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Real life motor training modifies spatial performance: The advantage of being drummers

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Abstract

We compared the performance of skilled drummers to that of non-drummers and non-musicians in the Simon and spatial stimulus-response compatibility (SRC) tasks to investigate whether and to what extent spatial performance can be modified by motor behaviors acquired in real life. Drummers were chosen because, compared to other musicians and to the general population, their efficient performance mainly depends on the processing of spatial information.

While the Simon effect was equivalent for the three groups, the spatial SRC effect was less pronounced in drummers. The advantage was present even when feet were used as responding effectors, suggesting a central locus of the effect. These results suggest that spatial S-R translations are influenced by real life motor training, with drummers' training speeding-up the intentional S-R translations when stimulus and response locations are on opposite sides.

Keywords: Spatial performance; Simon effect; spatial stimulus-response compatibility; motor training

Introduction

One of the most widely studied perception-and-action issue concerns how the locations of objects in space are coded and how actions are organized on the basis of these representations. Spatial performance is primarily studied by means of spatial correspondence effects, namely the spatial stimulus-response compatibility (SRC) proper effect (for a review see Proctor & Vu, 2006) and the Simon effect (for a review see Lu & Proctor, 1995). The typical condition in which both spatial correspondence effects are evident is a choice-reaction task in which the stimulus appears in a right or left location and the response is produced manually. In the spatial SRC-proper task, the response is selected on the basis of stimulus location. In compatible mappings participants are instructed to respond with the key that is located on the same side of the stimulus, whereas in incompatible mappings the instructions are reversed. In the Simon task, the task-relevant stimulus feature is non-spatial (e.g., shape or color), and subjects respond with assigned right and left keypresses. Thus, there are trials in which stimulus and response locations correspond (i.e., corresponding S-R pairings) and trials in which they do not (i.e., non-corresponding pairings).

In both tasks, performance is usually faster and more accurate when there is spatial correspondence between stimulus and response (i.e., when the mapping is compatible for the spatial SRC task and when stimulus and response locations correspond for the Simon task) than when there is not (i.e., when the mapping is incompatible for the spatial SRC task and when stimulus and response locations do not correspond for the Simon task). Thus, the spatial correspondence effect arises irrespective of whether stimulus location is relevant or irrelevant to select the correct response. Both the spatial SRC-proper effect (Vu, Proctor, & Pick, 2000) and the Simon effect (e.g., Rubichi, Nicoletti, & Umiltà, 2005; Vu, Pellicano, & Proctor, 2005) are also evident when stimuli and responses are arranged along the vertical dimension and stimulus-response (S-R) sets vary along orthogonal dimensions (for a review see Cho & Proctor, 2003), and when both the horizontal and the vertical dimensions vary simultaneously (for a review see Rubichi, Vu, Nicoletti, & Proctor, 2006).

Spatial correspondence effects belong to the family of cognitive conflict tasks and most accounts attribute them to response selection processes that activate spatial response codes (e.g., Umiltà & Nicoletti, 1990). In particular, these accounts assume that the response selection machinery selects responses by means of two processing routes (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990). By the *intentional* route, based on short-term, task-defined S-R links, the relevant attribute of the stimulus is translated into a response. This translation is presumed to occur faster when an *identity* rule (e.g., respond at the corresponding response location) rather than an *opposite* rule or a search from a list of arbitrary S-R translations can be used. By means of the *automatic* route, based on long-term S-R links, either established through training or habit or genetically determined (Tagliabue, Zorzi, Umiltà, & Bassignani, 2000), stimulus position directly activates the spatially corresponding response, irrespective of task instructions. This activation is supposed to be beneficial when it is correct and harmful when it is incorrect.

Both spatial SRC-proper and Simon effects depend on the automatic activation of stimulus ipsilateral responses that speeds-up or slows-down performance in compatible/corresponding and incompatible/non-corresponding trials, respectively. However, the two routes play a differential role in the two tasks. For instance, the Simon effect is supposed to result from the activation of the response ipsilateral to the stimulus by the *automatic* route. On the contrary, the size of the spatial SRC-proper effect also depends on the rule implemented by the *intentional* route. Indeed, while the faster *identity* rule is adopted for compatible mappings, that is, when to select the correct response it is sufficient to match the spatial value of the stimulus into the spatial value of the response, the slower *opposite* rule is adopted for incompatible mappings, when a left or right stimulus has to be translated into an opposite, right or left, response (Kornblum et al., 1990).

It has been shown that, although the magnitude of spatial correspondence effects reduces after extensive practice, they remain significant (e.g., Dutta & Proctor, 1992 for the spatial SRC effect; Proctor & Lu, 1999 for the Simon effect) thus suggesting that the way by which spatial information influences performance is a rather steady feature of human information processing, independently of whether S-R associations are hardwired or learned. In spatial two-choice tasks, practice seems to produce a quantitative change in processing efficiency, rather than a qualitative change. However, Proctor and Lu (1999) showed that when subjects performed a SRC task using an incompatible spatial mapping for more than 900 trials and then transferred to a Simon task, the Simon effect reversed, with better performance when stimulus and response did not correspond compared to when they did. Similarly, Tagliabue et al. (2000) demonstrated that as few as 72 spatially incompatible trials were sufficient to eliminate the Simon effect when the Simon task was performed 5 minutes later (see Iani, Rubichi, Gherri, & Nicoletti, 2009 for similar results) and to reverse it when the Simon task was performed after a week. To explain these results, it has been proposed that the spatially incompatible training leads to the acquisition of new incompatible S-R associations that counteract the effects of the automatic compatible associations. More recently, Vu (2007) suggested that with a modest spatially incompatible training, transfer effects are evident only when both stimulus and response vary along the horizontal dimension. Hence, the new associations seem to be between specific stimulus-location and response-location codes. However, a more extensive training is supposed to lead to the acquisition of a more general "*respond opposite procedure*" being able to exert its influence irrespective of the dimension practiced during training.

The finding that short-term, task defined associations continue to affect performance on a subsequent task even after many consecutive trials (Proctor & Lu, 1999) or after a 1-week delay (Tagliabue et al., 2000) suggests that they consolidate in long-term memory thus modifying, for at least a week, the participants motor behavior. An open question is whether spatial correspondence effects can be modulated in a similar way by specific motor behaviors acquired and performed throughout life. To note, the results of a recent study by Bialystok and DePape (2009) suggest the idea of a connection between musical experience and enhanced general cognitive performance. By comparing performance of bilinguals, monolinguals and musical performers (vocalists and instrumentalists) on a modified version of the Simon task with arrows stimuli, they found faster overall performance for bilinguals and musicians compared to monolinguals. In the present study we were interested in investigating whether a specific musical training may shape spatial performance to the point that the disadvantage for non-corresponding S-R pairings is overcome or reduced in subpopulations for which efficient motor performance is mainly based on spatial parameters. Such a finding would suggest that basic motor performance depends on, or is modulated by specific life experience.

To this end, we assessed the performance of skilled drummers in two spatial tasks, the Simon and the SRC tasks. Playing the drums requires both temporal processing and rhythmical precision. Nevertheless, this group was chosen because playing the drums is a skilled motor activity in which efficient performance equally depends on spatial parameters. Practicing this musical instrument consists in performing with the upper limbs a series of reaching movements towards the components of the drum-set (drums and hats), which are horizontally displaced in front of the player, to produce an effect (i.e., to produce a sound). To produce the intended effect, the player needs to select the *target* component which is located on the left or on the right of the body midline and the *hand* which is available to reach the target (see Stins & Michaels, 1997). This implies that both ipsilateral and contralateral movements are executed. In the ipsilateral reaching movements, the starting position of the hand corresponds to the position of the target (e.g., the left hand moves from the left position to a target component located on the left side), whereas in contralateral reaching movements the starting position of the hand and the position of the target do not correspond (e.g., the right hand moves from the right position to a target component located on the left).

Chua, Carson, Goodman and Elliott (1992) found that ipsilateral movements had shorter movement onset times than contralateral movements in pointing movements as well as in "mirror" movements. Furthermore, Stins and Michaels (1997) found that contralateral reaching movements toward a target took longer to initiate (RT measure) than ipsilateral reaching movements because non-corresponding hand-to-target relations needed to be processed. Similar results were obtained by Riggio, Gawryszewski, and Umiltà (1986) who used crossed and uncrossed hand-held sticks pressing left and right keys. In their study, RTs were faster when the sticks were uncrossed (i.e., both the hand and the target button laid in the same hemispace) than when they were crossed (e.g., the right hand in the right hemispace held a stick which pressed the target button located in the left hemispace). In all these studies, the speed and accuracy of effector selection was affected by the corresponding and non-corresponding target location.

Drummers' performance is characterized by the fact that the number of contralateral movements, in which the starting position of the hand is non-corresponding with the position of the target, is substantially comparable to the number of ipsilateral movements, in which the starting position of the hand and the position of the target correspond. Hence, it appears that playing the drums requires to counteract the disadvantage normally observed in performing non-corresponding movements. Differently from upper limbs, lower limbs operate solely in the ipsilateral space.

Furthermore, within the execution of a certain rhythmical pattern, drummers actively control their motor behaviors, deciding whether a corresponding or a non-corresponding movement has to be performed at a certain point of performance. More precisely, drummers do not perform rapid reactions to a pre-specified sequence of abrupt stimulus events, as in a typical experimental context. Rather, they respond to internally driven stimuli which consist in responding to (to hit) that, and only that, stimulus (left or right drum) in that particular moment with the available hand. This situation is supposed to train the ability to control motor performance, probably more effectively than during experimental tasks in which the response emitted depends on context-related and pre-specified task instructions. Moreover, response (hand) selection in drummers is a speeded process which is crucial for a correct motor performance. For this reason, the protocols we used in the present study involved choice-reaction time as the latter is considered the best measure of response selection processes in spatial tasks (e.g., Rubichi & Pellicano, 2004; Rubichi, Nicoletti, Umiltà, & Zorzi, 2000).

Based on the reasons outlined above, we hypothesized that playing the drums could influence performance in two different ways. On the one hand, as a consequence of the unusual increase of incompatible motor interactions with the drum set, a new automatism could be acquired so that stimuli automatically elicit spatially non-corresponding responses contrasting the “natural” corresponding ones. On the other hand, playing the drums could increase the capability to voluntarily reduce the slowing down of performance caused by performing non-corresponding responses. More precisely, frequently switching from corresponding to non-corresponding voluntary movements could speed-up the application of the opposite rule, that is, increase the speed of translation of the stimulus spatial dimension into its opposite spatial response. If the first hypothesis is true, the size of both SRC and Simon effects should be smaller in drummers than in the general population. Indeed, in both tasks the automatic activation of non-corresponding S-R links would counteract the effects of the preexisting corresponding S-R links. Instead, if the second hypothesis is true, solely the size of the SRC effect should differ, since in the Simon task the relevant stimulus feature is non-spatial.

To test these two hypotheses, the performance of skilled drummers in two spatial correspondence tasks was compared to that of two control groups which were non-drummer musicians (guitar and bass players) and non-musicians. Like drummers, guitarists and bassists were skilled musicians who underwent extensive musical and motor training, but like non-musicians, they did not share the same motor training as drummers. Thus, performance of drummers was expected to differ from that of both non-drummer musicians and non-musicians, whereas the performance of the two control groups should be equivalent. In Experiment 1, we compared the performance of these three groups of participants on the Simon task, whereas in Experiment 2 we compared their performance on the spatial SRC task. Since drummers frequently keep their hands crossed, placing the left and right hands in the contralateral side of space (a posture that is necessary to best perform certain basic rhythmical patterns), we included for both experiments a condition in which responses were executed with crossed hands. In Experiment 3, the spatial SRC task was administered to a group of drummers and a group of non-musician and responses were emitted with the lower limbs to control for a possible upper limbs advantage. Since the lower limbs act on the ipsilateral space, only the uncrossed feet condition was used.

Experiment 1

The performance of drummers on the Simon task was compared to that of guitar and bass players and of non-musicians. Unlike drummers, while playing their instruments guitarists and bassists do not perform contralateral and ipsilateral reaching movements. Rather, their hands move solely in ipsilateral space.

The presence of two control groups was necessary to rule out a potential confound between the specific motor skills we hypothesized for drummers and a possible, general motor skill shared by musicians. Thus, if the performance of the two control groups is equivalent and equally different from that of drummers, it will be plausible to conclude that the specific motor skills of drummers are responsible for the results. Specifically, if the magnitude of the Simon effect is less pronounced in drummers than in the other two groups, this might indicate that the long-time practice enhances the automatic activation of non-corresponding responses.

Method

Participants. Twenty-eight skilled drummers (26 males; age range: 18-35 years; 11 years of experience; 11 hours/week of practice in average), twenty-eight skilled guitarists and bassists[1] (20 guitarists and 8 bassists; 27 males; age range: 18-31 years; 8 years of experience; 11 hours/week of practice in average) and 28 non-musicians (16 males; age range: 21-32 years) participated. The non-musicians were university students with no musical experience by self report. Groups were equated for age (mean age was 26, 23 and 26 years for drummers, non-

[1] We originally tested thirty skilled guitarists and bassists. However, two guitarists were excluded from the analyses because they played the drums too and had a higher experience as drummers than as guitarists.

drummer musicians and non-musicians, respectively) and scores to the Edinburgh Handedness Inventory (58/100, 65/100 and 57/100 for drummers, non-drummer musicians and non-musicians, respectively; Oldfield, 1971). Since there are indications of a relationship between handedness and asymmetries in the Simon effect (Rubichi & Nicoletti, 2006), only right-handed participants were included in the study. All participants were naïve as to the purpose of the study and had normal or corrected-to-normal vision.

Apparatus and Stimuli. A PC with a 14-in. VGA monitor equipped with MEL 2 software was used for stimulus generation and response collection. Participants sat in front of the computer screen at a distance of 40 cm. Stimuli were red and green squares (1° x 1°) presented 10° to the left or right of a 0.7° x 0.7° central cross. Responses were made by pressing the “z” and “.” keys of a computer keyboard with the index fingers.

Procedure. The fixation cross remained visible across the trials. Stimuli were presented in random order for 100 ms each. Half of the subjects were instructed to press the ‘z’ key in response to the red square and the ‘.’ key in response to the green square, whereas the other half received the opposite instructions. The experimental session consisted of two blocks of 144 experimental trials each, preceded by a practice block, and separated by a rest break. Each practice block (maximum 24 trials) terminated when the participant had entered 10 correct responses in a row. In one experimental block the hands were uncrossed, whereas in the other one they were crossed. The order of the uncrossed- and crossed-hand conditions was counterbalanced across participants. The maximum time allowed for response was 1 sec. A blank frame or an error message frame (along with a 200 ms-300 Hz tone) was displayed for 1 sec following a correct or incorrect response, respectively. The intertrial interval was 1 sec.

Results and discussion

For each participant, responses that were more than two standard deviations greater than the participant's overall mean RT were excluded from the analyses. Correct RTs and arcsine-transformed error rates were submitted to an analysis of variance (ANOVA) with *group* (drummers, non-drummer musicians and non-musicians) as between-subjects factor, *hands* (uncrossed vs. crossed) and *correspondence* (corresponding vs. non-corresponding S-R pairings) as within-subject factors. The respective data are displayed in Table 1. The Tukey post-hoc test was used to assess the main effect of *group*, whereas independent- and paired-sample *t*-tests were performed for significant between- and within-subjects interactions, respectively.

(Insert Table 1 about here)

The RT analysis revealed main effects of *hands*, $F(1,81) = 16.12$, $p < .001$, and *correspondence*, $F(1,81) = 275.16$, $p < .001$. Responses were faster with uncrossed (442 ms) than with crossed hands (455 ms), and for corresponding (433 ms) than for non-corresponding trials (464 ms). The *hands* X *correspondence* interaction was significant, $F(1,81) = 42.79$, $p < .001$. Paired sample *t*-tests showed that crossed-hand responses were slower than uncrossed-hand responses in non-corresponding trials, $t(83) = 6.83$, $p < .001$ (453 vs. 476 ms, for uncrossed- and crossed-hand conditions, respectively), but did not differ in corresponding trials, $t(83) < 1$ (431 vs. 434 ms for uncrossed- and crossed-hand conditions, respectively). As a result of this, the Simon effect was significantly larger in the crossed-hand condition (42 ms) compared to the uncrossed-hand condition (22 ms). The Simon effect was equivalent for the three groups, as indicated by the lack of a significant *group* X *correspondence* interaction ($p = .19$).

As regards errors, the analysis revealed a main effect of *correspondence*, $F(1,81) = 51.43$,

$p < .001$, with fewer errors for corresponding (2.1%) than for non-corresponding (5%) trials. The *hands* X *correspondence* interaction was significant, $F(1,81) = 8.43$, $p < .01$. The percentage of errors was larger in the crossed-hand condition than in the uncrossed-hand condition when S-R pairings were non-corresponding, $t(83) = 2.55$, $p = .013$ (4.4 vs. 5.6% for uncrossed- and crossed-hand conditions, respectively), but not when S-R pairings were corresponding, $t(83) < 1$ (2.4 vs. 1.9% for uncrossed- and crossed-hand conditions, respectively). The *group* X *correspondence* interaction was also significant, $F(2,81) = 6.49$, $p < .01$, with a larger Simon effect for non-drummer musicians compared to drummers, $t(54) = 3.18$, $p < .01$, and to non-musicians, $t(54) = 2.45$, $p < .02$.

The results of Experiment 1 clearly showed that the spatial performance of drummers did not differ from that of non-drummer musicians and non-musicians. Hence, it seems that regular practice in playing the drums does not influence the automatic translation of stimulus location into response location operated by the response selection machinery. This result was not modified by hands position, indicating that the long-time practice, even though it brings drummers to frequently cross their hands, was ineffective at counteracting the inherent propensity for the hands to operate into the corresponding space.

Experiment 2

This experiment was designed to assess whether drummers differ compared to skilled guitar and bass players and to non-musicians on the spatial SRC task. According to the reasoning outlined in the Introduction, if the magnitude of the spatial SRC effect is less pronounced in drummers compared to the other two groups, this would suggest that drum training exerts its effects on the intentional incompatible translations.

Method

Participants. The same participants of Experiment 1 took part in this experiment.

Apparatus, Stimuli and Procedure. Apparatus, stimuli and procedure were the same as in Experiment 1 except for what follows. A light-grey square was the only imperative stimulus presented on the left and right of the central cross. The experiment was divided into two sessions. In one session the hands were uncrossed, whereas in the other they were crossed. Each session was divided into two blocks of 72 trials each: in one block, participants had to respond with the left key (‘z’) if the stimulus was presented on the left side and with the right key (‘.’) if the stimulus was presented on the right side. That is, position was the relevant stimulus feature, and the instructions were to execute responses being spatially compatible with the stimuli. In the other block the S-R mapping was reversed, so that participants were required to execute spatially incompatible responses. Hands position and S-R mapping were counterbalanced across participants.

Results and discussion

Data were treated as in Experiment 1 and submitted to an ANOVA with *group* (drummers, non-drummer musicians and non-musicians) as between-subjects factor, *hands* (uncrossed vs. crossed) and *compatibility* (compatible vs. incompatible S-R pairings) as within-subject factors. The respective data are reported in Table 2.

(Insert Table 2 about here)

The RT analysis revealed main effects of *hands*, $F(1,81) = 136.79$, $p < .001$, and *correspondence*, $F(1,81) = 287.71$, $p < .001$. Responses were faster with uncrossed (347 ms) than with crossed hands (373 ms), and for compatible (336 ms) than for incompatible trials (384 ms).

The *group x compatibility* interaction was significant, $F(2,81) = 4.86$, $p < .02$. Independent sample *t*-tests indicated that drummers were faster than non-drummer musicians, $t(54) = 2.15$, $p < .04$, and non-musicians, $t(54) = 2.92$, $p < .01$, when performing the incompatible trials, whereas performance was equivalent to that of non-drummer musicians and non-musicians in the compatible trials, $ts(54) < 2$. Furthermore, performance of non-drummer musicians and non-musicians did not differ in both incompatible and compatible mapping conditions, $ts(54) < 1$. Therefore, the spatial SRC effect was smaller for drummers (35 ms) than for non-drummer musicians (54 ms) and non-musicians (54 ms).

As regards errors, the main effect of *group* was significant, $F(2,81) = 7.87$, $p < .01$. Tukey post-hoc test showed that the percentage of errors was higher for the non-drummer musicians (3.3%) compared to drummers (1.6%, $p < .01$) and to non-musicians (1.4%, $p < .01$). The effect of *hands* was significant, $F(1,81) = 33.76$, $p < .001$, with fewer errors in the uncrossed-hand condition (1.3%) compared to the crossed-hand condition (2.9%). The effect of *compatibility* was significant, $F(1,81) = 52.40$, $p < .001$, with fewer errors for compatible (0.9%) than for incompatible (3.3%) trials. The *group* x *compatibility* interaction was significant, $F(2,81) = 3.96$, $p < .03$. Independent-sample comparisons indicated that the SRC effect was larger for non-drummer musicians compared to non-musicians, $t(54) = 2.35$, $p = .023$. No difference was evident between non-drummer musicians and drummers, $t(54) < 2$.

These results showed that when stimulus location was relevant for response selection the spatial performance of drummers differed from that of non-drummer musicians and non-musicians. The spatial SRC effect was smaller in drummers than in both non-drummer musicians and non-musicians because the execution of incompatible responses was faster. Hence, it seems that regular practice in playing the drums improves response selection in spatial tasks when there is the voluntary translation of stimulus location into response location, to the point that, in the incompatible mapping condition, the implementation of the *opposite* rule along the intentional route is faster in drummers than in non-drummer musicians and non-musicians.

Similarly to Experiment 1, performance for the three groups did not differ as a function of hands position, thus strengthening the conclusion that the long-time practice was ineffective at counteracting the inherent propensity for the hands to operate into the corresponding space.

Experiment 3

The speed-up of incompatible responses in the spatial SRC task observed for drummers could be related to central, response selection efficiency. Alternatively, it could be due to a sort of upper limbs advantage that might be evident after regular practice. Given that performance of non-musicians and non-drummer musicians resulted equivalent in Experiment 2, in the present experiment we employed non-musicians as the only control group.

To assess whether the advantage observed in Experiment 2 was related to response selection efficiency, in the present experiment we asked drummers and non-musicians to respond with their lower limbs in a spatial SRC task that was identical to that of Experiment 2. Contrary to upper limbs, the activity of playing the drums requires the feet to press pedals in the ipsilateral hemispace only. If the advantage observed for drummers in incompatible mappings is effector-dependent, it should disappear when participants respond with the lower limbs. On the contrary, if it depends on response selection efficiency, then it should be present even when feet are used as effectors.

Method

Participants. Twenty new skilled drummers (17 males; age range: 19-44 years; 11 years of experience; 11 hours/week of practice in average) and 20 new non-musicians (10 males; age range: 19-43 years) participated. Participants were selected as before.

Apparatus, Stimuli and Procedure. Apparatus, stimuli and procedure were the same as those used for the spatial SRC task in Experiment 2, except that participants responded with their lower limbs and feet were always uncrossed. Two foot-pedals were positioned on the floor on the left and right side of the body midline, 40 cm away from each other, and participants pressed the left pedal with the left foot and the right pedal with the right foot.

Results and discussion

Data were filtered as in the previous experiments. Errors were less than 1% and were not analyzed. Correct RTs were entered into a repeated-measures ANOVA with *group* (drummers vs. non-musicians) as between-subjects factor and *compatibility* (compatible vs. incompatible pairings) as within-subject factor. The respective data are reported in Table 3.

(Insert Table 3 about here)

The main effect of *compatibility* was significant, $F(1,38) = 108.83$, $p < .001$, showing that responses were faster for compatible (340 ms) than incompatible (394 ms) mappings. Although drummers were faster (356 ms) than non-musicians (378 ms), this difference did not reach significance, as indicated by the non-significant effect of *group,* $F(1,38) = 2.87$, $p = .098$. The *group x compatibility* interaction was significant, $F(1,38) = 9.78$, $p < .01$. Independent-sample comparisons showed that drummers were faster than non-musicians in incompatible trials, $t(38) = 2.34$, $p < .03$, whereas performance was equivalent in compatible trials, $t(38) < 1$. Therefore, the spatial SRC effect was smaller for drummers (38 ms) than for non-musicians (70 ms).

Results clearly showed that the advantage of drummers found in Experiment 2 was present also when the lower limbs were used. This result ruled out the possibility that drummers' advantage could be ascribed to post-selection, execution efficiency of the upper limbs.

General Discussion

Spatial correspondence effects mainly consist of a performance disadvantage for non-corresponding S-R pairings when stimulus position is either relevant (SRC effect) or irrelevant (Simon effect). Recent studies provided evidence that practicing with an incompatible spatial mapping (e.g., respond to the left stimulus with the right key and vice versa) before performing a Simon task can eliminate (Tagliabue et al., 2000) or even reverse the Simon effect (Proctor & Lu, 1999). In these studies, corresponding S-R associations were neither improved by compatible mapping training nor directly weakened by incompatible mapping training. Hence, the tendency to respond towards the source of stimulation, whatever it is hard-wired or learned, it is substantially unaffected by further training. The incompatible mapping training, however, led to the acquisition of new non-corresponding S-R associations that counteracted the effects of the original corresponding ones. Hence, the tendency to execute the response that does not correspond to the location of the stimulus can be acquired through experimental training.

An open question is whether spatial correspondence effects can be modulated in a similar way by specific motor behaviors acquired and performed outside from the laboratory, throughout life. More precisely, we were interested in assessing whether the frequent use of non-corresponding actions could eliminate the disadvantage for non-corresponding responses generally observed in the general population. To address this question, we assessed spatial correspondence effects in a group of drummers compared to two control groups which were guitarists and bassists (the non-drummer musicians group) and non-musicians. Since for drummers efficient performance is equally based on spatial corresponding and non-corresponding actions, they emit non-corresponding responses more frequently than other musicians and non-musicians.

Being a drummer could influence performance in spatial tasks in two different ways. On the one hand, as a consequence of massive increase of incompatible motor interactions with the drum set, new S-R links would be acquired so that spatial stimuli automatically elicit spatially non-corresponding responses which counteract the effects of the preexisting and "natural" S-R corresponding links. On the other hand, as drummers implement the *opposite* rule more frequently than non-drummers, this training would speed-up the implementation of the rule and eliminate or reduce the differences in performance between the *identity* and the *opposite* rules.

If the first hypothesis is true, both SRC and Simon effects should be reduced in magnitude for drummers compared to non-drummer musicians and non-musicians. Indeed, in both tasks the automatic activation of non-corresponding S-R links would counteract the effects of the preexisting corresponding S-R links. Instead, if the second hypothesis is true, only the SRC effect should be reduced in magnitude for drummers compared to the control groups, since the spatial SRC task alone implies a controlled translation of the spatial value of the stimulus into its assigned spatial response.

We found evidence that the spatial SRC effect was smaller in drummers than in the two control groups, due to a performance advantage in the incompatible condition (Experiments 2 and 3), whereas the three groups did not differ in Simon task performance (Experiment 1). Thus, the tendency to respond towards the source of stimulation appeared to be unaffected by long-term real-life training. Indeed, even though the Simon effect tended to be smaller for drummers in both RTs and errors, this difference was far from being significant. These results differ from what is found in the laboratory probably because drummers' training is not completely comparable to the pure spatially incompatible training administered in the laboratory. Indeed, while in this latter condition participants focus their practice on a single incompatible spatial mapping, in real life drummers experience both compatible and incompatible mappings. For this reason, it is plausible that incompatible S-R memory links are not created in drummers in the same way as it would be expected if their training consisted of incompatible S-R mappings, exclusively. Thus, results are to be intended as the product of different proportion of incompatible and compatible mappings which is more balanced in drummers compared to the general population.

Results support the second hypothesis, suggesting that the positive influence of drummers' motor training exerts its effects on the intentional incompatible S-R translations, rather than affecting the automatic associations between stimulus and response locations. Long-time practice of drums appeared then to speed-up the intentional route when the *opposite* rule needed to be implemented by task instructions.

Although our results provide clear evidence of the effects of playing drums on performance at the SRC task, we cannot disregard the opposite possibility, that our participants successfully became drummers in part because they had "innate talent", that is, they were already able to make incompatible stimulus-response translations faster than most other people. We believe, however, that, even though this possibility is theoretically plausible, it is less likely, and that even if they had some initial predisposition it would be really difficult to claim that lifelong training had no effect. This conclusion is in line with studies on deliberate practice in the acquisition of expert performances (Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Williams, 2007) which claim that the differences between expert performers and normal adults critically reflect a life-long period of deliberate effort to improve performance in a specific domain. Of course, only a within-subject, longitudinal study would allow for a more powerful demonstration of the relation between the effects of deliberate practice in drumming and performance to SRC tasks.

Our assumption that the advantage of being drummers is a response selection effect gathered empirical support in Experiment 3 where the drummers advantage in incompatible S-R pairings was evident even with the lower limbs. This result rules out that the drummers' advantage was "effector-dependent", a possibility that would suggest a response execution locus of the drums training effect. The finding that the drummers' advantage is effector-independent is in line with the view that actions are coded in terms of their distal features rather than of their proximal ones (Hommel, Müsseler, Aschersleben, & Prinz, 2001) and suggests that actions are represented in terms of their goals, not in terms of specific muscle innervations patterns. Further support comes from the finding that the effect of drummers' training was evident in a discrete motor task that differs from the motor activity drummers perform in real-life settings.

The effects of real life training found in the present study are in line with proposals that combine nativist and empirist claims. According to these proposals, innate predispositions would be coded at the subcortical level, whereas at the cortical level representations would not be hard-wired but would rather emerge through experience (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1997). The strong effects of real life training that we found is consistent with the view that representations emerge through experience, from the interaction between the organisms and the environment.

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References

Bialystok, E., DePape, A.-M. (2009). Musical expertise, bilinguism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 565-574.

Cho, Y. S., & Proctor, R. W. (2003). Stimulus and response representations underlying orthogonal stimulus-response compatibility effects. *Psychonomic Bulletin & Review*, *10*, 45-73.

Chua, R., Carson, R.G., Goodman, D., & Elliott, D. (1992). Asymmetries in the spatial localization of transformed targets. *Brain and Cognition*, *20*, 227-235.

De Jong, R., Liang, C. C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 731-750.

Dutta, A., & Proctor, R.W. (1992). Persistence of stimulus-response compatibility effects with extended practice. *Journal of Experimental Psychology: Learning, Memory, &, Cognition, 18,* 801-809.

Elman, J.L., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1997). *Rethinking innateness. A connectionist perspective on development.* Cambridge, MA: MIT.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363-406.

Ericsson, K. A., & Williams, A.M. (2007). Capturing naturally occurring superior performance in the laboratory: translational research on expert performance. *Journal of Experimental Psychology: Applied*, *13*, 115-123.

Hommel, B., Müsseler, J., Arschersleben, G., & Prinz, W. (2001). The Theory of Event Coding

(TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24,* 849-937.

Iani, C., Rubichi, R., Gherri, E., Nicoletti, R. (2009). Co-occurrence of sequential and practice effects in the Simon task: Evidence for two independent mechanisms affecting response selection. *Memory & Cognition*, *37*, 358-367.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility – A model and taxonomy. *Psychological Review*, *97,* 253-270.

Lu, C. H., & Proctor, R.W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*, 174–207.

Oldfield, R. C. (1971). The assessment and analysis of handedness. The Edinburgh Inventory. *Neuropsychologia*, *9*, 97-114.

Proctor, R. W., & Lu, C. H. (1999). Processing irrelevant location information: Practice and transfer effects in choice-reaction tasks. *Memory & Cognition, 27,* 63-77.

Proctor, R.W., & Vu, K-P. L. (2006). *Stimulus-Response Compatibility Principle: Data, theory, and application.* Boca Raton, FL: Taylor & Francis.

Riggio, L., Gawryszewski, L., & Umiltà, C. (1986). What is crossed in crossed-hand effects? *Acta Psychologica*, *62*, 89-100.

Rubichi, S., & Nicoletti, R. (2006). The Simon effect and handedness: Evidence for a dominant-hand attentional bias in spatial coding. *Perception & Psychophysics*, *68*, 1059-1069.

Rubichi, S., & Pellicano, A. (2004). Does the Simon effect affect movement execution? *European Journal of Cognitive Psychology, 16*, 825-840.

Rubichi, S., Nicoletti, R., Umiltà, C. (2005). Right-left prevalence effect with task-irrelevant spatial code activation. *Psychological Research*, 69, 167-178.

Rubichi, S., Nicoletti, R., Umiltà, C., & Zorzi, M. (2000). Response strategies and the Simon effect. Psychological Research, 63, 129-136.

Rubichi, S., Vu, K.-P. L., Nicoletti, R., Proctor, R. (2006). Two-dimensional spatial coding. *Psychonomic Bulletin & Review, 13*, 201-216.

Stins, J.F., & Michaels, C.F. (1997). Stimulus-target compatibility for reaching movements. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 756-767.

Tagliabue, M., Zorzi, M., Umiltà, C., & Bassignani, F. (2000). The role of long-term memory and short-term memory links in the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 648–670.

Umiltà, C., & Nicoletti, R. (1990). Spatial stimulus-response compatibility. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. 89-143). Amsterdam: North-Holland.

Vu, K.-P.L. (2007). Influences on the Simon effect of prior practice with spatially incompatible mappings. Transfer within and between horizontal and vertical dimensions. *Memory & Cognition*, *35*, 1463-1471.

Vu, K.-P. L., Pellicano, A., & Proctor, R. W. (2005). No overall right-left prevalence for horizontal and vertical Simon effects. *Perception & Psychophysics, 67,*929-938.

Vu, K.-P. L., Proctor, R.W., & Pick, D.F. (2000). Vertical versus horizontal spatial compatibility: right-left prevalence with bimanual responses. *Psychological Research, 64*, 25-40.

Table 1: Mean RTs (ms), standard deviation (SD) and errors (%) for the Simon task in Experiment 1.

	SIMON TASK													
	uncrossed hands						crossed hands							
	Corresponding			Non-corresponding			Corresponding			Non-corresponding			Simon effect	
Group	RT	SD	Error	RT	SD	Error	RT	SD	Error	RT	SD	Error	RT	Error
Drummers	415	46	2.6	431	46	2.9	422	52	1.9	460	60	4.8	26	1.5
Non-drummer musicians	440	82	2.3	466	75	6.8	443	65	2.0	486	66	7.2	35	4.8
Non-musicians	438	53	2.2	462	45	3.5	438	37	1.8	483	36	5.0	34	2.2

Table 2: Mean RTs (ms), standard deviation (SD) and errors (%) for the spatial SRC task in Experiment 2.

	SPATIAL SRC TASK													
	uncrossed hands						crossed hands							
	Compatible			Incompatible			Compatible			Incompatible			Spatial SRC effect	
Group	RT	SD	Error	RT	SD	Error	RT	SD	Error	RT	SD	Error	RT	Error
Drummers	320	37	0.3	348	36	1.5	338	36	1.0	380	42	3.7	35	2
Non-drummer musicians	322	52	0.4	381	56	4.2	352	61	2.6	401	58	6.1	54	3.6
Non-musicians	331	40	0.2	382	44	1.5	356	38	1.0	411	51	2.8	54	1.6

Table 3: Mean RTs (ms) and standard deviation (SD) for the spatial SRC task in Experiment 3.

	Compatible		Incompatible		SRC effect
Group	RT	SD	RT	SD	RT
Drummers	337	31	375	35	38
Non-musicians	343	39	413	64	70