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

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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, in which participants are presented with 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, particularly when the cues indicate a switch of attention to the other side of the screen. Similarly, in the color-word Stroop task, Kane and Engle (2003) demonstrated that participants incorrectly verbally name the words rather than the stimulus color when maintenance of the color-naming rule is not encouraged.

Instead of verbal responses, more recent work has assessed goal neglect in either complex feature-matching tasks (e.g., Bhandari & Duncan, 2014) or Stroop tasks (e.g., Galer, Schmitz, Leproult, De Tiège, Van Bogaert, & Peigneux, 2014) using manual responses. Similar to the letter-monitoring task, goal neglect in these tasks presents as inappropriate responses, with participants pressing an inappropriate key or producing responses to inappropriate stimuli. In both vocal goal maintenance tasks such as the letter-monitoring task (Duncan et al., 2008) and manual goal maintenance tasks such as the feature-matching task (Bhandari & Duncan, 2014), increasing the complexity of the task rules presented to participants further increases the rate of goal neglect. As the task rules to be maintained and used become more complex one or more task rules are insufficiently maintained, leading to frequent neglect-like behavior.

Although goal neglect has been observed in both vocal and manual responses, the rate of goal neglect has never been formally compared between different 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 and colleagues (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; Houghton, Pritchard, & Grange, 2009).

However, the consequences of complex S-R mappings for goal neglect may not be inherent to manual tasks. Once equated for the number of task rules (Duncan et al., 2008) and the complexity of S-R mappings, similar rates of goal neglect may be observed between manual and other response conditions. Furthermore, 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 be observable within a response modality. 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 from each participant 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 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 structure of 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, and non-target pairs consisted of two triangles. In the case of non-target triangles, the orientation of each was 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" – which 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 during which to make a response. 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 SSI cue indicated the same side as the FSI cue) and 'switch' (i.e., where the SSI cue indicated the opposite side as the FSI cue) 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 versions of the task (simple vocal and complex vocal), participants responded out-loud. In the vocal task with a simple S-R mapping, participants were required to respond "Maru" ("Circle" in Japanese) to circles and "Hoshi" ("Star" in Japanese) to stars. In the vocal task with a complex S-R mapping, participants were required to respond using non-words: "Sari" to circles, and "Kuno" to stars. These non-words were chosen for their high phonotactic frequency. In the complex manual version of the task, 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, response mapping prompt sheets were placed in front of the participant throughout the task. All participants then had the chance to practice 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 were able to 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 administered to each participant as a measure of 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 was not a result of 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 side than the uncued side a trial was assigned a Side Error score of 0. If more uncued shapes were reported than cued shapes the trial received a score of 1. If there were equal numbers of cued and uncued shapes reported, or no responses were given at all during the post-SSI phase, the trial was given 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 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 that participants contributed. Finally, correlations between MSE scores and fluid intelligence scores were calculated for each of the three response conditions.

Results

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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 intrusion errors (i.e., responding to the shape on the uncued side) committed during the pre-SSI phase 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 non-response errors in the pre-SSI phase 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

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. A post-hoc t-test demonstrated that neglect of the SSI cue was common regardless of whether it was preceded by a complex response (Weighted Mean = 0.30) or not (Weighted Mean = 0.31), t(285.98) = -0.35, p = 0.72.

However, there was no significant difference in the number of goal neglect errors committed 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 Mean = 0.29) or was not (Weighted Mean = 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 in which responses were given 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 differ not just in terms of the modality of responses, but also in the complexity of S-R mappings they use. 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, when comparing within a (vocal) modality, the rate of goal neglect appeared to be sensitive to the complexity of the S-R mappings required by the task, with more frequent goal neglect when more complex mappings were maintained.

Goal neglect and response modality

Despite the difference in difficulty between the complex vocal and complex manual conditions, as evidenced by the pattern of pre-SSI accuracy, MSE scores were similar between the modalities. As such, vocal and manual responses appear to place roughly equivalent demands on goal maintenance processes. Duncan and colleagues (Duncan et al., 2008; Bhandari & Duncan, 2014) have previously shown that the rate of goal neglect is sensitive to the type and number of task rules presented. In our task, the task rules were identical between conditions, resulting in a similar goal maintenance load between the vocal and manual response conditions of similar S-R complexity.

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. Notably, task difficulty – as indicated by pre-SSI performance – was also higher in the complex response conditions. In these conditions, participants not only had to maintain more complex S-R mappings but also had to use them within the time constraints of the task. Thus, it is possible that the online attentional demands of the complex response conditions (particularly the complex manual condition) may have driven poor post-SSI performance. Furthermore, 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. The attentional demands or attentional blink assumptions, however, cannot fully explain the pattern of our data.

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 et al., in press). Note that 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.

The attentional blink assumption predicts that MSE scores should have been higher when a response preceded the SSI cue. However, neglect of the SSI cue was frequent even when a response was not required immediately before it. Furthermore, Duncan and colleagues (1996) noted that inducing attentional blindness to the SSI cue (by introducing a dual-task component) results in participants reporting being unable to detect the cue. In the present study, all participants reported seeing the SSI cue when debriefed after the task.

Another possible cause of the increased frequency of goal neglects could be response competition between learned responses and arbitrary responses in the complex S-R mapping conditions. This response competition assumption predicts that performance should be particularly poor in the complex vocal condition where response competition is strongest (e.g., a circle associates with both the word "maru" and the non-word "sari"). Again, this was not the case.

Instead of task difficulty, we suggest that goal neglect in the complex response conditions is driven by 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 SSI rule. Since the number of task rules were equivalent between response conditions, more frequent goal neglect in the complex vocal condition indicates that maintaining complex S-R mappings likewise taxes working memory resources. As observed by Duncan and colleagues (1996; 2008), it is the task rule presented last – the SSI rule – which is consequently neglected. 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 (see Hommel, 1998) and do not require active representation within working memory in order to be used efficiently (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 use of transparent task goals can be achieved 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 complexity effects in terms of 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 caution when designing goal maintenance tasks. If participants must use unfamiliar S-R mappings then goal neglect may be unintentionally frequent regardless of any manipulation of goal maintenance load. However, future research may find confidence in the observation that the modality of responses does not fundamentally change the goal maintenance load presented by the task, only the difficulty of the task. Indeed, the results presented here lend support to previous observations of frequent goal neglect in both vocal and manual response modalities.

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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

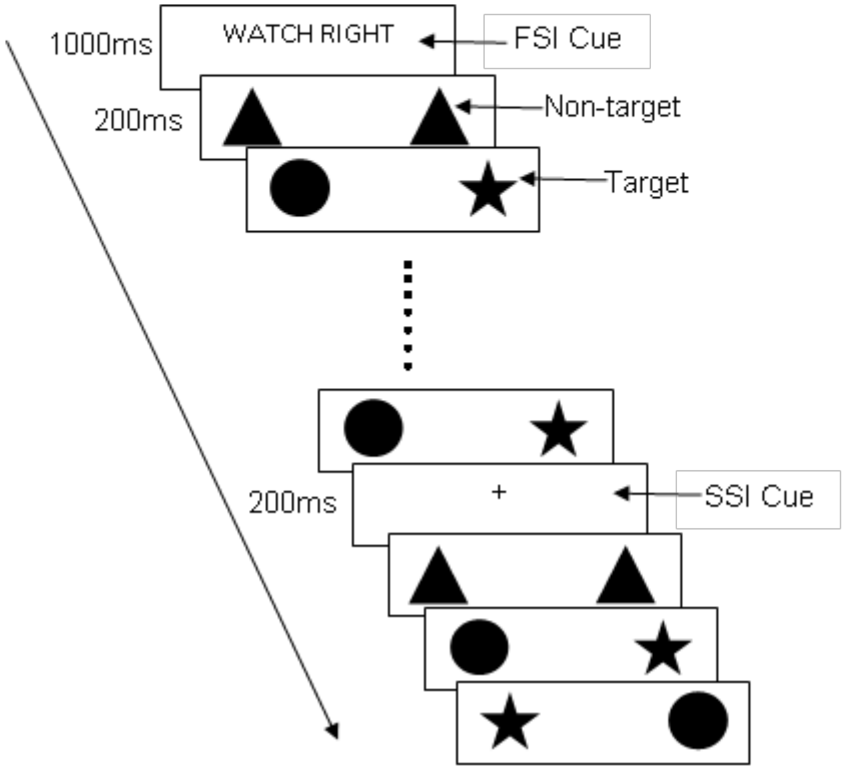
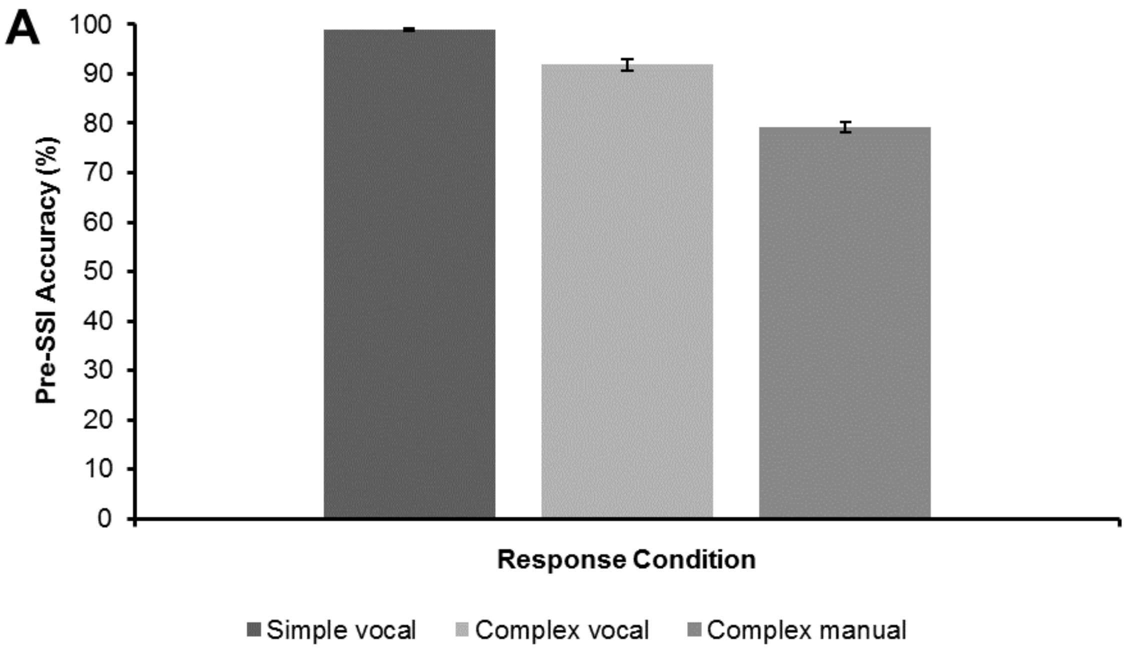


Figure 1. The time course of an example trial from the shape-monitoring task.



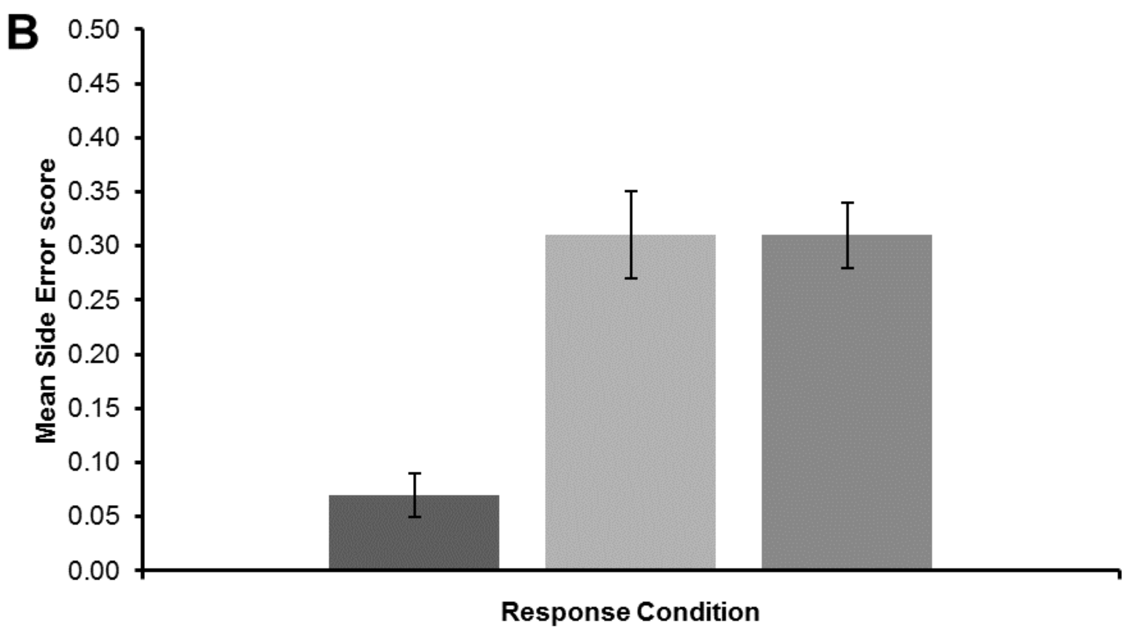


Figure 2. (A) Pre-SSI accuracy (percentage correct) and (B) MSE scores, for Simple vocal (N = 24), Complex vocal (N = 24) and Complex Manual (N = 24) conditions. Error bars represent +/- 1 SE.