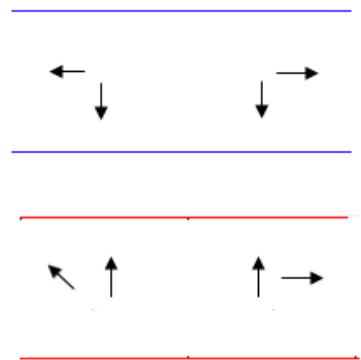
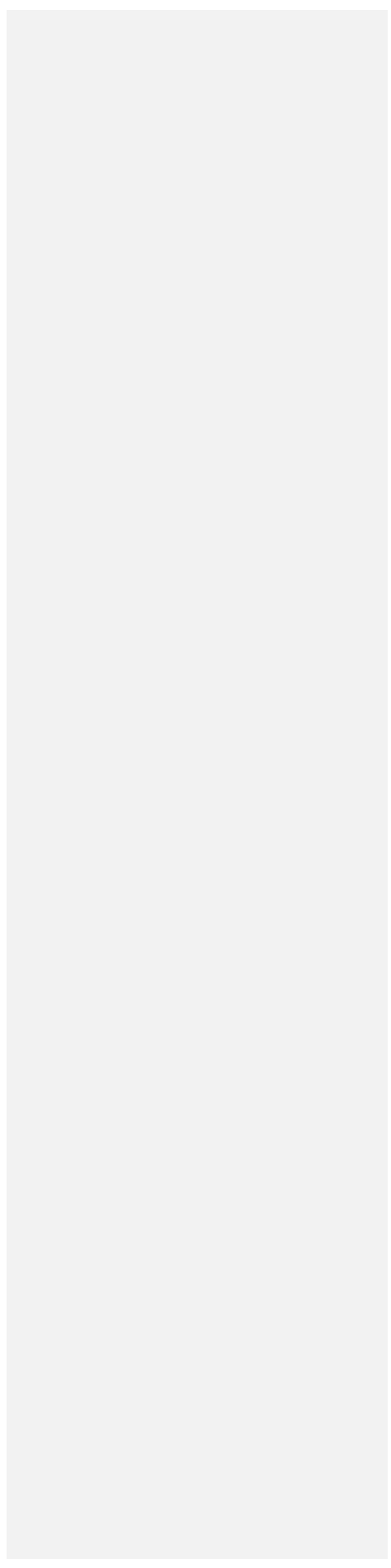


Figure 3



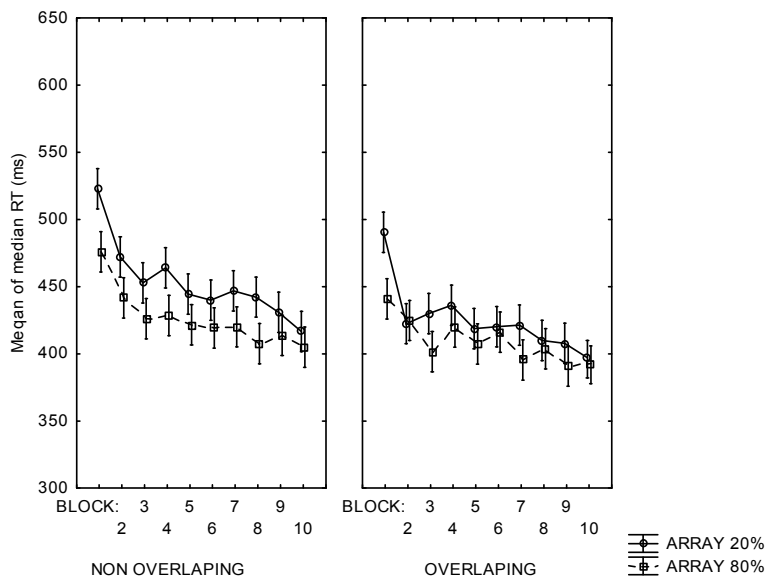


Figure 4

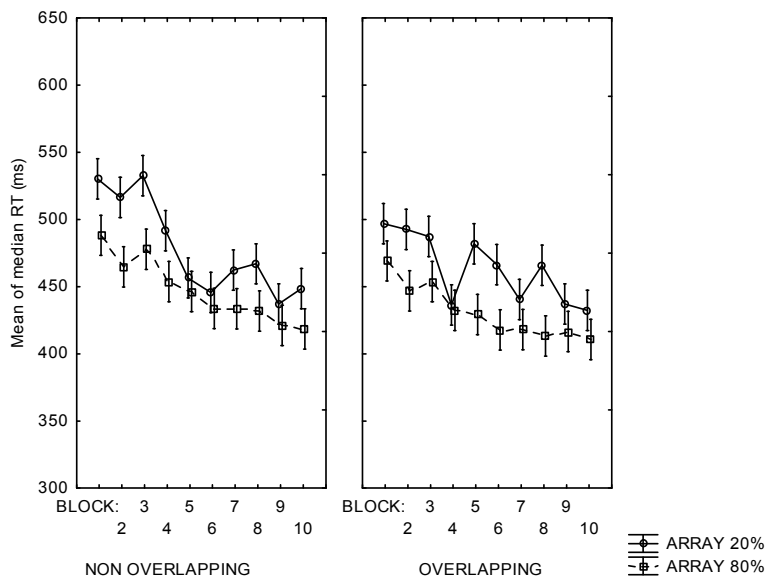


Figure 5

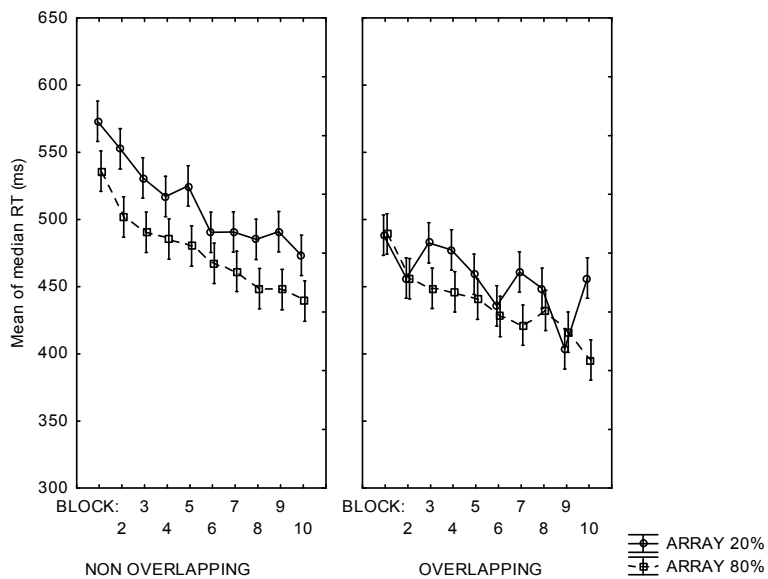


Figure 6

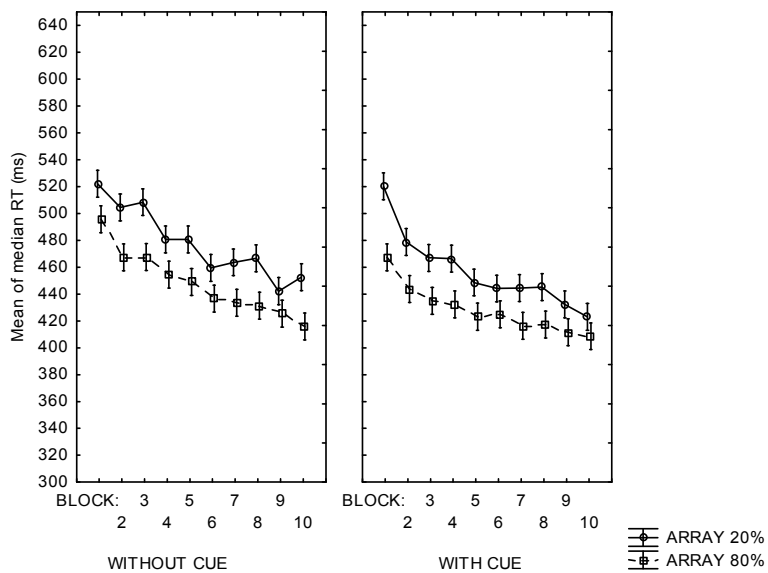


Figure 7