

Perlman, A., Hoffman, Y., Tzelgov, J., Pothos, E. M. & Edwards, D. J. (2016). The notion of contextual locking: Previously learnt items are not accessible as such when appearing in a less common context. *Quarterly Journal of Experimental Psychology*, 69(3), pp. 410-431. doi: 10.1080/17470218.2015.1054846



**CITY UNIVERSITY
LONDON**

[City Research Online](#)

Original citation: Perlman, A., Hoffman, Y., Tzelgov, J., Pothos, E. M. & Edwards, D. J. (2016). The notion of contextual locking: Previously learnt items are not accessible as such when appearing in a less common context. *Quarterly Journal of Experimental Psychology*, 69(3), pp. 410-431. doi: 10.1080/17470218.2015.1054846

Permanent City Research Online URL: <http://openaccess.city.ac.uk/13034/>

Copyright & reuse

City University London has developed City Research Online so that its users may access the research outputs of City University London's staff. Copyright © and Moral Rights for this paper are retained by the individual author(s) and/ or other copyright holders. All material in City Research Online is checked for eligibility for copyright before being made available in the live archive. URLs from City Research Online may be freely distributed and linked to from other web pages.

Versions of research

The version in City Research Online may differ from the final published version. Users are advised to check the Permanent City Research Online URL above for the status of the paper.

Enquiries

If you have any enquiries about any aspect of City Research Online, or if you wish to make contact with the author(s) of this paper, please email the team at publications@city.ac.uk.



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

Journal:	<i>Quarterly Journal of Experimental Psychology</i>
Manuscript ID:	QJE-STD 14-100.R3
Manuscript Type:	Standard Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Perlman, Amotz; Bar-Ilan University, Hoffman, Yaakov; Bar-Ilan University, Tzelgov, Joseph; Ben-Gurion University of the Negev, Pothos, Emmanuel; City University, Edwards, Darren; Swansea University,
Keywords:	Context, Implicit, Binding, Memory

SCHOLARONE™
Manuscripts

Running head: **Contextual locking**

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

Amotz Perlman, Department of Management, Bar-Ilan University

*Yaakov Hoffman, Interdisciplinary Department of Social Sciences, Bar Ilan University.

Joseph Tzelgov, Department of Psychology, Ben-Gurion University of the Negev and Department of psychology, Achva Academic College

Emmanuel M. Pothos, Department of Psychology, City University London

Darren J. Edwards, Department of Psychology, Swansea University

*Please note that Amotz Perlman and Yaakov Hoffman contributed equally to this publication (order of authorship for these authors was determined by coin toss).

Address correspondence to: Amotz Perlman, Department of Management,

Bar-Ilan University, Ramat-Gan 52900 Israel

Email: amotz@bgu.ac.il

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

1
2
3
4
5
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

42
43 In general, context can be defined as a surrounding stimulus (Smith, 2007).
44
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

1
2
3
4
5
6 context may have nothing to do with its item, but rather, just happen to be in the same
7
8 place at the same time (cf. background contexts). Such contexts have been termed
9
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
19
20 context versus a *new* context has been observed, this finding has been labeled the
21
22 *context effect* (Light & Carter-Sobell, 1970; Smith, 1988; Tulving & Thomson, 1973).
23
24 For example, the popular butcher-on-the-bus-phenomenon (Mandler, 1980) relates to
25
26 meeting your local butcher instead of in the butcher shop (original context), on a bus,
27
28 in a completely new and different context. Like the butcher case, incidental context
29
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
33
34 incidental background contexts (e.g., Murnane & Phelps, 1995).

35
36 One final point is that context has been theoretically conceptualized in
37
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
45
46 representation (e.g., global matching theories, see Murnane, Phelps, & Malmberg,
47
48 1999, see also Hayes, Nadel, & Ryan, 2007). One central difference between these
49
50 positions from the current perspective is that if context functions as a cue that predicts
51
52 responses, in the presence of a stronger cue, it may be outshone, i.e., its cuing power

1
2
3
4
5
6 may become redundant (Smith & Vela, 2001). On the other hand, if context is
7
8 automatically bound to its item, as shown for incidental contexts (Hoffman &
9
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

18
19 Verbal implicit memory shows typically no benefit of environmental context
20
21 on performance with implicit perceptual memory tasks (e.g., Jacoby, 1983; McKone
22
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,
26
27 perspective on implicit processes, tying implicitness to lack of intentionality, and not
28
29 necessarily a lack of awareness). However, context effects have been shown in
30
31 implicit motor sequence learning (e.g., Ruitenberg, Abrahamse, De Kleine, &
32
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
36
37 complex picture. Namely, in such experiments the sequence is fixed, and context
38
39 functions as a cue. Accordingly, some have suggested that the first stimulus of the
40
41 sequence may be a strong enough cue for loading the sequence (Ruitenberg et al.,
42
43 2012a), rendering the context as a predictive cue, redundant (outshone). Thus context
44
45 effects, (e.g., diminished performance in a different context) were evident only with
46
47 limited practice and before the sequence was sufficiently learned (Ruitenberg et al.,
48
49 2012a). When processing of the redundant context was intentional, there was no effect
50
51 of contextual influences at all (Abrahamse, Van der Lubbe, Verwey, Szumska, &
52

1
2
3
4
5
6 Jaskowski, 2012). Such a result, that a cue (e.g., context) can be outshone by a
7
8 stronger cue (e.g., the sequence itself) is a central theme in the context literature
9
10 (Smith & Vela, 2001). In another study, context effects were evident in motor
11
12 sequence learning only when an opposite context, signaling a different sequence,
13
14 created a direct conflict, (Ruitenberg et al., 2012b).

15
16
17 There are other considerations which also lead to a somewhat puzzling picture
18
19 regarding context effects in implicit memory. In addition to color, the location of a
20
21 place holder (the square in which a stimulus will appear in a serial reaction time task)
22
23 also does not produce context effects; only the place holder shape, e.g., changing from
24
25 square to triangle, appears to create a context effect (Abrahamse & Verwey, 2008).
26
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).

30
31 Overall, while implicit learning of motor sequences is affected in some cases
32
33 by incidental context, the following points should be noted. First, in all these cases,
34
35 the items did not appear in a random order, but rather in a sequence of sorts. Second,
36
37 the context functioned as a cue that enabled greater prediction of the next response.

38
39 Taken together, the context could have been outshone by the robust cueing of the
40
41 sequence, where each previous response cues the next (with sufficient practice).

42
43 Incidental contexts, however, which correspond to inherently unrelated stimuli, that
44
45 do not cue a subsequent response, have been shown to be bound to their items
46
47 (Hoffman & Tzelgov, 2012) in an obligatory fashion (e.g., Hayes et al., 2007). Here
48
49 we address whether several items appearing in a single common context may be
50
51 bound to this common context, to the extent that the items become unitized. Can the

1
2
3
4
5
6 motoric response of a random sequence (which by definition cannot be chunked) be
7
8 unitized via the locking of each and every stimulus to its common context?
9

10
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.
24
25
26
27
28
29
30
31
32
33
34
35
36

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
45
46
47
48
49
50
51
52

1
2
3
4
5
6 locked on to two different contexts at the same time. Obtaining such effects would
7
8 suggest that context may play a role in determining an item's identity and not merely
9
10 facilitate its processing.

11 The present paradigm

12
13
14
15 The notion of contextual locking is examined by using a novel spatial task,
16
17 which we briefly summarize below, along with considering possible outcomes and
18
19 their theoretical implications. Participants are trained on two different lists (arrays)
20
21 each comprising four arrows (Figure 1 a). By array, we mean a collection of four
22
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
26
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
30
31 button press, according to its (fixed) spatial position. For example in Figure 1 b, the
32
33 arrow pointing down (always) appears in the second spatial position of the array and
34
35 should always be responded to with the second response key, regardless of its
36
37 presentation order, relative to the other items in an array, that is, regardless of whether
38
39 it appears first, second etc. As addressed below, on a straightforward explicit level,
40
41 the participant's sole task requirement was to indicate via button press the spatial
42
43 position of each of the four items in a given array. Responding to the entire array (i.e.,
44
45 making four responses to the four corresponding items in the array) constituted a
46
47 single trial in the experiment.

48
49
50 Participants knew which array they were about to see, because a blue or red
51
52 rectangle, containing all four stimuli appeared prior to the beginning of each trial. The

1
2
3
4
5
6 blue rectangle, containing its array of four arrows appearing in fixed screen locations,
7
8 prompted the more (80%) frequent array (list) and a red rectangle, containing its array
9
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
15
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
19
20 appeared individually, in a random order, in their fixed screen position. Each arrow
21
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
25
26 items, positioned in the same location, and required the same response.

27
28 We use this task to address the notion of contextual locking. Several potential
29
30 outcomes can ensue from such a task, each of which reflects a specific type of
31
32 processing. Three potential types of processing, along with their expected results are
33
34 discussed below, followed by a fourth possibility, which specifically focuses on the
35
36 overlapping stimuli, namely differences regarding the same item appearing in two
37
38 different contexts.

41 Possible empirical outcomes

42
43 Let us first consider ‘straw man’ possibilities for the possible underlying
44
45 processes indicated by potential results in the present task. If participants only process
46
47 the *stated* task requirement of responding to the spatial position of each arrow, e.g.,
48
49 any item appearing in the second position is responded to with the second key etc., ~~so~~
50
51 ~~that~~ there would be no effect of array frequency. Namely, there should be no
52
53

1
2
3
4
5
6 difference in responding to the more or less common arrays. Because both arrays are
7
8 composed of four arrows in the *same* four distinct locations, items from each array
9
10 should be responded to in the same manner. Such a result is predicated on the
11
12 assumption that participants only process task requirements. Based on the
13
14 automaticity literature such an assumption is unlikely (see e.g., Perlman, & Telgov,
15
16 2006, and as we shall shortly see, it is also inconsistent with our results). A second
17
18 possibility is that participants *only* encode arrow orientation. While such an option
19
20 may be implausible as participants in *contrast* to instructions to process spatial
21
22 location, solely process arrow orientations without concern for spatial location, it
23
24 leads to a specific profile. Namely, if participants were behaving in this way,
25
26 performance would be at chance; i.e., error rates would be high, (as it turns out such
27
28 an option is also inconsistent with results). A third possibility is that participants
29
30 encode both spatial orientation and item identity, we would expect shorter response
31
32 times to non-overlapping items in the more frequent array versus the less frequent
33
34 array a finding typically observed in such paradigms (Perlman, et al., 2010; and
35
36 observed in all current experiments).

37
38 Finally, the hypothesized critical outcome concerns possible evidence for
39
40 contextual locking, a process which relies on binding (e.g., Hayes et al., 2007;
41
42 Hoffman & Tzelgov, 2012) that addresses the extent to which, each item in a given
43
44 array is bound to its context. Overlapping items (the same items appearing in both
45
46 arrays in the very same spatial location and requiring the very same response) should
47
48 be responded to significantly faster in the more common context than in the less
49
50 common context. In effect, response data for the overlapping items allows us to
51
52 explore the empirical question of interest, that is, to establish whether participants are

1
2
3
4
5
6 locking an item to its relevant array (this is the phenomenon of contextual locking).

7
8 Such a result would indicate that an item is no longer perceived solely by its own
9
10 properties, e.g., arrow orientation, but that item identity is determined by its context as
11
12 well.

13 14 15 Statistical definition of contextual locking and implications

16
17 Contextual locking can be operationally defined as the difference in response
18
19 time between processing of the same item, in two different contexts. Contextual
20
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
24
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.
28
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*
32
33 differences between the more and less common frequencies for both the different
34
35 items (non-overlapping) and same items (overlapping). Statistically, this would be
36
37 indicated by a main effect of Array frequency, in the absence of an Array frequency
38
39 by Overlap interaction. Such an outcome indicates that the very same item is treated
40
41 as if it were a *completely* different item, when it appears in another context. To
42
43 anticipate our results, we provide support for contextual locking of both types across
44
45 four experiments.

46
47 Another interesting analysis concerns the effect of practice on contextual
48
49 locking. If the context is automatically bound with its item (Hayes, et al., 2007), then
50
51 contextual locking should be evident early on, say, during the course of the first
52

1
2
3
4
5
6 block, and it should not necessarily diminish with practice. This possibility would be
7
8 consistent with contextual locking being a result of the representations, which are
9
10 created when the stimuli are first perceived. Indeed, there is corresponding evidence
11
12 in explicit item memory (e.g., Godden, & Baddeley, 1975; Hayes et al., 2007; 2010;
13
14 Murnane, & Phelps, 1995) where a single presentation is sufficient for context effects.
15
16 We addressed this issue by assessing performance across blocks. All the variables
17
18 (Array, Overlap and Block) are within participant variables.

19
20
21 We conclude the introduction by reconsidering the relevance of our research to
22
23 research on learning as chunking. According to this pervasive and influential idea,
24
25 learning involves a gradual recognition of co-occurring elementary units, and so the
26
27 formation of corresponding chunks. Theories of chunking have been extremely
28
29 influential in psychology and applied to a wide range of domains (e.g., Rosenbaum, et
30
31 al., 1987; Simon & Barenfeld, 1969; also, cf. our own work, Perlman, et al., 2010). As
32
33 discussed above, we stress the important point that all forms of chunking work by
34
35 taking advantage of regularities in the *sequential* presentation of elementary units
36
37 (e.g., symbols or elementary stimuli). In our experiments, as the sequence of items in
38
39 each array presentation is *random*, there is no basis for the typical type of chunking
40
41 observed in motor tasks, i.e., items can only be bound to their common context in the
42
43 way we outline above. Thus, if unitized representations exist they must originate from
44
45 the binding of items with the common context.

46
47 -----
48
49 Figure 1

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

1
2
3
4
5
6 keyboard. The onset of an item started the timer; the item disappeared as soon as
7
8 participants responded.
9

10 Stimuli and Procedure

11
12
13
14
15

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.
19
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
24 arrays.
25
26
27
28
29
30
31

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 keys 1 through 4 (Figure 1 b). Participants were asked to use the index and the middle
37 fingers of both hands for responding. The current experiments used either six
38 (Experiments 1 and 3) or seven (Experiments 2 and 4) S-R mappings. Responses
39 triggered the onset of the next item in the array. After the last response, a response
40 stimulus interval (RSI) of 1000 ms followed. Participants were not informed that there
41 were two different arrays. After being instructed about the spatial coding of items
42
43
44
45
46
47
48
49
50
51
52

1
2
3
4
5
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).
11
12
13
14
15

16 Results and Discussion

17
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.
22
23
24 Average error rates were 2.2% for the more frequent blue array and 2.4% for the less
25 frequent red array ($p > .1$).
26
27
28
29
30

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.
36
37
38
39
40
41

42 -----
43
44 Figure 2
45
46 -----
47
48

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),
51
52
53

1
2
3
4
5
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.
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

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.

1
2
3
4
5
6 We conducted the same analyses separately for the latter 9 blocks to address if
7
8 the Block with Array interaction would remain significant, namely, whether it was
9
10 dependent on the first block. Results of this interaction were not significant $F(8,$
11
12 $112)=1.80$, $MSE=921$, $\eta_p^2=0.11$, $p>.08$, suggesting that the data from the first block
13
14 played a critical role in this interaction. Further confirmation of the role of the first
15
16 block was obtained by applying this three-way within subjects analysis to the first
17
18 block, with Array, Sub-block (within the first block, there were 5 sub blocks, each
19
20 comprising 40 stimuli) and Overlap as the manipulated factors. We found a
21
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 $F(1, 14)=9.29$,
25
26 $MSE=7271$, $\eta_p^2=0.39$, $p<.01$; the Sub-block with Array interaction was also
27
28 significant $F(4, 56)=9.29$, $MSE=6719$, $\eta_p^2=0.16$, $p<.05$, indicating that participants'
29
30 ability to respond faster to the more frequent Array improved over the course of the
31
32 five sub-blocks of Block 1.
33

34
35 In summary, the main result of this experiment is that RTs were significantly
36
37 shorter for the more frequent array (Figure 2). Critically, this effect persevered even
38
39 when the very same overlapping items were presented. Note though that these
40
41 differences were larger for the non-overlapping items than for the overlapping items,
42
43 suggesting that, in Experiment 1, item identity was only partly bound to a specific and
44
45 non-transferable context, i.e., item identity may have moderated the effect of context.
46
47 In any event, demonstrating significant differences between the more and less
48
49 frequent array for the very same overlapping items reflects contextualization.
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
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.
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35

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
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 presentation order we employed, was different in every trial. We found similar results,
7
8 notably, a significant effect for Array $F(1, 14)=39.18$, $MSE=8724$, $\eta_p^2=0.73$, $p<.001$,
9
10 indicating that the more frequent Array was responded to faster than the less frequent
11
12 Array, and for Block $F(9, 126)= 4.60$, $MSE=13548$, $\eta_p^2=0.24$, $p<.001$, indicating that
13
14 performance improved across Blocks.
15

16
17 Interestingly, we also found similar results for the last target, for which
18
19 prediction is highest: responses to the more frequent Array were faster than responses
20
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 $F(9, 126)= 23.18$, $MSE=5092$, $\eta_p^2=0.62$,
24
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
28

29 Experiment 2

30
31
32 The results of Experiment 1 show a significant RT difference when
33
34 responding to the same items in different contexts. In Experiment 2, we ask if an
35
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, &
39
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
47
48 (Hayes, et al., 2007; Hayes, et al., 2010); contextual locking should be the same,
49
50 regardless of the degree of array overlap.
51

1
2
3
4
5
6 Method

7
8
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).
13
14
15

16
17 -----
18
19
20 Figure 3
21
22
23 -----
24

25 Results and discussion

26
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.
31
32
33
34

35
36 -----
37
38
39 Figure 4
40
41
42 -----
43

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
49
50
51
52

1
2
3
4
5
6 performance for the more frequent array (415 vs. 438). The Block effect was also
7
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, $F(1,$
19
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
23
24 latencies to both overlap and non-overlap items were equally resistant to practice.
25
26 Critically, to reiterate, as shown in Figure 4, the very same overlapping item was
27
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.
31

32
33 In order to examine if these effects existed without prolonged training, we
34
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
38
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 $F(4,$
46
47 $56)=25.73$, $MSE=13076$, $\eta_p^2=0.64$, $p<.001$, indicating that participants improved
48
49 across these 5 sub-blocks.
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 As before, in order to verify that the effects reported in Experiment 2 were
7
8 not due to the more frequent array containing more repeat trials, as opposed to the less
9
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%),
13
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, MSE=1115, $\eta_p^2=0.47$, $p>.05$], Repetition did not interact
19
20 with any other factor, i.e., responses were not affected by repeat vs. switch trials, [F(1,
21
22 14)=1.245, 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
25
26 costs.

27
28 As in Experiment 1, it is important to demonstrate if these effects were evident
29
30 for the first target, for which response predictability would be lowest. Thus, we
31
32 performed the same analyses as above, but only for the target presented first. We
33
34 found similar results and in particular significant effects for Array F(1, 14)=18.14,
35
36 MSE=16375, $\eta_p^2=0.56$, $p<.001$ and for Overlap F(1, 14)= 51.17, MSE=8504,
37
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, MSE=4093,
41
42 $\eta_p^2=0.62$, $p<.001$ and for Block F(9, 126)= 12.19, MSE=10829, $\eta_p^2=0.46$, $p<.001$; the
43
44 three-way interaction F(9, 126)= 2.03, MSE=2453, $\eta_p^2=0.12$, $p<.05$ was also
45
46 significant, indicating faster RTs across blocks in the more frequent array for the
47
48 overlapping target F(1, 14)=6.28, MSE=4048, $\eta_p^2=0.30$, $p<.05$. These results indicate
49
50 that contextual locking is not dependent on predictive ability.
51

1
2
3
4
5
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.
15
16
17
18
19
20
21
22
23

24 Experiment 3

25
26
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
40
41
42
43
44
45
46
47
48
49
50
51
52

1
2
3
4
5
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
9
10 list and not individual items within a list.

11 12 13 Methods

14
15 Fifteen university students (five males; mean age 23.6, range 20-25)
16
17 participated in this experiment. The experiment was identical to Experiment 1, but for
18
19 the fact that the colored rectangles were removed. Accordingly, there were two lists of
20
21 items – response associations. As previously, participants were exposed to the (entire)
22
23 item set within each array prior to responding, but without the colored rectangle.
24

25 26 Results and Discussion

27
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
31
32 Array, Block and Overlap (overlap vs. non-overlap items) as the manipulated factors
33
34 (see Figure 5). The Array effect was significant $F(1, 14)=44.10$, $MSE=3579$,
35
36 $\eta_p^2=0.75$, $p<.001$, indicating that the more common array was responded to faster
37
38 (438 vs. 471). The Block effect was significant, $F(9, 126)=8.13$, $MSE=4396$,
39
40 $\eta_p^2=0.37$, $p<.001$, indicating overall attenuation of differences across blocks. The
41
42 Overlap effect was also significant $F(1, 14)=7.12$, $MSE=5156$, $\eta_p^2=0.33$, $p<.05$,
43
44 indicating (438 vs. 471) that RT for overlapping stimuli was shorter than for non-
45
46 overlapping stimuli (447 vs. 462). No other effects (including interactions) were
47
48 significant, $ps > .1$.

49
50 As in Experiment 2, the lack of an Array with Block interaction indicates that
51
52 the contextual locking effect was practice resistant. The lack of an Overlap with Array

1
2
3
4
5
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, $F(1, 14) = 20.25$,
9
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
13
14 Experiment 2, the very same overlapping item was treated as if it were a *completely*
15
16 different item, when it appeared in a different context.
17
18
19
20

21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figure 5

Additionally, in order to examine the pattern of results within Block 1, the data were submitted to a three-way within participant analysis with Array, Sub-block (5 sub blocks within the first block) and Overlap as the manipulated factors. We found a significant effect for Array $F(1, 14) = 13.68$, $MSE = 12265$, $\eta_p^2 = 0.49$, $p < .01$, indicating faster performance for the more vs. the less frequent Array, and for Sub-block $F(4, 56) = 16.10$, $MSE = 11417$, $\eta_p^2 = 0.53$, $p < .001$ indicating improvement across the five sub-blocks. These results suggest, as previously observed, an overall improvement in the first block as well as revealing evidence for the key effects without practice.

In order to verify that the effects reported in Experiment 3 were not due to the more frequent array containing more repeat trials, as opposed to the less frequent

1
2
3
4
5
6 array, for which there were more switch trials, we reanalyzed the data in a three-way
7
8 within subjects analysis of variance (ANOVA), with the factors Array (80% vs. 20%),
9
10 Overlap (overlap vs. non-overlap) and Repetition (repeat vs. switch). While repeat
11
12 trials were responded to faster than switch trials, $[F(1, 14)=9.27, MSE=326, \eta_p^2=0.39,$
13
14 $p<.05]$, the Repetition factor (repeat vs. switch) as previously observed did not
15
16 interact with any other variable, i.e. had no effect on performance, all F 's <1 . Thus
17
18 contextualization effects were not driven by putative switch costs.
19

20
21 As in Experiments 1 and 2, it is important to demonstrate the Array effect for
22
23 the first target, for which predictability is lowest. We performed the above analyses,
24
25 but only for the target that was presented first. We found similar results; the main
26
27 effect of Array $F(1, 14)=25.58, MSE=11076, \eta_p^2=0.64, p<.001$ was significant, as
28
29 well as the main effect of Block $F(9, 126)= 2.51, MSE=7906, \eta_p^2=0.15, p<.05$. The
30
31 interaction of Array with Overlap was also significant $F(1, 14)=4.82, MSE=6051,$
32
33 $\eta_p^2=0.25, p<.05$. Data from the last target where predictive ability is highest were also
34
35 similarly analyzed. There was a significant effect for Array $F(1, 14)=28.20,$
36
37 $MSE=4636, \eta_p^2=0.66, p<.001$ and for Block $F(9, 126)= 22.01, MSE=6500, \eta_p^2=0.61,$
38
39 $p<.001$. These results show that contextual locking is independent of predictive
40
41 strength.
42

43 The present results replicate and extend the results of Experiment 1 and 2,
44
45 where we also observed shorter RTs for the overlapping items in the more vs. less
46
47 frequent array. These findings indicate that, even when context is neither salient nor
48
49 extrinsic (red vs. blue rectangles), but rather just consists of neighboring items, the
50
51 common overlapping items appearing in the less frequent context are treated as if they
52

1
2
3
4
5
6 were different, than when they appeared in the more frequent array. In the final
7
8 experiment, we ask if contextualization of an item, relative to the other items
9
10 appearing in the same group, exists even when only one item overlaps between the
11
12 two arrays.

13 14 Experiment 4

15
16
17 Fifteen university students (4 males; mean age 22.9, range 21- 27),
18
19 participated in this experiment which was identical to Experiment 2, where there was
20
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,
24
25 relative to the previous experiments.
26

27 28 Results and Discussion

29
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
33
34 submitted to a three-way within subjects ANOVA with Array, Block and Overlap
35
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,
41
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 $F(1,14)=29.83$, $MSE=11220$, $\eta_p^2=0.68$,
45
46 $p < .001$, indicating that participants performed differently across conditions (442 vs.
47
48 494). The Block with Overlap interaction was also significant $F(9, 126)=1.98$,
49
50 $MSE=1705$, $\eta_p^2=0.12$, $p < .05$, and this may indicate that the RT decrease across blocks
51
52 for overlap items was weaker than for non-overlap items (Figure 4). No other effects
53

1
2
3
4
5
6 were significant $p > 0.1$. This pattern of results suggests that the difference between
7
8 the more and less common array was the same for both overlap items $F(1, 14) = 14.16$,
9
10 $MSE = 2021$, $\eta_p^2 = 0.50$, $p < .01$ and non-overlap items $F(1, 14) = 31.85$, $MSE = 3247$,
11
12 $\eta_p^2 = 0.69$, $p < .001$. Namely, the very same overlapping item was treated as a
13
14 *completely* different item when it appeared in the less frequent array as opposed to
15
16 when it appeared in the more frequent array.
17

18
19 As in Experiment 1, where Block interacted with Array, here we also further
20
21 analyzed the Block with Overlap interaction, to examine if this effect depended on the
22
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
26
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.
34

35
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-
45
46 block $F(4, 56) = 12.66$, $MSE = 10364$, $\eta_p^2 = 0.47$, $p < .001$, indicating improvement across
47
48 Sub-blocks; no other effects were significant.
49

50 -----
51

1
2
3
4
5
6 Figure 6
7
8
9 -----
10

11 Figure 6 critically shows a clear difference in the mean RTs between arrays.
12
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.
21
22
23
24
25
26
27
28
29

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.
39
40
41
42
43
44
45
46
47

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
50
51
52

1
2
3
4
5
6 analysis as presented above, but only for the target that was presented first. We found
7
8 similar results, particularly, significant effects of Array $F(1, 14)=26.54$, $MSE=5645$,
9
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 $F(1, 14)=24.38$, $MSE=36663$, $\eta_p^2=0.63$, $p<.001$.
13

14
15 Similarly, for the last target we also found significant effects for Array $F(1,$
16
17 $14)=28.28$, $MSE=5801$, $\eta_p^2=0.66$, $p<.001$, Block $F(9, 126)= 24.01$, $MSE=5776$,
18
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
20
21 Array with Overlap $F(1, 14)=25.42$, $MSE=1917$, $\eta_p^2=0.64$, $p<.001$, and Block with
22
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
30
31 sequence learning), but rather due to contextual locking.
32

33
34 The finding of contextual locking in Experiment 4 is especially revealing as
35
36 both the absence of a salient context in the form of a colored rectangle and the
37
38 minimal degree of overlap between arrays might have led us to expect that the effect
39
40 would be weaker. Now we turn to one final analysis conducted on data collapsed
41
42 across all experiments, which addresses how context Type (with rectangle vs. without
43
44 rectangle) and Similarity between arrays (one vs. two overlapping items) affected
45
46 results. The mean RT for each block was submitted to a five-way mixed model
47
48 ANOVA, with Array, Block and Overlap, as within subjects factors and Type
49
50 (with/without rectangle) and Similarity (one/two overlapping items) as between
51
52 subjects factors. The Array effect was significant, $F(1, 56)=101.16$, $MSE=5229$,
53

1
2
3
4
5
6 $\eta_p^2=0.54$, $p<.001$, indicating that responses were faster to the more common array.
7
8 The Block effect was significant, $F(9, 504)=17.73$, $MSE=4697$, $\eta_p^2=0.33$, $p<.001$,
9
10 indicating a decrease in RT across blocks. The Overlap effect was also significant
11
12 $F(1, 56)=14.77$, $MSE=5925$, $\eta_p^2=0.53$, $p<.001$, indicating larger RTs for the non-
13
14 overlapping items. Significant interactions were Overlap with Type $F(1, 56)= 4.10$,
15
16 $MSE=5925$, $\eta_p^2=0.06$, $p<.05$, Overlap with Similarity $F(1, 56)= 9.45$, $MSE=5925$,
17
18 $\eta_p^2=0.14$, $p<.01$, Array with Block $F(9, 504)= 2.37$, $MSE=1124$, $\eta_p^2=0.04$, $p<.05$,
19
20 Array with Overlap $F(1, 56)= 6.51$, $MSE=2599$, $\eta_p^2=0.10$, $p<.05$, Block with Overlap
21
22 $F(9, 504)= 6.51$, $MSE=1741$, $\eta_p^2=0.04$, $p<.01$, and the triple interaction (Figure 7) of
23
24 Array, Block and Type $F(9, 504)= 2.12$, $MSE=1124$, $\eta_p^2=0.03$, $p<.05$. Critically,
25
26 neither the Type with Array interaction ($F<1$) nor the Similarity with Array
27
28 interaction, $F(1, 56)= 2.50$, $MSE=5229$, $\eta_p^2=0.04$, $p>.1$) were significant, indicating
29
30 that contextual locking is independent of both Context Type and degree of Similarity
31
32 (i.e., the degree of overlap between arrays). Different types of context with different
33
34 degrees of overlap induce the same form of unitization based on contextualized
35
36 locking.

37 38 39 40 41 General Discussion

42
43
44 The aim of this paper was to examine if items in a motor response tasks can
45
46 become unitized even when they do not appear in a fixed order. Such unitization of
47
48 items can only occur via their binding to a common context, which we called
49
50 contextual locking, a term operationally defined as the difference in response time
51
52 between processing of the same item, in two different contexts. Accordingly, we

1
2
3
4
5
6 hypothesized that responding to the same stimulus, with the same response will be
7 significantly faster in the more common context than the less common context. As
8 distinguishing between the same overlapping item in the more and less frequent arrays
9 was possible only via contextual factors comprised of the neighboring list items
10 (Experiments 3 and 4) and the color of a rectangular external frame (in Experiments 1
11 and 2), these differences between arrays for the overlapping stimuli can only have
12 been driven by the locking of the task goal with its context. The emerging pattern of
13 results across four experiments, in which the same item was responded to faster when
14 it appeared in a more common context than in the less common context, is consistent
15 with this hypothesis. There was no benefit of binding items to a common context for
16 participants, as neither the items themselves nor the context were informative of the
17 responses that had to be given. This evidently differs from other studies on context
18 effects, in which actions were associated to a specific context (e.g., Ruitenberg, et al
19 2012a.). These results were reliable across Experiments 1-4². These results were not
20 affected by putative switch costs, i.e., by the more frequent array including more
21 Repeat trials, as opposed to the less frequent Array, which included more Switch
22 trials.

23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40 Our results suggest that the individual items are not identified by their unique
41 properties alone (e.g., arrow orientation), but also by their context. In effect, in each
42 of the contexts, neither the spatial position nor the arrows' unique orientation were the

43
44
45
46
47 ² Occasionally, in particular blocks it seems that random noise caused an apparent weakening
48 of these effects (Exp 2, block 2; Exp 3, block 4, Exp 4, blocks 1,2, and 9). Random noise is often
49 typical in such paradigms, where an overall consistent effect may be less evident in particular blocks.
50
51
52

1
2
3
4
5
6 main driving force underlying responses. Moreover, in three of the four experiments
7
8 the difference between arrays was as great for the overlapping items as it was for the
9
10 non-overlapping items. Accordingly, it seems that contextual locking can occur to the
11
12 extent that items lose an individual identity in favor of a more contextual-driven
13
14 representation; i.e., it is possible that an item is defined by its context. This contextual
15
16 locking could only have arisen from the binding of items with their context. While
17
18 such binding is more typically observed for *related* contexts that co-occur with items
19
20 (e.g., butcher-in-the-butcher-shop), it has been observed for unrelated contexts too
21
22 (e.g., Hayes et al., 2010; Hoffman, & Tzelgov, 2012).
23

24
25 Evidence of contextual locking was obtained both for salient extrinsic contexts
26
27 (Baddeley, 1982) and less salient contexts, involving just inter-item relations (Sirotnin,
28
29 et al., 2005). Furthermore, analogous results were obtained both when the inter-item
30
31 contexts across the two arrays were more similar (in which case contextualization
32
33 may have played a role in facilitating item distinction) and when arrays were less
34
35 similar (where distinguishing between these differentiated arrays was less necessary;
36
37 Diana et al., 2007). As contextualization was evident across different levels of context
38
39 salience and array distinguishability, the present results are in line with Hayes et al.'s
40
41 (2007; 2010) suggestion that the binding of items with their context may be
42
43 obligatory. The present results are also consistent with Perlman and Tzelgov's (2006)
44
45 definition of automaticity. If indeed such binding is obligatory, it is no surprise that
46
47 contextual locking is fairly ubiquitous and immediate, i.e., evident from the first
48
49 block.
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 It might be claimed that participants did not notice the overlapping items
7
8 between the two contexts, especially in experiments 3 and 4, where no colored
9
10 rectangle was presented. Accordingly, the difference between the overlapping stimuli
11
12 in the frequent vs. the non-frequent array may simply reflect greater practice. Our
13
14 results preclude this possibility. There were only four stimuli in each array presented
15
16 over 1000 training trials, thus it is likely that the overlap was noticed. Furthermore,
17
18 across all four experiments, the overlap stimuli were responded to significantly
19
20 different than the non-overlap stimuli, further indicating that participants noticed their
21
22 overlapping. Finally, had participants somehow mis-perceived the overlapping
23
24 stimuli, then their performance level would have been low (e.g., high error rates), but
25
26 our results indicate otherwise. What is surprising is that exactly the same stimulus is
27
28 responded to differently in the frequent array vs. the infrequent one. Regardless of
29
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.
33

34
35 It might be claimed that the S-R mapping of overlapping and non-overlapping
36
37 stimuli may have been different. For overlapping stimuli there was a 1 S-R mapping
38
39 (i.e., for a given stimulus there was only one response) as opposed to non-overlapping
40
41 stimuli which had a 2 S-R mapping (two different stimuli, one in the frequent array
42
43 and another in the infrequent one, had the same response). This claim is of arguable
44
45 relevance as it necessitates between array mapping, an unlikely assumption (both
46
47 theoretically and) given the obtained results which demonstrate that mapping was
48
49 conducted within array and not between array. However, even if the overlap and non-
50
51 overlap stimuli do not have the same S-R mapping, it would nevertheless be
52
53 compatible with our conclusions as they stem from analyses comparing between
54

1
2
3
4
5
6 responses to the *overlapping* stimuli in frequent and infrequent arrays (for which the
7
8 same S-R mapping exists).
9

10
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
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

1
2
3
4
5
6 becoming locked to their specific context, so that the other items in the array cease to
7
8 exist in a non-bound, context-less manner.
9

10
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 (Ruitenber et al.,
29 2012a) especially as the public bathroom is not an opposite context (Ruitenber 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
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

1
2
3
4
5
6 – thus when for example one shaves outside the familiar environment the very same
7
8 behavior might be performed slower.
9

10
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.
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47

48
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
51
52

1
2
3
4
5
6 the item information, extends the known incidental context effects to implicit tasks.
7
8 By implicit, we do not mean that participants were unaware of the two different
9
10 arrays, but that they were learning something they were not instructed to learn
11
12 (Perlman & Tzelgov, 2006). Hitherto context effects were typically shown to occur in
13
14 explicit semantic tasks where items appearing in an original context are processed
15
16 better than different items appearing in a *new* context (e.g., Godden & Baddeley,
17
18 1975; Light & Carter-Sobell, 1970; Smith, 1988; Smith & Vela, 2001; Tulving &
19
20 Thomson, 1973). In implicit tasks context effects were either not obtained (e.g.,
21
22 Jacoby, 1983; McKone & French, 2001; also see Mulligan, 2011) or limited (e.g.,
23
24 Ruitenberg et al., 2012a; 2012b, see above). Applying incidental context to
25
26 demonstrate contextual locking we show that the effect of context on item processing
27
28 is more pervasive than originally conceived; this effect also appears to be (fairly)
29
30 ubiquitous, in the sense that it is not linked to a certain type of test (e.g., explicit) or
31
32 the available information about context. The notion of contextual locking is highly
33
34 ecological, since one can speculate that many daily activities involve the kind of
35
36 implicit, perhaps even procedural learning, which our task was meant to engage, such
37
38 as shaving in the dorm vs. a public bathroom.

39
40 In summary, we showed that contextual locking is robust. It was observed for
41
42 different degrees of array overlap (both for 50% overlap and 25% overlap) and with
43
44 and without an extrinsic context. The results demonstrate that the impact of context on
45
46 learning extends beyond its typically assumed impact on explicit memory processes
47
48 and can be strong to the extent that stimulus identity is altered across different
49
50 contexts. The notion of contextual locking opens a new line of research, concerning
51
52 the performance of the *same* act, in more vs. less common contexts. It also relates to
53
54

1
2
3
4
5
6 key theoretical questions in cognitive psychology, such as those relating to chunking
7
8 and the transfer of learning to novel situations.
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

Formatted: Indent: First line: 0"

References

Abrahamse, E. L., & Verwey, W. B. (2008). Context dependent learning in the serial RT task. *Psychological research*, 72, 397-404.

Abrahamse, E. L., Van der Lubbe, R. H. J., Verwey, W. B., Szumska, I., & Jaskowski, P. (2012). Redundant sensory information does not enhance sequence learning in the serial task. *Advances in cognitive psychology*, 8, 109-120.

Baddeley, A. D. (1982). Domains of recollection. *Psychological Review*, 89, 708.

Bjork, R. A., & Richardson-Klavehn, A. (1989). On the puzzling relationship between environment context and human memory. In C. Izawa (Ed.), *Current issues in cognitive processes: The Tulane Flowerree Symposium on Cognition*. Hillsdale, NJ: Erlbaum.

Cleeremans, A., & McClelland, J. L. (1991). Learning the structure of event sequences. *Journal of Experimental Psychology: General*, 120, 235.

Boucher, L., & Dienes, Z. (2003). Two ways of learning associations. *Cognitive Science*, 27, 807-842.

D'Angelo, M. C., Milliken, B., Jiménez, L., & Lupiáñez, J. (2014). Re-examining the role of context in implicit sequence learning. *Consciousness and cognition*, 27, 172-193.

Formatted: Font: Italic

1
2
3
4
5
6 Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2007). Imaging recollection
7 and familiarity in the medial temporal lobe: A three-component model. *Trends in*
8 *Cognitive Sciences*, 11, 379-386.

11
12 Eich, E. (1984). Memory for unattended events: Remembering with and
13 without awareness. *Memory & Cognition*, 12, 105-111.

16
17 Eich, E., Macaulay, D., & Ryan, L. (1994). Mood dependent memory for
18 events of the personal past. *Journal of Experimental Psychology: General*, 123, 201.

20
21 Godden, D. R., & Baddeley, A. D. (1975). Context-dependent memory in two
22 natural environments: On land and underwater. *British Journal of Psychology*, 66,
23 325-331.

26
27 Godden, D., & Baddeley, A. (1980). When does context influence recognition
28 memory? *British Journal of Psychology*, 71, 99-104.

31
32 Goldstone, R. L. (2000). Unitization during category learning. *Journal of*
33 *Experimental Psychology: Human Perception and Performance*, 26, 86-112.

36
37 Gopher, D., Well, M., & Bareket, T. (1994). Transfer of skill from a computer
38 game trainer to flight. *Human Factors: The Journal of the Human Factors and*
39 *Ergonomics Society*, 36, 387-405.

42
43 Green, C. S., & Bavelier, D. (2008). Exercising Your Brain: A Review of
44 Human Brain Plasticity and Training-Induced Learning. *Psychology & Aging*, 23,
45 692-701.

Formatted: Font: Italic

Formatted: Font: (Default) Times New Roman, 12 pt

1
2
3
4
5
6
7
8
9 Hayes, S. M., Nadel, L., & Ryan, L. (2007). The effect of scene context on
10 episodic object recognition: Parahippocampal cortex mediates memory encoding and
11 retrieval success. *Hippocampus*, 17, 873-889.
12
13

14
15 Hayes, S. M., Baena, E., Truong, T. K., & Cabeza, R. (2010). Neural
16 mechanisms of context effects on face recognition: automatic binding and context
17 shift decrements. *Journal of cognitive neuroscience*, 22, 2541-2554.
18
19

20
21 Hoffman, Y., & Tzelgov, J. (2012). Representation of unattended material in
22 memory. *Consciousness and cognition*, 21, 1504-1508.
23
24

25
26 Jacoby, L. L. (1983). Perceptual enhancement: Persistent effects of an
27 experience. *Journal of Experimental Psychology: Learning, Memory and Cognition*,
28 9, 21-38.
29
30

31
32
33 Karni, A., & Sagi, D. (1991). Where practice makes perfect in texture
34 discrimination: Evidence for primary visual cortex plasticity. *Proceedings of the*
35 *National Academy of Sciences*, 88, 4966-4970.
36
37

38
39
40 Knowlton, B. J., & Squire, L. R. (1996). Artificial Grammar Learning
41 Depends on Implicit Acquisition of Both Abstract and Exemplar-Specific
42 Information. *Journal of Experimental Psychology: Learning, Memory and Cognition*,
43 22, 169-181.
44
45

46
47
48 Light, L. L., & Carter-Sobell, L. (1970). Effects of changed semantic context
49 on recognition memory. *Journal of Verbal Learning and Verbal Behavior*, 9, 1-11.
50
51

1
2
3
4
5
6 Mandler, G. (1980). Recognizing: The judgment of previous occurrence.
7
8 *Psychological Review*, 87, 252-271.

9
10 Monsell, S. (2003). Task switching. *Trends in cognitive sciences*, 7, 134-140.

11
12
13 McKone, E., & French, B. (2001). In what sense is implicit memory
14
15 ‘episodic’? The effect of reinstating environmental context. *Psychonomic Bulletin &*
16
17 *Review*, 8, 806–811.

18
19
20 Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some
21
22 Limits on Our Capacity for Processing Information. *The Psychological Review*, 63,
23
24 81-97.

25
26
27 Mulligan, N. W. (2011) Conceptual implicit memory and environmental
28
29 context. *Consciousness and Cognition*, 20, 737–744.

30
31
32 Murnane, K., & Phelps, M. P. (1995). Effects of changes in relative cue
33
34 strength on context-dependent recognition. *Journal of Experimental Psychology:*
35
36 *Learning, Memory, and Cognition*, 21, 158.

37
38
39 Murnane, K., Phelps, M. P., & Malmberg, K. (1999). Context-dependent
40
41 recognition memory: The ICE theory. *Journal of Experimental Psychology: General*,
42
43 128, 403-415.

44
45
46 Pashler, H., & Baylis, G. (1991). Procedural learning: 2. Intertrial repetition
47
48 effects in speeded choice tasks. *Journal of Experimental Psychology: Learning,*
49
50 *Memory & Cognition*, 17, 33–48.

1
2
3
4
5
6 Perruchet, P., Vinter, A., Pacteau, C., & Gallego, J. (2002). The formation of
7 structurally relevant units in artificial grammar learning. *The Quarterly Journal of*
8 *Experimental Psychology*, 55A, 485-503.

11
12 Perlman, A., Pothos, E. M., Edwards, D. & Tzelgov, J. (2010). Task-relevant
13 chunking in sequence learning. *Journal of Experimental Psychology: Human*
14 *Perception & Performance*. 36, 649-661.

18
19 Perlman, A., & Tzelgov, J. (2006). Interactions between encoding and
20 retrieval in the domain of sequence-learning. *Journal of Experimental Psychology:*
21 *Learning, Memory, and Cognition*, 32, 118.

24
25 Pothos, E. M., & Wolff, J. G. (2006). The Simplicity and Power model for
26 inductive inference. *Artificial Intelligence Review*, 26, 211-225.

29
30 Rosenbaum, D. A., Kenny, S. B., & Derr, M. A. (1983). Hierarchical control
31 of rapid movement sequences. *Journal of Experimental Psychology: Human*
32 *Perception and Performance*, 9, 86-102.

36
37 Rosenbaum, D. A., Hindorff, V., & Munro, E. M. (1987). Scheduling and
38 programming of rapid finger sequences: Tests and elaborations of the hierarchical
39 editor model. *Journal of Experimental Psychology: Human Perception and*
40 *Performance*, 13, 193-203.

44
45 Ruitenbergh, M. F., Abrahamse, E. L., De Kleine, E., & Verwey, W. B. (2012).
46 Context-dependent motor skill: perceptual processing in memory-based sequence
47 production. *Experimental brain research*, 222, 31-40. a

1
2
3
4
5
6 Ruitenbergh, M. F., De Kleine, E., Van der Lubbe, R. H., Verwey, W. B., &
7
8 Abrahamse, E. L. (2012). Context-dependent motor skill and the role of practice.
9
10 *Psychological research*, 76, 812-820. b

11
12 Simon, H. A., & Barenfeld M. (1969), Information-Processing Analysis of
13
14 Perceptual Processes in Problem Solving. *Psychological Review*, 76, 473-483.

15
16
17 Sirotin, Y. B., Kimball, D. R., & Kahana, M. J. (2005). Going beyond a single
18
19 list: Modeling the effects of prior experience on episodic free recall. *Psychonomic*
20
21 *Bulletin & Review*, 12, 787-805.

22
23
24 Smith, S. M. (1988). Environmental context-dependent memory. In G.M.
25
26 Davies & D.M. Thomson (Eds.), *Memory in context: Context in memory* (pp. 13–34).
27
28 New York: Wiley.

29
30
31 Smith, S. M. (2007). Context: A reference for focal experience. *Science of*
32
33 *memory: Concepts*, 111-114.

34
35
36 Smith, S. M., & Vela, E. (2001). Environmental context-dependent memory:
37
38 A review and meta-analysis. *Psychonomic Bulletin and Review*, 8, 203-220.

39
40
41 Tulving, E., & Thomson, D.M. (1973). Encoding specificity and retrieval
42
43 processes in episodic memory. *Psychological Review*, 80, 352–373.

44
45
46 Wright, D. L., & Shea, C. H. (1991). Contextual dependencies in motor skills.
47
48 *Memory & Cognition*, 19, 361-370.

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.

1
2
3
4
5
6
7
8
9
10
11 Figure Captions
12
13

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.
18
19
20
21

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.
24
25
26

27 *Figure 3.* The stimuli presented in Experiment 2.
28
29

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.
32
33
34

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.
37
38

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.
41
42
43

44 *Figure 7.* Mean of the median response times as a function of Array, Block,
45 Type and Similarity across all experiments.
46
47
48
49
50
51
52

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

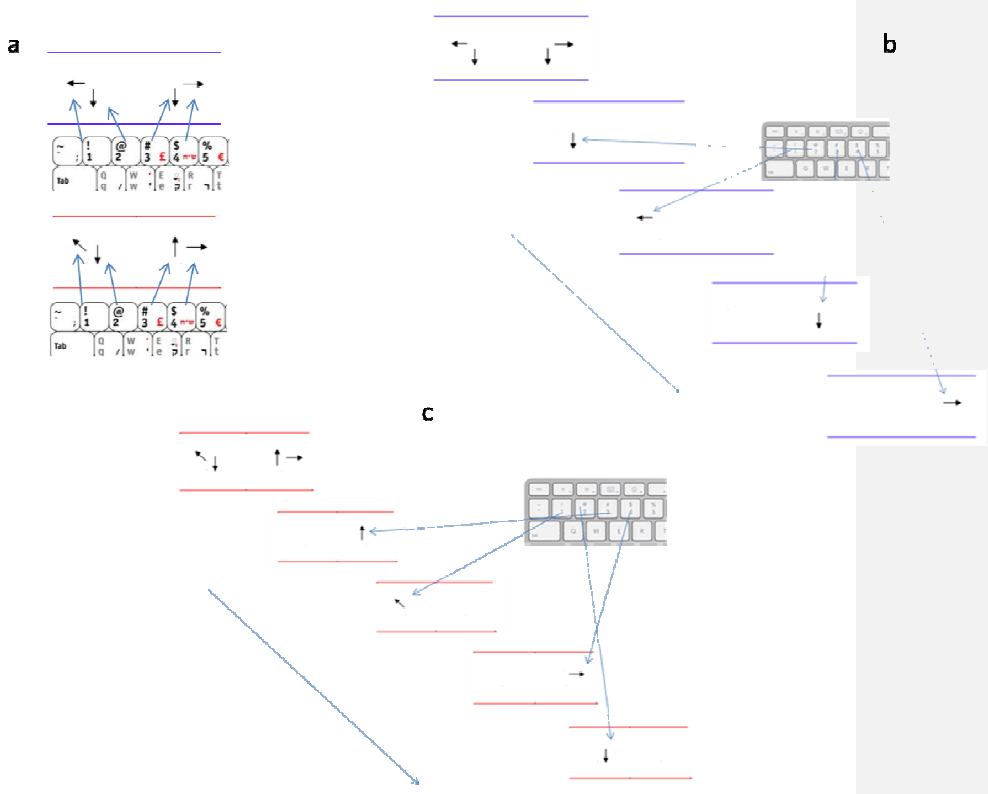


Figure 1

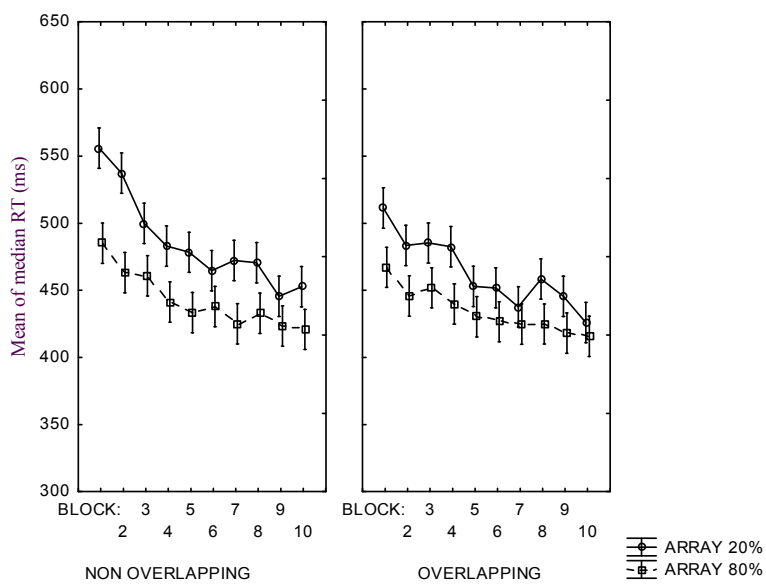


Figure 2

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

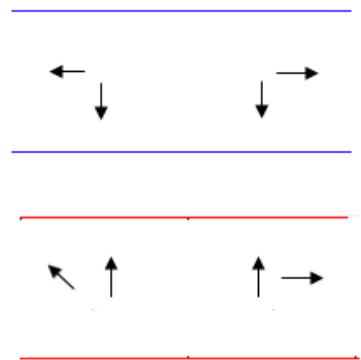
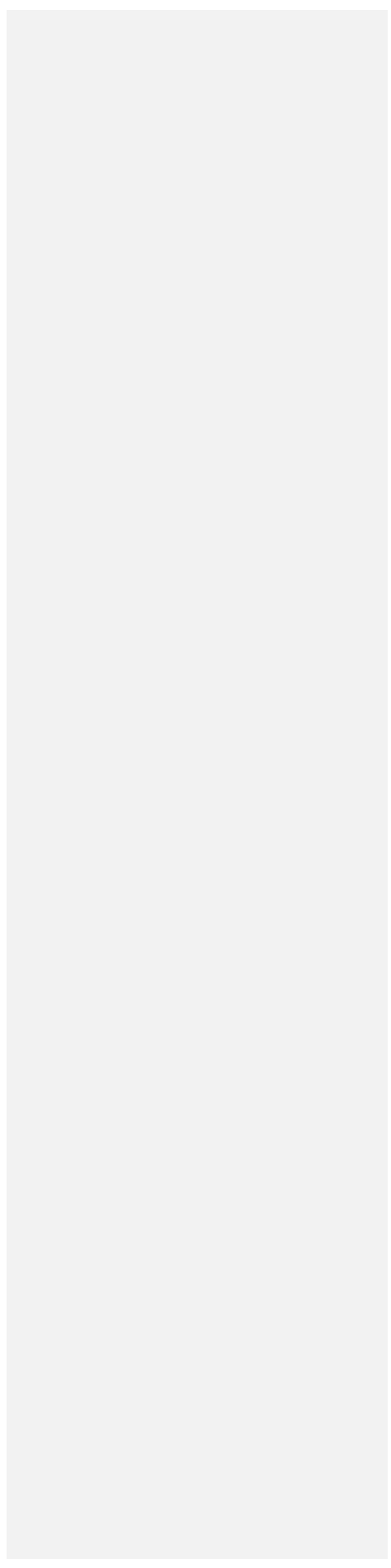


Figure 3



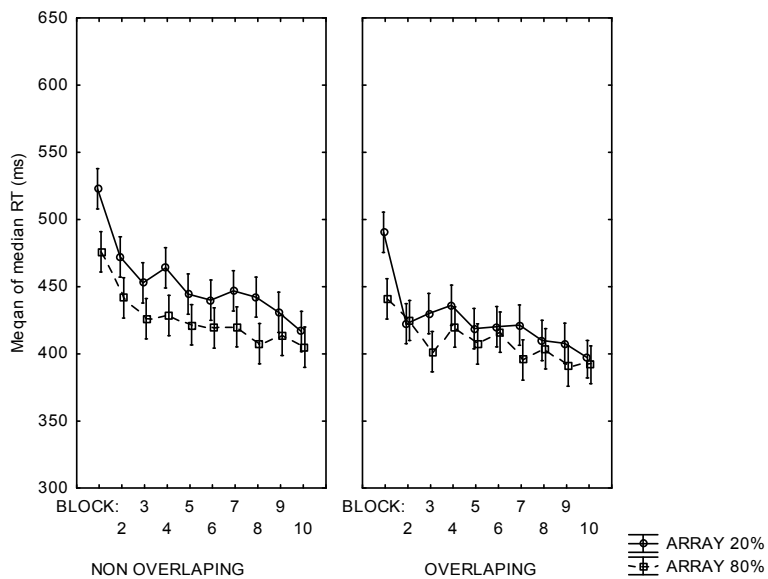


Figure 4

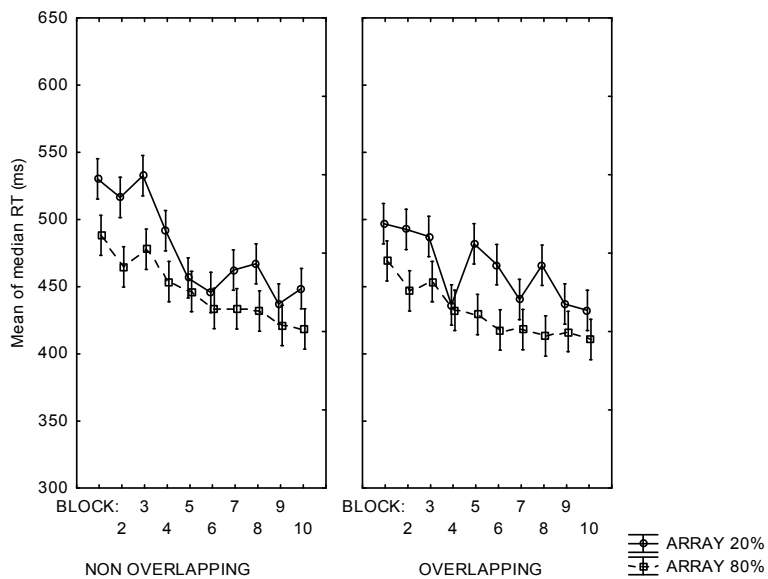


Figure 5

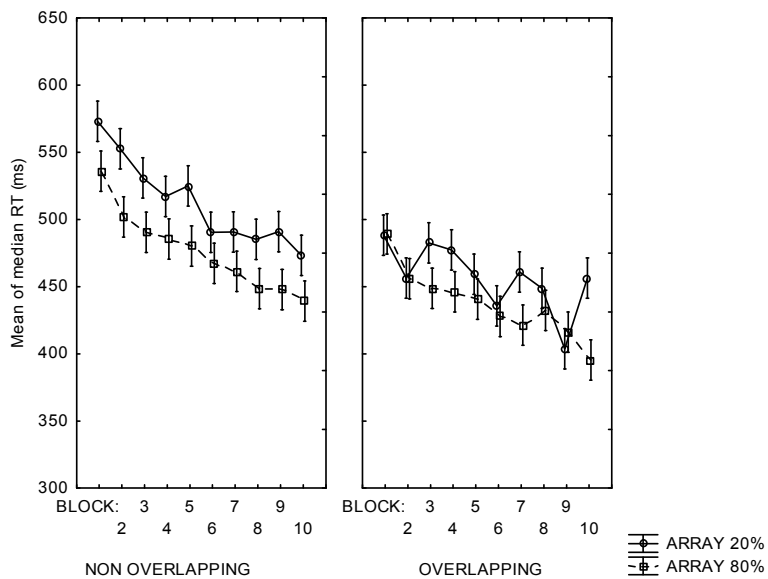


Figure 6

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

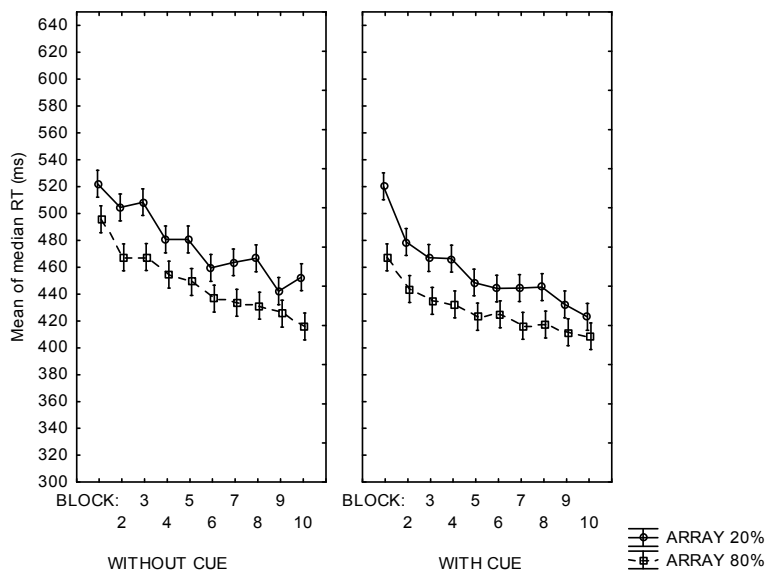


Figure 7