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ORIGINAL ARTICLE

# Asymmetrical effects of control on the expression of implicit sequence learning

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**Abstract**
As an automatic process, implicit learning effects have been characterized as inflexible and largely tied to the reinstatement of the acquisition context. However, implicit learning transfer has been observed under certain conditions, depending on the changes introduced between training and transfer. Here, we assess the hypothesis that transfer is specifically hindered by those changes that increase the control demands required by the orienting task with respect to those faced over training. Following on previous results by Jiménez et al. (J Exp Psychol Learn Memory Cognit 32(3):475–490, 2006), which showed that the learning acquired over a standard serial reaction time task was not transferred to conditions requiring a more demanding search task, we explored the impact of symmetrical training and transfer conditions, and showed that sequence learning survived such transfer. Four additional experiments designed to assess transfer to either lower or higher control demands confirmed that the expression of learning was selectively hindered by those transfer conditions requiring higher levels of control demands. The results illustrate how implicit sequence learning can be indirectly subjected to cognitive control.

## Introduction

Implicit learning is typically defined as the acquisition of knowledge that takes place independently of conscious attempts to learn and in such a way that the resulting knowledge is difficult to express (Berry & Dienes, 1993; Reber, 1993). As an automatic process, this form of learning has been characterized as inflexible (Dienes & Berry, 1997; Reber, Knowlton, & Squire, 1996) and largely tied to the overall reinstatement of the context in which it was acquired (Abrahamse & Verwey, 2008; Berry & Dienes, 1993, Cleeremans & Jiménez, 2002; Dienes & Berry, 1997; Reber et al., 1996; Song & Bédard, 2015). However, some studies have shown that implicit learning might be transferable under certain conditions (Abrahamse, Jiménez, Verwey, & Clegg, 2010).

## Transfer in implicit sequence learning

Transfer of implicit learning has been most frequently addressed using the sequence learning paradigm developed by Nissen and Bullemer (1987). In the typical paradigm, participants are instructed to respond as fast and accurately as possible to a stimulus that appears on each trial at one of four possible locations marked on a computer screen, using a spatially consistent response key. Unknown to the participants, the successive locations follow a sequence that is continuously repeated over each practice block, and participants become progressively sensitive to this pattern, as attested by the slower responses produced when that regularity is removed.

Transfer in sequence learning has been used as a tool to investigate the perceptual vs. motor nature of this learning. Indeed, the standard procedure generates two simultaneous motor and perceptual sequences, as the series of locations and responses are completely isomorphic. Thus, the transfer procedures have been used as a way to dissociate both components. Willingham (1999), for instance, showed that the expression of sequence learning could be transferred over changes in the stimulus features (e.g., from digits to locations, or between two different sequences of perceptual locations that were mapped to the same responses) as far as the same sequence of responses was maintained. Other studies

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revealed that sequence learning can be flexibility adapted to changes in the effectors as long as the series of response locations (i.e., response keys) was maintained between training and transfer phases (Cohen, Ivry, & Keele, 1990; Keele, Jennings, Jones, Caulton, & Cohen, 1995; Stadler, 1989; Willingham, Wells, Farrel, and Stemwedel, 2000). Thus, the series of response locations seems to play a key role in this form of learning, although effector-specific effects can also be obtained, at least after unusually long periods of training (Verwey & Clegg, 2005).

Despite such previous demonstrations of transfer in implicit sequence learning over several stimulus and response changes, there are other variations in the standard serial reaction time (SRT) procedure which appear to be less open to transfer, even after stimulus changes that do not compromise the sequence of response locations (Abrahamse, Van del Lubbe, & Verwey, 2008; Clegg, 2005; Willingham, Nissen, & Bullemer, 1989). For instance, Willingham et al. (1989) did not observe transfer in one of the earlier studies conducted with this paradigm, in which participants were initially trained to respond to a sequence of colors, and were later required to respond to an analogous series of spatial locations. Similarly, Abrahamse et al. (2008) showed that the expression of learning was reduced from training with four visual locations to transfer over tactile stimuli, and Abrahamse and Verwey (2008) also found a reduction of the effects after a simpler change, where the transfer conditions modified just the shapes of the placeholders which marked the potential locations of the stimuli. Therefore, and in contrast with some of the earlier reports of successful transfer, these results indicate that even minor context transformations could hinder the expression of sequence learning.

## Episodic accounts or changes in the task and control set

Abrahamse et al. (2010) attributed such complex pattern of results to the conjunction of two related facts: first, that the SRT task can produce a complex pattern of associations between successive stimulus features, response features, and response-to-stimulus compounds; and, second, that the specific set(s) of associations produced by each training procedure could depend on the "specific processing priorities stressed by a given task set" (Abrahamse et al., 2010, p. 617). Following this reasoning, one might argue that the key role attributed to the response locations in the previous transfer studies could be due to the fact that the task used in the standard paradigm precisely emphasizes the processing (and learning) of a sequence of response locations, whereas other variations of the paradigm could stress slightly different task demands, and, therefore, result in different patterns of learning and transfer.

The notion of "task set" put forward by Abrahamse et al. (2010) has some features in common with the episodic accounts of implicit learning (Neal & Hesketh, 1997), and with the principle of procedural reinstatement put forward by Healy and colleagues in the context of skill learning (Fendrich, Gesi, Healy & Bourne, 1995; Healy, Wohldmann & Bourne, 2005). However, whereas the latter proposals have been taken to predict that any context change between training and transfer could potentially interfere with the expression of learning, the "task set" approach stresses the interaction between those context changes and the processing demands made by the orienting task, thus predicting that only those procedural changes that significantly alter the task demands, for instance by requiring an additional processing step, or by altering the control requirements of the task, could actually interfere with the expression of implicit learning.

In accordance with these predictions, Jiménez, Vaquero and Lupiáñez (2006) observed that the learning acquired in a standard SRT task in which participants responded to the location of an even number that appeared at one of four possible locations did not transfer to a block in which the same sequence of targets required the same sequence of responses, but where the target appeared surrounded by task irrelevant odd numbers that filled the remaining locations, thus requiring participants to conduct a search task before responding to the target's location. As expected, introducing the search task produced long delays in performance, but, most importantly, it removed the expression of sequence learning, and it did so selectively for incidental learners. In contrast, the expression of sequence learning was maintained in a group of participants who were explicitly instructed to look for regularities.

The observation of different transfer effects depending on the intentional vs. incidental orientation to learning was explained by pointing to the flexible use that intentional learners could make of their explicit knowledge to simplify the search for the upcoming targets. In contrast, the absence of transfer in incidental learners was accounted for in terms of a strict episodic account, assuming that any change in the acquisition context interfered with the expression of implicit sequence learning. Alternatively, an account in terms of changes in the task set could also explain this absence of transfer as a consequence of the change in the selection demands imposed over the transfer phase.

One important question that remains to be tested from the task set account is whether any possible change in task demands would equally interfere with the expression of implicit sequence learning, or whether the interference over the expression of learning could depend on the direction of the change in task demands, either toward an increase or a decrease in the control demands. Even though the effects of implicit learning are usually considered as automatic, and, therefore, to run without control, there is growing evidence that automatic effects are also open to control (Moors & De Houwer, 2006), and that one of the main functions of cognitive control is precisely to make sure that the cognitive system is able to pursue goal-directed behavior in the face of more habitual or compelling (i.e., more automatic) behaviors (Cohen, 2017). In other words, if cognitive control has evolved to counteract the impact of automatic or otherwise overlearned behaviors, then it is reasonable to predict that the effects of implicit learning could be specially hindered by those transfer conditions that impose an increase in the control demands, rather than by comparable changes that reduce such task demands. Because the components of cognitive control include basically the selection, maintenance, and updating of the features that are relevant to pursue the task goal, and the inhibition of any other conflicting or competitive features (Cohen, Aston-Jones, & Gilzenrat, 2004), we surmise that the expression of implicit learning should be specially interfered by those transfer conditions that increase the selection demands, and by those that include conflicting irrelevant information, rather than by comparable task changes that produce a reduction in those demands. According to this reasoning, the first aim of the present study was to test whether a transfer change symmetrical to that arranged in Jiménez et al. (2006), in which participants are trained to respond to the location of an even number presented together with three odd distracters, and are then transferred to a more standard version of the SRT task, could produce an interference effect analogous to that found in the previous experiment. If implicit sequence learning was strictly tied to the reinstatement of the training context, one could predict this transfer to produce similar deleterious effects to those found in Jiménez et al. (2006) when the change occurred in the other way round. In contrast, if the interference found in the previous study was due to the direction of the change toward conditions that impose higher control requirements, we could predict better transfer to be obtained in the present conditions, where learning was acquired in more demanding settings, and it was later tested in conditions imposing lower control demands.

To further investigate this issue, we set out two additional series of experiments that introduced new variants on these symmetrical transfer designs, relying on different manipulations that affected those control demands without incurring in the long temporal delays caused by the inclusion of a search task. Thus, in Experiments 2a and 2b, we used the Simon effect (Simon, 1969) to increase control demands over either the transfer (Experiment 2a) or the training (Experiment 2b) phase. In Experiments 3a and 3b, we extended the exploration to conditions in which the crucial change did not involve any feature of the stimulus display, but exclusively a change in the response instructions, by inserting a proportion of No-Go trials. In all these cases, experiments a and b tested symmetrical conditions of training versus transfer, either training participants with low-control conditions and transferring them to higher control conditions (Experiments 2a and 3a), or the other way round (Experiments 2b and 3b). If the expression of implicit learning was strictly tied to the reinstatement of the training contexts, then transfer would be expected to produce symmetrical interference effects in all of these experiments. In contrast, if interference is driven specifically by those changes that resulted in increased control demands, then one could expect transfer to be observed selectively in those conditions in which the task change implies a decrease, rather than an increase, in the control demands (Experiments 1, 2b, and 3b). The pattern of interference obtained in Jiménez et al. (2006) would be conceptually replicated in Experiments 2a and 3a, where participants trained under simpler conditions were transferred to more demanding Simon or Go-NoGo tasks.

## Experiment 1

Experiment 1 assessed the effect of a manipulation symmetrical to that arranged by Jiménez et al. (2006). Thus, participants were trained with a search task, and were then transferred to a standard single-stimulus SRT task. The entire task entailed 14 blocks in which the location of a target followed the same probabilistic structure. Over the first 12 training blocks, the target was an even number that was presented amongst three distracters (odd numbers), which filled the non-target locations. Participants needed to search for the target, and to press on the key corresponding to its location. Over the transfer block 13, participants were presented with the same sequential structure, only without distracters. Therefore, the context change made the task easier, faster, and less control demanding than it was before transfer.

As in previous studies carried out in our lab (Jiménez et al., 2006, Jiménez & Vázquez, 2005; Vaquero, Jiménez & Lupiáñez, 2006), we used a variation of the probabilistic sequence learning paradigm introduced by Schvaneveldt and Gomez (1998). In this procedure, most of the trials followed a frequent sequence, but we also included a proportion of control trials generated from a different, infrequent sequence, to serve the double purpose of making the frequent sequence more difficult to discover explicitly, and to allow for a continuous assessment of sequence learning over the training blocks. At variance with the procedure developed by Schvaneveldt and Gomez, we used a complete sequence substitution rather than a trial by trial substitution procedure, so as to allow participants to be exposed to complete series that followed the same structure, as it usually occurs in comparable deterministic paradigms.

## Method

### Participants, apparatus, and materials

Twenty students from the University of Granada took part in the experiment in exchange for course credits. The experiment was run on INQUISIT 1.31 software (2002), and presented on a 14-inch computer screen. Participants responded on a keyboard by pressing one of four possible keys marked as response keys. Two analogous second-order conditional (SOC, Reed & Johnson, 1994) sequences were counterbalanced across participants as either training or infrequent sequences. The two SOC sequences used contained a series of 12 stimuli; if we label the target locations from left to right with letters A–D, the sequences were, SOCa: A–B–A–D–C–B–D–A–C–D–B–C; and SOCb: C–B–C–D–A–B–D–C–A–D–B–A. Each location appears with the same likelihood in any of the two sequences, and each first-order transition (with the exception of repetitions, which are forbidden) is also equally likely in each of them. In addition, both SOC sequences include a minimum of reversals (one per sequence, as in A–B–A), and they are maximally discriminative, since the successor of any series of two items is always different between SOCa and SOCb. In fact, both sequences are structurally identical to each other, being produced one from the other by a simple transformation A ↔ C.

### Procedure

One random even number (2, 4, 6, or 8) and three random odd numbers (1, 3, 5, 7 or 9) appeared on each trial at four possible locations distributed over the horizontal axis of a computer screen. Four horizontal lines underlined the four locations, separated by intervals of 3.5 cm. Participants had to search for the even number among the three odd numbers, and to respond to the location of that even number by pressing on a spatially compatible key. The response keys corresponded to the letters Z, X, N, and M on a Spanish keyboard. If a wrong key was pressed, an error tone was presented over 100 ms. Next trial followed 200 ms after any response.

After instructions, participants responded to a warm-up random series of 14 trials, which was followed by 14 structured blocks of 120 trials. Each block featured eight repetitions of the frequent sequence plus two repetitions of the infrequent sequence. SOCa and SOCb were used, respectively, as training or transfer sequences for half of the participants. Each block started with a token of the frequent sequence, with its starting point chosen randomly. From here on, the remaining nine series of 12 trials were pseudorandomly selected to include two control series interspersed with seven exemplars of the training series. Therefore, over an entire block, the series of 12 trials followed the frequent sequence in 80% of trials and the infrequent sequence in 20%. The series were linked in such a way that its starting point displayed the appropriate successor of the last two locations. This connection made it possible to maintain the SOC structure during all the trials of each block. Learning was assessed as the difference in RTs between responses to the frequent and infrequent sequences. A transfer block was included at block 13, in which participants were informed that the odd numbers had been removed from the non-target locations, but that they should keep responding to the location of the even number. After the transfer block, the previous conditions were restored, and participants were presented again with a search task over a final block.

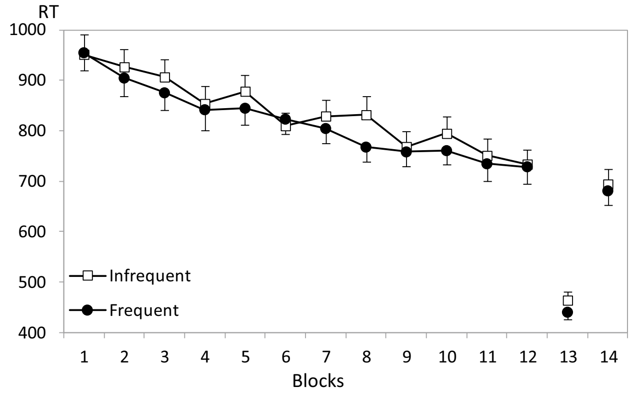

**Fig. 1** Mean reaction times (RT) across training and transfer blocks. Filled marks correspond to trials generated according to the frequent sequence and open marks to trials that follow the infrequent sequence. Block 13 was designed as a transfer block in which the selection task was replaced by the standard serial reaction time (SRT) task. Error bars correspond to standard errors

## Results

RT data were taken exclusively from hits, and the first two trials from each block were discarded, as they were not predictable. We restrict our report to the effects observed in RT, as accuracy data were convergent with them. Mean RTs over the entire experiment are plotted in Fig. 1, separately for training and infrequent sequences. An analysis of variance (ANOVA) conducted over the 12 practice blocks, with sequence (frequent vs. infrequent) and block (1–12) as within-participants variables, revealed that RTs improved across blocks, $F(11, 209) = 42.35$, $p < 0.001$, $\eta_p^2 = 0.69$, and that responding to the frequent sequence was faster than responding to the infrequent sequence, $F(1, 19) = 19.31$, $p < 0.001$, $\eta_p^2 = 0.50$. The block × sequence interaction failed to reach significance, $F(11, 209) = 1.56$, $p$(Greenhouse–Geisser corrected) $= 0.175$, $\eta_p^2 = 0.08$, thus suggesting that the effect of sequence learning was not steadily growing with practice. Of particular interest were the

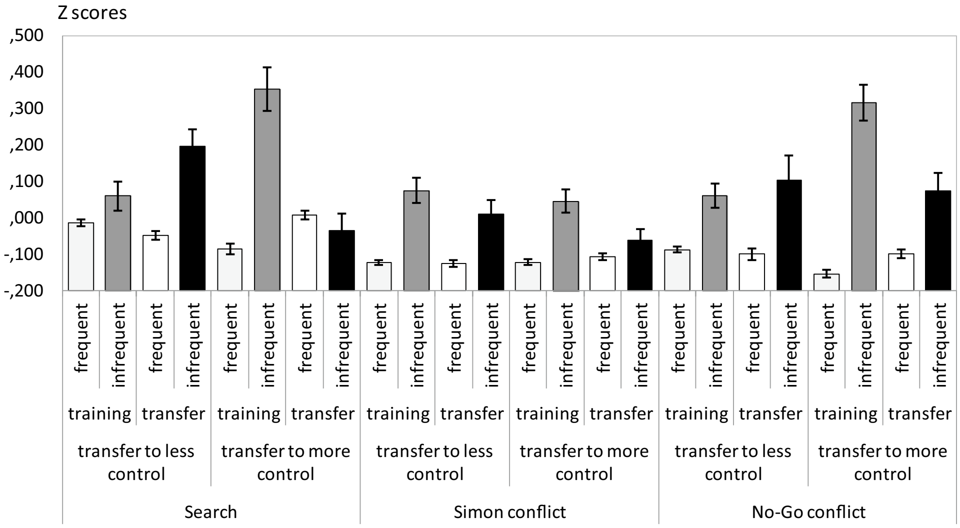

**Fig. 2** Mean standard (*z*) scores computed over the transfer block(s) separately for trials generated according to the frequent and infrequent sequences, compared to the scores obtained for the same trials over the neighboring training blocks. From left to right, the figure represents separately the results obtained in Experiment 1 (search task, transfer to less control) as compared to the analogous results obtained from Jiménez et al. (2006, Experiment 1, search task, transfer to more control), and those obtained in Experiments 2a and 2b (Simon conflict), and in Experiments 3a and 3b (No-Go conflict). Error bars correspond to standard errors

results obtained on the transfer block, which indicated that, despite the context change, the effect of sequence was still found over that transfer block.

To assess the effects of this context change, we averaged performance on the pre-transfer and post-transfer blocks and compared it with that observed on the transfer block. However, because higher control contexts also resulted in slower RT baselines, leaving more room for the expression of any learned improvement, but also increasing the variances, and thus making more difficult to obtain significant effects, we decided to adopt a common solution used in the literature that compares performance between samples with different baselines, normalizing the scores, and analyzing the differences in *z* scores computed in terms of the mean and standard deviation produced by each participant in each block[1] (Christ, White, Mandernach, & Keys, 2001; Janacsek, Fiser, & Nemeth, 2012). An ANOVA with Phase (training vs. transfer) and sequence as within-participants factors revealed significant effects of sequence, $F(1, 19)=17.30$, $p=0.001$, $\eta_p^2=0.48$, and phase, $F(1, 19)=5.00$, $p=0.038$, $\eta_p^2=0.21$, as well as a phase × sequence interaction, $F(1, 19)=5.17$, $p=0.035$, $\eta_p^2=0.21$. As shown in Fig. 2, these results indicated that the effect of sequence was clearer over the transfer block, $F(1, 19)=18.10$, $p<0.001$, $\eta_p^2=0.49$ than over its neighboring training blocks $F(1, 19)=2.19$, $p=0.155$, $\eta_p^2=0.10$ Thus, the transfer to a new context imposing lower control demands not only did not impair the expression of previously acquired learning, but rather it appeared to have strengthened its effects.

## Discussion

This experiment constitutes a natural follow-up of those reported by Jiménez et al. (2006). It shows that implicit sequence learning can be acquired in the context of a search task, although their effects appeared weaker than those found in conditions imposing a less demanding task. Importantly, this learning can be safely transferred to a simplified task that removes the need to search for the even target among a set of distracters. If anything, the effect of learning attested over this transfer block appeared to be larger and more robust than that found over its neighboring training blocks, despite the fact that the baseline RTs were significantly reduced over transfer. This finding, together with the absence of transfer reported in the symmetrical design by Jiménez et al. (2006), indicates that the expression of implicit sequence knowledge is not inflexibly dependent on a complete reinstatement of the acquisition context, but it rather depends on whether the conditions of transfer imposed either an increase or a decrease in the control demands. To make the results comparable to those found by Jiménez et al. under the symmetrical

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[1] Notice that, in the referenced studies, the normalization procedure was conducted to control for between-participants differences in RT baselines, and thus, they normalized the scores on the basis of the individual means and standard deviations computed over the whole task. In the present conditions, because the source of different baselines was the task used in some blocks, the normalization was conducted in terms of the individual mean and standard deviation computed for each block.

conditions of training and transfer, we also normalized the previous results and represented them together with those obtained in the present experiment (see Fig. 2). A similar analysis conducted on these results also confirmed the significant effects of sequence $F(1, 15) = 18.93$, $p = 0.001$, $\eta_p^2 = 0.56$, and phase, $F(1, 15) = 25.06$, $p > 0.001$, $\eta_p^2 = 0.63$, and the sequence × phase interaction, $F(1, 15) = 25.14$, $p < 0.001$, $\eta_p^2 = 0.63$, but, now, this interaction revealed the opposite pattern, where the effect was clearly significant over the neighboring training blocks $F(1, 15) = 35.56$, $p < 0.001$, $\eta_p^2 = 0.70$, but it was not so over the transfer block, $F(1, 15) = 0.58$, $p = 0.458$, $\eta_p^2 = 0.04$.

The results of this experiment are consistent with a few other results, such as those reported by Ruitenberg, De Kleine, Van der Lubbe, Verwey, and Abrahamse (2012) in the related discrete sequence production (DSP) task. In this task, which involves conditions similar to the SRT task, but slightly more conductive to explicit knowledge, the authors showed that learning of the relevant sequences occurred even in conditions in which a predictable distracter was included together with the sequence of targets. More importantly for the present purposes, they found that a change in the sequence of distracters introduced over the transfer test interfered with the expression of learning of the sequence of targets, whereas simply removing those distracters did not hinder the expression of that learning. Thus, it appears that not every context change, and not every adjustment of the task set would equally interfere with the expression of sequence learning (cf. Abrahamse et al. 2010; Logan et al. 1996), but rather that these effects would be selectively hindered by those changes that induce more demanding conditions, and not by those that lead to conditions requiring less control.

Alternatively, one may argue that a simpler account could attribute this pattern of presence vs. absence of transfer to the temporal differences established between training and transfer in each case. For instance, in Jiménez et al. (2006), the training-to-transfer change produced a large increase in RT that would amount to more than a 100% of the previous baseline. In the present experiment, in contrast, training with the search task produced a steady improvement of responses over training, and the training-to-transfer change resulted in a further improvement that could be estimated as a 50% of the baseline RTs achieved by the end of training. Even though assessing the effects in terms of normalized scores should have removed any difference in the effect attributable to the metrics of the raw scores, if the effect of implicit sequence learning results from a fast-decaying pre-activation of predictable successors, which arises in phase with the trained intervals, one could explain why participants have more troubles to extend these pre-activations over the longer intervals imposed by a search task, than over the shorter intervals produced when participants are transferred from a slower to a faster task. Thus, to better distinguish between this temporal account and an explanation in terms of changes in the control demands, we set out to compare conditions that differ in their control demands, but that would not incur in such long increases in RT. In Experiments 2a and 2b, we introduced a Simon task to manipulate the control demands while minimizing its impact on the overall RT.

## Experiments 2a and 2b

In Simon tasks, participants are instructed to respond to a non-spatial feature of the stimuli using a series of spatially distributed responses (e.g., a row of keys), and the stimuli are presented at different locations, thus inducing a spatial stimulus–response location interference. Such interference needs to be controlled, also leading to an increase in RT, but typically only between 20 and 30% of the baseline performance (Simon, 1969; Simon & Wolf, 1963). In Experiments 2a and 2b, we relied on this manipulation to explore the effects of symmetrical changes in the task set on the expression of sequence learning. Thus, in Experiment 2a, participants first learned to respond to a probabilistic sequence of symbols that appeared at the center of the screen, using a series of four keys assigned arbitrarily to each stimulus, and which were spatially distributed over the bottom row of the computer keyboard. After training with this task, participants were transferred to a phase in which exactly the same task was performed in response to the same symbolic stimuli, but they were now randomly presented at one of four possible locations distributed over the horizontal axis of the screen, thus producing a Simon interference which would recruit control to avoid it.

In Experiment 2b, training and transfer conditions were reversed, and therefore, participants were trained to respond to the symbols presented in potentially conflicting locations, and were then transferred to a simpler condition in which the symbols were consistently presented at the center of the screen. We surmise that the temporal impact of this manipulation would be considerably smaller than that produced in Experiment 1. Still, if the expression of learning is modulated by the amount of control demands induced by each context change, one may expect that learning could survive transfer better when it induces a reduction in the control demands (i.e., in Experiment 2b), than when the change induces an increase in such control demands (i.e., in Experiment 2a).

### Method

#### Participants

As we found in Experiment 1 that implicit learning is weaker and more difficult to acquire in control demanding conditions, we increased the number of participants in these experiments. Thus, 72 students from the University of Granada were recruited to take part in these experiments; in exchange for course credits; 43 participants carried out the Experiment 2a and 29 the Experiment 2b. As we expected learning to decrease or disappear in the transfer block of Experiment 2a, a larger N was used in this experiment to have enough statistical power to detect this reduced learning in case there was any. Participants had never participated in similar experiments before.

### Apparatus and materials

The sequence of stimuli was generated by a personal computer and presented on a 14-inch screen. The program that controlled the experiment was written using E-prime software (Schneider, Eschmann, & Zuccolotto, 2002). Participants responded to the identity of four stimuli (!, ?, @ or #) using four arbitrary keys located at the bottom row from the Spanish keyboard. The keys corresponding to the letters Z, X, N, and M were assigned arbitrarily to each of these four symbols.

### Procedure

On each trial, one symbol appeared on the computer screen and participants were instructed to respond using the key assigned to that symbol. If a wrong key was pressed, participants were presented with an error tone over 100 ms. Next trial followed 200 ms after any response, regardless of whether it was correct or wrong. As in Experiment 1, participants were presented with an initial series of 14 trials in which the series of symbols were random, and then they responded to 14 blocks of 120 trials. All details about the structure and blending of frequent (training) and infrequent sequences were the same as in Experiment 1, but instead of series of four stimulus locations, now the series corresponded to four symbols (which were responded by pressing the same series of response keys).

The transfer block was included over the block 13. In Experiment 2a, the transfer display included four short lines (1 cm in length) which were evenly distributed over the horizontal axis of the screen. The distance between the middle points of each pair of adjacent lines, which acted as placeholders, was 4.5 cm. On each trial, the relevant symbol appeared randomly over one of these four locations, and participants were informed that they should keep responding to the identity of the symbol regardless of its specific location. Therefore, over this transfer block, the task was more demanding, but both the sequence of symbols and the required series of motor responses remained unchanged. After the transfer block, participants were informed that the conditions presented over the previous blocks would be restored, and therefore, they were again presented with the symbols located at the center of the screen.

Experiment 2b explored the effect of a symmetrical change, and thus trained participants to respond to the identity of a series of symbols which appeared randomly in one of four possible locations distributed over the horizontal axis of the screen, and over the block 13, it transferred participants to a condition in which the same series of symbols were all presented at the center of the screen.

## Results

There was no indication of a trade-off effect between speed and accuracy throughout the set of experiments. Therefore, we focused on the analyses of RT. To carry out these analyses, we removed the first two trials from each block, error responses (5%) and outliers (2%), defined as those trials departing more than 3 standard deviations from the specific mean from each participant and block.

### Experiment 2a: training at center, transfer to spatial uncertainty

As shown in Fig. 3 (upper panel), RTs was progressively reduced across blocks, but it increased over the transfer block, when spatial uncertainty was introduced. Importantly, the frequent sequence tended to be responded faster than the infrequent sequence, showing the evidence of sequence learning. Of particular interest is the result that arises on block 13, showing that, over transfer, RTs for the frequent sequence were no longer faster than those computed for the infrequent sequence. This suggests that the expression of sequence learning did not resist transfer over this context change.

An ANOVA conducted over the 12 practice blocks with sequence (frequent vs. infrequent) and block (1–12) as within-participants variables revealed significant main effects of block, $F(11, 462)=4.55$, $p<0.001$, $\eta_p^2=0.098$ and sequence, $F(1, 42)=49.04$, $p<0.001$, $\eta_p^2=0.54$, as well as a non significant trend in the block × sequence interaction, $F(11, 462)=1.696$, $p$(Greenhouse–Geisser corrected) $=0.101$, $\eta_p^2=0.04$. To determine more specifically the effects of the context, we conducted an analysis similar to that conducted on Experiment 1, normalizing the scores in terms of the mean and standard deviation of each participant on each block, and then submitting these $z$ scores to an ANOVA with phase (transfer vs. the neighboring training blocks) and sequence (frequent vs. infrequent) as within-participants factors. The analysis showed main effects of phase, $F(1, 42)=13.06$, $p=0.001$, $\eta_p^2=0.24$, and sequence, $F(1, 42)=9.86$, $p=0.003$, $\eta_p^2=0.19$, and a phase × sequence interaction, $F(1, 42)=6.94$, $p=0.012$, $\eta_p^2=0.14$. As shown in Fig. 2, this interaction showed that

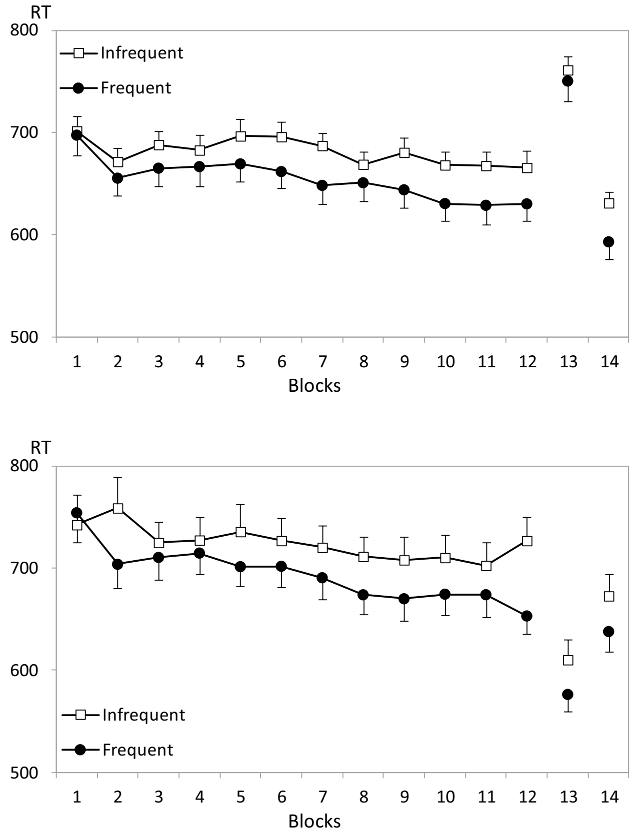

**Fig. 3** Mean reaction times (RT) across training and transfer blocks. Filled marks correspond to trials generated according to the frequent sequence and open marks to trials that follow the infrequent sequence. Block 13 was designed as a transfer block. In the training center condition (upper panel), participants were trained to respond to the identity of symbols which appeared in the center of the screen, and over the block 13 they were transferred to a condition where the same symbols appeared randomly in one of four possible locations distributed over the horizontal axis. In the spatial uncertainty condition (bottom panel) training and transfer conditions were reversed. Error bars correspond to standard errors

the effect of sequence was far from significant over the transfer block, $F(1, 42) = 1.55$, $p = 0.220$, $\eta_p^2 = 0.04$, but it was clearly observed over its neighboring training blocks $F(1, 42) = 19.02$, $p < 0.001$, $\eta_p^2 = 0.31$.

### Experiment 2b: training with spatial uncertainty, transfer to center

Figure 3 (bottom panel) shows that the overall RTs were reduced across blocks, but they decreased more dramatically when the spatial uncertainty was removed at the transfer block 13. Importantly, frequent trials were responded to faster than infrequent trials, indicating sequence learning. This difference appears to survive transfer over the block 13. An analysis of variance (ANOVA) conducted over the 12 practice blocks with sequence (frequent vs infrequent) and block (1–12) as within-participants variables revealed significant main effects of block, $F(11, 308) = 4.14$, $p < 0.001$, $\eta_p^2 = 0.13$ and sequence, $F(1, 28) = 6.23$, $p = 0.019$, $\eta_p^2 = 0.18$. The block × sequence interaction was also significant, $F(11, 308) = 3.17$, $p$(Greenhouse–Geisser corrected) $= 0.004$, $\eta_p^2 = 0.10$, thus, suggesting that the effect of block grew larger for the frequent than for the infrequent trials.

As in the previous experiments, the effects of the context were analyzed by normalizing the scores for each participant and block, and averaging the pre-transfer and post-transfer blocks (blocks 12 and 14) to compare it with the $z$ score found over the transfer block 13. An ANOVA with phase (transfer vs. training) and sequence (frequent vs. infrequent) as within-participants factors showed a main effect of sequence, $F(1, 28) = 24.23$, $p < 0.001$, $\eta_p^2 = 0.46$, but not a significant effect of phase, $F(1, 28) = 2.98$, $p = 0.095$, $\eta_p^2 = 0.10$. The phase × sequence interaction was not significant either, $F(1, 28) = 1.71$, $p = 0.202$, $\eta_p^2 = 0.06$, showing that the effect of sequence learning was significant at both training, $F(1, 28) = 24.32$, $p < 0.001$, $\eta_p^2 = 0.47$, and transfer blocks, $F(1, 28) = 10.323$, $p = 0.003$, $\eta_p^2 = 0.27$ (see Fig. 2).

## Discussion

The pattern of results found in Experiments 2a and 2b indicates that an asymmetric pattern of transfer analogous to that found between the results of Jiménez et al. (2006) and those reported in Experiment 1 can also be obtained when the manipulation of control does not result in the long delays of responding provoked by the inclusion of the search task, thus ruling out a temporal account of these results. Indeed, Experiment 2a showed that an analogous pattern of interference at transfer arises using the Simon effect as the manipulation to increase the control demands over the transfer phase, even though, in this case, the induction of control resulted only in moderate increases in RTs, roughly about 75 ms. In contrast, Experiment 2b showed both that implicit sequence learning can be acquired under conditions of Simon interference, and that transfer from this task to a less demanding task can also obtained by removing this source of interference. Thus, the results observed in these experiments are entirely consistent with the claim that implicit sequence learning can be transferred between similar contexts, but that the expression of that learning is selectively hindered by those manipulations that impose an increase in the control demands with respect to those trained over the practiced task.

Even though the pattern of results reported so far clearly reinforces the claim that the expression of implicit sequence learning over a transfer phase depends on the direction of the change in the control demands, all the previous manipulations have induced those changes by adding some new perceptual features to the display, either using distracters that filled the non-target locations, or using the location of the stimuli as an irrelevant, and interfering feature. In a final series of experiments, we aimed at replicating the same pattern using a new manipulation of the control demands that depends exclusively on task instructions rather than being supported by any change in the perceptual context.

## Experiments 3a and 3b

Experiments 3a and 3b were designed to conceptually replicate the symmetrical transfer manipulations (to higher vs. lower control demands) without introducing any change in the visual displays. Thus, instead of changing the stimuli, as we did in the previous experiments, we changed the task instructions to introduce NoGo trials on a proportion of trials. Go-NoGo tasks have been extensively used as a simple procedure to induce controlled processing (Garavan, Ross, Murphy, Roche, & Stein, 2002; Menon, Adleman, White, Glover, & Reiss, 2001) without requiring any perceptual change, and without incurring in long delays in responding. Thus, it appears as an optimal manipulation to address the present goals. Importantly, however, removing the response on a proportion of trials changes the response sequence, that is supposed to be an important part of what participants are learning in these conditions (Abrahamse et al., 2010). To alleviate this problem, and considering that the sequences employed in this study have a second-order structure, in which the two previous responses are informative to predict the following one, the analysis of learning over the no-go blocks considered exclusively go responses which occurred after two or more consecutive go trials.

In these two experiments, we went back to the basic procedure used in Experiment 1 and in Jiménez et al. (2006). Thus, participants were instructed to respond to the location of an even number that could appear at one of four possible locations on a computer screen, using four keys spatially corresponding to the stimulus location. In the standard task, participants responded to all trials. In the Go-NoGo version of the task, participants were instructed to respond to all trials excepting those featuring a specific number (e.g., number 2). In this way, participants were forced to adopt a more controlled stance toward the task, without including any perceptual change in the sequence of stimuli.

In Experiment 3a, participants were trained with the standard SRT task over 11 blocks of training, and were then transferred for two blocks to the Go-NoGo task, before returning again to the original conditions for a final block. We included two transfer blocks rather than only one as a way to compare transfer and their neighboring training blocks over a similar amount of trials, and to be able to explore the effects of transfer over a longer period. Experiment 3b was designed analogously, but we trained participants with the Go-NoGo task, and presented the standard SRT task over the transfer blocks. According to the hypothesis that sustains an asymmetrical influence of the changes in the control demands on the expression of implicit learning, we expected that participants trained on the standard SRT task (i.e. Experiment 3a) would not express their learning when they were transferred to a Go-NoGo task. In contrast, participants trained with the Go-NoGo task would be expected to be able to acquire learning, and to express that learning over the transfer phase, when they were tested with the standard SRT task.

### Method

#### Participants

Forty-two students from the University of Granada took part in these series of experiments, in exchange for course credits. Twenty participants were assigned to Experiment 3a, and twenty-two participants were assigned to Experiment 3b.

#### Procedure

Participants trained with the standard SRT task (Experiment 3a) were asked to respond to the location of an even number (2, 4, 6, or 8) that appeared alone in one of four locations, over a series of 11 training blocks. Participants trained with the Go-NoGo task (Experiment 2b) were instructed to do the same task over the training phase, with the important exception that they were told to withhold responding to those trials featuring number 2. No-Go trials appeared randomly at about 25% of the trials, and they remained on the screen for 600 ms, unless a response was issued. In that case, an error tone was presented for 100 ms, and the next event was presented after the usual response-to-stimulus interval of 200 ms. In both experiments, participants were transferred to the complementary task over blocks 12 and 13, and then, they returned to their original training task for block 14.

### Results

#### Experiment 3a: transfer from the standard SRT task to a Go-NoGo SRT task

Error responses amounted to 2% and outliers were less than 2%. Go-NoGo instructions at the transfer phase produced false alarms on an average of 7% of the NoGo trials. NoGo trials were not further analyzed, and two trials coming right after an NoGo trial were also discarded from the analyses, to make sure that the second-order informative response sequence was maintained over the training trials even in NoGo blocks.

RTs for all remaining trials are shown separately for each block and type of sequence, in the upper panel of Fig. 4.

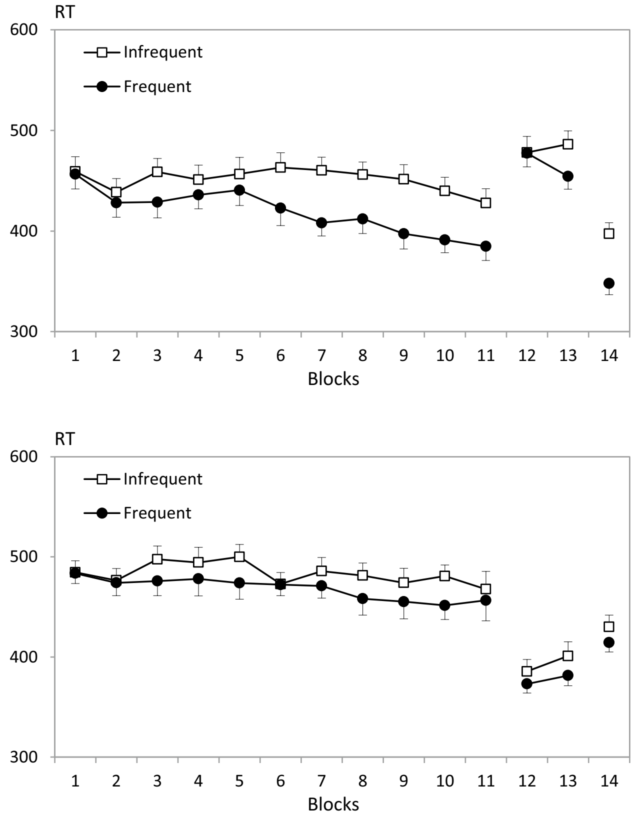

**Fig. 4** Mean reaction times (RT) across training and transfer blocks. Filled marks correspond to trials generated according to the frequent sequence and open marks to trials that follow the infrequent sequence. Blocks 12 and 13 were designed as transfer blocks. In the standard training conditions (upper panel), participants trained with the standard SRT task were transferred to the Go-NoGo task. In the Go-NoGo training condition (bottom panel), participants trained with the Go-NoGo task were transferred to the standard serial reaction time (SRT) task. Error bars correspond to standard errors

Over the first 11 training blocks, it can be observed that RTs are faster for training than for control trials. A mixed ANOVA with sequence (frequent vs. infrequent) and block (1–11) as within-participants variables showed significant main effects of block, $F(10, 190) = 6.48$, $p < 0.001$, $\eta_p^2 = 0.25$, and sequence, $F(1, 19) = 68.01$, $p < 0.001$, $\eta_p^2 = 0.78$, as well as a significant interaction block × sequence, $F(10, 190) = 6.68$, $p < 0.001$, $\eta_p^2 = 0.26$, indicating that the effect of sequence learning increased over training.

As for the analysis of transfer, we computed the *z* scores for all valid trials from each participant and block, averaged separately over the neighboring training (11 and 14) and transfer (12–13) blocks, and for frequent and infrequent trials. A mixed ANOVA with sequence (frequent vs. infrequent) and phase (training vs. transfer) as within-participants variables showed a significant main effect of sequence $F(1, 19) = 51.87$, $p < 0.001$, $\eta_p^2 = 0.73$, but not a significant effect of phase, $F(1, 19) = 3.87.57$, $p = 0.064$, $\eta_p^2 = 0.17$. The phase × sequence interaction was significant, $F(1, 19) = 10.46$, $p = 0.004$, $\eta_p^2 = 0.36$, reflecting that the expression of sequence learning was larger over the training blocks than over the transfer blocks, thus, confirming that the expression of sequence learning was hindered by transfer from the standard training to a Go-NoGo task.

A detailed inspection of Fig. 4 (upper panel) suggests, however, that the interference found over the transfer phase could be due to an initial blocking of the expression of learning, which was later recovered over the second transfer block. A specific analysis conducted on the *z* scores obtained separately from these two blocks of transfer, with block and sequence as within-participants variables confirmed this impression, as attested by a significant block × sequence interaction, $F(1, 19) = 7.55$, $p = 0.013$, $\eta_p^2 = 0.28$. Thus, the effect of sequence was lost over the first transfer block, $F(1, 19) = 0.01$, $p = 0.98$, $\eta_p^2 = 0.00$, but recovered to a great extent over the second of these blocks, $F(1, 19) = 16.28$, $p = 0.001$, $\eta_p^2 = 0.46$. Although these results should be taken with caution, it appeared that the transfer to high-control demands could exert an initial interference effect that would become diluted after a longer period of practice with this task.

### Experiment 3b: transfer from a Go-NoGo SRT task to regular standard SRT task

Error responses were 3% and outliers less than 2%. Go-NoGo instructions during the training blocks produced false alarms on an average of 10% of the NoGo trials. As in the previous experiment, only those Go trials that occurred after two or more consecutive Go trials were included in the analyses.

The ANOVA performed over the first 11 training blocks revealed a significant effect of sequence, $F(1, 21) = 26.92$, $p < 0.001$, $\eta_p^2 = 0.56$, whereas the main effect of block, $F(1, 21) = 2.03$, $p$(Greenhouse–Geisser corrected) = 0.096, $\eta_p^2 = 0.08$ and the interaction block × sequence $F(1, 21) = 2.09$, $p$(Greenhouse–Geisser corrected) = 0.058, $\eta_p^2 = 0.09$ just missed significance. Importantly, as shown in Fig. 4 (bottom panel), sequence learning was completely absent over the first two training blocks, and then, it became evident in most of the remaining blocks, showing that the differences between responding to frequent and infrequent sequences arose as the result of practice with the training one.

The analysis conducted to compare the effect of sequence over the transfer blocks (12 and 13) and the two neighboring training blocks (11 and 14) was conducted on the average *z* scores, and it showed a main effect of sequence $F(1, 21) = 14.41$, $p = 0.001$, $\eta_p^2 = 0.41$, but not an effect of phase, $F(1, 21) = 0.02$, $p = 0.905$, $\eta_p^2 = 0.00$, nor a sequence × phase interaction $F(1, 21) = 0.12$, $p = 0.730$, $\eta_p^2 = 0.01$. Separated ANOVAs confirmed that the effect of sequence was observed both over the training blocks with the Go-NoGo task, $F(1, 21) = 26.10$, $p < 0.001$, $\eta_p^2 = 0.55$, and over the transfer blocks with the standard SRT task, $F(1, 21) = 5.80$, $p = 0.025$ $\eta_p^2 = 0.22$.

### Discussion

As expected, the results of Experiments 3a and 3b confirmed that the expression of sequence learning over a transfer task depends on whether the transfer condition implies either an increase or a decrease in the control demands, with respect to those faced over the practice phase. The results also show that the interference caused by transferring participants to a more demanding task does not require including a more complex stimulus display, or a task that induces long temporal delays. In the case of the Go-NoGo task, higher control demands were induced without changing the stimulus context, and producing relatively short delays of about 50 ms, or roughly a 10% of the baseline responding to the standard SRT task. Obviously, making the Go-NoGo task depending on the identification of certain numbers includes an additional demand, but there is evidence showing that, when the sequence is complex and probabilistic, as in the present case, implicit learning is barely affected by the addition of secondary tasks involving the identification (and even keeping a running count) of certain target symbols (Jiménez & Méndez, 1999, 2001).

Plainly then, it appears that the Go-NoGo task disrupts participants' reliance on the processing mode developed over training with the standard SRT task, arguably by inducing a more controlled response strategy that interferes with the expression of implicit learning. This interference appears to be more clearly observed over the first transfer block, and tends to be alleviated over the second block. This trend toward a recovery of the expression of learning with continued practice with the Go-NoGo task could indicate that the source of interference is not the task itself (i.e., the inhibition of responding over a number of trials), but rather the need to adapt the expression of learning to the increased demands made by the Go-NoGo task, which require participants to postpone their responses until they have confirmed the identity of the even number. Over practice with the Go-NoGo task, participants seem to learn to integrate this new component into the task stream, and, therefore, to recover the expression of sequence learning. This argument is consistent with the fact that the group that was trained from the beginning with the Go-NoGo task (Experiment 3b) was also able to express learning over their practice phase, even though, in this case, the effects were generally smaller and less consistent than those observed in Experiment 3a. Importantly, however, transferring these participants to a less demanding task did not produce a similar impairment in the expression of sequence learning as that caused by the symmetrical transfer.

## General discussion

The previous evidence of transfer in implicit sequence learning has been mixed so far, with some studies showing complete transfer depending exclusively on the maintenance of the series of response locations (Willingham, 1999; Willingham et al. 2000), whereas others suggest that even minor perceptual or task changes could potentially interfere with the expression of learning (Abrahamse et al., 2008; Jiménez et al., 2006; Willingham et al., 1989). Several factors could be partially responsible for these apparently contradictory results, including differences in the specific tasks arranged for training and transfer, the type of sequence trained, the amount of practice provided with those sequences, or the implicit vs. explicit nature of the resulting knowledge.

In an attempt to improve the current understanding of this question, we relied on a probabilistic version of the SRT task, and trained participants under incidental conditions analogous to those used by Jiménez et al. (2006). With this training procedure, the authors found no transfer to conditions that maintained exactly the same structure of relevant stimuli and responses, but that added distracters to fill the irrelevant locations, thus including an additional search component to the practiced task.

In Experiment 1, we tested whether a change inverse to that arranged in that previous study produced analogous interference effects, as it could be predicted if the expression of knowledge was dependent on amount of context change. Thus, we trained participants with the search task, and then tested the expression of the resulting knowledge over a transfer block in which the distracters were removed. The results indicated that participants trained with the more control demanding conditions were able to learn about the frequent sequence across the training blocks, and that their sequence knowledge was successfully expressed over the simpler, less control demanding, transfer task.

The series of experiments 2 and 3 were designed as conceptual replications of this asymmetrical pattern of transfer, using manipulations that affected more specifically the control requirements of the task, without incurring in the long temporal delays provoked by the inclusion of a search task and, in the case of Experiment 3, even without including any change in the perceptual features of the display. The results of these experiments showed that probabilistic sequence learning arose also under conditions of Simon interference and in the context of a Go-NoGo task, and that, in both conditions, this learning was successfully transferred toward the simpler conditions created by removing those control demands (Experiments

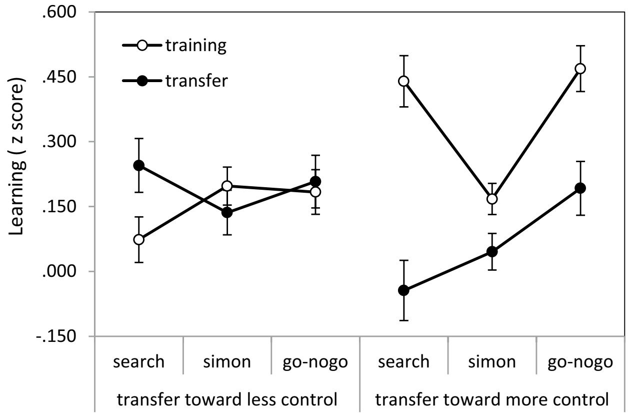

**Fig. 5** Mean effect of learning (*z* score for infrequent sequence − *z* score for frequent sequence) for the average of the pre-transfer and post-transfer blocks (training) and the transfer block (the average of the two transfer blocks in Experiment 3), for the three experiments, as a function of whether the transfer imposes a higher (left panel) or a lower (right panel) control demanding context. Bars represent 95% confidence interval. To complete the symmetric transfer for the three experiments, data from Experiment 1 of Jiménez et al. (2006) are also considered ("search" condition, transfer to high control demands)

2b and 3b). In contrast, when participants were trained under the less control demanding conditions, and were later transferred to the high control demanding tasks (i.e., Experiments 2a and 3a), we found that sequence learning of a probabilistic series of symbol identities was not transferred to conditions in which the symbols appeared at locations that induced a Simon interference (Experiment 2a), and that learning of a probabilistic sequence of locations was hindered by transfer to a Go-NoGo task, in which participants had to avoid responding to particular items depending on their identity.

Figure 5 summarizes these findings. To test the asymmetrical nature of transfer, and to test this hypothesis with more statistical power, an ANOVA was conducted with the data collected from the five experiments reported in this article, plus those coming from Experiment 1 of Jiménez et al. (2006), which provided the symmetric condition for Experiment 1. A mixed ANOVA was performed on the learning effect (*z* score for infrequent sequence − *z* score for frequent sequence) as the dependent variable, with phase (transfer vs. training, computed as the average *z* score measured over the transfer block/s, and that computed over the pre- and post-transfer blocks) as a within-participants independent variable, and with direction of transfer (toward a lower vs. higher demanding context) and experiment (search task, Simon task, Go-NoGo task) as between participants variables. This analysis clearly supported our prediction that the decrease in the expression of learning depended on the direction of transfer (phase × direction of transfer, $F(1, 143) = 34.41$, $p < 0.001$, $\eta_p^2 = 0.19$).

Partial ANOVAs confirmed that there was a clear decrease in the expression of learning upon transfer to a higher control demanding context, $F(1, 76) = 49.08$, $p < 0.001$, $\eta_p^2 = 0.39$ (0.36–0.07), whereas the change was not significant and in the opposite direction when the transfer was to a lower control demanding context, $F(1, 67) = 1.28$, $p = 0.26$, $\eta_p^2 = 0.02$ (0.15–0.20). Importantly, Bayesian paired samples *T* tests showed very strong evidence ($BF_{10} = 56{,}378$) that learning expression did change when the transfer was to a more control demanding context, whereas evidence rather supported the hypothesis that learning expression did not change when the transfer direction was toward a less control demanding task ($BF_{01} = 5.64$).

As a whole, the results of this series of experiments offer some valuable insights on the contexts that allow the acquisition of implicit sequence learning, and specially on the context changes that either hinder or support a continued expression of that learning. A few previous studies have already reported that sequence learning arises also in the context of control demanding tasks such as those provoked by Simon (Koch, 2007) or Stroop interference (Deroost, Vandenbossche, Zeischka, Coomans & Soetens, 2012). In both previous studies; however, the emphasis was put more on the question of whether sequence learning might reduce the interference effects provoked by either Simon or Stroop conflict, than on the complementary question of how changes in the amount of conflict could affect the acquisition or the expression of implicit sequence learning. In fact, Deroost et al. also tested, but discarded, the hypothesis that sequence learning could be improved by those training conditions which required higher control demands (cf. Deroost & Soetens, 2006), but they concluded that the expression of sequence learning improved under high conflict conditions, arguably because reliance on that knowledge would decrease the impact of other conflicting features.

In contrast, Koch suggested that this effect of shielding participants' performance from conflicting stimulus information would only arise for the more explicit learners (as shown by Jiménez et al., 2006, Experiment 2). Even though the present experiments were not aimed at exploring that issue, the adoption of a probabilistic procedure allows for an online assessment of the amount of learning expressed by the end of training, respectively, under high- versus low-control demanding conditions. Figure 5 represents the average learning effects expressed at the end of the training period (averaged over the pre- and post-transfer blocks) as the difference between the *z* scores obtained in response to frequent vs. infrequent trials, and, hence, allows for a visual comparison of the effects attained after training in different conditions, depending on whether these conditions impose lower or higher control demanding tasks. Comparisons between experiments indicate that the learning expressed after training over the higher control demanding conditions was either significantly lower than those shown over the less demanding conditions, as it occurs in the search condition, $t(34) = 4.25$, $p = 0.001$, and in the Go-No-Go condition, $t(39) = 4.25$, $p < 0.001$, or that the difference between them was not significant (in the experiments involving a Simon task, $t(70) = 0.53$, $p = 0.60$). Thus, even though the pattern is not completely univocal, it does not support the claim that the expression of implicit learning gets improved under conditions of higher conflict.

As for the main purpose of this study, concerning the pattern of transfer of previously acquired sequence knowledge over different context changes, the results of our symmetrical manipulations clearly indicate that not every context change impairs equally the expression of sequence learning. Rather, they suggest that relying on the previous sequence knowledge is specifically hindered by those transfer conditions that impose higher control demands with respect to those faced over the original training task. These results are consistent with different lines of research which point to the conclusion that automatic processes, in general, can be affected by the amount of control imposed by a given task environment, not only when these control requirements are strategically imposed to the performer (for instance in terms of explicit instructions that stress the accuracy of responding, see Hoyndorf & Haider, 2009), but also when those control demands are imposed indirectly in terms of the amount of conflict observed over the previous trials (Jiménez & Méndez, 2013; Klapp, 2007).

Indeed, that conclusion is also consistent with the observation that, in probabilistic versions of the SRT tasks, the expression of sequence learning decreases immediately after responding to a non-sequential trial (D'Angelo, Jiménez, Milliken, & Lupiáñez, 2013; Jiménez, Lupiáñez, & Vaquero, 2009), thus resembling the "congruency sequence effect" often observed in interference tasks (Gratton, Coles, & Donchin, 1992), and that has been interpreted as resulting from an adaptation to past conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). It is open to question how each of these effects could arise as a blend between top–down or strategic decisions, and bottom–up, or environmental modulations, but together they open an interesting avenue of research with both basic and applied implications on how implicit learning could be expressed in conditions different than those practiced over the training phase, or how could it be modulated by controlled processes. Especially interesting are the results shown with the Go-NoGO task, which imposed conditions requiring to withhold responding on some trials, and indicated that transfer from the standard conditions to these highly demanding task was particularly difficult over the first transfer block, but was finally obtained after some more extended practice with the Go-NoGo task, as if participants were able to get progressively tuned to the requirements of the task, and to make it compatible with the expression of learning.

In sum, the transfer effects observed when implicit learning was acquired under a high control demanding task and then assessed in the context of a less demanding task indicate that such effects do not depend entirely on the reinstatement of the training conditions, and, hence, points against an extreme view of the reinstatement principle of procedural learning (Healy et al., 2005). Moreover, these results reinforce the observation made by Abrahamse et al. (2010) with respect to the importance of sharing the task set between training and transfer, but they point to necessary adjustments in this notion, that should make a special emphasis on the dimension of control as a major determinant of transfer.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical standards** All procedures performed in the study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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