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Citation for published version:
Iveson, MH, Tanida, Y & Saito, S 2016, 'Same task rules, different responses: Goal neglect, stimulus-response mapping and response modalities' Psychonomic Bulletin & Review, vol. 23, no. 6, pp. 1968-1973. DOI: 10.3758/s13423-016-1052-3

Digital Object Identifier (DOI):
10.3758/s13423-016-1052-3

Published In:
Psychonomic Bulletin & Review

Same task rules, different responses: Goal neglect, stimulus-response mappings and response modalities.

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Abstract word count: 222
Main text word count: 3996

Abstract

In order to complete complex tasks individuals must actively maintain task rules so as to correctly direct behavior. Failure to use task rules appropriately, termed goal neglect, has been shown across both vocal and manual response modalities. However, previous goal maintenance studies have differed not only in the response modality which they require, but also in the complexity of the stimulus-response mappings participants must use during the task. The present study examines the effects of both response modality and stimulus-response mapping complexity, separately, on the rate of goal neglect in a modification of a classic goal maintenance task. Seventy-two younger adults were administered a shape-monitoring task, with three between-subjects response conditions: a vocal response with a simple stimulus-response mapping, a vocal response with a complex stimulus-response mapping, and a manual response with a complex stimulus-response mapping. Contrasting the rate at which task rules were neglected between response conditions showed that participants using complex stimulus-response mappings committed more frequent goal neglect than those using simple mappings, but that participants using vocal or manual responses did not differ in their rate of goal neglect once both responses required complex mappings. This suggests that the need to represent novel and complex stimulus-response mappings, of any modality, at the same time as novel task rules within working memory leads to some task rules being insufficiently maintained.

Goal maintenance is the process by which task rules and instructions are held actively in-mind so as to control behavior during the task. When maintenance of a rule fails it appears to be ignored during the task, even though participants are able to accurately recall it after the task has finished (Duncan, Emslie, Williams, Johnson, & Freer, 1996). Such online ‘goal neglect’ has been demonstrated in the normal population using a variety of tasks. For example, Duncan and colleagues (1996; 2008) have administered the letter-monitoring task, involving a rapid series of letter- and number-pairs, interspersed by cues indicating which side of the screen participants must respond to. Goal neglect in this task often manifests as a failure to follow these side cues, with participants – particularly those with lower levels of fluid intelligence – verbally reporting letters from the incorrect side. Similarly, in the color-word Stroop task, Kane and Engle (2003) have demonstrated that participants incorrectly verbally name the words rather than the stimulus color when maintenance of the color-naming rule is not encouraged. In these tasks, goal maintenance becomes harder as the complexity of the task rules increases, leading to more frequent task-irrelevant verbal responses (e.g., Duncan et al., 2008).

Instead of verbal responses, recent work has assessed goal neglect in tasks requiring manual responses, such as complex feature-matching tasks (e.g., Roberts & Anderson, 2014) and Stroop tasks (e.g., Galer, Schmitz, Leproult, De Tiège, Van Bogaert, & Peigneux, 2014). Similar to the letter-monitoring task, goal neglect in these tasks presents as inappropriate responses, with participants pressing a key associated with task-irrelevant stimuli. As in verbal tasks, introducing more complex task rules has been shown to increase the number of inappropriate manual responses (e.g., intrusion errors), due to the increased goal maintenance load (e.g., Roberts & Anderson, 2014).

Although goal neglect has been observed in both vocal and manual responses, the rate of goal neglect has never been formally compared between modalities, and it is unclear whether a common factor underlies performance in both types of task. Unlike vocal response tasks, manual response tasks tend to require the use of complex stimulus-response (S-R) mappings in addition to the rules of the task itself (e.g., color-key associations in the Stroop task; Galer et al., 2014). Previous work has shown that, like task rules (Duncan et al., 2008; Saeki & Saito, 2009), novel S-R mappings require working memory resources in order to be represented and used throughout the task (van't Wout, Lavric, & Monsell, 2013). As both task rules and S-R mappings form part of the same task set, the rate of goal neglect in manual tasks may be driven by the additive working memory load resulting from concurrently maintaining complex S-R mappings. Indeed, in a task-switching study, Houghton, Pritchard, and Grange (2009) have demonstrated that more complex S-R mappings increase the rate of goal neglect exhibited when returning to a previously-used task (i.e., greater backwards inhibition).

However, the consequences of complex S-R mappings for goal neglect may not be inherent to manual tasks. If S-R mapping complexity results in concurrent working memory load, then differences in the rate of goal neglect between simple and complex response tasks should also be observable within a verbal modality. Furthermore, similar rates of goal neglect should be observed between manual and verbal response conditions once equated for the complexity of task rules and the complexity of S-R mappings. The present study examined this relationship between S-R mapping complexity, response modality, and goal neglect by administering three response conditions in a shape-monitoring task designed to test goal maintenance (similar to the letter-monitoring task described by Duncan et al., 1996). The effect of S-R mapping complexity was investigated by comparing performance between two vocal conditions – one with a simple, well-learned S-R mapping (i.e., "circle" for circles) and one with a complex, arbitrary mapping (e.g., "sari" for circles). The effect of response modality was investigated by contrasting the rate of goal neglect in a vocal condition and a manual condition, both of which required complex, arbitrary S-R mappings. Crucially, the instructions given in each condition were identical in order to hold task rule-related goal maintenance load constant.

Method

Participants

Seventy-two younger adults (aged 18-32 years-old) were recruited from the

Kyoto University undergraduate and postgraduate students' pool – 24 participants in each of the three response conditions. Individuals received a book token for their participation. In accordance with the Declaration of Helsinki, written informed consent was collected prior to the experiment, and debriefing was given after the study had finished. The study was approved by the Psychological Research Ethics Committee at the Graduate School of Education, Kyoto University.

Demographic details for each participant group are shown in Table 1. Between the three response conditions, there was no significant difference in terms of intelligence, $F(2, 69) = 0.43$, $p = 0.65$, $\eta^2 = 0.01$, years of age, $F(2, 69) = 0.31$, $p = 0.74$, $\eta^2 = 0.01$, or time spent in full-time education, $F(2, 69) = 0.89$, $p = 0.41$, $\eta^2 = 0.03$.

-Insert Table 1 around here-

Procedure

The shape-monitoring task

The shape-monitoring task was based on the letter-monitoring task reported by Duncan et al. (1996). It rapidly presented a series of pairs of black shapes in the middle of a white computer screen (see Figure 1). Each shape in the pair was 0.5 degrees of visual angle (deg) tall and wide. For each pair, one shape appeared 0.85 deg to the left and the other 0.85 deg to the right of the center; left and right positions were assigned randomly. Target pairs consisted of a circle and a star. Non-target pairs consisted of two triangles, with the orientation of each assigned randomly from either 0° or 180°. A total of 12 trials (each with 13 shape pairs) were presented.

-Insert Figure 1 around here-

Although described in English here, all instructions and stimuli were presented in Japanese. Each trial began with a First Side Instruction (FSI) – either "Watch left" or "Watch right" – that told participants which side of the screen to respond to. This FSI cue was presented for 1000ms, with a 200ms blank interval after. Then followed 10 shape pairs (5 target pairs and 5 non-target pairs, randomly selected and ordered), each presented for 200ms with a 200ms inter-stimulus interval. Notably, this meant that participants had only a 400ms window to respond. After 10 pairs a Second Side Instruction (SSI) cue – either a “+” or a “-” sign – appeared in the middle of the screen for 200ms and again indicated which side of the screen (right and left respectively) to attend to. Equal numbers of ‘stay’ (i.e., where the FSI and SSI cues indicated the same side) and ‘switch’ (i.e., where the FSI and SSI cues indicated opposite sides) trials were presented in a pseudorandom order. Then followed 3 shape pairs, the first of which was always a non-target pair. The final 2 pairs were randomly selected from possible target pairs.

Participants were assigned to one of three response conditions – simple vocal responses, complex vocal responses, or complex manual responses. In the two vocal conditions (simple vocal and complex vocal), participants responded out-loud. In the simple vocal condition, participants responded “Maru” (“Circle” in Japanese) to circles and “Hoshi” (“Star” in Japanese) to stars. In the complex vocal condition, participants responded using non-words chosen for their high phonotactic frequency: “Sari” to circles, and “Kuno” to stars. In the complex manual condition, participants responded by pressing the left (for circles) or right (for stars) arrow keys on a keyboard using their dominant hand. The keys were labelled with the relevant shape. For all three response conditions, S-R mapping prompt sheets were placed in front of the participant throughout the task. All participants then practiced the relevant mappings over 48 trials in which a single star or circle (24 trials of each) appeared in the middle of the screen for 200ms, with a 200ms ISI.

After practicing the S-R mappings, participants were given 3 task instructions: 1) to only respond to stars and circles, and not triangles; 2) to respond only to shapes from one side of the screen, indicated by the FSI cue; 3) to follow the SSI cue, and switch or stay as indicated. Participants then received practice trials until they produced a response and could recall the rules to the experimenter. Recall of the rules was also assessed after the task had ended.

Other measures

The Cattell Culture Fair Test of Intelligence – Form 2A (IPAT, 1978) was used to measure fluid intelligence. Administration was conducted according to standard instructions translated into Japanese from the test manual. Scoring and transformation into full-scale intelligence scores were conducted as detailed in the test manual.

Data Analysis

Goal Neglect

All participants could recall the 3 instructions both before and after the shape-monitoring task, ensuring that poor performance did not result from forgetting the task rules. Furthermore, all participants reported seeing the SSI cue when debriefed after the task. Consistent with previous studies, the percentage of correct responses during the pre-SSI phase was taken as a measure of task difficulty (Duncan et al., 1996; 2008). Goal neglect was measured in each trial using a weighted measure of post-SSI performance – the Side Error score (Duncan et al., 2008). If, during the post-SSI phase, more shapes were reported from the cued- than the uncued-side a trial received a Side Error score of 0. If more uncued than cued shapes were reported the trial received a score of 1. If there were equal numbers of cued and uncued shapes reported, or no responses were given, the trial received a score of 0.5. The Mean Side Error (MSE) score was calculated by averaging Side Error scores across all 12 trials. Neglect of the SSI cue (i.e., continuing to report from the initially-cued side) throughout the task should lead to a MSE score of 0.5 (i.e., goal neglect on half of trials; see Duncan et al., 2008), with higher MSE scores indicating more frequent goal neglect errors.

The effect of S-R mapping complexity was examined by contrasting pre-SSI accuracy and MSE scores between the simple vocal and complex vocal response conditions using a 2-tailed Welch's t-test. Response modality effects were similarly examined by contrasting both pre-SSI accuracy and MSE scores between the complex vocal and complex manual response conditions. In order to demonstrate that neglect of the SSI cue in the complex conditions was not due to a response-induced psychological refractory period, post-hoc within-subjects t-tests contrasted MSE scores between trials in which the SSI was preceded by a target pair (circle/star) and trials in which the SSI was preceded by a non-target pair (triangles). As target and non-target pairs were distributed randomly in the pre-SSI phase, this analysis was weighted by the number of each trial type performed. Finally, correlations between MSE scores and fluid intelligence scores were calculated for each of the three response conditions.

Results

-Insert Figure 2 around here-

Pre-SSI performance

Participants made significantly fewer pre-SSI errors in the simple vocal condition than in the complex vocal condition (see Figure 2A), $t(47) = -5.77$, $p < 0.001$, *95% CI* [-10.16, -3.71], $d = 1.68$. This was despite participants in the complex vocal condition experiencing significantly more practice trials ($M = 1.21$, $SD = 0.51$) than those in the simple vocal condition ($M = 1.08$, $SD = 0.28$), $t(47) = 2.82$, $p < 0.01$, 95% CI [0.10, 0.65], $d = 0.82$.

Complex vocal participants made significantly fewer errors in the pre-SSI phase than those in the complex manual condition (see Figure 2A), $t(47) = 7.64$, $p < 0.001$, *95% CI* [8.78, 16.43], $d = 2.23$. Examining types of errors, the number of pre-SSI intrusion errors (i.e., responding to a shape from the uncued-side) did not significantly differ between the modalities (complex vocal: $M = 6.42$, $SD = 6.11$; complex manual: $M = 6.12$, $SD = 3.92$), $t(47) = 0.20$, $p = 0.85$, *95% CI* [-3.16, 3.75], $d = 0.06$, but participants in the complex manual condition ($M = 18.83$, $SD = 5.04$) committed significantly more pre-SSI non-response errors than those in the complex vocal condition ($M = 3.42$, $SD = 2.99$), $t(47) = -12.89$, $p < 0.001$, *95% CI* [-18.21, -12.62], $d = 3.76$.

Post-SSI performance

Examining MSE scores, participants in the complex vocal condition committed significantly more goal neglect errors in the post-SSI phase than those in the simple vocal condition (see Figure 2B), $t(47) = 5.58$, $p < 0.001$, *95% CI* [0.14, 0.33], indicating poorer use of the SSI rule. Neglect of the SSI cue was common regardless of whether it was preceded by a complex response (*Weighted M* = 0.30) or not (*Weighted M* = 0.31), $t(285.98) = -0.35$, $p = 0.72$.

There was no significant difference in MSE scores between the complex vocal and complex manual response conditions (see Figure 2B), $t(47) = 0.04$, $p = 0.97$, *95% CI* [-0.11, 0.11]. Similarly, in the complex manual condition, there was no significant difference in MSE scores when the SSI was (*Weighted M* = 0.29) or was not (*Weighted M* = 0.33) preceded by a response, $t(278.45) = -1.71$, $p = 0.09$.

The correlation between intelligence scores and MSE scores was not significant in either the simple vocal condition, $r = 0.26$, $p = 0.22$, the complex vocal condition, $r = -0.004$, $p = 0.98$, or the complex manual condition, $r = -0.21$, $p = 0.33$.

Discussion

The present study investigated whether the rate of goal neglect could be affected by the modality of response or by the complexity of the stimulus-response (S-R) mapping to be used. Previous goal maintenance studies have observed frequent goal neglect in both vocal (e.g., Duncan et al., 2008) and manual (e.g., Galer et al., 2014) response modalities. However, these studies have differed in the complexity of S-R mappings required. Consistent with these reports, the present study observed that goal neglect (i.e., failure to use the SSI rule) was equally common in both vocal and manual modalities. However, within a (vocal) modality, neglect of critical task rules was more frequent when participants had to use more complex S-R mappings.

Goal neglect and response modality

Although the complex manual condition proved to be more difficult than the complex vocal condition, as evidenced by the pattern of pre-SSI accuracy, this difficulty did not affect neglect of the task rules. Indeed, MSE scores were similar between the modalities, suggesting that vocal and manual responses place roughly equivalent demands on goal maintenance processes. Notably, the task rules and level of S-R complexity were similar between the complex manual and complex vocal conditions. This is consistent with observations that goal neglect is influenced by the complexity of the task model, rather than the online demands of the task (Duncan et al., 2008; Bhandari & Duncan, 2014); similarly-complex task models will result in similar maintenance demands.

Goal neglect and stimulus-response complexity

Although the frequency of goal neglect did not differ between the modalities, neglect-like errors were more common in the complex vocal condition than the simple vocal condition. However, in the complex response conditions participants had to not only maintain more complex S-R mappings but also use them within the time constraints. As such, task difficulty – as indicated by pre-SSI performance – was also higher in the complex response conditions. It is therefore possible that the online attentional demands of the complex response conditions (particularly the complex manual condition), combined with the limited time window for responses, drove poor post-SSI performance (see Duncan et al., 2008). Similarly, production of a complex response may have caused a delay in the processing of subsequent stimuli, thus creating an attentional blink-like phenomena similar to the psychological refractory period (e.g., Jolicoeur, 1998). However, neither the attentional demands nor the attentional blink assumptions can fully explain the pattern of our data.

In terms of attentional demands, if participants simply struggled to produce a more complex response within the 400ms response window then this should have equally affected both the pre- and post-SSI phases (see Iveson, Della Sala, Anderson, & MacPherson, in press). Pre-SSI performance was poorest in the complex manual condition, indicating that participants struggled to produce a speeded response relative to those in the complex vocal condition. MSE scores, however, did not increase in line with this task difficulty. This pattern is consistent with Duncan et al.’s (2008) finding that manipulating the online attentional demands of each frame, by increasing the number of stimuli from 2 to 4, only affects pre-SSI performance and not MSE scores.

Similarly, the attentional blink assumption predicts that MSE scores should have been higher when a response preceded the SSI cue. However this was not the case; neglect of the SSI cue was frequent even when a response was not required immediately before it. Furthermore, while Duncan et al. (1996) have shown that requiring additional responses (using a dual-task paradigm) during the letter-monitoring task results in self-reported attentional blindness to the SSI cue, all participants in the present study reported being able to see the SSI cue when debriefed after the task, even when using complex S-R mappings.

Another possible cause of the poor performance in complex S-R conditions is competition between learned and arbitrary responses (e.g., MacLeod & Dunbar, 1988; Hommel, 1998). Kane and Engle (2003) have raised similar concerns in their examination of Stroop interference, noting the contribution of both response competition and goal maintenance to intrusion errors. In the present study, this response competition assumption predicts that performance should be particularly poor in the complex vocal condition where there is strong competition between the novel non-word mapping (e.g., a circle with “sari”) and the familiar word mapping (e.g., a circle with “maru”). Again, this was not the case.

Instead of being driven by attentional demands or response competition, we suggest that goal neglect in the complex response conditions arises from the need to maintain a complex S-R mapping alongside already complex task rules. Indeed, the S-R complexity effect resembles the instruction load effect reported by Duncan et al. (2008; see also Roberts, Jones, Davis, Ly, & Anderson, 2014) where maintaining more task rules taxes the capacity of the working memory systems involved, resulting in frequent neglect of the task-relevant information presented last during the instruction phase – the SSI rule. In the present study, however, three identical task rules were presented regardless of the condition. Therefore, the increase in goal neglect with S-R complexity indicates that maintaining complex S-R mappings likewise taxes working memory resources. This concurrent load may be driven by the relative novelty of the complex, arbitrary mappings in the present task. Novel S-R mappings, such as the shape to non-word pairings used in the complex vocal condition, have been shown to rely on working memory and top-down cognitive control, and this reliance diminishes with practice (Mayr & Kliegl, 2000; van't Wout et al., 2013). More familiar S-R mappings, such as the shape to word pairings used in the simple vocal condition, become proceduralized (Hommel, 1998) and can be used efficiently without working memory involvement (Oberauer, 2009). This is similar to the suggestion that familiar task goals can be passively followed without requiring active cognitive control (Duncan et al., 1996), and that transparent task goals can be followed despite online suppression of working memory (Saeki & Saito, 2009). As such, ensuring S-R mappings are well-practiced, and so are proceduralized, prior to the task may reduce the effect of complexity in goal neglect.

Unlike the present study, previous work has demonstrated strong correlations between intelligence and MSE scores, with less frequent goal neglect in highly-intelligent individuals (e.g., Duncan et al., 1996; Bhandari & Duncan, 2014). In the present study, the strength of this correlation is likely limited by the narrow range of intelligence scores observed. Furthermore, the high MSE scores exhibited by highly-intelligent individuals indicates that they are not immune to goal neglect. Given that young, intelligent individuals tend to adopt a proactive approach to goal maintenance – activating task rules before they are required, rather than activating them in response to task stimuli (Braver, 2012) – it is likely that goal neglect resulted from fluctuations in sustained maintenance leading up to the SSI cue rather than an absolute failure in goal maintenance (see Kane & Engle, 2003; West, 2001). Regardless, a similar pattern of complexity effects should be apparent in individuals with lower levels of intelligence, such as those used in previous studies of goal neglect (e.g., Duncan et al., 1996; 2008).

The present study suggests that goal maintenance load can be affected by the complexity of the S-R mappings to be used. The need to maintain novel S-R mappings alongside complex task rules results in neglect of rules that are critical to performance.

However, once the effect of complexity is accounted for, goal maintenance load does not fundamentally change according to the modality of responses required. Indeed, the results presented here lend support to previous observations of frequent neglect of important task rules in both vocal and manual tasks.

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Table 1. Demographic details for participants in each response condition.

	Response condition					
	Simple Vocal (N = 24)		Complex Vocal (N = 24)		Complex Manual (N = 24)	
	Mean	SD	Mean	SD	Mean	SD
Full-scale intelligence	134.50	13.46	138.08	14.22	136.58	12.82
Age (in years)	20.92	1.89	20.46	2.79	20.92	2.34
Years of full-time education	13.96	1.57	14.46	2.69	14.79	2.13
Gender (female/male)	9/15		10/14		10/14	
Handedness (left/ambidextrous/right)	3/0/21		1/1/22		2/1/21	

Figure captions

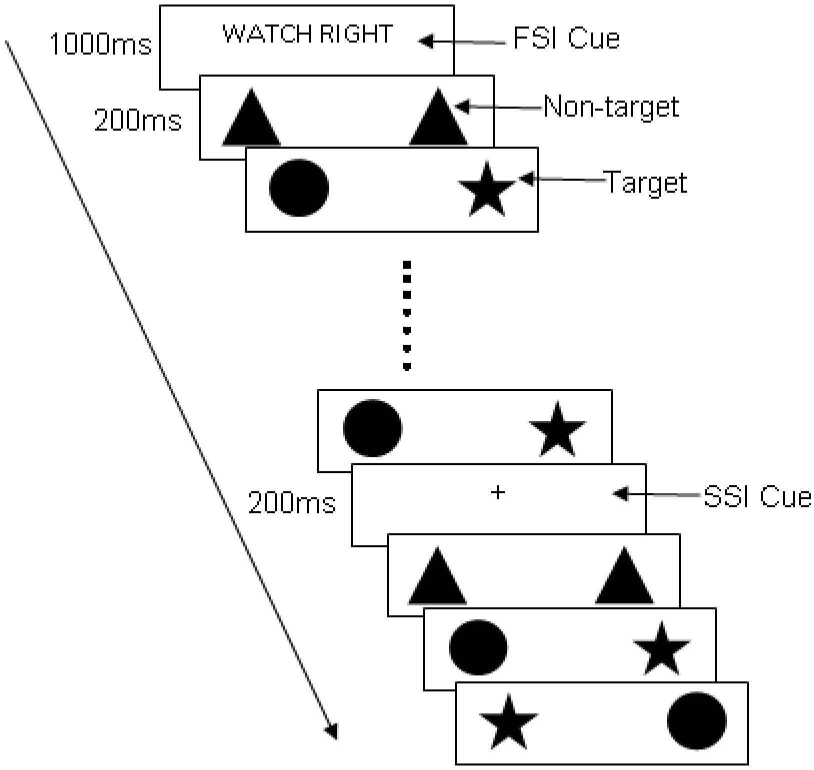

Figure 1. The time course of an example trial from the shape-monitoring task.

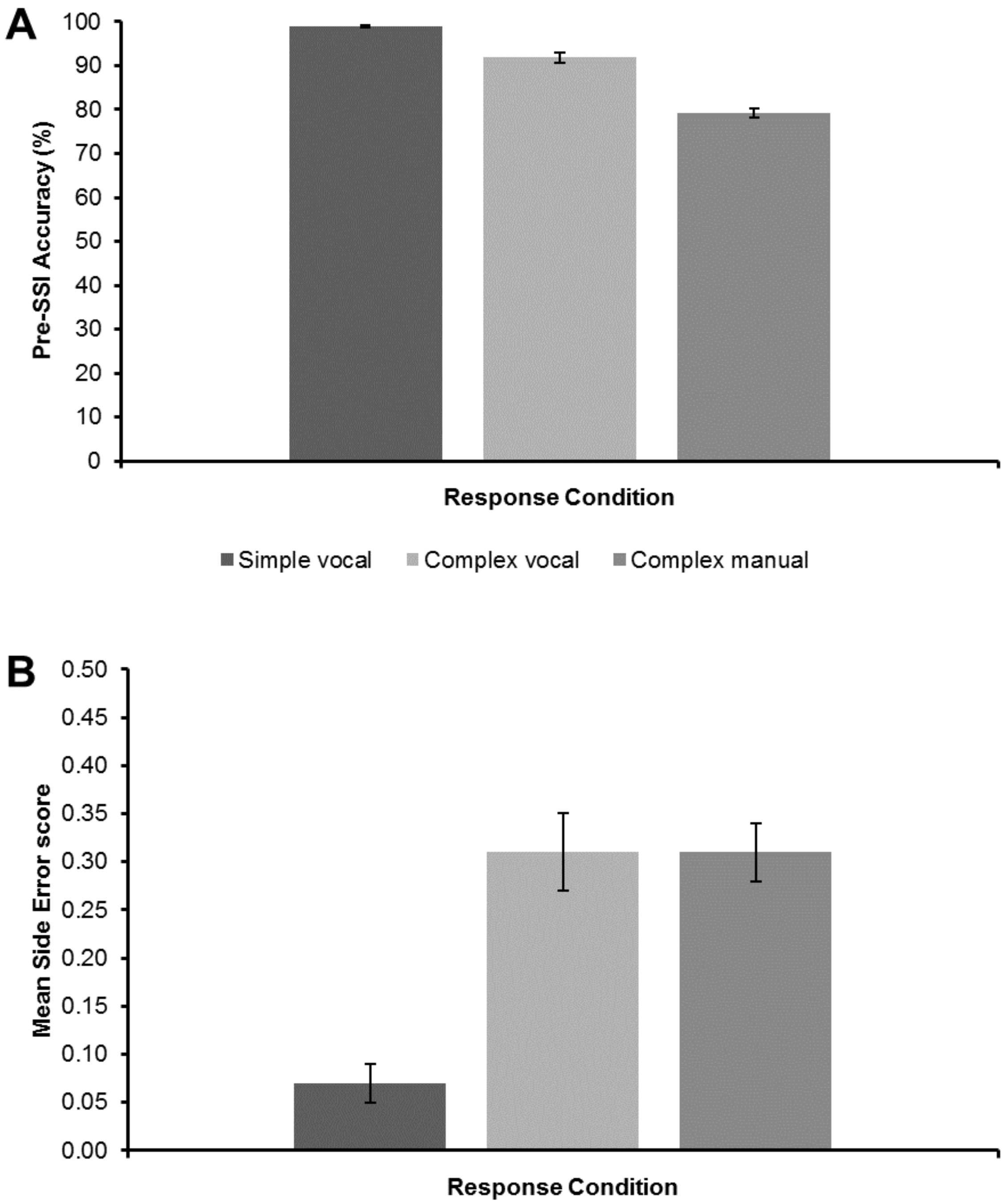

Figure 2. (A) Pre-SSI accuracy (percentage correct) and (B) MSE scores, for Simple vocal (N = 24), Complex vocal (N = 24) and Complex Manual (N = 24) conditions. Error bars represent +/- 1 SE.