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Neural Correlates of Spatial Location Mapping on the Simon Effect

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Abstract

Previous studies show that the effect of practice with incompatible location mapping results in a reverse Simon effect. However, the neural correlates of this phenomenon are yet to be clarified. This study used functional magnetic resonance imaging (fMRI) to explore the neural correlates of the Simon effect after location mapping in 20 healthy young adults who are native English speakers. The results show that incompatible location mapping leads to reduced activation in the premotor, primary motor, supplementary motor area (SMA) and mid-cingulate cortex. As practice with the Simon effect reveals subtle changes in motor function, application of the Simon task in rehabilitation training programs is recommended.

Every day, we are faced with the task of selecting appropriate responses to guide our voluntary behaviour. Cognitive control includes the ability to guide thoughts and actions in accord with internal intentions, which is central to most higher cognitive functions, ranging from language, motor planning, reasoning to problem solving (Cohen, Botvinick, & Carter, 2000; Miller & Cohen, 2001). In all of these domains, cognitive control is crucial for behavioural response selection. How the process of control of behaviour changes with experience (e.g. practice) is thus a growing topic of interest in the field of cognition and human performance.

One of the most reliable paradigms to study cognitive control is the Simon task. The Simon task is a type of forced choice-reaction paradigm that has been developed to study the relationship between cognitive control, practice and performance (Lu & Proctor 1995; Proctor, Yamaguchi, Zhang, & Vu, 2009) as well as relationships between automaticity and attention (Proctor & Lu, 1999). The Simon effect refers to the finding that reaction time (RT) is shorter when the spatial location of a target stimuli corresponds to the location of a response (i.e. compatible condition) compared to when there is no such correspondence (incompatible condition). The effect occurs even though the spatial information about task stimuli is irrelevant to the task performed (Lu & Proctor, 1995; Umilta & Nicoletti, 1990). For example, the participant is presented with one of two colour stimuli on the left or right side of the computer screen, and is asked to press the left key in response to one colour and to press the right key in response to the other colour (Tagliabue, Zorzi, Umilta, & Bassignani, 2000). Faster response is noted when the position (left or right) of the colour stimulus corresponds to the position (left or right) of the response key (Tagliabue et al., 2000). The Simon task has been replicated in hundreds of experiments and has come to be used a standard for investigating the relationship between cognitive control and behaviour (Proctor et al., 2009).

Due to the reliability of the Simon effect in experimental studies, functional magnetic resonance imaging (fMRI) studies have recently begun to investigate the neural correlates of the Simon effect (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Liu, Banich, Jacobson, & Tanabe, 2004; Maclin, Gratton, & Fabiani, 2001; Peterson et al., 2002). The results show that a fronto-parietal neural network is activated during performance on the Simon task. Specifically, the anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), precuneus and pre-supplementary motor area (pre-SMA) are more activated in the incompatible condition than the compatible condition (Liu et al., 2004). Such findings agree with a theory proposed by Botvinick and colleagues which assumes that the ACC is responsible for monitoring conflict and response errors, while the DLPFC receives signals from ACC and then modulates the processing in the posterior parietal cortex by biasing towards the task-relevant information (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Botvinick, Braver, Barch, Carter, & Cohen, 2001).

Recent research attention has turned to the effect of practice on the Simon effect. One reason for this research focus is that the Simon effect can be modulated by experience. Studies show that the typical Simon effect is eliminated following practice trials requiring participants to make an incompatible pairing of left-right locations to the key press prior to the color relevant Simon task (e.g., right key press in response to the left side of a stimulus; left key press in response to the right side of a stimulus) (Tagliabue et al., 2000). In fact, the Simon effect can be *reversed* via practicing trials (Proctor & Lu, 1999). This phenomenon is called the reverse Simon effect. Such findings add validity to experiments that have adapted the Simon task as a paradigm to study relationships between control, practice and behaviour.

Why does practice modulate the Simon effect? According to one theoretical account, practice with new spatial mappings forms new arbitrary stimulus-response associations in short-term memory that are created online by the task instructions (Tagliabue et al., 2000).

According to Tagliabue et al. (2000), the short-term memory stimulus-response (S-R) links formed during the learning of arbitrary associations in the incompatible location mapping condition will influence the direction and size of the Simon effect after only a few trials and can remain active for up to 7 days. The effect of practice on the Simon effect is therefore a viable paradigm for studying the effects of practice on skilled behaviour in the laboratory.

Although studies have identified brain regions that are active during the Simon task, no study has used brain imaging methods to examine the influence of practice on the reverse Simon effect. The aim of this project is to use fMRI to investigate reverse Simon effects with native English speakers. The majority of studies performed with the Simon task have tested native English speakers. It is important to control for language background in studies using the Simon task. One reason why this is relevant in the local context is that bilingual speakers do not show the Simon effect as readily as monolingual speakers. For example, a study by Bialystok, Craik, Klein and Viswanathan (2004) showed that bilinguals responded faster to both congruent and incongruent trials when compared to monolinguals and they produced a reduced Simon effect. In order to minimize any effect of cultural and language background on the Simon effect, the present study recruited native English speakers only excluding participants who are bilingual based on language screening.

Hypotheses

It was hypothesized that neural activation during the Simon task before practice (baseline session) and after practice (transfer session) would be different due to the modulation of spatial location mapping. Furthermore, there would be differences in neural activation for the congruent and incongruent trials in the baseline session and the transfer session respectively. From the above hypotheses, specific predictions could be derived. First, the anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC) and pre-supplementary motor area would be significantly activated in incongruent trials compared to

congruent trials. Second, the intensity of brain activation in different brain regions would be different between the baseline and the transfer sessions.

Method

Participants

Twenty English-speaking participants (6 females and 14 males), ranging in age between 18 – 35 years old were recruited from the local community. Participants were selected if they had normal or corrected to normal vision and no history of neurological diseases or neuro-developmental delay. All participants were right handed in terms of the Edinburgh Handedness Inventory (Oldfield, 1971).

Questionnaire on language background

A questionnaire was used to select native English speakers who were monolinguals only. Participants were asked to fill in a language questionnaire prior to the experiment. The questionnaire requested information about the percentage of native language use (English) and use of other languages at home, in school, with friends and for leisure activities within a day. Participants with English as their first language and who used English to communicate for more than 70% of the day were selected.

Working memory test

Tagliabue et al. (2000) proposed that the effect of practice on the Simon effect can be attributed to stimulus-response associations formed as short-term memory links. Therefore, individual differences in working memory were tested to investigate the effect of short-term memory capacity on the experiment results. The participants were given the modified operation-word span (OSPAN) task in which they were asked to solve a series of simple mathematical operations and at the same time trying to remember a list of unrelated words (Kane, Bleckley, Conway, & Engle, 2001). Participants were shown one operation-word

strings one at a time, with each set of operation-word strings ranging from two to six items in length (Kane et al., 2001). For example, a set of two strings might be,

IS (5X2) - 8 = 2? snake

IS 7- (10/2) = 4? car

Participants were instructed to read the operation-word pair aloud and respond using a key press to indicate whether the equation was correct. Participants were then asked to read the word aloud again. The next operation appeared immediately after. The participants repeated the steps with other stimuli, until three question mark (???) cues were shown and participants had to recall all of the words from that set only. Participants had to write the words on an answer sheet in the same order in which they had been presented. They were not permitted to write the last word first. If the participants failed to recall the words, they could make a cross to indicate the missing words. The OSPAN score was the sum of recalled words for all sets recalled in the correct order (Kane et al., 2001). Three sets of variable commands (from two to six operation-word pairs) were administered (Kane et al., 2001). Hence, there were 15 trials in the regular test. Two practice trials were also given. The different set sizes appeared in a randomized order, thus the participant would not know the number of words to recall until the reappearance of the recall cue.

Design and procedure

A 2 x 2 x 2 mixed design was used to investigate the behavioral results and neural correlates of practice on the Simon effect. The between-subject factor was “group” with two levels (experimental and control groups). The twenty participants were randomly assigned to each group, with 10 participants in each group. The within-subject factors were “session” with two levels (baseline and transfer sessions) and “spatial congruency” with two levels (congruent and incongruent conditions) for describing the stimulus-response compatibility.

Participant reaction time and neural activation in the control and transfer sessions was measured and compared.

Behavioral results were obtained using experimental tasks administered in the scanner with instructions administered offline (out of the scanner) and brain activity of participants measured using functional magnetic resonance imaging (fMRI) in three sessions - (1) baseline, (2) practice and (3) transfer sessions. Both baseline and practice sessions began with a block of practice trials or 20 and 16 trials respectively to make sure participants understood task instructions.

The baseline session was presented to obtain an estimate of the Simon effect for each participant. Participants performed a two-choice color discrimination task involving green or red stimuli as fast and accurately as possible. There were 120 congruent trials and 120 incongruent trials. Each trial began with a fixation cross (+) presented in the centre of the screen. A stimulus was presented on either the left or the right side of the cross. Participants were instructed to respond to one color by pressing the left-side key and respond to the other color by pressing the right-side key. The assignment of the color (red or green) to the left and right responses was counterbalanced across subjects, with the same assignment used by a participant for both control and transfer sessions.

In between the baseline and transfer sessions, the participants performed a “practice” session, in which the control group engaged in compatible spatial location mapping and the transfer group engaged in incompatible location mapping. In the practice session, the experimental group was asked to respond to the location (left or right) of stimuli in monochrome respectively for 300 trials. This required an incompatible mapping because when the stimulus was presented on the left side of the screen, participants had to press the right key as quickly as possible. Similarly, when the stimulus was presented on the right side, participants had to press the left-side key. According to the dual route theory, new

associations were formed between spatial locations in short term memory in this session. In the transfer session, the same color discrimination task as the baseline session was presented to the participants with the same number of trials.

Imaging data acquisition

All MRI images were acquired with a Philips Achieva 3-T scanner (Best, Netherlands). A gradient echo planar imaging (EPI) sequence to was used to acquire fMRI data with the following parameters: repetition time (TR) = 2,000 ms, echo time (TE) = 30 ms, field of view (FOV) = 240 mm, 32 axial slices, slice thickness = 3.0 mm, slice gap = 0.75 mm, in-plane resolution = 3.0×3.0 mm^2, and flip angle = 90°. The first 4 volumes were discarded to allow for T1 equilibration effects. Additional high-resolution anatomical images (voxel size = $1 \times 1 \times 1$ mm^3) were acquired using a standard T1-weighted 3-D Magnetization-Prepared Rapid Gradient-Echo (MP-RAGE) sequence.

fMRI data analysis

Images were analyzed using statistical parametric mapping (SPM8) software (Wellcome Trust Centre for Neuroimaging, University College London, London, UK). EPI volumes were first corrected for head movements by affine registration. After realignment, the high-resolution T1-weighted image of the respective subject was co-registered to the mean realigned image. The co-registered T1-weighted image was spatially normalized to the Montreal Neurological Institute (MNI) template using the unified segmentation approach (Ashburner & Friston, 2005). The resulting deformation parameters were then applied to the individual EPI volumes. All images were thereby transformed into standard stereotaxic space and re-sampled at $2 \times 2 \times 2$ mm^3 voxel size. The normalized images were smoothed using an 8 mm full-width at half-maximum (FWHM) isotropic Gaussian kernel to compensate for residual variability after spatial normalization across subjects.

For the first-level individual statistical analysis, the fMRI blood-oxygen-level dependent (BOLD) data were analyzed in the framework of a general linear model (GLM). Each experimental condition was time-locked to the onset of the target color stimulus and was modelled using delta functions convolved with a canonical hemodynamic response function (HRF) and its temporal and dispersion derivatives (Friston, Fletcher, Josephs, Holmes, Rugg & Turner, 1998). Low-frequency signal drifts were high-pass filtered using a cut-off period of 128 seconds. Temporal autocorrelation of fMRI volumes was modeled using an AR(1) process. The head movement estimates from the realignment procedure were entered as covariates to remove movement-related variance from the EPI time series. The following experimental conditions were modelled using an SPM design matrix: (1) congruent and (2) incongruent conditions in the baseline session, (3) congruent and (4) incongruent conditions in the transfer session. In addition, the (5) left and (6) right stimuli in the practice session were also modeled, respectively, in the design matrix. For each subject, six contrast images were created for each experimental condition (each trial type versus baseline) and entered into the subsequent group analysis.

For the second-level random-effects analysis, parameter estimates of BOLD response derived from the first-level analysis were entered into a fully factorial 3 way mixed ANOVA with the factors ‘‘group” (experimental and control groups), “session” (baseline and transfer sessions), and ‘‘spatial congruency’’ (congruent and incongruent conditions), similar to the behavioral analysis. The statistical threshold was set at $p < 0.05$ (false discovery rate [FDR] corrected at the cluster level; $p < 0.001$ uncorrected at the voxel level).

Behavioral Results

Working memory test score

The descriptive statistic of the participant’s working memory score given correct word and also correct order in the OSPAN task is shown in Table 1. A t-test found no

significant difference between the experimental and control groups' means (t = .897, p = .191, 1-tailed).

Table 1

Mean Score and Standard Deviation of Participants in the OSPAN Task

Group	Mean	SD
Experimental (N = 10)	32.1	10.35
Control (N = 10)	27.5	12.47

The change in magnitude of the Simon effect and error rate between baseline and transfer sessions for the experimental and control groups (see table 2) were also correlated with the OSPAN task score (score from correct word and correct order) respectively. Individual differences in the effect size and the error rate were adjusted in order to have the differences in score represented on a common scale. Analyses with Spearman's correlation were performed.

For the experimental group, the analysis found no significant correlation between the change in magnitude of the Simon effect and the OSPAN task score r = .15, p = .34, 1-tailed. The correlation between the change of magnitude of error rate and the OSPAN task score was also not significant r = .11, p = .39, 1-tailed.

For the control group, the analyses also found no significant correlations between the change in magnitude of the Simon effect and the OSPAN task score r = -.06, p = .43, 1-tailed and between the change in magnitude of error rate and the OSPAN task score r = .40, p = .12, 1-tailed respectively.

Table 2

Mean Change in Magnitude of the Simon Effect (in millisecond) and Error Rate between the Transfer and Baseline Sessions of Both Groups

Group	T-B Simon effect	T-B error rate
Experimental (N = 10)	-25.8	-.057
Control (N = 10)	8.9	-.004

Note. T-B, transfer session minus baseline session.

Between group comparison

Three-factor mixed analysis of variance (ANOVA) with the variables Group x Session x Spatial congruency, were performed separately on the reaction time (RT) and error rates. The descriptive statistics of the participants' performance in the experiments are shown in Tables 3 and 4.

There was a significant main effect of session for RT $F(1, 18) = 4.60$, $p < .05$ and error rate $F(1, 18) = 11.60$, $p < .05$, with longer reaction time in the control sessions than in the transfer sessions as shown in Table 1 and a main effect of spatial congruency for RT $F(1, 18) = 13.11$, $p < .05$ but not for error rate $F(1, 18) = 2.94$, $p = .103$. The main effect of group was not significant for RT $F(1, 18) = .17$, $p = .682$ and error rate $F(1,18) = .057$, $p = .814$.

There were significant three way interactions between group, session and spatial congruency for both the RT $F\ (1, 18) = 20.464$, $p < .001$ and error rate $F(1, 18) = 4.729$, $p < .05$. Therefore post-hoc analyses were carried out to explain main effects and interactions in baseline and transfer sessions between the experimental and control group.

Table 3

Mean Reaction Time and Standard Deviation (in Millisecond) of Participants in Different Sessions

	Baseline session		Transfer session	
Group	Congruent	Incongruent	Congruent	Incongruent
Experimental (*N*=10)				
Mean	452.8	471.7	448.7	441.8
SD	59.1	41.7	53.9	39.1
Control (*N*=10)				
Mean	440.3	462.9	421.9	453.3
SD	59.3	56.3	56.3	52.5

Note. For the experimental group, incompatible spatial location mapping was done between baseline and transfer sessions. For the control group, compatible spatial location mapping was done between baseline and transfer sessions.

Table 4

Mean Error Rate and Standard Deviation of Participants in Different Sessions

	Baseline session		Transfer session	
Group	Congruent	Incongruent	Congruent	Incongruent
Experimental (*N*=10)				
Mean	.018	.036	.090	.050
SD	.016	.018	.061	.041
Control (*N*=10)				
Mean	.027	.062	.043	.074
SD	.021	.055	.023	.036

Note. For the experimental group, incompatible spatial location mapping was done between baseline and transfer sessions. For the control group, compatible spatial location mapping was done between baseline and transfer sessions.

Two-way mixed ANOVAs were conducted separately for the RT and error rate for the control sessions. The main effect of group was not significant for both RT $F(1, 18) = .198$, $p = .662$ and error rate $F(1,18) = 2.471$, $p = .133$. There was no significant interaction effect between Group and Spatial Congruency for the RT $F(1, 18) = .167$, $p = .687$ and error rate $F(1, 18) = 1.012$, $p = .328$. These results indicate that there was no significant difference between the two groups during the control session (the baseline session).

Two-way mixed ANOVAs were also performed separately for both the RT and error rate for the transfer session. The main effect of group was not significant for RT $F(1, 18) = 1.592$, $p = .735$ and error rate $F(1, 18) = 0.494$, $p = .491$. However, there was a significant interaction effect between group and spatial congruency for RT $F(1, 18) = 13.075$, $p < .05$

and error rate $F(1, 18) = 16.236$, $p < .001$, with reaction time for the incongruent condition in the experimental group faster than for the congruent condition while reaction time for the incongruent condition for the control group is slower than that for the congruent condition (refer to Table 4), thus indicating a reverse Simon effect in the experimental group. For error rate, errors in the incongruent condition for the experimental group were fewer than errors made in the incongruent condition for the control group while the reverse is true for the congruent condition, in which more errors were made by the experimental group compared with the control group.

Within group comparison

In the experimental group, there was a significant interaction between session and spatial congruency for RT $F(1, 9) = 32.47$, $p < .001$ and error rate $F(1, 9) = 9.16$, $p < .05$. A t-test found that there was a significant Simon effect on RT in the baseline session $t = 2.611$, $p < .05$, 1-tailed. A reverse Simon effect of 6.83 ms was noted in the transfer session. However the effect did not reach significance $t = .904$, $p = .195$, 1-tailed. There was an almost significant reverse Simon effect for error rate in the transfer session $t = 1.805$, $p = .0525$, 1-tailed.

In the control group, the interaction between session and spatial congruency was not significant for RT $F(1, 9) = 2.060$, $p = .185$, and error rate $F(1, 9) = .059$, $p = .814$. A t-test found a significant Simon effect in the baseline session for RT $t = 4.041$, $p < .05$, 1-tailed and error rate $t = 2.348$, $p < .05$, 1-tailed. A t-test also found significant Simon effects in the transfer session for both RT $t = 4.247$, $p < .05$, 1-tailed and error rate $t = 3.287$, $p < .05$, 1-tailed. The Simon effect in the transfer session (31.39 ms) even showed a slight increase (8.83 ms) compared to that in the control session (22.56 ms), although statistically it was not significant (or marginal sig.; $p = .185$).

Practice session

Two-way ANOVAs were performed on the RT and error rate from participants in the practice session. The main effect of group was significant for RT $F(1, 18) = 5.36$, $p < .05$ but not for error rate $F(1,18) = .13$, $p = .716$. The interaction between group and location (left, right) was not significant for RT $F(1, 18) = 2.00$, $p = .173$ and error rate $F(1,18) = .30$, $p = .590$. Practice with compatible spatial mapping produced a larger Simon in the transfer session compared to the control session, which showed that there was a practice effect.

Imaging Results

A conservative significant threshold of $p < .005$ and family wise error (FWE) of less than .05 was used for the analysis of the imaging data. For both the control and experimental groups, there were significant main effects of session comparing the baseline session > transfer session contrast respectively. Diminished brain activity in the baseline session > transfer session contrast for the experimental group and the control group showed different patterns.

In the experimental group, brain areas activated more in baseline sessions compared to the transfer session were left premotor cortex, left primary motor cortex, left and right SMA and mid-cingulate cortex (see Table 5). Figure 1 shows beta values of activation in the $x = -12$, $y = -18$, $z = 58$ (premotor area) for the four conditions in the experimental group. There was significant reduction of activation in that area in the transfer session for both congruent condition $t = 2.622$, $p < .05$, 1-tailed, and incongruent condition $t = 2.004$, $p < .05$, 1-tailed, compared to the respective conditions in the baseline sessions.

In the control group, the brain areas activated more in the baseline session compared to the transfer session were the right cerebellum vermis, left parahippocampal gyrus, and left and right cerebellum (see Table 6). Figure 2 shows beta values of activation in left cerebellum vermis ($x = 2$, $y = -50$, $z = -10$) across all sessions and conditions for both control and experimental groups. The reduction in activation was significant in both congruent

condition $t = 3.553$, $p < .05$, 1-tailed, and incongruent condition $t = 5.462$, $p < .05$, 1-tailed, in the transfer session compared to the respective conditions in the baseline session for the control group.

In the baseline session of both the experimental and control group respectively, there were no significant differences in brain activation during the incongruent trials as compared to the congruent trials in the baseline session in either groups, $p > .005$. In the transfer session in the experimental group, there was also no significant difference in the brain activation for both classic Simon effect (incongruent trials minus congruent trials), $p > .005$ and reverse Simon effect (congruent trials minus incongruent trials), $p > .005$.

Table 5

Brain Areas Activated in the Experimental Group with the Contrast: Baseline Session > Transfer Session

L/R	Region	*x*	*y*	*z*	Max *t* value
Left	Precentral gyrus	-24	-14	58	4.01
Left	Premotor area	-12	-18	58	3.55
Left	Mid-cingulate cortex	-8	-8	44	3.46
Left	Supplementary motor area	-2	-12	56	3.32
Right	Supplementary motor area	2	-14	56	3.31

Note. $p < .005$, family wise error (FWE) $< .05$

Table 6

Brain Areas Activated in the Control Group with the Contrast: Baseline Session > Transfer Session

L/R	Region	*x*	*y*	*z*	Max *t* value
Right	Cerebellar vermis	2	-50	-10	4.19
Left	Parahippocampal gyrus	-16	-24	-22	4.04
Left	Cerebellum	-12	-56	-22	3.98
Right	Cerebellum	8	-50	-20	3.84

Note. $p < .005$, FWE < .05

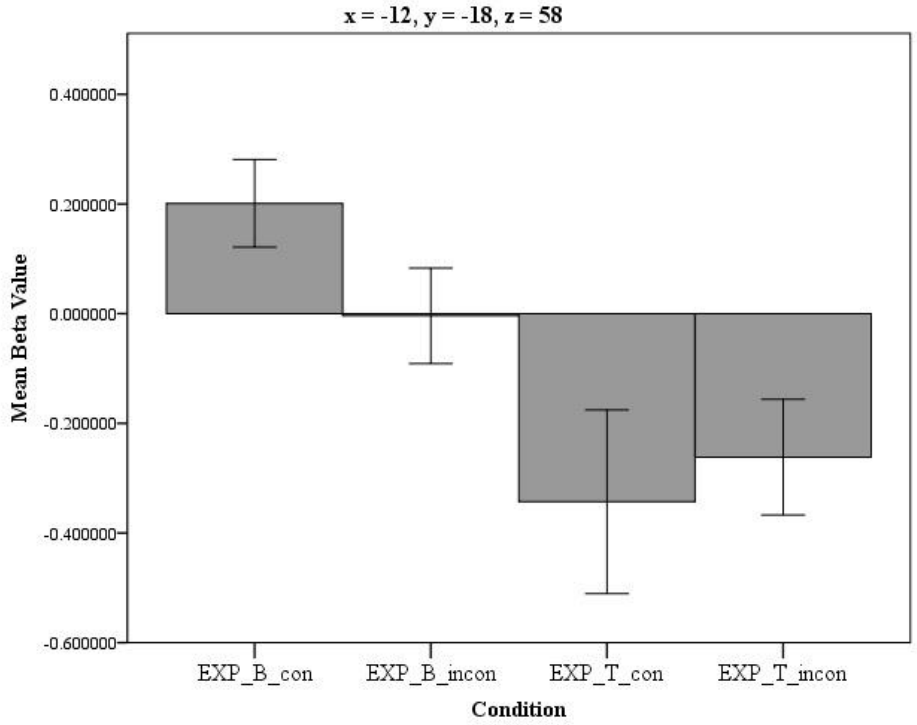

Figure 1. Mean beta values of activation in *x* = -12, *y* = -18, *z* = 58 (premotor area) for the four testing conditions of the experimental group. EXP, experimental group; B, baseline session; T, transfer session; con, congruent condition; incon, incongruent condition. The activation in the transfer session diminishes after practice with incompatible location mapping. Standard errors are represented in the figure by the error bars attached to each column.

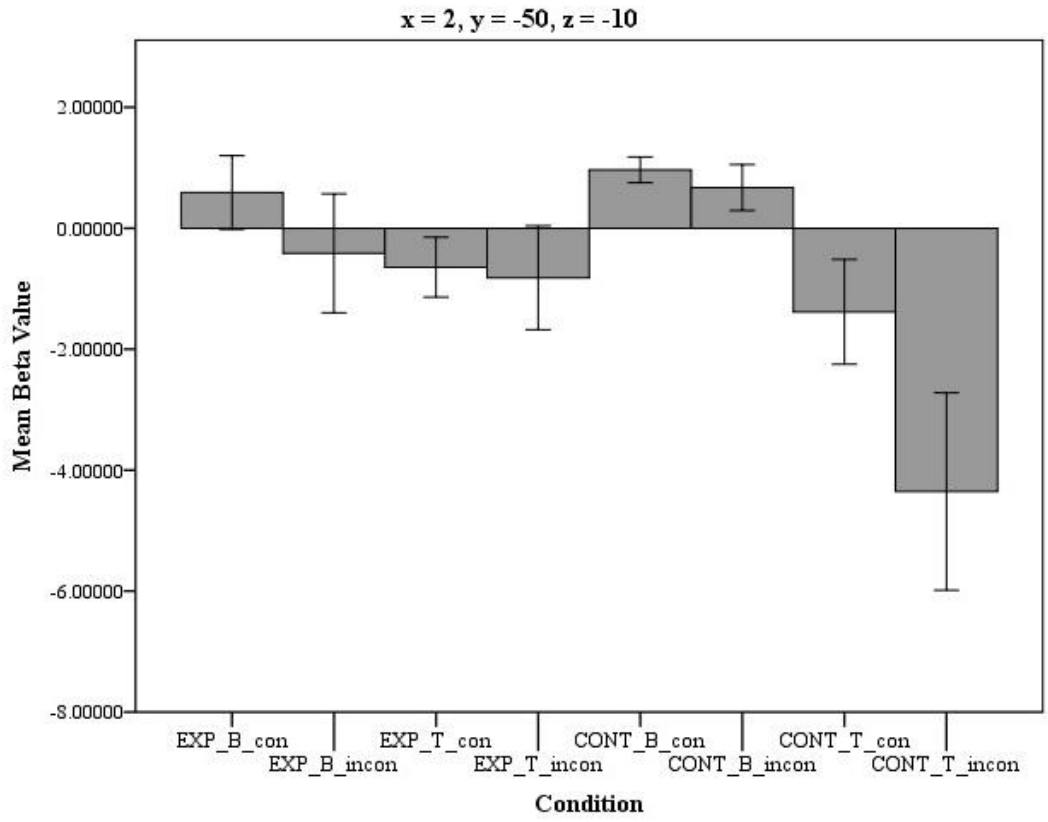

Figure 2. Mean beta values of activation in *x* =2, *y* = -50, *z* = -10 (cerebellar vermis) for the eight testing conditions. EXP, experimental group; CONT, control group; B, baseline session; T, transfer session; con, congruent condition; incon, incongruent condition. The activation in the transfer session of the control group is greatly reduced after practice with compatible location mapping. Standard errors are represented in the figure by the error bars attached to each column.

Discussion

The behavioral results are consistent with previous findings and replicate the Simon effect and the reverse Simon effect. The within group results indicate that the Simon effect was reversed after practice with an incompatible mapping in the experimental group as was predicted. Proctor and Lu (1999) argued that learning incompatible spatial location mappings eliminates or reverses the benefit for corresponding stimuli and response locations after 1800 trials. The present data confirms that a reverse Simon effect is observed after 300 trials of

incompatible location mapping. For the control group who practiced the compatible spatial mapping, the Simon effect was enhanced although the change in performance did not reach statistical significance.

For the practice session, there was a significant interaction between group and location (left, right) for RT and a significant main effect of group. The control group was faster than the experimental group overall, which makes sense according to Botvinick et al. (1999) given the experimental group practiced an incompatible location mapping task which is not automatic and therefore requires greater cognitive/neural computation (see also Botvinick et al., 2001; Tagliabue et al., 2000). In the control group, participants responded faster when the stimulus was presented on the right side than when it was presented on the left side, as all the participants were right-handed. There was also a slight handedness effect (6 ms) in the experimental group but this was not statistically significant, suggesting handedness may be modulated by task demands.

For errors, an interaction between session and spatial congruency was observed for the experimental group, showing that the participants learning the incompatible spatial mapping subsequently made more errors for congruent trials in the transfer session. This suggests that effects of incompatible mapping were at least as strong as the original spatially compatible mapping. For the control group, although no interaction effect was found, the error rate for incompatible trials increased more than for compatible trials in transfer session. This shows that spatial location mapping not only has an effect on reaction time but also on error rate presumably because practice enhances links between the compatible stimulus and response location.

On the other hand, the correlation between scores from the OSPAN task, which was designed to measure working memory of the participants and changes to the Simon effect were not significant. These null results contrast with previous studies such as Tagliabue et al.

(2000). There are several reasons for the failure to replicate here. First, only ten participants were tested in each group and the range of scores in the OSPAN task is limited. The OSPAN task might not be a sensitive enough to measure the working memory demands required for the Simon task. Thus, it is recommended that future studies on the relationship between working memory and the Simon effect exploit other working memory tasks that are more sensitive to the working memory demands in the Simon task.

The imaging results support the hypothesis that neural activation in the Simon task will be different before practice (baseline session) and after practice (transfer session). However, there was no significant difference in neural activation for the congruent and incongruent trials in the control and transfer sessions contrary to prediction. This is likely due to a small sample size. Nonetheless this is the first study to identify a neural correlate for the reverse Simon effect with native English speakers. Somewhat unexpectedly the results showed the effects of practice could be located at a motoric level. In the reverse Simon effect, there was less activation in the premotor area, primary motor area, SMA, mid-cingulate cortex in the transfer session compared to the baseline session for the experimental group.

From the beta values of activation in the right cerebellar vermis ($x = 2$, $y = -50$, $z = -10$) (see Figure 1), we can see there is general practice effect in the cerebellum for both groups and reaction times also reflect a general practice effect for both groups after the transfer session. Cerebellum is related to general motor function (FitzGerald, Gruener, & Mtui, 2012; Laforce Jr. & Doyon, 2001). The reduced activation after practice suggests habituation of the cerebellum through practice. The beta values of the activation in the right cerebellar vermis shows that there is a significant reduction to blood oxygen level, in another words, reduced activation of the same area in the transfer session for the congruent trials in the control group. As the participants in the control group practiced compatible location mapping, this finding confirms that practice led to habituation in the cerebellum and therefore

less activation was then required to carry out a similar motor activity subsequently. It is interesting to note that not only was less neural activity required after practice, reduced reaction time also showed that performance was more efficient after compatible location mapping.

The involvement of the parahippocampal gyrus implicates new learning activity. This is because the parahippocampal gyrus is associated with using the episodic memory system (FitzGerald et al., 2012; Ofen, Kao, Sokol-Hessner, Kim, Whitfield-Gabrieli, & Gabrieli, 2007). In the baseline session, all participants received new learning of stimulus-response mappings as they performed a Simon task for the first time. The diminished activation after practice in the parahippocampal gyrus points to habituation as the Simon task in the transfer session no longer required the episodic memory system after a block of practice.

The findings from the experimental group also implicate the advantage of practice on the subsequent Simon task as there were diminished activations in the premotor area, primary motor area, supplementary area and the mid-cingulate area. The significant reduction in activation in the premotor area (the congruent and incongruent conditions in the transfer session compared to the baseline session in the experimental group as shown in Figure 2 suggests that practice has the effect of requiring less planning for subsequent Simon task performance due to habituation to both the congruent and incongruent trials. The premotor area is necessary for the development of a plan for motor execution (FitzGerald et al., 2012). Diminished activation in this brain region after a block of practice suggests less planning is needed after the location mapping. Diminished activation in the primary motor area (such as at the precentral gyrus, x = -24, y = -14, z = 58) and the left and right SMA also show less activity at the motoric level is required for subsequent Simon task performance after practice. Some practice has led to the habituation of the motor system. This shows an advantage of practice.

The findings in this study have some clinical value. As the results point to a reduction in activation in motor and premotor areas after practice, further research could investigate whether habituation observed in the Simon task is an index of the integrity of motor control for persons with motor speech disorders. Due to the constraint of time and resources, the current study investigated the neural correlates of healthy participants. Future investigations could examine other populations such as those with apraxia of speech. Training programmes for motor speech disorders, such as those for apraxia of speech use motor learning principles (Ballard, Granier & Robin, 2000; Maas, Robin, Austermann Hula, Freedman, Wulf, Ballard & Schmidt, 2008). Among the motor learning principles, is the principle of practice (Maas et al., 2008) that is a crucial factor in predicting success for motor speech training programs. As the Simon task is able to reveal motor changes that are subtle, it might be of value to investigate the role of the Simon task in tapping the integrity of neural correlates prior and after motor speech training programs. It would be of value to find out the predictive value of the Simon task in tapping the changes over time in motor control because this information might be able to inform clinical decisions, such as the setting of treatment targets and goals regarding the intensity and frequency of training based on the integrity of the motor system.

Tagliabue et al. (2000) found that the effect of compatible location mapping on the reverse Simon effect was persistent for as long as seven days. Future research could focus on the retention and transfer of practice and neural correlates of the Simon task with a longer interval between practice and transfer. This may provide useful information about the integrity of neural correlates in motor control. Of clinical value is that retention and transfer of skilled practice in motor speech programs are also important in the field of rehabilitation (Maas et al., 2008). With information about the neural correlates of retention and transfer in practice with Simon task performance it may be possible to inform further investigation on the relevance of the task as an index for the integrity of voluntary control in those patients

requiring motor speech training. Although application of the Simon task to the rehabilitation field still requires intensive investigation, exciting results seems promising.

One of the limitations of the current study is the small sample size. Previous studies of the Simon task usually involved more than 20 participants (see Fan et al., 2003; Proctor et al., 2009 and Tagliabue et al., 2000). If investigation of the neural correlates of Simon effect after practice uses a larger sample size, more significant results may be obtained.

Conclusion

In conclusion, although the current study found no significant differences in neural activation between incongruent condition and congruent conditions prior or after practice in the Simon task, the imaging results support the hypothesis that neural activation during the Simon task is different after practice. The study shows that practice with location mapping results in significantly less activation in regions of the brain that are necessary for controlled movement including the cerebellum and for new learning such as the parahippocampal gyrus. Practice with incompatible location mapping lead to significantly less activation in primary motor cortex, premotor area, SMA, and mid-cingulate cortex. The utility of the Simon task for revealing subtle changes in motor and premotor brain regions after practice raises possible applications to motor rehabilitation training programs such as motor speech training using a noninvasive measure of brain activity and a task that requires no verbal responding and very minimal cognitive demands. The Simon task could also be used as a control task to measure effects of rehabilitation in aphasia. Further investigation on the neural correlates of practice after a longer interval between practice and transfer session would also be recommended.

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Appendix A

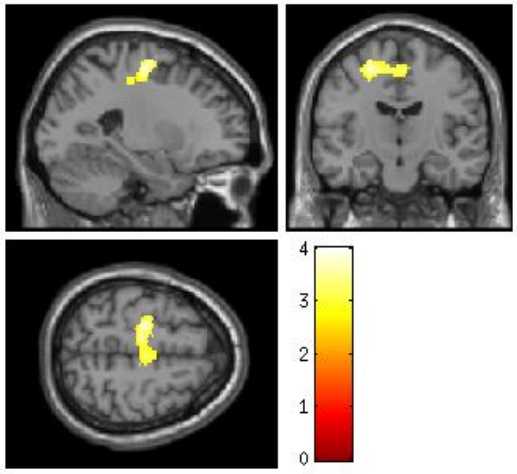

Figure A1. Brain activation in left precentral gyrus (x = -24, y = -14, z = 58) from the baseline session > transfer session contrast of the experimental group.

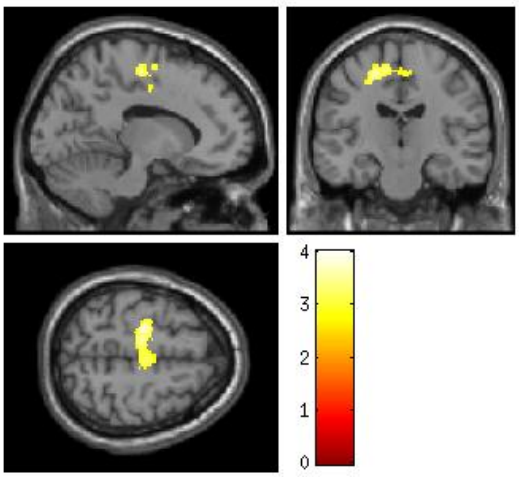

Figure A2. Brain activation in left premotor area (x = -12, y = -18, z = 50) from the baseline session > transfer session contrast of the experimental group.

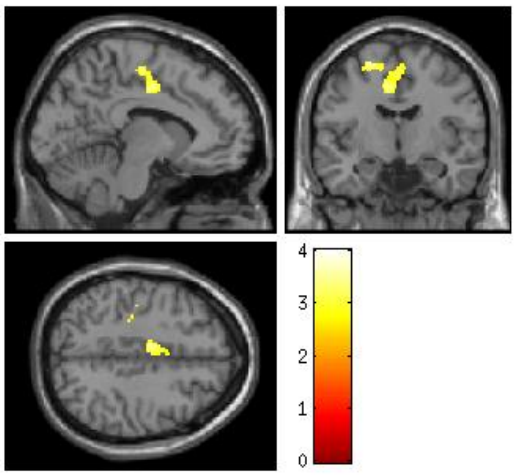

Figure A3. Brain activation in mid-cingulate cortex (x = -8, y = -8, z = 44) from the baseline session > transfer session contrast of the experimental group.

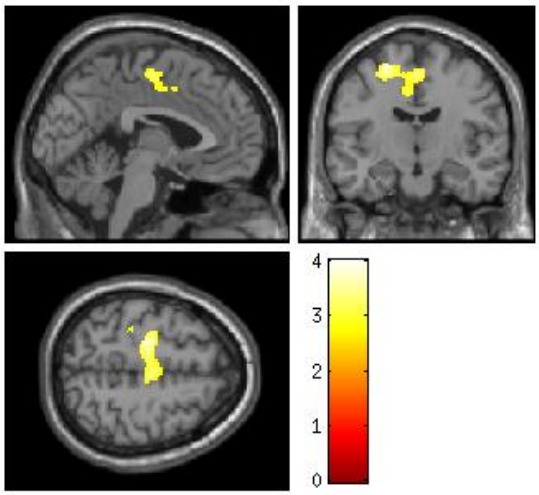

Figure A4. Brain activation in left supplementary motor cortex (SMA) (x = -2, y = -12, z = 56) from the baseline session > transfer session contrast of the experimental group.

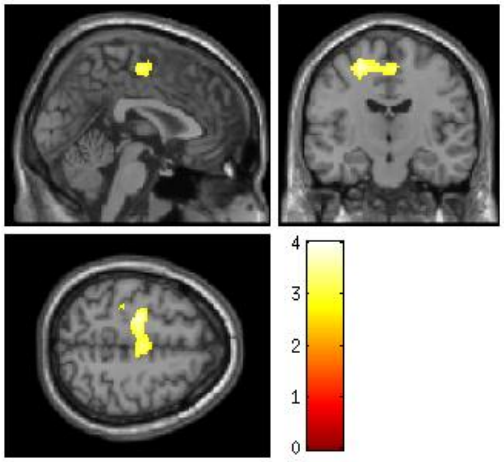

Figure A5. Brain activation in right SMA (x = 2, y = -14, z = 56) from the baseline session > transfer session contrast of the experimental group.

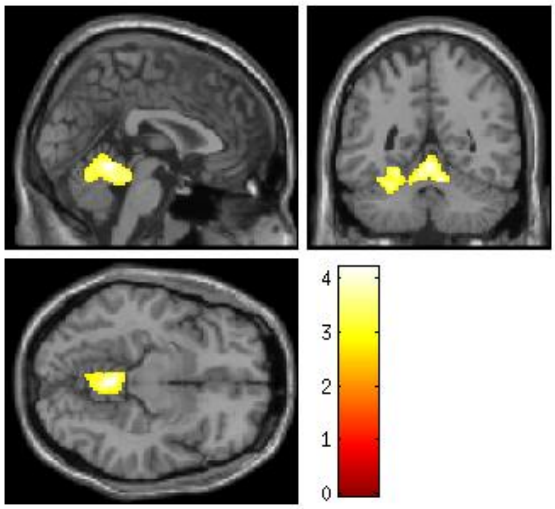

Figure A7. Brain activation in right cerebellar vermis (x = 2, y = -50, z = -10) from the baseline session > transfer session contrast of the control group.

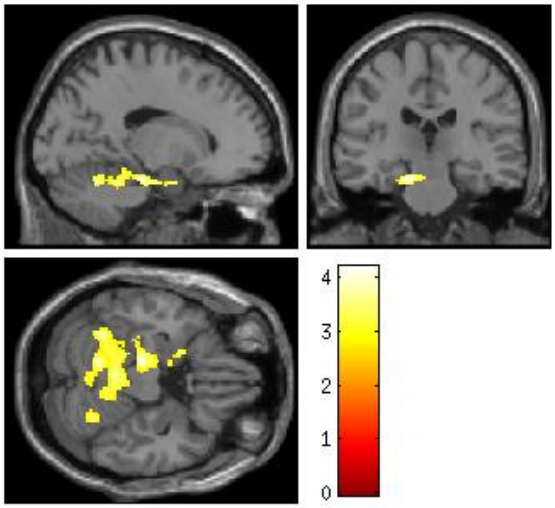

Figure A8. Brain activation in left parahippocampal gyrus (x = -16, y = -24, z = -22) from the baseline session > transfer session contrast of the control group.

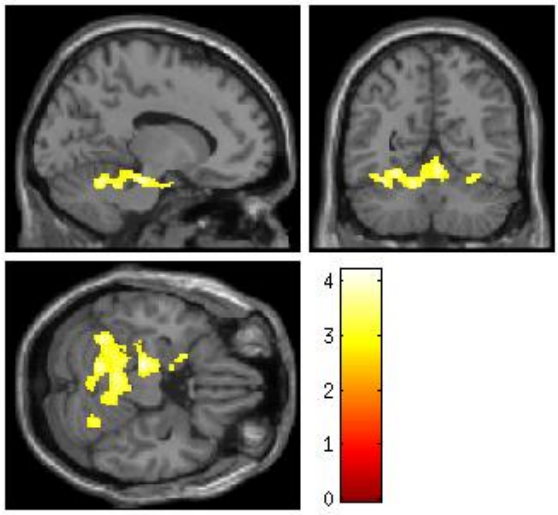

Figure A9. Brain activation in the left cerebellum (x = -12, y = -56, z = -22) from the baseline session > transfer session contrast of the control group.

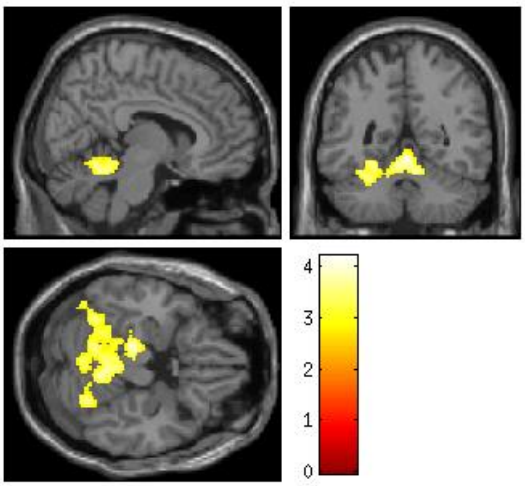

Figure A10. Brain activation in the right cerebellum (x = 8, y = -50, z = -20) from the baseline session > transfer session contrast of the control group.

Appendix B

Questionnaire on language background

Name: _____ Year of Birth:_____ Gender:_____ Phone number: _____

What is your mother language (**L1**)? Please highlight or **bold**: English / Cantonese / Mandarin / Others: _____

What is your second language (**L2**)? Please highlight or **bold**: None / English/ Cantonese / Mandarin / Others: _____

Are you currently learning other languages? No / Yes (please specify: _____ since (MM/YYYY): _____)

Please try to estimate how many hours ***per day*** you use L1 and L2 in your daily life (L1 + L2 will sum up to at most only **24 hours**):

	Activities	**L1**	**L2**	**L1/CT**	**L2/CT**
1	TV				
2	Radio / Music				
3	Family				
4	Courses				
5	Classmates				
6	Friends (not classmates)				
7	Girlfriend / Boyfriend				
8	Hobby				
9	Readings				
10	Writing				
	Total number of hours	**L1 =**	**L2 =**		
	Cumulative total	CT = L1 + L2 =			
	Percent of the day-time	L1/CT =	L2/CT =		