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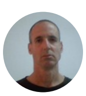

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The notion of contextual locking: Previously learnt items are not accessible as such when appearing in a less common context

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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*—that is, response times to the very same item in a more common context (80%) were significantly shorter than those in a less common context (20%). Contextual locking was obtained both when the context was more salient (Experiments 1 and 2) and less salient (Experiments 3 and 4). In addition, results were obtained even when contextualization seemed less necessary (Experiments 2 and 4). Binding of information to context is discussed in relation to chunking, transfer effects, and practical applications pertaining to professional training.

Keywords: Context; Memory; Implicit; Binding.

The grouping of elementary units in collective chunks is one of the basic processes of the cognitive system and one that 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 neighbours to form subunits (e.g., AB, CD), which eventually may be bound to form a unitized presentation composed of the entire set (ABCD). For the entire

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

Definition of context and context effects

In general, context can be defined as a surrounding stimulus (Smith, 2007). There are many types of context, each with its own specific definition. Studies distinguish between contexts that are explicitly encoded with their items and independent contexts (Baddeley, 1982), which are encoded separately (Eich, Macaulay, & Ryan, 1994; Godden & Baddeley, 1980). Moreover, an independent context may have nothing to do with its item but, rather, just happen to be in the same place at the same time (cf. background contexts). Such contexts have been termed incidental, which means that a context not only is "independent or isolated from the target information, but also does not influence the subject's interpretation of, or interaction with, the target material" (Bjork & Richardson-Klavehn, 1989, p. 316). Incidental context is processed without being part of task requirement in any way.

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

One final point is that context has been theoretically conceptualized in different ways leading to different predictions (cf. Hoffman & Tzelgov, 2012). While some theories postulate that a context can function as an external retrieval cue for item information (cf. Smith & Vela, 2001), other theories claim that a context binds to relevant items and forms an item–context trace, compounded into a single representation (e.g., global matching theories, see Murnane, Phelps, & Malmberg, 1999; see also Hayes, Nadel, & Ryan, 2007). One central difference between these positions from the current perspective is that if context functions as a cue that predicts responses, in the presence of a stronger cue, it may be outshone—that is, its cueing power may become redundant (Smith & Vela, 2001). On the other hand, if context is automatically bound to its item, as shown for incidental contexts (Hoffman & Tzelgov, 2012), its representation should be independent of other cues, and its influence should be ubiquitous. As shown below, this issue distinguishes the present studies from previous studies addressing context in implicit paradigms.

Context in implicit tasks

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

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

Overall, while implicit learning of motor sequences is affected in some cases by incidental context, the following points should be noted. First, in all these cases, the items did not appear in a random order, but rather in a sequence of sorts. Second, the context functioned as a cue that enabled greater prediction of the next response. Taken together, the context could have been outshone by the robust cueing of the sequence, where each previous response cues the next (with sufficient practice). Incidental contexts, however, which correspond to inherently unrelated stimuli, which do not cue a subsequent response, have been shown to be bound to their items (Hoffman & Tzelgov, 2012) in an obligatory fashion (e.g., Hayes et al., 2007). Here we address whether several items appearing in a single common context may be bound to this common context, to the extent that the items become unitized. Can the motoric response of a random sequence (which by definition cannot be chunked) be unitized via the locking of each and every stimulus to its common context?

Developing and exploring this idea of contextual locking can additionally help clarify two important issues in memory/learning research. First, rather than measuring context effects via an old versus novel context (e.g., Hoffman & Tzelgov, 2012), we ask whether contextual effects can be observed when a more and less common context are available from the start of the relevant task. Namely, would recognition of the butcher on the bus be diminished, if, from the very first time she was encountered, she would be seen continuously in both a more frequent (e.g., 80% in the butcher shop) and less frequent context (20% on the bus). This is a strong test for contextualization, as a single item is never uniquely paired with a single context; rather from the initial encounter, the item of interest appears in one of two contexts. Thus if contextualization does occur, it suggests that when the same item is viewed in the two different contexts it appears to be different, as in each case it is bound to a different context.

A second issue of interest related to the idea of contextual locking is that context effects have been typically tested and demonstrated as *between*-item effects (e.g., Godden & Baddeley, 1975; Light & Carter-Sobell, 1970; Smith & Vela, 2001), so that, for example, some original items (appearing in one context) are compared to other original items (appearing in another context). By contrast, the butcher-on-the-bus phenomenon and the more general kind of contextual locking that we address, focus on *same*-item comparisons in different contexts. As stated, the term *contextual locking* is exactly meant to indicate that the very same item can independently be locked on to two different contexts at the same time. Obtaining such effects would suggest that context may play a role in determining an item's identity and not merely facilitate its processing.

The present paradigm

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

Participants knew which array they were about to see, because a blue or red rectangle containing all four stimuli appeared prior to the beginning of each trial. The blue rectangle, containing its array of four arrows appearing in fixed screen locations, prompted the more (80%) frequent array (list), and a red rectangle, containing its array of four arrows also appearing in the same fixed screen locations, prompted the less (20%) frequent array. To emphasize this important point, the *entire* array (i.e., the four arrows and their locations, contained within its rectangle) was shown prior to each trial for 1000 ms. After this initial presentation (Figure 1), the screen went blank. Subsequently, each of the arrows from the array that was just presented appeared individually, in a random order, in their fixed screen position. Each arrow remained on the screen until it was responded to. In Experiment 1, two out of the four items overlapped (Items 2 and 4 from the left, in Figure 1)—that is, the same items, positioned in the same location—and required the same response.

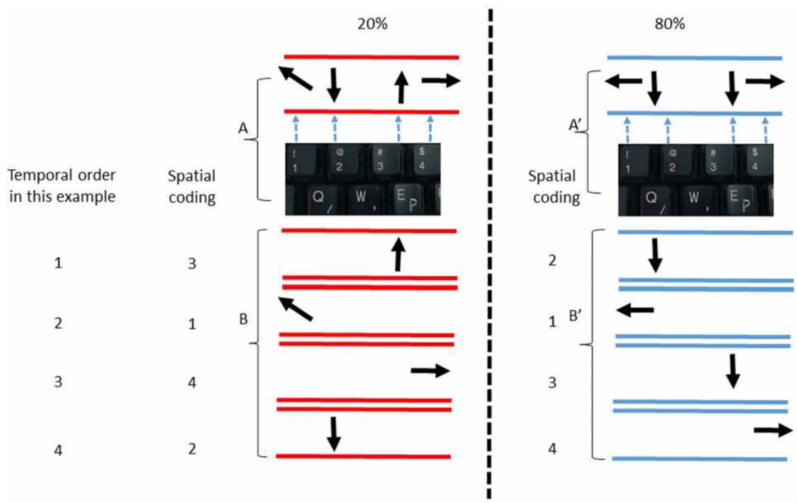

Figure 1. *Stimuli presented in Experiment 1. Two arrays are shown. The red array on the left panel appeared 20% of the time whilst the blue array shown on the right panel appeared 80% of the time. A and A′ depict the mapping of stimuli to responses for each of these lists. B and B′ depict examples of a given trial for each list. Order of correct responses for the randomly presented stimuli in the left list (red–20%) was 3,1,4,2, and for the more common list (blue–80%) was 2,1,3,4. Please note that while presentation order varied from trial to trial in a random manner, the spatial mapping was constant throughout. To view this figure in colour, please visit the online version of this Journal.*

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

Possible empirical outcomes

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

Finally, the hypothesized critical outcome concerns possible evidence for contextual locking, a process that relies on binding (e.g., Hayes et al., 2007; Hoffman & Tzelgov, 2012), which addresses the extent to which each item in a given array is bound to its context. Overlapping items (the same items appearing in both arrays in the very same spatial location and requiring the very same response) should be responded to significantly faster in the more common context than in the less common context. In effect, response data for the overlapping items allow us to explore the empirical question of interest—that is, to establish whether participants are locking an item to its relevant array (this is the phenomenon of contextual locking). Such a result would indicate that an item is no longer perceived solely by its own properties—for example, arrow orientation—but that item identity is determined by its context as well.

Statistical definition of contextual locking and implications

Contextual locking can be operationally defined as the difference in response time between processing of the same item, in two different contexts. Contextual locking may present itself in two manners. The moderate effect occurs when there is an overall response latency difference between the more and less frequent array, but this effect is smaller for overlapping items than for nonoverlapping items. Statistically this would be indicated by a main effect of array frequency (80% vs. 20%) and a significant interaction between array frequency and overlap (overlap vs. nonoverlap). A stronger effect of contextual locking would be indicated by similar differences between the more and less common frequencies for both the different items (nonoverlapping) and the same items (overlapping). Statistically, this would be indicated by a main effect of array frequency, in the absence of an array frequency by overlap interaction. Such an outcome indicates that the very same item is treated as if it were a completely different item, when it appears in another context. To anticipate our results, we provide support for contextual locking of both types across four experiments.

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

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

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, in the more and less frequent contexts; this should hold both for the dissimilar items (nonoverlapping) 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 years, range 21–27 years) 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 was run on IBM compatible Pentium III computers with 17″ monitors, which were placed approximately 60 cm from participants. Participants responded by using the computer keyboard. The onset of an item started the timer; the item disappeared as soon as participants responded.

Stimuli and procedure

The experiment was organized in 10 training blocks, each consisting of 200 individual item presentations—that is, 50 array presentations. A blue or red rectangle, 6 centimetres wide and 3 centimetres tall, was presented in the middle of the screen. The frequent context (blue rectangle) appeared 40 times in each block (followed by the four corresponding items and responses; Figures 1a and 1b), and the nonfrequent context (red rectangle) appeared 10 times in each block (the rectangles appeared for 1000 ms.). Note that the second and fourth arrows (items) were identical in both arrays.

Each block began with the written message “press any key to continue”, after which the screen went blank for 1000 ms. Subsequently a blue or red rectangle (Figure 1), containing the four items (the arrow orientations we used are the ones shown in the figures), appeared for 1000 ms. Responses were indicated by pressing the keys 1 through 4 (Figure 1). Participants were asked to use the index and the middle fingers of both hands for responding. The current experiments used either six (Experiments 1 and 3) or seven (Experiments 2 and 4) stimulus–response (S–R) mappings. Responses triggered the onset of the next item in the array. After the last response, a response–stimulus interval (RSI) of 1000 ms followed. Participants were not informed that there were two different arrays. After being instructed about the spatial coding of items (e.g., the item in the extreme left location was to be responded to with the extreme left key), they were told to respond as quickly and as accurately as possible. Presentation order of arrays and items within each array was randomized. Participants could rest between blocks for about one minute, and, on average, it took participants about 20 min to complete the experiment (the same applies to subsequent experiments).

Results and discussion

Both response time (RT) and error data for all trials were recorded. While analyses on both measures were similar, some effects were significant only for the RT data. There was no evidence of a speed–accuracy trade-off in any experiment. Thus, here and elsewhere, only RT data are presented, which are based on only correct responses. Average error rates were 2.2% for the more frequent blue array and 2.4% for the less frequent red array ($p > .1$).

To reduce the influence of outliers, the median and not the mean was used; extreme outliers (below 200 ms and above 2500 ms) were removed from the analyses. For each participant, the median RT for each item was calculated separately for each block in each array. The mean of the median RTs is presented in Figure 2 as a function of block, for each array.

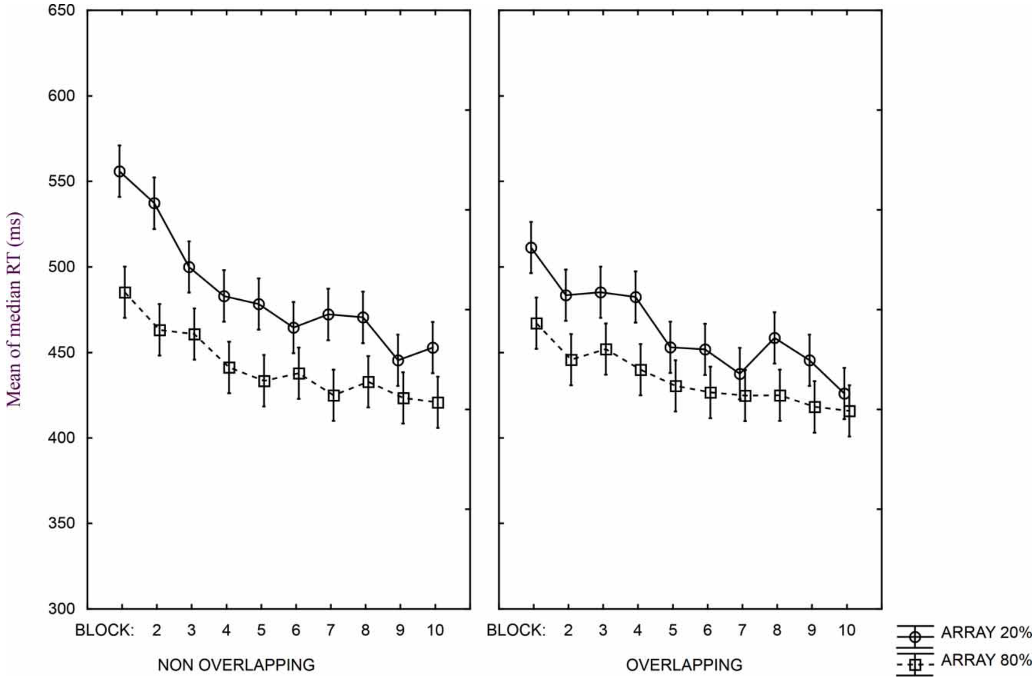

Figure 2. *Mean of the median response times (RTs) to overlap and nonoverlap items as a function of array and block in Experiment 1.*

In all statistical analyses, the significance level was set to .05. These mean RTs were submitted to a three-way within-subjects analysis of variance (ANOVA), with array (20% vs. 80%), block, and overlap (overlap vs. nonoverlap items) as the manipulated factors. The array effect was significant, $F(1, 14) = 17.97$, $MSE = 10{,}992$, $\eta_p^2 = .56$, $p < .001$, indicating that response times were shorter for the more common array (438 vs. 474 ms). The block effect was significant, $F(9, 126) = 14.73$, $MSE = 2368$, $\eta_p^2 = .51$, $p < .001$, indicating a decrease in RT across blocks. The overlap effect was significant $F(1, 14) = 14.77$, $MSE = 2340$, $\eta_p^2 = .51$, $p < .01$, indicating larger RTs for the nonoverlapping items (449 vs. 464). The Block × Array interaction was significant, $F(9, 126) = 2.30$, $MSE = 1002$, $\eta_p^2 = .14$, $p < .05$, and this may indicate larger differences between arrays at earlier blocks than later blocks (Figure 2). The Array × Overlap interaction was significant, $F(1, 14) = 6.55$, $MSE = 1232$, $\eta_p^2 = .31$, $p < .05$, indicating larger differences between the frequent and nonfrequent arrays for nonoverlap stimuli than for overlap stimuli. Yet simple main effects analyses revealed significant differences between responding to the more and less common array for both the nonoverlap items, $F(1, 14) = 18.82$, $MSE = 7585$, $\eta_p^2 = .57$, $p < .01$, and, more importantly, for the overlap items, $F(1, 14) = 13.55$, $MSE = 4639$, $\eta_p^2 = .49$, $p < .001$—that is, the very same item was responded to faster in the more common array than in the less common array, demonstrating contextual locking.[1] No other effects were significant (Fs < 1). Note that the absence of a three-way interaction of array, block, and overlap indicates that the smaller differences between arrays at later blocks versus earlier blocks was the same for both

[1]Both here and in the remaining experiments we examined whether this pattern was evident in each of the four items of each array; see the Appendix.

overlapping and nonoverlapping items—that is, both were affected by practice to the same extent.

We conducted the same analyses separately for the latter nine blocks to address whether the Block × Array interaction would remain significant, namely, whether it was dependent on the first block. Results of this interaction were not significant, $F(8, 112) = 1.80$, $MSE = 921$, $\eta_p^2 = .11$, $p > .08$, suggesting that the data from the first block played a critical role in this interaction. Further confirmation of the role of the first block was obtained by applying this three-way within-subjects analysis to the first block, with array, sub-block (within the first block, there were five sub-blocks, each comprising 40 stimuli), and overlap as the manipulated factors. We found a significant effect for array, $F(1, 14) = 18.71$, $MSE = 23{,}090$, $\eta_p^2 = .57$, $p < .001$, for sub-block, $F(4, 56) = 28.56$, $MSE = 7271$, $\eta_p^2 = .67$, $p < .001$, and for overlap, $F(1, 14) = 9.29$, $MSE = 7271$, $\eta_p^2 = .39$, $p < .01$; the Sub-block × Array interaction was also significant, $F(4, 56) = 9.29$, $MSE = 6719$, $\eta_p^2 = .16$, $p < .05$, indicating that participants' ability to respond faster to the more frequent array improved over the course of the five sub-blocks of Block 1.

In summary, the main result of this experiment is that RTs were significantly shorter for the more frequent array (Figure 2). Critically, this effect persevered even when the very same overlapping items were presented. Note though that these differences were larger for the nonoverlapping items than for the overlapping items, suggesting that, in Experiment 1, item identity was only partly bound to a specific and nontransferable context—that is, item identity may have moderated the effect of context. In any event, demonstrating significant differences between the more and less frequent array for the very same overlapping items reflects contextualization.

It could be the case that this anticipated pattern of results was driven by switch costs (Monsell, 2003). Namely, the more common array (80%) may be responded to faster, because it appears more often after itself, as opposed to the less common array, which predominantly appears after the more common array. To ensure that the observed results did not stem from switch costs, data from both arrays were also binned into repeat and nonrepeat kinds. This "switch factor" was employed in our statistical models, to address the possibility that switch costs partly or wholly drive a difference in responding to the frequent versus infrequent arrays. Data were subjected to a three-way within-subjects ANOVA, with the factors array (80% vs. 20%), overlap (overlap vs. nonoverlap), and repetition (repeat vs. switch). Critically, contextual locking was not differentially affected by repeat versus switch trials, $F(1, 14) = 2.75$, $MSE = 521$, $\eta_p^2 = .16$, $p > .1$. Incidentally, repetition was not significant either as a main effect or in any of the remaining interactions. Thus, as no interactions with the repetition factor were significant, the observed contextual locking could not have been driven by putative switch costs.

Note again that the order of the items in each array presentation was random; thus, whether the first, second, third, or fourth sequential response corresponded to overlapping items or not varied from trial to trial. However, another important aspect of sequencing that should be considered is that the predictive power increases with each subsequent response—for example, the first target out of four had the lowest predictive power while the last response was completely predictable. Accordingly, to make a strong case for contextual locking it is important to demonstrate this effect even for the first target, for which prediction is lowest. Thus we performed the same analyses as that presented above, but only for the first presented target, which, due to the random presentation order that we employed, was different in every trial. We found similar results—notably, a significant effect for array, $F(1, 14) = 39.18$, $MSE = 8724$, $\eta_p^2 = .73$, $p < .001$, indicating that the more frequent array was responded to faster than the less frequent array, and for block, $F(9, 126) = 4.60$, $MSE = 13{,}548$, $\eta_p^2 = .24$, $p < .001$, indicating that performance improved across blocks.

Interestingly, we also found similar results for the last target, for which prediction is highest: Responses to the more frequent array were faster than responses to the less frequent array, $F(1, 14) = 27.76$, $MSE = 9521$, $\eta_p^2 = .66$, $p < .001$. In addition, performance improved across blocks, $F(9, 126) = 23.18$, $MSE = 5092$, $\eta_p^2 = .62$, $p < .001$. Observing similar contextual locking for both low- and high-predictability responses suggest that contextual locking is independent of sequence predictability

EXPERIMENT 2

The results of Experiment 1 show a significant RT difference when the same items are responded to in different contexts. In Experiment 2, we ask whether an effect of contextual locking holds when the overlap between the two arrays is minimal. If we assume, as some theorists do (e.g., Diana, Yonelinas, & Ranganath, 2007), that one of the main functions of context is to support distinctive item information, contextualization should decrease with less array overlap. Reducing array overlap renders each array more distinctive, and there may be less need to rely on context. Yet if contexts are automatically bound to their items (Hayes et al., 2010; Hayes et al., 2007), contextual locking should be the same, regardless of the degree of array overlap.

Method

Fifteen experimentally naïve university students (6 males; mean age 22.9 years, range 20–26 years) participated in this experiment. Conditions were similar to those of Experiment 1, except that only one of the four items was identical between the two arrays (see Figure 3).

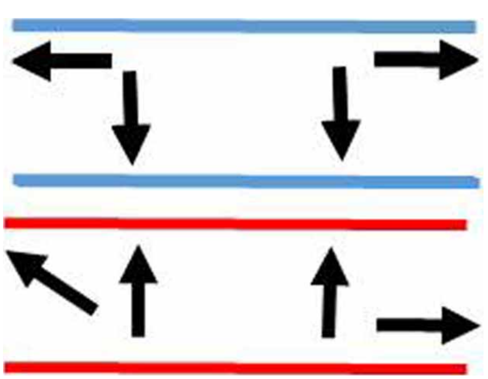

Figure 3. *The stimuli presented in Experiment 2 (The above frame in blue and the frame below in red). To view this figure in colour, please visit the online version of this Journal.*

Results and discussion

Visual inspection of the mean latencies in the various conditions (Figure 4) show broadly similar results to those of Experiment 1. Of particular interest is the RT for the single item common to both arrays, since this informs both whether contextual locking occurred and to what extent.

Average error rates were 5.20% for the more frequent red array and 4.00% for the less frequent blue array ($p > .1$). The mean RTs for each block of responses were submitted to a three-way within-subjects ANOVA with array, block, and overlap (overlap vs. nonoverlap items) as the manipulated factors. The array effect was significant, $F(1, 14) = 18.82$, $MSE = 3750$, $\eta_p^2 = .57$, $p < .001$, indicating better performance for the more frequent array (415 vs. 438 ms). The block effect was also significant, $F(9, 126) = 3.91$, $MSE = 7453$, $\eta_p^2 = .21$, $p < .001$, indicating a decrease in RT across blocks. The overlap effect, $F(1, 14) = 14.88$, $MSE = 4983$, $\eta_p^2 = .51$, $p < .01$ (Figure 4), was significant, indicating differences in response latencies between the overlapping and nonoverlapping items (415 vs. 438 ms). No other effects were significant ($p > .1$). This result pattern indicates that the observed effect (RT more common array < RT less common array) was analogous for both overlap, $F(1, 14) = 5.07$, $MSE = 3793$, $\eta_p^2 = .26$, $p < .05$, and nonoverlap items, $F(1, 14) = 21.83$, $MSE = 2572$, $\eta_p^2 = .60$, $p < .001$, and was the same across all blocks—that is, responding latencies to both overlap and nonoverlap items were equally resistant to practice. Critically, to reiterate, as shown in Figure 4, the very same overlapping item was treated as if it were a different item when it appeared in the less frequent array as opposed to when it appeared in the more frequent array.

In order to examine whether these effects existed without prolonged training, we additionally analysed data from the first block separately (breaking up the data in the first block into five sub-blocks). Data were

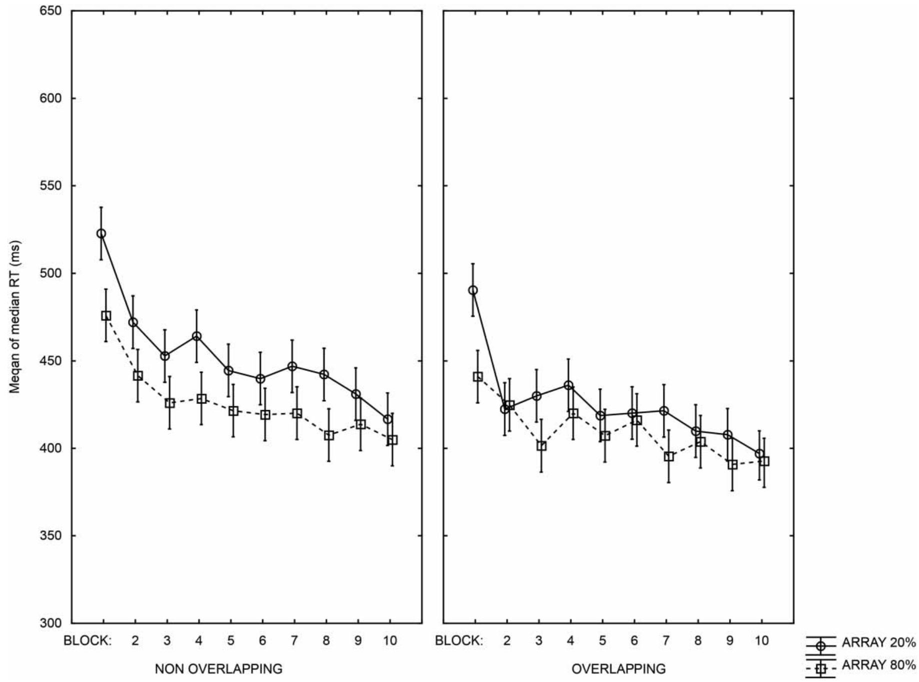

Figure 4. *Mean of the median response times (RTs) to overlap and nonoverlap items as a function of array and block in Experiment 2.*

submitted to a three-way within-participant analysis with array, sub-block (five blocks within the first block), and overlap as the manipulated factors. We found a significant effect for array, $F(1, 14) = 34.22$, $MSE = 11{,}478$, $\eta_p^2 = .70$, $p < .001$, indicating that the more frequent array was responded to faster than the less frequent array, and for sub-block, $F(4, 56) = 25.73$, $MSE = 13{,}076$, $\eta_p^2 = .64$, $p < .001$, indicating that participants improved across these five sub-blocks.

As before, in order to verify that the effects reported in Experiment 2 were not due to the more frequent array containing more repeat trials, as opposed to the less frequent array, for which there were more switch trials, we reanalysed the data in a three-way within-subjects ANOVA, with array (80% vs. 20%), overlap (overlap vs. nonoverlap), and repetition (repeat vs. switch) as within-participant factors. While the repetition main effect (switch vs. repeat) was significant, $F(1, 14) = 12.74$, $MSE = 1115$, $\eta_p^2 = .47$, $p > .05$, repetition did not interact with any other factor—that is, responses were not affected by repeat versus switch trials, $F(1, 14) = 1.245$, $MSE = 8208$, $\eta_p^2 = .08$, $p > .1$. Similar to the results of Experiment 1, these results also indicate that contextualization effects were not driven by putative switch costs.

As in Experiment 1, it is important to demonstrate whether these effects were evident for the first target, for which response predictability would be lowest. Thus, we performed the same analyses as those above, but only for the target presented first. We found similar results and, in particular, significant effects for array, $F(1, 14) = 18.14$, $MSE = 16{,}375$, $\eta_p^2 = .56$, $p < .001$, and for overlap, $F(1, 14) = 51.17$, $MSE = 8504$, $\eta_p^2 = .78$, $p < .001$. Results were also similar for the last target for which predictability was highest: There was a significant effect for array, $F(1, 14) = 22.87$, $MSE = 4093$, $\eta_p^2 = .62$, $p < .001$, and for block, $F(9, 126) = 12.19$, $MSE = 10{,}829$, $\eta_p^2 = .46$, $p < .001$; the three-way interaction, $F(9, 126) = 2.03$, $MSE = 2453$, $\eta_p^2 = .12$, $p < .05$, was also significant, indicating faster RTs across blocks in the more frequent array for the overlapping target, $F(1, 14) = 6.28$, $MSE = 4048$, $\eta_p^2 = .30$, $p < .05$. These results indicate that contextual locking is not dependent on predictive ability.

In summary, the main result of this experiment is that RTs were significantly shorter for the more frequent array, and, moreover, this effect persevered even when the very same overlapping item was considered. Interestingly, in this experiment, the difference in responding to nonoverlapping items in the more and less frequent arrays was equivalent to that for the overlapping item, indicating that the same overlapping item in the less frequent context was treated just like any other item in the less frequent array. These results replicate and extend the results of Experiment 1, demonstrating that contextual locking can occur, even when the arrays (contexts) are more discriminable.

EXPERIMENT 3

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

Method

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

Results and discussion

Average error rates were 3.00% in both arrays ($p > .1$). The mean RTs for each block of responses were submitted to a three-way within-subjects ANOVA with array, block, and overlap (overlap vs. nonoverlap items) as the manipulated factors (see Figure 5). The array effect was significant, $F(1, 14) = 44.10$, $MSE = 3579$, $\eta_p^2 = .75$, $p < .001$, indicating that the more common array was responded to faster (438 vs. 471 ms). The block effect was significant, $F(9, 126) = 8.13$, $MSE = 4396$, $\eta_p^2 = .37$, $p < .001$, indicating overall attenuation of differences across blocks. The overlap effect was also significant, $F(1, 14) = 7.12$, $MSE = 5156$, $\eta_p^2 = .33$, $p < .05$, indicating that RT for overlapping stimuli (438 vs. 471 ms) was shorter than that for nonoverlapping stimuli (447 vs. 462 ms). No other effects (including interactions) were significant, ps $> .1$.

As in Experiment 2, the lack of an array with block interaction indicates that the contextual locking effect was practice resistant. The lack of an overlap with array interaction ($F < 1$) indicates that the advantage of responding to the more versus less frequent array that was observed for the nonoverlapping items, $F(1, 14) = 20.25$, $MSE = 3762$, $\eta_p^2 = .59$, $p < .001$, was analogous to the very same effect observed for overlapping items, $F(1, 14) = 22.14$, $MSE = 3688$, $\eta_p^2 = .61$, $p < .001$, Thus as in Experiment 2, the very same

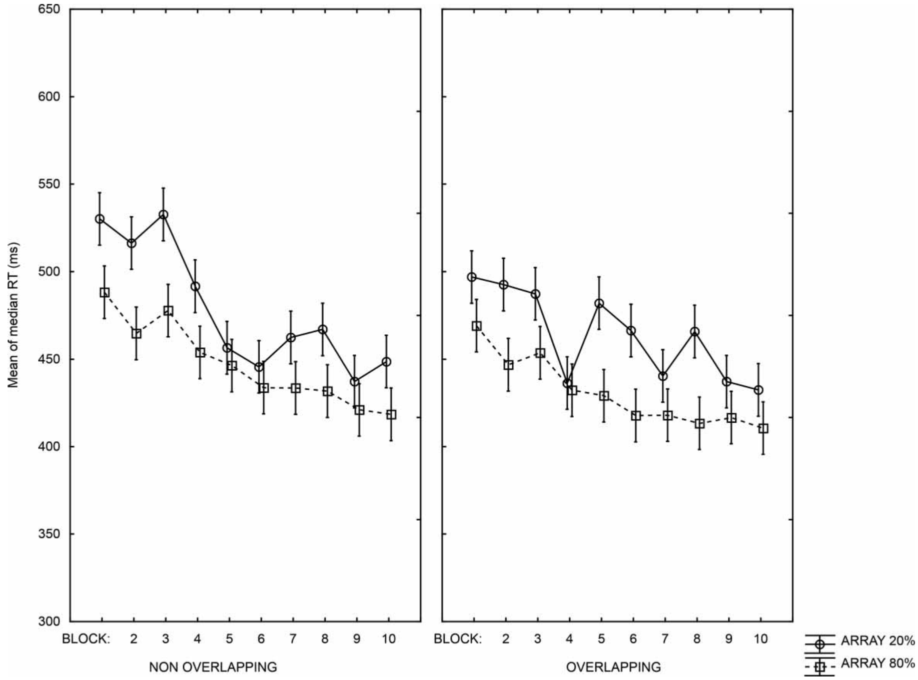

Figure 5. *Mean of the median response times (RTs) to overlap and nonoverlap items as a function of array and block in Experiment 3.*

overlapping item was treated as if it were a completely different item, when it appeared in a different context.

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 (five sub-blocks within the first block), and overlap as the manipulated factors. We found a significant effect for array, $F(1, 14) = 13.68$, $MSE = 12{,}265$, $\eta_p^2 = .49$, $p < .01$, indicating faster performance for the more than for the less frequent array, and for sub-block, $F(4, 56) = 16.10$, $MSE = 11{,}417$, $\eta_p^2 = .53$, $p < .001$, 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 array, for which there were more switch trials, we reanalysed the data in a three-way within-subjects ANOVA, with the factors array (80% vs. 20%), overlap (overlap vs. nonoverlap), and repetition (repeat vs. switch). While repeat trials were responded to faster than switch trials, $F(1, 14) = 9.27$, $MSE = 326$, $\eta_p^2 = .39$, $p < .05$, the repetition factor (repeat vs. switch) as previously observed did not interact with any other variable—that is, had no effect on performance, all Fs < 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, $F(1, 14) = 25.58$, $MSE = 11{,}076$, $\eta_p^2 = .64$, $p < .001$, was significant, as well as the main effect of block, $F(9, 126) = 2.51$, $MSE = 7906$, $\eta_p^2 = .15$, $p < .05$. The interaction of Array × Overlap was also significant, $F(1, 14) = 4.82$, $MSE = 6051$, $\eta_p^2 = .25$, $p < .05$. Data from the last target where predictive ability is highest were also similarly analysed. There was a significant effect for array, $F(1, 14) = 28.20$, $MSE = 4636$, $\eta_p^2 = .66$, $p < .001$, and for block, $F(9, 126) = 22.01$, $MSE = 6500$, $\eta_p^2 = .61$, $p < .001$. These results show that contextual locking is independent of predictive strength.

The present results replicate and extend the results of Experiments 1 and 2, where we also observed shorter RTs for the overlapping items in the more than for those in the less frequent array. These findings indicate that, even when context is neither salient nor extrinsic (red vs. blue rectangles), but rather just consists of neighbouring items, the common overlapping items appearing in the less frequent context are treated as if they were different, in contrast to when they appeared in the more frequent array. In the final experiment, we ask whether contextualization of an item, relative to the other items appearing in the same group, exists even when only one item overlaps between the two arrays.

EXPERIMENT 4

Fifteen university students (4 males; mean age 22.9 years, range 21–27 years), participated in this experiment, which was identical to Experiment 2, where there was only one overlapping item (at Location 4), with the exception that the coloured rectangles were removed. In this experiment, contextualization may be more elusive than in the previous experiments.

Results and discussion

Average error rates were 4.4% for the more frequent red array and 3.5% for the less frequent blue array ($p > .1$). The mean RTs for each block of responses were submitted to a three-way within-subjects ANOVA with array, block, and overlap (overlap vs. nonoverlap items) as the manipulated factors. The array effect was significant, $F(1, 14) = 40.46$, $MSE = 2596$, $\eta_p^2 = .76$, $p < .001$, indicating that the more frequent array was responded to faster (456 vs. 484 ms). The block effect was significant, $F(9, 126) = 8.76$, $MSE = 4571$, $\eta_p^2 = .38$, $p < .001$, indicating that RTs decreased with practice. The overlap effect was significant, $F(1, 14) = 29.83$, $MSE = 11{,}220$, $\eta_p^2 = .68$, $p < .001$, indicating that participants performed differently across conditions (442 vs. 494 ms). The Block × Overlap interaction was also significant, $F(9, 126) = 1.98$, $MSE = 1705$, $\eta_p^2 = .12$, $p < .05$, and this may indicate that the RT decrease across blocks for overlap items was weaker than that for nonoverlap items (Figure 6). No other effects were significant $ps > 0.1$. This pattern of results suggests that the difference between the more and less common array was the same for both overlap items, $F(1, 14) = 14.16$, $MSE = 2021$, $\eta_p^2 = .50$, $p < .01$, and nonoverlap items, $F(1, 14) = 31.85$, $MSE = 3247$, $\eta_p^2 = .69$, $p < .001$. Namely, the very same overlapping item was treated as a completely different item when it appeared in the less frequent array as opposed to when it appeared in the more frequent array.

As in Experiment 1, where block interacted with array, here we also further analysed the block with overlap interaction, to examine whether this effect depended on the first block. Accordingly, we conducted the above analysis only with the latter nine blocks, which showed that the block with overlap interaction was no longer significant, $F(8, 112) = 1.86$, $MSE = 1656$, $\eta_p^2 = .11$, $p > .07$. However, there was a significant triple interaction, $F(8, 112) = 2.04$, $MSE = 1302$, $\eta_p^2 = .12$, $p < .05$, indicating that participants' shorter RTs for the more frequent array across blocks was greater for overlap than for nonoverlap stimuli.

To complete the picture, the mean RTs of the responses for Block 1 were submitted to a three-way within-subjects ANOVA, with array, sub-block (five sub-blocks within the first block), and overlap as the manipulated factors. We found a significant effect for array, $F(1, 14) = 9.84$, $MSE = 15{,}259$, $\eta_p^2 = .41$, $p < .01$, indicating that participants responded faster to frequent than to nonfrequent arrays, and for sub-block, $F(4, 56) = 12.66$, $MSE = 10{,}364$, $\eta_p^2 = .47$, $p < .001$, indicating improvement across sub-blocks; no other effects were significant.

Figure 6 critically shows a clear difference in the mean RTs between arrays. As noted, these RT differences between the more and less frequent

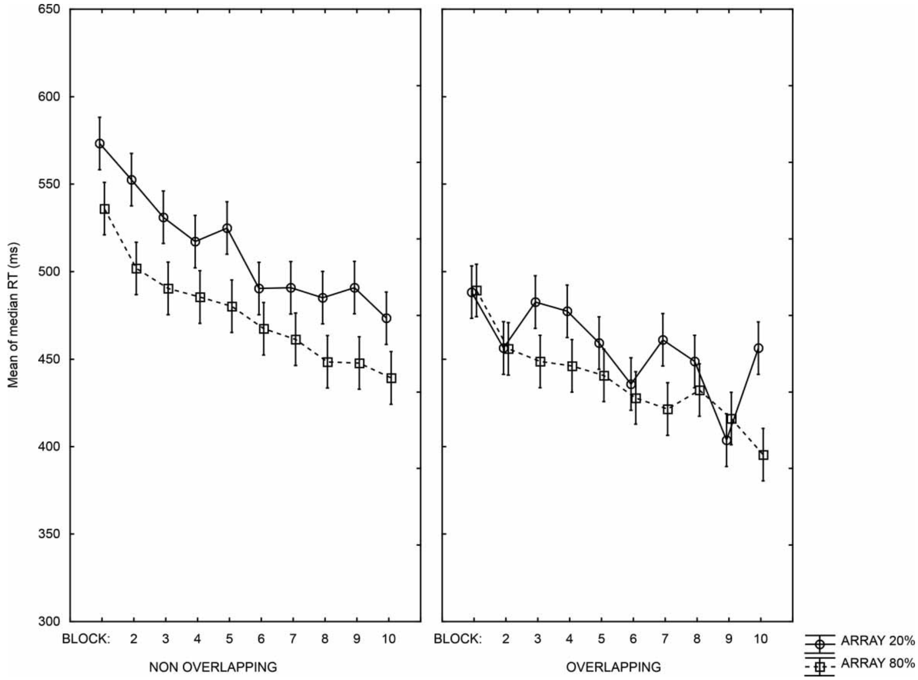

Figure 6. *Mean of the median response times (RTs) to overlap and nonoverlap items as a function of array and block in Experiment 4.*

arrays were the same for the overlapping and nonoverlapping stimuli. These results demonstrate that locking of items to context occurs even without a salient context, such as the rectangle and even when arrays were more distinguishable, because of a lower degree of overlap. These RT differences between the more and less common arrays were constant across blocks—that is, there was no effect of practice on these RT differences, $F < 1$. As shown previously, contextual locking was practice resistant in this experiment as well.

In order to verify that the effects reported in Experiment 4 were not due to the more frequent array containing more repeat trials, as opposed to the less frequent array, for which there were more switch trials, we reanalysed the data in a three-way within-subjects ANOVA, with the factors array (80% vs. 20%), overlap (overlap vs. nonoverlap), and repetition (repeat vs. switch). While the more frequent array was responded to faster, $F(1, 14) = 34.79$, $MSE = 1397.0$, $\eta_p^2 = .71$, $p < .01$, the repetition factor did not interact with any other variable—that is, results were the same for repeat and switch trials, $F(1, 14) = 1.34$, $MSE = 935.0$, $\eta_p^2 = .08$, $p > .1$. Thus, contextualization effects were not driven by putative switch costs.

As in Experiments 1, 2, and 3, it is important to demonstrate the key effect for the first target, for which predictability was lowest. Thus, we performed the same analysis as that presented above, but only for the target that was presented first. We found similar results—particularly, significant effects of array, $F(1, 14) = 26.54$, $MSE = 5645$, $\eta_p^2 = .65$, $p < .001$, block, $F(9, 126) = 3.35$, $MSE = 9940$, $\eta_p^2 = .19$, $p < .01$, and overlap, $F(1, 14) = 24.38$, $MSE = 36{,}663$, $\eta_p^2 = .63$, $p < .001$.

Similarly, for the last target we also found significant effects for array, $F(1, 14) = 28.28$, $MSE = 5801$, $\eta_p^2 = .66$, $p < .001$, block, $F(9, 126) = 24.01$, $MSE = 5776$, $\eta_p^2 = .63$, $p < .001$, and overlap, $F(1, 14) = 16.41$, $MSE = 9234$, $\eta_p^2 = .53$, $p < .01$. Both the Array × Overlap, $F(1, 14) = 25.42$, $MSE = 1917$, $\eta_p^2 = .64$, $p < .001$, and Block × Overlap, $F(9, 126) = 3.00$, $MSE = 2563$, $\eta_p^2 = .17$, $p < .01$, interactions were significant.

We also found shorter RTs in the more frequent array, for overlapping targets, $F(1, 14) = 4.78$, $MSE = 3548$, $\eta_p^2 = .25$, $p < .05$. These results further confirm that the observed effects were not a result of response predictability (which is common in sequence learning), but rather due to contextual locking.

The finding of contextual locking in Experiment 4 is especially revealing as both the absence of a salient context in the form of a coloured rectangle and the minimal degree of overlap between arrays might have led us to expect that the effect would be weaker. Now we turn to one final analysis conducted on data collapsed across all experiments, which addresses how context type (with rectangle vs. without rectangle) and similarity between arrays (one vs. two overlapping items) affected results. The mean RT for each block was submitted to a five-way mixed-model ANOVA, with array, block, and overlap as within-subjects factors and type (with/without rectangle) and similarity (one/two overlapping items) as between-subjects factors. The array effect was significant, $F(1, 56) = 101.16$, $MSE = 5229$, $\eta_p^2 = .54$, $p < .001$, indicating that responses were faster to the more common array. The block effect was significant, $F(9, 504) = 17.73$, $MSE = 4697$, $\eta_p^2 = .33$, $p < .001$, indicating a decrease in RT across blocks. The overlap effect was also significant, $F(1, 56) = 14.77$, $MSE = 5925$, $\eta_p^2 = .53$, $p < .001$, indicating larger RTs for the nonoverlapping items. Significant interactions were Overlap × Type, $F(1, 56) = 4.10$, $MSE = 5925$, $\eta_p^2 = .06$, $p < .05$, Overlap × Similarity, $F(1, 56) = 9.45$, $MSE = 5925$, $\eta_p^2 = .14$, $p < .01$, Array × Block, $F(9, 504) = 2.37$, $MSE = 1124$, $\eta_p^2 = .04$, $p < .05$, Array × Overlap, $F(1, 56) = 6.51$, $MSE = 2599$, $\eta_p^2 = .10$, $p < .05$, Block × Overlap, $F(9, 504) = 6.51$, $MSE = 1741$, $\eta_p^2 = .04$, $p < .01$, and the triple interaction (Figure 7) of Array × Block × Type, $F(9, 504) = 2.12$, $MSE = 1124$, $\eta_p^2 = .03$, $p < .05$. Critically, neither the Type × Array

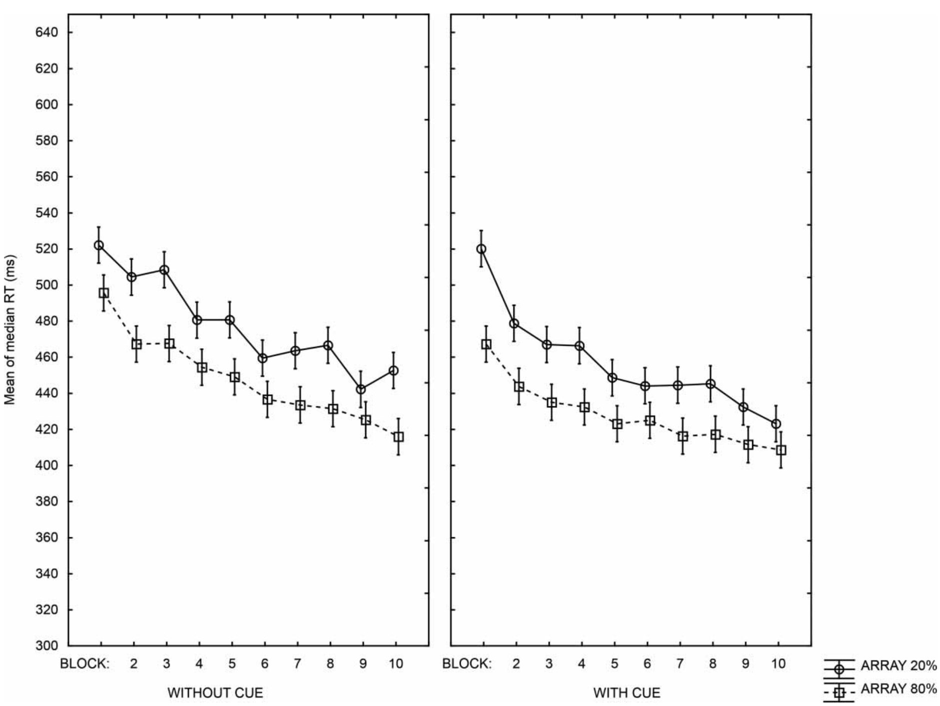

Figure 7. *Mean of the median response times (RTs) as a function of array, block, type, and similarity between arrays (one vs. two overlapping items) across all experiments.*

interaction ($F < 1$) nor the Similarity × Array interaction, $F(1, 56) = 2.50$, $MSE = 5229$, $\eta_p^2 = .04$, $p > .1$, were significant, indicating that contextual locking is independent of both context type and degree of similarity (i.e., the degree of overlap between arrays). Different types of context with different degrees of overlap induce the same form of unitization based on contextualized locking.

GENERAL DISCUSSION

The aim of this paper was to examine whether items in a motor response tasks can become unitized even when they do not appear in a fixed order. Such unitization of items can only occur via their binding to a common context, which we called contextual locking, a term operationally defined as the difference in response time between processing of the same item, in two different contexts. Accordingly, we hypothesized that responding to the same stimulus with the same response will be significantly faster in the more common context than in the less common context. As distinguishing between the same overlapping item in the more and less frequent arrays was possible only via contextual factors composed of the neighbouring list items (Experiments 3 and 4) and the colour of a rectangular external frame (in Experiments 1 and 2), these differences between arrays for the overlapping stimuli can only have been driven by the locking of the task goal with its context. The emerging pattern of results across four experiments, in which the same item was responded to faster when it appeared in a more common context than in the less common context, is consistent with this hypothesis. There was no benefit of binding items to a common context for participants, as neither the items themselves nor the context were informative of the responses that had to be given. This evidently differs from other studies on context effects, in which actions were associated to a specific context (e.g., Ruitenberg, Abrahamse, et al., 2012). These results were reliable across Experiments 1–4.[2] These results were not affected by putative switch costs—that is, by the more frequent array including more repeat trials, as opposed to the less frequent array, which included more switch trials.

Our results suggest that the individual items are not identified by their unique properties alone (e.g., arrow orientation), but also by their context. In effect, in each of the contexts, neither the spatial position nor the arrows' unique orientation were the main driving force underlying responses. Moreover, in three of the four experiments the difference between arrays was as great for the overlapping items as it was for the nonoverlapping items. Accordingly, it seems that contextual locking can occur to the extent that items lose an individual identity in favour of a more contextual-driven representation; that is, it is possible that an item is defined by its context. This contextual locking could only have arisen from the binding of items with their context. While such binding is more typically observed for related contexts that co-occur with items (e.g., butcher in the butcher shop), it has been observed for unrelated contexts too (e.g., Hayes et al., 2010; Hoffman & Tzelgov, 2012).

Evidence of contextual locking was obtained for both salient extrinsic contexts (Baddeley, 1982) and less salient contexts, involving just interitem relations (Sirotin et al., 2005). Furthermore, analogous results were obtained both when the interitem contexts across the two arrays were more similar (in which case contextualization may have played a role in facilitating item distinction) and when arrays were less similar (where distinguishing between these differentiated arrays was less necessary; Diana et al., 2007). As contextualization was evident across different levels of context salience and array distinguishability, the present results are in line with Hayes et al.'s (2010; Hayes et al., 2007) suggestion that the binding of items with their context may be obligatory. The present

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

results are also consistent with Perlman and Tzelgov's (2006) definition of automaticity. If indeed such binding is obligatory, it is no surprise that contextual locking is fairly ubiquitous and immediate—that is, evident from the first block.

It might be claimed that participants did not notice the overlapping items between the two contexts, especially in Experiments 3 and 4, where no coloured rectangle was presented. Accordingly, the difference between the overlapping stimuli in the frequent versus the nonfrequent array may simply reflect greater practice. Our results preclude this possibility. There were only four stimuli in each array presented over 1000 training trials, and thus it is likely that the overlap was noticed. Furthermore, across all four experiments, the overlap stimuli were responded to significantly differently than the nonoverlap stimuli, further indicating that participants noticed their overlapping. Finally, had participants somehow misperceived the overlapping stimuli, then their performance level would have been low (e.g., high error rates), but our results indicate otherwise. What is surprising is that exactly the same stimulus is responded to differently in the frequent array versus the infrequent one. Regardless of whether participants explicitly noticed the two contexts or not (or the fact that there were overlapping stimuli), there is clear evidence of contextual locking.

It might be claimed that the S–R mapping of overlapping and nonoverlapping stimuli may have been different. For overlapping stimuli there was a 1 S–R mapping (i.e., for a given stimulus there was only one response), as opposed to nonoverlapping stimuli, which had a 2 S–R mapping (two different stimuli, one in the frequent array and another in the infrequent one, had the same response). This claim is of arguable relevance as it necessitates between-array mapping, an unlikely assumption, both theoretically and given the obtained results, which demonstrate that mapping was conducted within array and not between array. However, even if the overlap and nonoverlap stimuli do not have the same S–R mapping, it would nevertheless be compatible with our conclusions as they stem from analyses comparing between responses to the overlapping stimuli in frequent and infrequent arrays (for which the same S–R mapping exists).

Demonstrating such contextual locking can bridge the general theory of chunking with a theory of binding items with contexts. Chunking, one of the most basic processes of the cognitive system (e.g., Boucher & Dienes, 2003; Rosenbaum et al., 1987; Rosenbaum, Kenny, & Derr, 1983; Goldstone, 2000; Knowlton & Squire, 1996; Miller, 1956; Simon & Barenfeld, 1969), relates to how elementary units can be bound together in aggregate chunks. In sequence learning (e.g., Cleeremans & McClelland, 1991), for example, the notion of chunking is central and refers to a situation where adjacent stimuli in a fixed sequence (e.g., A and B) may eventually be chunked (i.e., eventually the response to A may automatically generate the B response). Perlman et al. (2010) showed that, as chunking knowledge develops, participants respond in a manner suggesting that the smaller units of a chunked sequence disappear or decay as larger units of representation are developed (see also, e.g., Perruchet, Vinter, Pacteau & Gallego, 2002; Pothos & Wolff, 2006). In essence, while chunking is conceived as a hierarchical process by which items are bound to each other to form subunits, which eventually will be bound to form a unitized presentation composed of the entire set, the notion of contextual locking is a lateral form of unitization, whereby different items are unitized by being bound to a common context. Contextual locking of the kind observed here offers a form of unitization that does not necessitate a fixed order, such that items are not bound to each other, but rather to a common context. Accordingly, the aforementioned decay of individual elements (e.g., Perruchet et al., 2002) may stem possibly from items becoming locked to their specific context, so that the other items in the array cease to exist in a nonbound, contextless manner.

Following from this point, it is important to note that chunking and contextualization are not mutually exclusive. There are many scenarios where processing can be driven both by chunking and by contextualization. For example, if one is repeatedly shown a list of items in a fixed order, items may gradually be chunked to each other via the formation of specific subunits (chunking), yet items can also be simultaneously bound to the general list (gist) which is common to all items, irrespective of their order contextualization. Plausibly, context can extend beyond contextual stimuli in a given task, to include environmental contexts—for example, underwater versus on land (Godden & Baddeley, 1975)—or emotional context—for example, happy versus sad moods (Eich, 1984). The notion of contextual locking would predict that the very same daily activities, such as shaving, may be affected by the corresponding environment—for example, whether an activity is performed in the more common environmental context of the dorm bathroom or in the less common context of a public bathroom. Thus, it is possible that the very same behaviour may be performed differently in different contexts. According to the simple notion of motor chunking, performance of the same action will always be similar. As shaving has a fixed sequence, based on previous studies we would speculate that context effects would not affect shaving, as it is a highly practised sequence of actions (Ruitenberg, Abrahamse, et al., 2012) especially as the public bathroom is not an opposite context (Ruitenberg, De Kleine, et al., 2012). However, given the current results of contextual locking, it may very well be that incidental environmental contexts are bound to the shaving behaviour and unitize it—thus when, for example, one shaves outside the familiar environment the very same behaviour might be performed slower.

Another related idea concerns the transfer of learning. Transfer refers to learning acquired in one context benefiting performance in another setting. Usually the two settings are an original setting (e.g., as relevant to a training phase) and a new setting (e.g., as relevant to a test phase). While we do not apply a new setting, our results do relate to the notion of transfer, since the two arrays in the experimental tasks represent two different contexts. In terms of transfer, our research question concerns whether enhanced performance acquired in a frequent context can transfer to a less frequent context. In many cases, skill learning remains specific, such as in perceptual (e.g., Karni & Sagi, 1991) or motor tasks (e.g., Pashler & Baylis, 1991). In other instances, however, learning does transfer, such as in the cases of pilots benefiting from a simulation of a flight experience (Gopher, Well, & Bareket, 1994). Transfer of learning has been a central theme in both cognitive psychology and practical daily training courses. One factor that has been suggested to account for these disparate results is the extent to which the learning procedure is varied (e.g., Green & Bavelier, 2008). When the learning procedure is varied, transfer of learning from one situation to another is usually enhanced. This observation is compatible with the present results, as under varied learning conditions—that is, an item appearing in a different context every presentation—contextualization may not occur, in which case the behaviour will not be locked to its context.

Our main finding, showing that the very same item was responded to significantly faster in the more than in the less common context, when implicitly processing the item information, extends the known incidental context effects to implicit tasks. By implicit, we do not mean that participants were unaware of the two different arrays, but that they were learning something that they were not instructed to learn (Perlman & Tzelgov, 2006). Hitherto, context effects were typically shown to occur in explicit semantic tasks where items appearing in an original context are processed better than different items appearing in a new context (e.g., Godden & Baddeley, 1975; Light & Carter-Sobell, 1970; Smith, 1988; Smith & Vela, 2001; Tulving & Thomson, 1973). In implicit tasks, context effects were either not obtained (e.g., Jacoby, 1983; McKone & French, 2001; also see Mulligan, 2011) or limited (e.g., Ruitenberg, Abrahamse, et al., 2012; Ruitenberg, De Kleine, et al., 2012, see above). Applying incidental context to demonstrate contextual locking, we show that the effect of context on item processing is more pervasive than originally conceived; this effect also appears to be (fairly) ubiquitous, in the sense that it is not linked to a certain type of test (e.g., explicit) or the available information about context. The notion of contextual locking is highly ecological, since one can speculate that many daily activities involve the kind of implicit, perhaps even procedural, learning, which our task was meant to engage, such as shaving in the dorm versus in a public bathroom.

In summary, we showed that contextual locking is robust. It was observed for different degrees of array overlap (both for 50% overlap and for 25% overlap) and with and without an extrinsic context. The results demonstrate that the impact of context on learning extends beyond its typically assumed impact on explicit memory processes and can be strong to the extent that stimulus identity is altered across different contexts. The notion of contextual locking opens a new line of research, concerning the performance of the same act, in more versus less common contexts. It also relates to key theoretical questions in cognitive psychology, such as those relating to chunking and the transfer of learning to novel situations.

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APPENDIX

Analysis of performance

In all experiments the data were analysed by comparing performance on overlap versus nonoverlap 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—for Experiment 1: Location 1, $F(1, 14) = 10.62$, $MSE = 8865.59$, $\eta_p^2 = .43$, $p < .01$, Location 2, $F(1, 14) = 14.31$, $MSE = 5020$, $\eta_p^2 = .50$, $p < .01$, Location 3, $F(1, 14) = 23.73$, $MSE = 8488.2$, $\eta_p^2 = .62$, $p < .001$, and Location 4, $F(1, 14) = 9.06$, $MSE = 4857$, $\eta_p^2 = .39$, $p < .01$. For Experiment 2, aside from the nonoverlapping item at the first location, which was faster but not significantly so, $F(1, 14) = 1.68$, $MSE = 4737.70$, $\eta_p^2 = .10$, $p > .1$, response latencies were faster in the more than in the less common arrays: Location 2, $F(1, 14) = 20.50$, $MSE = 5483.20$, $\eta_p^2 = .59$, $p < .001$, Location 3, $F(1, 14) = 24.21$, $MSE = 3391.87$, $\eta_p^2 = .63$, $p < .001$, and for the critical overlapping stimulus at Location 4, $F(1, 14) = 5.07$, $MSE = 3793.59$, $\eta_p^2 = .26$, $p < .05$. For Experiment 3: Location 1, $F(1, 14) = 6.13$, $MSE = 6415.80$, $\eta_p^2 = .30$, $p < .05$, Location 2, overlap, $F(1, 14) = 12.74$, $MSE = 7705.90$, $\eta_p^2 = .47$, $p < .01$, Location 3, $F(1, 14) = 14.92$, $MSE = 8380.20$, $\eta_p^2 = .51$, $p < .01$, and Location 4, overlap, $F(1, 14) = 26.02$, $MSE = 3832.06$, $\eta_p^2 = .65$, $p < .001$. In Experiment 4: Location 1, $F(1, 14) = 10.60$, $MSE = 5694.79$, $\eta_p^2 = .43$, $p < .01$, Location 2, $F(1, 14) = 23.28$, $MSE = 5209.9$, $\eta_p^2 = .62$, $p < .001$, Location 3, $F(1, 14) = 14.37$, $MSE = 9557.4$, $\eta_p^2 = .50$, $p < .01$, and for the overlapping item at Location 4, $F(1, 14) = 14.16$, $MSE = 2021.67$, $\eta_p^2 = .50$, $p < .01$. Thus as shown, response times to items at all four locations, across all four experiments, were shorter in the more than in the less frequent array.