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Feature integration is not the whole story of the sequence effects of symbolic cueing

Qian Qian[a,b], Jiawen Pan[a,b], Miao Song[c], Yong Feng[a], Yunfa Fu[a,b] and Keizo Shinomori[d,e]

[a]Yunnan Key Laboratory of Computer Technology Applications, Faculty of Information Engineering and Automation, Kunming University of Science and Technology, Kunming, People's Republic of China; [b]Brain Cognition and Brain-Computer Intelligence Fusion Innovation Group, Kunming University of Science and Technology, Kunming, People's Republic of China; [c]School of Information and Engineering, Shanghai Maritime University, Shanghai, People's Republic of China; [d]School of Information, Kochi University of Technology, Kami-city, Japan; [e]Vision and Affective Science Integrated Laboratory, Research Institute, Kochi University of Technology, Kami-city, Japan

ABSTRACT

Sequential modulations in symbolic cueing tasks have been attributed to complete versus partial repetition/alternation of stimulus features between consecutive trials. This feature-integration hypothesis is questioned by recent findings and further investigated in the present study. In the first two experiments, when the cueing axes switched between trials, only complete alternation of cue directions and target locations existed. Nevertheless, significant sequence effects were still found in this condition, which did not support the feature-integration hypothesis. Furthermore, although sequence effects were still significant when stimulus identities were manipulated in Experiment 3, it was abolished when different cue categories (gaze and arrow) were presented as cues in Experiment 4. The findings suggest that the integration of stimulus features is not the only source of the sequential effect and some higher level cognitive mechanisms, possibly as described in the task-file or task organization hypotheses, are involved in the sequential modulations of symbolic cueing.

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KEYWORD
Sequence effect; cueing effect; feature integration; task file; task organization

In daily life, simply perceiving a gazing face of another person or a pointing arrow in a traffic sign is enough to orient our attention to the location indicated by these cues. In the laboratory, this attention orienting phenomenon has been deeply investigated through the spatial orienting paradigm with centrally presented symbolic cues (Chica et al., 2014; Frischen et al., 2007). Traditional spatial orienting paradigms include both peripheral and central cues, but symbolic cueing tasks focus on the attention mechanisms induced by centrally-presented cues which have directional meanings. Typically, there are two kinds of trials during a symbolic cueing task: valid trials and invalid trials. In valid trials, participants need to respond to the appearance of a target that is presented at the location indicated by a prior cue (i.e. a pointing arrow, a directional word, or a gazing face), and in invalid trials, the target will be presented opposite to the direction of the cue. Participants' performance will be facilitated in valid trials than in invalid trials, and this difference in reaction times (called cueing effects) is considered to represent an attention shift by the central cues. The most interesting findings about cueing effects are that they can happen automatically when the central cue is uninformative for the upcoming target locations (i.e. there are the same proportion of valid and invalid trials in an experiment). Furthermore, it is even obligatory at short cue-target intervals (e.g. 100 ms SOA) when the central gaze cue actually counter-predicts the possible target locations (Friesen et al., 2004; Tipples, 2008).

In the last decade, a new finding about the symbolic cueing task is the phenomenon of a significant influence of previous cue validity on the subsequent cueing effect (Gomez et al., 2009; Jongen & Smulders, 2007; Qian et al., 2012). Specifically, a previous valid trial, compared with a previous invalid trial, will lead to stronger cueing effects in current trials. Since recent studies have continuously demonstrated that the sequence effects of symbolic cueing do not rely on the voluntary control of the

CONTACT Qian Qian qianqian_yn@126.com

participants (Qian, Wang, Song, Feng, et al., 2017; Qian et al., 2018), a feature-integration account is proposed to explain the sequence effects (Hommel et al., 2004). Notice that this feature-integration account is different from the famous feature-integration theory of attention (FIT) by Anne Treisman (Wolfe, 2020) and only focuses on the influence of trial-by-trial feature variations in several attentional paradigms. The definition of features here includes sensory or perceptual shapes, locations, and even responses, rather than conceptual or abstract features. Specifically, the feature-integration hypothesis assumes that perceptual features of stimuli are reflexively integrated into a transient representational structure (a so-called 'event file'). Therefore, the task performance will be facilitated or not influenced when the features of cues and targets are fully repeated or alternated between trials, but the performance will be attenuated when only part of the features are repeated. For example, a left cue with a left target will be followed by a left cue with a left target again (i.e. complete repetition) or a right cue with a right target (i.e. complete alternation) in valid→valid trial sequences. In contrast, a left cue with a left target will be followed by a left cue with a right target or a right cue with a left target (i.e. partial repetition of cue directions or target locations) in valid→invalid trial sequences. Such complete versus partial repetition/alternation relationships also exist between invalid→invalid sequences and invalid→valid sequences. Participants will respond faster in valid→valid (or invalid→invalid) trial sequences than in invalid→valid (or valid→invalid) trial sequences. As a result, the cueing effects after a previous valid trial will be enhanced and the cueing effects after a previous invalid trial will be weakened, leading to the appearance of the sequence effects.

The feature-integration account seems the most possible explanations for the sequence effects (Qian et al., 2015; Qian, Wang, Song, Feng, et al., 2017). For example, Qian, Wang, Song, Feng, et al. (2017) used either symmetrical ("X" and "T") or asymmetrical ("d" and "b") letters as cue stimuli, and only found significant sequence effects in the asymmetrical cue condition, but not in the symmetrical cue condition. This suggests that the spatial feature association between cue directions and target locations is easier when the central cues are visually asymmetrical compared with instances in which the cues are visually symmetrical (Shin et al., 2011). The results showed the important role of the feature association between the cue stimuli and the target locations, thus supporting the feature-integration account.

The feature-integration account, however, cannot explain all observations: significant sequence effects were also found when directional words, i.e. the Chinese characters"左" (which means "left") and "右" (which means "right"), were tested (Qian, Wang, Song, Feng, et al., 2017). The finding suggests that overlearned symbols without feature-integration, such as directional words, can also induce sequence effects. Furthermore, in the study of Qian, Wang, Song, and Wang (2017), significant sequence effects are still found even when the cue categories and target identities are alternated between trials. Such a finding questions the validity of the feature-integration account because the sequence effects are preserved even when visual features of both cues and targets are alternated. Of course, since the other task-related features, such as the exact cue directions and target locations, still can be completely or partially repeated/alternated between trials, new evidence is needed to be against the feature-integration account.

The traditional way to investigate the sequence effects of cueing tasks usually involves presenting cues and targets along the horizontal axis of the screen. Consequently, complete repetition/alternation of stimulus features always happens when trial types (valid or invalid) are repeated between trials, and partial repetition of stimulus features always happens when trial types are switched between trials. As a result, it is impossible to test the validity of the feature-integration account by presenting stimuli only along the horizontal axis. The present study aims to further investigate the validity of the feature-integration account by giving several modified symbolic cueing experiments. In the first experiment, the axes of the arrow cueing could be either repeated or alternated between trials. When the axes are alternated, a complete alternation of cue directions and target locations will always happen regardless of the type of trial sequence. The feature-integration account will predict a non-significant sequence effect under this condition because no partial repetitions of cue directions and target locations exist. In the second experiment, the cue directions and target locations are chosen randomly from four possible options. Therefore, there will be three trial types: valid trials (e.g. a left cue with a left target), traditional invalid-opposite trials (e.g. a left cue with a right target), and new invalid-adjacent trials (e.g. a left cue with an up or down target). The new trial type provides additional data that can be used to further test the feature-integration account. Specifically, the reaction times (RTs) of a specific trial sequence can be compared between the condition with complete feature alternations and the condition with partial feature repetitions. Based on the results of the first two experiments, two additional experiments are conducted, and the description and the rationale of the last two experiments can be found at the beginning part of Experiment 3 and Experiment 4.

Experiment 1

Participants

A total of 30 students (with a mean age of 24.8 years, range 19–31 years, 13 females) consented to participate in this experiment. All participants were right handed. All participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment. Previous studies have found significant sequence effects in symbolic cueing tasks with a sample size of 16 or more (e.g. Qian et al., 2012), therefore, the sample sizes of the present study were kept equal or over 20 to ensure the statistical power of the data.

Apparatus

The stimuli were presented on a 19-inch 5:4 LCD display operating at a 60 Hz frame rate. The participants were seated approximately 57 cm away from the screen in a dimly-lit room. A chin-rest was used to prevent any unnecessary head movements.

Stimuli

A cross, subtending 1.5°, was placed at the center of the screen as a fixation point. The central cue was an arrow. The central horizontal or vertical line of the arrow was 3.5 ° in length. An arrow head and an arrow tail were displayed at the ends of the central line, pointing to the left, right, up, or down locations. The length of an arrow, from the tip of the arrow head to the ends of the tail, was 4.5 °. The target stimulus was a capital letter "X" measuring 1° wide and 1° high, and it was presented 12° away from the fixation point to the top, bottom, left, or right of the screen. There were four square placeholders that were always presented during the experiment for the four possible target locations. The side length of the placeholders was 3.5 °. The stimuli were all white and were presented on a black background.

Design

Two cue-target SOAs (i.e. 300 and 600 ms) were used to reduce anticipatory responses. On each trial, the cue direction and the SOA were selected pseudo-randomly. The target always appeared at the location pointed by the cue or the directly opposite location. Therefore, in each trial, the overall cue validity was 50%, even though the number of the display locations was four. There were six blocks with 100 trials each. 20 trials in each block were catch trials in which the target did not appear. The participants were instructed not to respond if the target did not appear. Including 20 training trials, there were in all 620 trials for each participant. The RTs of the first trials on each block, the RTs of the error trials, and the RTs of the trials followed a catch trial or an error trial were excluded from the analysis.

Sequence effects were tested in a four-way analysis of variance (ANOVA) with the within-participant factors of the axis repetition condition between trials (repeated or switched), SOA (300 ms or 600 ms), previous cue validity (pre-valid or pre-invalid) and current cue validity (valid or invalid) on RTs. A significant interaction between the previous and the current cue validities would represent a significant sequence effect between trials. In addition, if the axis repetition condition influenced the magnitude of the sequence effect, the axis repetition condition × previous cue validity × current cue validity interaction should also be significant.

There are two effects in the experiment: cueing effects and sequence effects. The size of cue effects is calculated by RTs of invalid trials minus RTs of valid trials; the calculation of the size of sequence effects is based on the calculation of cueing effects under different previous trial types (pre-valid or pre-invalid), it is calculated by cueing effects of pre-valid trials minus cueing effects of pre-invalid trials.

Procedure

As illustrated in Figure 1, participants were instructed to keep fixating on the center of the screen. First, a fixation cross appeared at the center of the screen for 1000 ms, after which the cue stimulus appeared. After a certain SOA, a target letter "X" appeared at one of the possible locations until participants had responded or 1200 ms had elapsed. Participants were instructed to respond when the target appeared by pressing the “SPACE” key with the index finger of their right hand as quickly and accurately as possible. Participants were also informed that the central stimuli did not predict the location at which the target would appear and that they should try to ignore the central cues.

Results

Errors

The participants missed an average of approximately 0.2% of the targets and made false alarm errors on approximately 2.3% of the catch trials. Anticipations (RTs of less than 100 ms) and outliers (RTs over 1000 ms) were classified as errors and were excluded from further analysis. After that, responses with RTs exceeding ±2 *SD* of each participant’s mean RT on each single cell of the design were also removed. As a result, around 5.6% of all trials were excluded as errors. An ANOVA as that described in Design part was conducted on the percent errors. None of the factors or interactions was significant (*ps* > .064).

RTs

The average RTs under different conditions are shown in Table 1 and Figure 2. An ANOVA as described in Design part was conducted on RTs. There was a significant effect of current cue validity, F (1, 29) = 21.324, p < .001, η_p^2 = .424, indicating

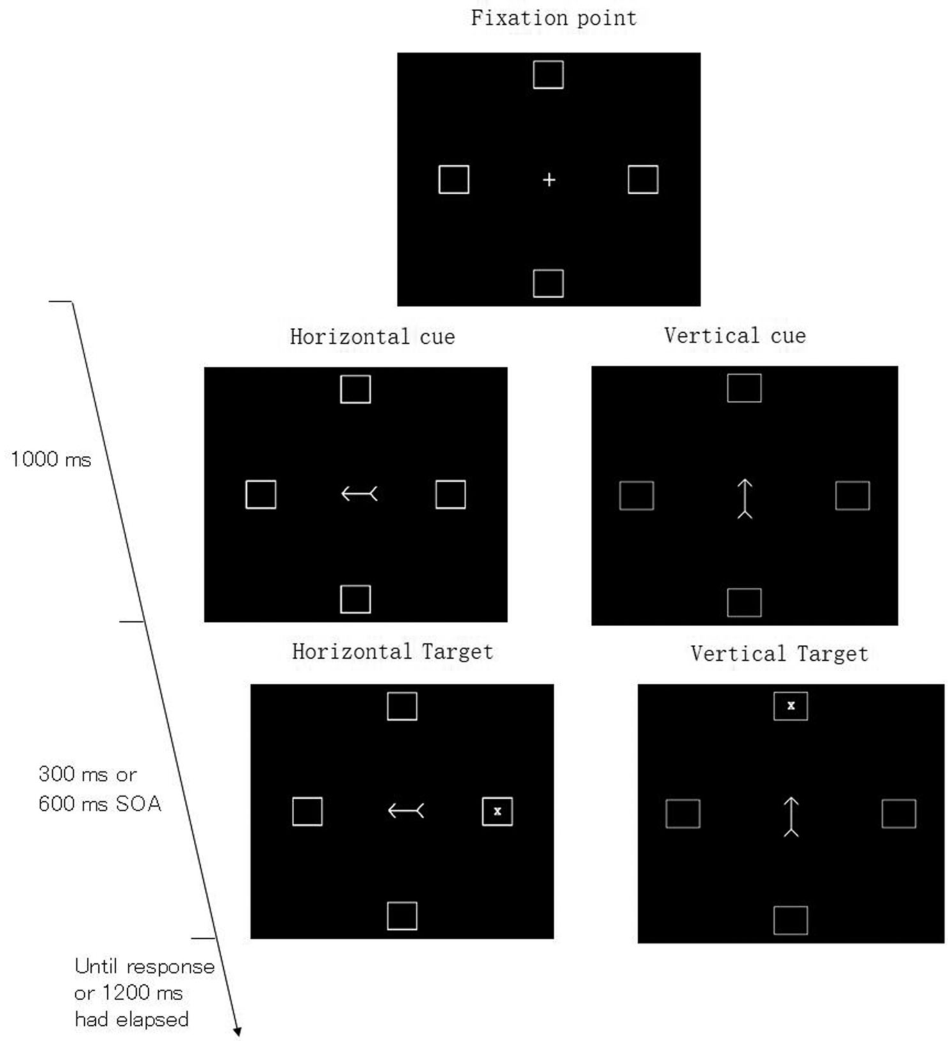

Figure 1. Illustration of the experimental procedure for Experiment 1, the cueing could happen along horizontal or vertical axes. In Experiment 2, the cue directions and target locations are chosen randomly, so additional trial type (invalid-adjacent, such as a left cue with a top target) is also possible. Besides additional target (letter “O”), the horizontal cue is replaced by another arrow (see Figure 5) in Experiment 3 and by a gazing face in Experiment 4.

Table 1. The mean RTs (accurate to bits) and Errors (accurate to the first decimal place) under different conditions and experiments. The error rates include the trials in which RTs were outside the 100 ms to 1000 ms and exceeding ±2 SD of each participant's mean RT on each single cell of the design. For Exp.2, the invalid condition means invalid-opposite, the data related to invalid-adjacent trials can be found in Figure 2.Standard deviations for each condition are shown in brackets.

	RTs and ERs							
	Axis repeated				Axis switched			
	Pre-valid		Pre-invalid		Pre-valid		Pre-invalid	
	Valid	Invalid	Valid	Invalid	Valid	Invalid	Valid	Invalid
Exp. 1								
300 ms SOA	368(38)	380(34)	370(39)	375(43)	364(41)	374(37)	368(42)	373(35)
	4.8%(3.4)	5.8%(2.6)	5.4%(3.2)	5.6%(3.2)	5.8%(3.3)	5.5%(2.7)	5.0%(2.5)	5.3%(2.8)
600 ms SOA	346(41)	361(38)	355(36)	359(39)	343(40)	356(39)	344(41)	355(38)
	6.4%(4.4)	5.6%(3.9)	5.0%(2.4)	6.1%(3.4)	5.6%(3.6)	6.3%(3.3)	6.5%(3.3)	5.8%(2.9)
Exp. 2								
	374(67)	388(68)	373(62)	377(74)	355(66)	386(50)	366(61)	377(56)
	1.8%(4.5)	5.4%(4.9)	4.1%(3.9)	3.8%(6.0)	5.9%(4.8)	4.6%(4.3)	4.1%(4.1)	3.9%(4.6)
Exp. 3								
Horizontal Arrow	347(37)	370(46)	353(46)	364(45)	345(41)	359(39)	342(41)	358(42)
	5.4%(3.2)	4.4%(2.8)	4.6%(1.9)	5.3%(3.1)	5.2%(3.0)	5.1%(2.0)	5.3%(2.4)	5.2%(2.2)
Vertical Arrow	349(40)	366(43)	354(40)	364(46)	347(39)	362(45)	350(38)	359(36)
	4.7%(2.8)	5.0%(2.6)	6.2%(2.8)	5.8%(3.3)	5.3%(2.0)	6.3%(3.5)	5.5%(3.2)	5.0%(2.1)
Exp. 4								
Gaze cue	376(59)	392(68)	389(66)	390(70)	384(60)	392(57)	374(57)	385(58)
	5.5%(3.8)	5.8%(3.3)	4.8%(3.0)	4.4%(3.2)	6.2%(4.3)	4.6%(3.8)	5.4%(2.7)	5.1%(3.5)
Arrow cue	370(62)	403(71)	384(61)	383(62)	378(62)	393(66)	385(59)	399(68)
	5.2%(3.0)	5.8%(3.1)	5.5%(3.2)	5.7%(3.8)	5.0%(3.4)	5.9%(3.4)	5.9%(3.6)	6.7%(3.2)

cueing effects (with about 10 ms effect size, calculated by RTs of invalid trials minus RTs of valid trials), i.e. RTs in the valid trials (about 357 ms) were shorter than those in the invalid trials (about 367 ms). The interaction between previous and current cue validities was also significant, F (1, 29) = 7.177, p = .012, η_p^2 = .198, indicating sequence effects (with about 6.3 ms effect size, calculated by cueing effects of pre-valid trials minus cueing effects of pre-invalid trials), i.e. cueing effects of

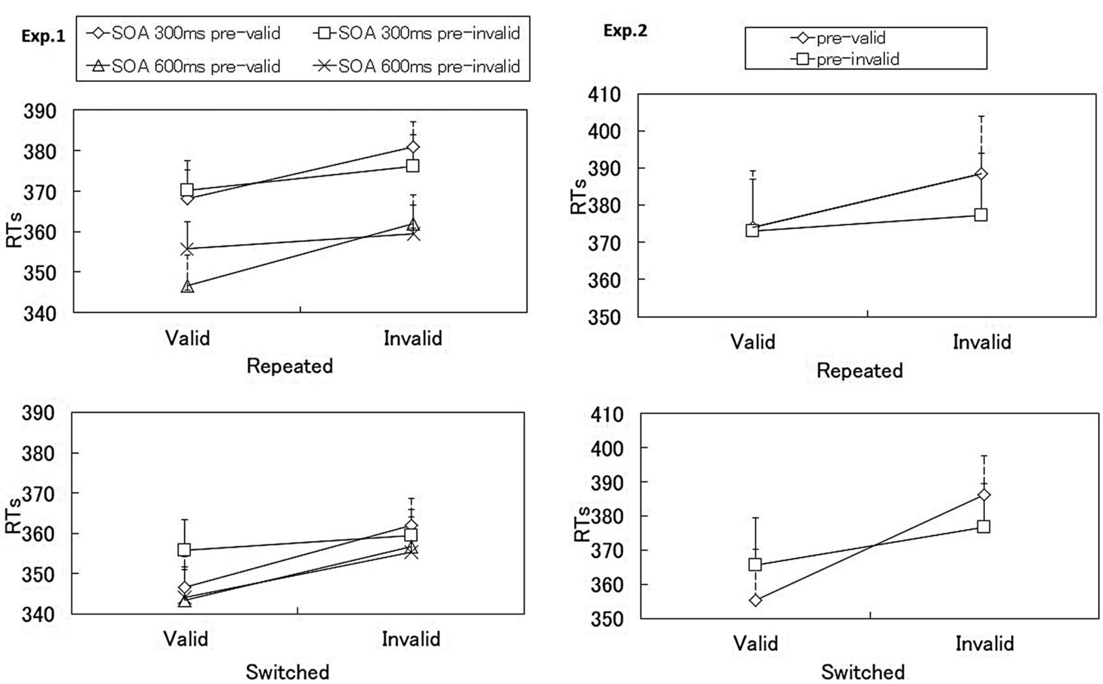

Figure 2. The average RTs under different conditions in Experiment 1 and Experiment 2. For Exp.2, the invalid condition means invalid-opposite, the data related to invalid-adjacent trials can be found in Figure 3.The error lines denote standard errors.

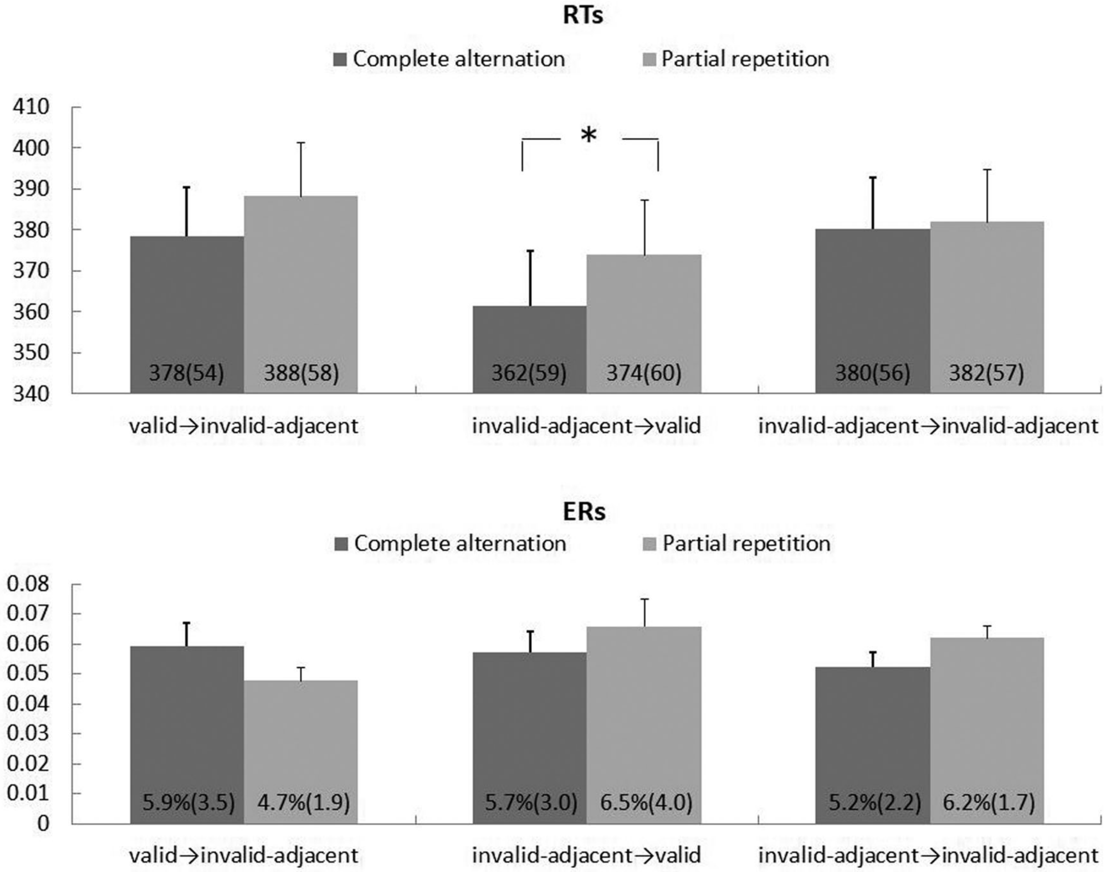

Figure 3. The average RTs and ERs of trial sequences related to invalid-adjacent trials in Experiment 2. The asterisks mark the statistically significant differences (significant level 0.05). Error bars denote standard errors of the mean. The numbers above the horizontal lines denote the exact values and SDs (in brackets).

trials following a valid trial (about 12.6 ms, calculated by averaging the cueing effects on each axis conditions and SOAs) were stronger than those following an invalid trial (about 6.3 ms). A paired-samples t-test on the size of cueing effects between pre-valid and pre-invalid conditions confirmed this result, $t(29) = 2.734$, $p = .011$. Importantly, the observed sequence effect did not interact with the axis repetition condition ($p = .189$) and any other factors or interactions ($ps > .329$). The average sequence effects for different conditions were 6.7 ms with a 95% confidence interval [−4.3, 17.8] (300 ms SOA and axis repeated), 4.9 ms with a 95% confidence interval [−4.1, 14.1] (300 ms SOA and axis switched), 11.5 ms with a 95% confidence interval [3.5, 19.6] (600 ms SOA and axis repeated), and 2.0 ms with a 95% confidence interval [−5.1, 9.3] (600 ms SOA and axis switched).

The other factors in the ANOVA on RTs reached significance were as follows. The main effect of SOA, F (1, 29) = 38.754, $p < .001$, $\eta_p^2 = .572$, demonstrating that RTs were shorter in 600 ms SOA than in 300 ms SOA; the main effect of axis repetition condition, F (1, 29) = 16.377, $p < .001$, $\eta_p^2 = .361$, demonstrating that RTs were facilitated when the cue axis switched between trials. No other factors or interactions reached significance. Furthermore, the ANOVA of the log-transformed RTs did not show any differences compared to the initial ANOVA.

Discussion

Although the partial repetition of cue directions and target locations is eliminated when the axis is alternated, significant and undistinguishable sequence effects are still found. Therefore, the feature-integration account is not supported by the results of Experiment 1.

Experiment 2

Since the target always appears at the valid location or the directly opposite location in Experiment 1, participants may have utilized the cue to predict the possible axis on which targets may occur, leading to an increment of cue processing and a reduction of the uncertainty of the target locations. To clarify these possibilities, both the cue direction and the target location were chosen randomly in Experiment 2. Another advantage of a fully random design is that a new trial type can be analyzed. As described in the introduction, there will be three trial types: valid trials (e.g. a left cue with a left target), traditional invalid-opposite trials (e.g. a left cue with a right target), and new invalid-adjacent trials (e.g. a left cue with an up or down target).

First, based on the data of valid trials and invalid-opposite trials, similar analyses as those performed in Experiment 1 will be conducted. Second, the trial sequences related to invalid-adjacent trial types will be analyzed to show whether the RTs of a specific trial sequence are really different between the condition with complete feature alternation and the condition with partial feature repetition as was predicted by the feature-integration account. For example, when the previous trial is a valid trial with a left cue and a left target, the current invalid-adjacent trials can be a left cue with an up or down target and an up or down cue with a left target (in these cases, stimulus features are partially repeated) or a right cue with an up or down target and an up or down cue with a right target (in these cases, stimulus features are completely alternated). The feature-integration hypothesis would predict a significant RT difference between these two conditions. Similar comparisons can be done for invalid-adjacent→valid trial sequences or invalid-adjacent→invalid-adjacent trial sequences.

Participants

A total of 20 students (with a mean age of 24.4 years, range 22–27 years, 9 females) consented to participate in this experiment. All participants were right handed. All participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment.

Apparatus, stimuli, design, and procedure

The apparatus, stimuli, design, and procedure were the same as those in Experiment 1 except for the following two differences. First, both cue directions and target locations were chosen randomly. Second, only 600 ms SOA was included since no significant influence of SOA on the sequence effects was found in Experiment 1.

Results

Errors

The participants missed an average of about 0.3% of the targets and made false alarm errors on approximately 0.9% of the catch trials. After the same data pre-processing process, about 4.2% of all trials were excluded as errors. An ANOVA similar to that in Experiment 1 was conducted on the percent errors of trial sequences with valid and invalid-opposite trials. None of the factors or interactions was significant (*ps* > .117). In addition, for the trial sequences related to invalid-adjacent trials, paired-samples t-tests were used to compare the percent errors between the trial sequences with partial repetition of features and the same trial sequences with complete alternation of features. None of the comparisons was significant (*ps* > .154).

RTs of trial sequences with valid and invalid-opposite trials

The average RTs under different conditions are shown in Table 1 and Figure 2. An ANOVA as that in Experiment 1 was conducted on the RTs. There was a significant effect of current cue validity, F (1, 19) = 8.970, p = .007, η_p^2 = .321, indicating cueing effects (with about 15 ms effect size). The interaction between previous and current cue validities was also significant, F (1, 19) = 7.671, p = .012, η_p^2 = .288, indicating sequence effects (with about 15 ms effect size). A paired-samples t-test on the size of cueing effects between pre-valid and pre-invalid conditions confirmed this result, t(19) = 2.771, p = .012. In summary, RTs were lower under valid (about 367 ms) than under invalid (about 382 ms) conditions, and this cueing effect was stronger following pre-valid (about 22.6 ms) than pre-invalid (about 7.5 ms) trials. Importantly, the cue axis repetition condition × previous cue validity × current cue validity interaction was not significant (p = .605), which was similar to the finding of Experiment 1. The average sequence effects for different conditions were 10.2 ms with a 95% confidence interval [−15.1, 35.6] (axis repeated) and 19.9 ms with a 95% confidence interval [0, 39.8] (axis switched). None of the other factors or interactions was significant (*ps* > .065). Furthermore, the ANOVA of the log-transformed RTs did not show any differences compared to the initial ANOVA.

RTs of trial sequences related to invalid-adjacent trials

The average RTs under different conditions are shown in Figure 3. Paired-samples t-tests were used to compare the RTs between the trial sequences with partial repetition of features and the same trial sequences with complete alternation of features. For valid→invalid-adjacent trial sequences, $t\ (19) = 1.748$, $p = .097$; for invalid-adjacent→valid trial sequences, $t\ (19) = 2.706$, $p = .014$, indicating that RTs with complete feature alternation were shorter than that with partial feature repetition; and for invalid-adjacent→invalid-adjacent sequences, $t\ (19) = 0.461$, $p = .650$. Note that cue directions and target locations could be completely repeated in invalid-adjacent→invalid-adjacent trial sequences (e.g. a left cue with a up target in both previous and current trials), but such trials were too rare to be analyzed. Furthermore, the comparisons based on the log-transformed RTs did not show any differences compared to the initial analyses. In all, only small part of the results (i.e. RTs in invalid-adjacent→valid trial sequences) supported feature-integration hypothesis.

Discussion

Similar to Experiment 1, the results of Experiment 2 still do not provide evidence to support the feature-integration hypothesis. Because the sequence effects are still significant in both axis switched and axis repeated conditions, it is difficult to attribute the lack of significant difference between axis switched and axis repeated conditions to a lack of power. At least, the findings suggest that sequence effects do not necessarily rely on the feature integration of cue directions and target locations.

Experiment 3

Since the cue and target stimuli with identical features were presented even when the axis was switched in Experiment 1 and Experiment 2, the perceived significant sequence effects on axis switched conditions may result from a kind of object-based perceptual feature integration. For example, though targets are presented later than cues, both the cue and the target stimuli are presented on the screen after the appearance of the target in the current experiments; therefore, a left pointing arrow and a left target are possible to be perceived as an object with specific combined perceptual features. Under such postulation, the performance facilitation is still possible when the same objects (e.g. an up pointing arrow and an up target) are perceived again along different axes, compared with when the different objects (e.g. an up pointing arrow and a down target) are perceived. In this case, though the exact arrow directions and target locations are changed, a left arrow with a left target as a whole has the same (though rotated 90° clockwise) features as an up arrow with an up target. Feature integration is still possible in such conditions. To clarify this possibility, two different arrow cues and two different targets were presented along different axes in Experiment 3. Consequently, any kinds of feature integrations are impossible when the axes are switched.

Participants

A total of 24 students (with a mean age of 24.5 years, range 23–26 years, 7 females) consented to participate in this experiment. All participants were right handed. All participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment.

Apparatus, stimuli, design, and procedure

The apparatus, stimuli, design, and procedure were the same as those in Experiment 1 except for the following three differences. First, the cue stimuli along horizontal axis were changed into an arrow with symmetrical layout around the screen center indicating the left (< <) or the right (> >). An illustration of the two arrow cues can be seen from Figure 4. Second, the target stimuli were letter 'X' or 'O'. One target letter was associated with one kind of arrow cues. The mapping between the cue identities and the target letters was counterbalanced among participants. Third, only 600 ms SOA was included.

Sequence effects were tested in a four-way analysis of variance (ANOVA) with the within-participant factors of cue identities (horizontal arrow or vertical arrow), cue axis repetition condition (repeated or switched), previous cue validity (pre-valid or pre-invalid), and current cue validity (valid or invalid) on RTs.

Results

Errors

The participants missed an average of about 0.1% of the targets and made false alarm errors on

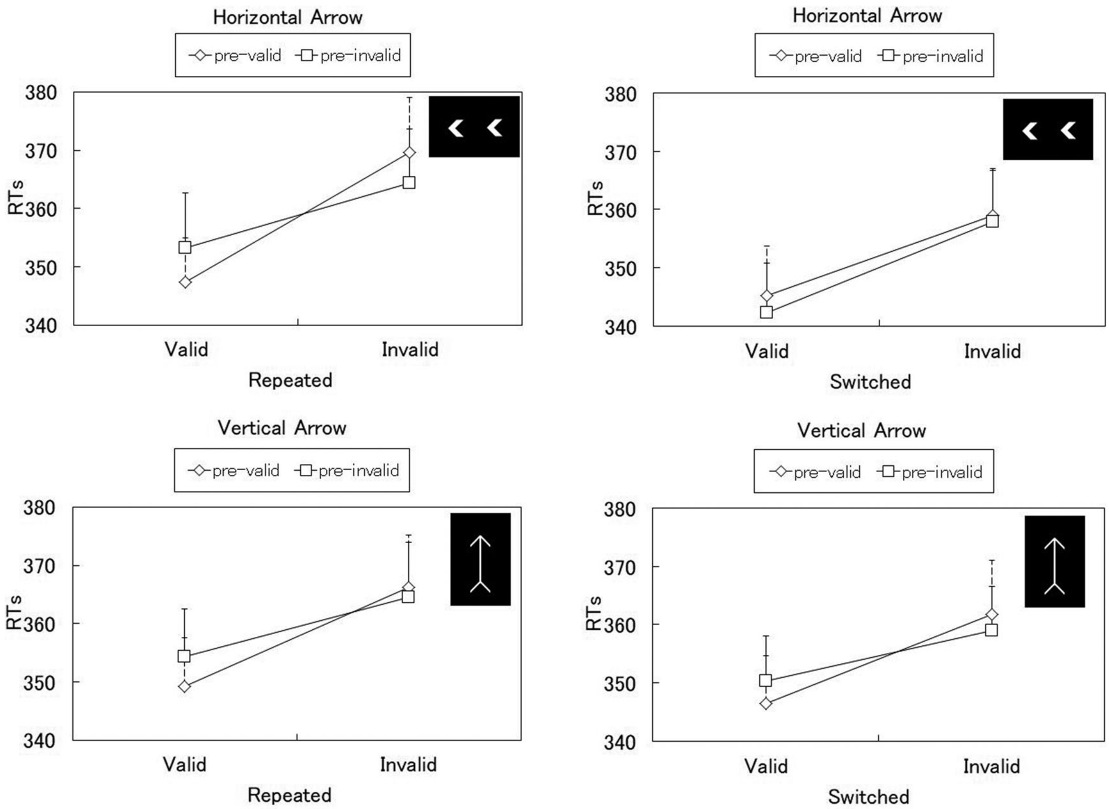

Figure 4. The average RTs under different conditions in Experiment 3. The error lines denote standard errors.

approximately 1.0% of the catch trials. After the same data pre-processing process, about 5.3% of all trials were excluded as errors. An ANOVA as that described in Design part was conducted on the percent errors. None of the factors or interactions was significant (*p*s > .101).

RTs

The average RTs under different conditions are shown in Table 1 and Figure 4. An ANOVA as that described in Design part was conducted on the RTs. There was a significant effect of current cue validity, F (1, 23) = 15.359, p = .001, η_p^2 = .400, indicating cueing effects (with about 14 ms effect size). The interaction between previous and current cue validities was also significant, F (1, 23) = 5.036, p = .035, η_p^2 = .180, indicating sequence effects (with about 6 ms effect size). A paired-samples t-test on the size of cueing effects between pre-valid and pre-invalid conditions confirmed this result, t(23) = 2.233, p = .036. In summary, RTs were lower under valid (about 348 ms) than under invalid (about 362 ms) conditions, and this cueing effect was stronger following pre-valid (about 17 ms) than pre-invalid (about 11 ms) trials. Importantly, the cue axis repetition condition × previous cue validity × current cue validity interaction was failed to reach significance (p = .159), similar to the findings of Experiment 1 and Experiment 2.

The average sequence effects for different conditions were 11.3 ms with a 95% confidence interval [−4.0, 26.6] (horizontal arrow cue and axis repeated), −1.8 ms with a 95% confidence interval [−11.8, 8.1] (horizontal arrow cue and axis switched), 6.8 ms with a 95% confidence interval [−3.3, 11.0] (vertical arrow cue and axis repeated), and 6.6 ms with a 95% confidence interval [−6.3, 19.5] (vertical arrow cue and axis switched). Although the above analyses did not indicate a significant influence of cue axis repetition conditions, a tendency could be perceived from the amount of average sequence effects and from the Figure 3. Specifically, relatively small amount of sequence effects were induced for horizontal arrow cue conditions when axes were switched. The other factors reached significance were the main effect of cue axis repetition condition, F (1, 23) = 11.879, p = .002, η_p^2 = .341, indicating that RTs were facilitated when the cue axis switched between trials. None of the other factors or interactions was significant (*p*s > .165). Furthermore, the ANOVA of the log-transformed RTs did not show any differences compared to the initial ANOVA.

Discussion

When cue and target identities are alternated along with the presentation axes, significant sequence effects are still found (at least for vertical arrow condition). Since the features of both arrow cues and targets are completely changed when the cue axes are switched, the observed sequence effects cannot be attributed to any kinds of feature integration. In conclusion, feature integration cannot explain both of the findings of the first two experiments and the findings of the current experiment.

Experiment 4

Significant sequence effects were still found under axis switch conditions in the above three experiments, so that the feature-integration account was not supported, are there other possible explanations for the observed sequence effects? Based on the findings of congruency sequence effects in flanker, simon, and stroop tasks, Schumacher and Hazeltine (2016) proposed a task-file theory that attributes the sequential modulations to a combination of associations from not only stimulus and response features, but also higher properties that belong to the same task, such as abstract relationships between stimuli and responses, contexts and actions, and task rules and goals. According to this theory, as long as the same task representations are preserved or shared, cognitive control under the sequential modulations can generalize between stimuli with different features. As for the previous three experiments, although the exact cue directions and target locations changed, the abstract relationships between cue and target (i.e. cue validity, the most significant task factor) were not changed. Therefore, the sequence effects could generalize between different axes conditions.

To further test the boundaries of such generalization of the sequence effects, both cue categories and cue axes (along with target identities and target axes) were changed between trials in Experiment 4. In this way, the increased difference between conditions may enable the gaze cueing and arrow cueing along different axes to be perceived as different (sub)tasks, so as to hinder the sequential processing between them.

Participants

A total of 24 students (with a mean age of 24.6 years, range 22–26 years, 8 females) consented to participate in this experiment. All participants were right handed. All participants reported normal or corrected-to-normal vision and were naive to the purpose of the experiment.

Apparatus, stimuli, design, and procedure

The apparatus, stimuli, design, and procedure were the same as those in Experiment 3 except for the following one difference. The arrow cues with a pointing direction along horizontal axis in Experiment 3 were changed into the gazing faces of a female model from ATR Facial Expression Image Database (DB99). The left and right gazing photographs of the model were cut and only the oval-shaped faces (10.5 ° in height and 8.5 ° in width) were used. Therefore, the central cue of each trial could be a left gazing face, a right gazing face, an up pointing arrow, or a down pointing arrow.

Sequence effects were tested in a four-way analysis of variance (ANOVA) with the within-participant factors of cue categories (gaze or arrow), cue axis repetition condition (repeated or switched), previous cue validity (pre-valid or pre-invalid), and current cue validity (valid or invalid) on RTs.

Results

Errors

The participants missed an average of about 0.3% of the targets and made false alarm errors on approximately 0.7% of the catch trials. After the same data pre-processing process, about 5.5% of all trials were excluded as errors. An ANOVA as that described in Design part was conducted on the percent errors. The only significant interaction was cue types × current cue validity, $F\ (1, 23) = 4.403$, $p = .047$, $\eta_p^2 = .161$, indicating that arrow cues induce more errors than gaze cues in invalid trials. None of the other factors or interactions was significant ($ps > .160$).

RTs

The average RTs under different conditions are shown in Table 1 and Figure 5. An ANOVA as that described in Design part was conducted on the RTs. There was a significant effect of current cue validity, $F\ (1, 23) = 21.140$, $p < .001$, $\eta_p^2 = .479$, indicating

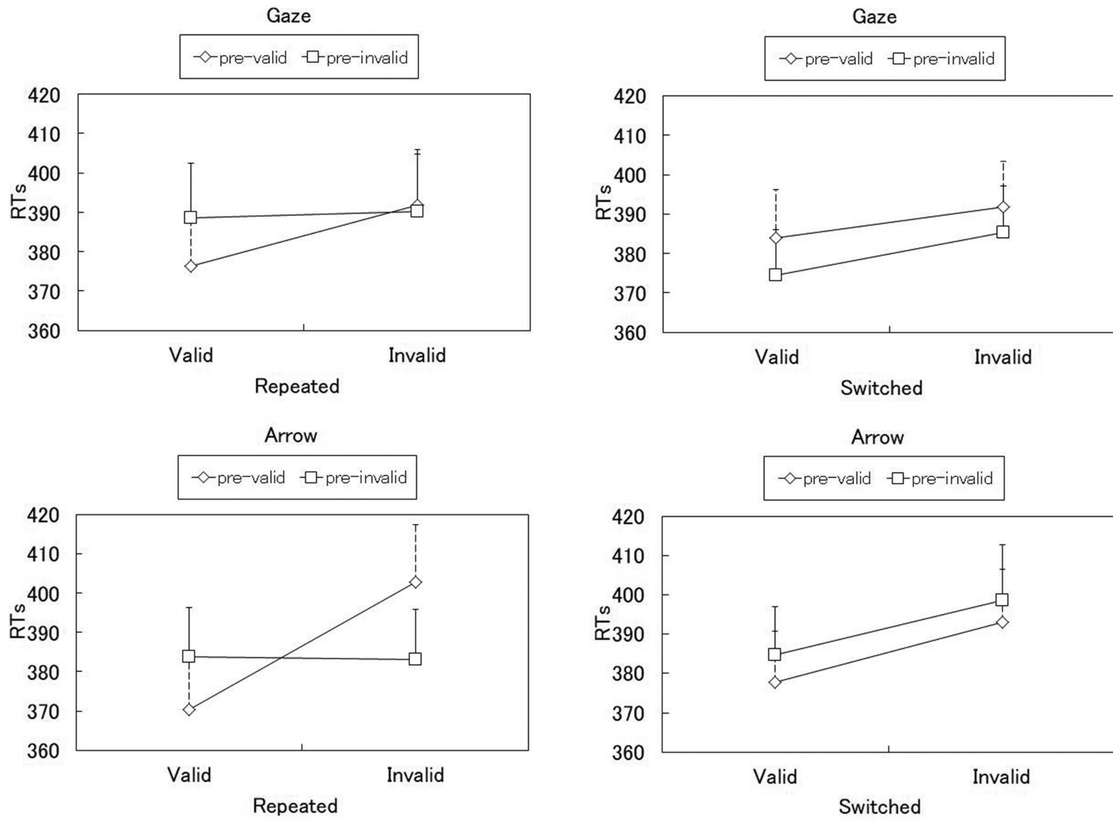

Figure 5. The average RTs under different conditions in Experiment 4. The error lines denote standard errors.

cueing effects (with about 12 ms effect size). The interaction between previous and current cue validities was also significant, F (1, 23) = 11.772, p = .002, η_p^2 = .339, indicating sequence effects (with about 11.3 ms effect size). A paired-samples t-test on the size of cueing effects confirmed this result, t(23) = 3.425, p = .002. In summary, RTs were lower under valid (about 380 ms) than under invalid (about 392 ms) conditions, and this cueing effect was stronger following pre-valid (about 17.7 ms) than pre-invalid (about 6.4 ms) trials. Importantly, the cue axis repetition condition × previous cue validity × current cue validity interaction was significant, F (1, 23) = 8.229, p = .009, η_p^2 = .264, reflecting that significant sequence effects were only found when cue axis (along with cue categories) repeated between trials. The average sequence effects for different conditions were 14.0 ms with a 95% confidence interval [−7.8, 35.9] (gaze cue and axis repeated), −2.9 ms with a 95% confidence interval [−18.1, 12.1] (gaze cue and axis switched), 33.0 ms with a 95% confidence interval [13.9, 52.0] (arrow cue and axis repeated), and 1.1 ms with a 95% confidence interval [−13.0, 15.2] (arrow cue and axis switched). An additional ANOVA with the within-participant factors of the cue categories and cue axis repetition condition was conducted on the size of sequence effects. There was a significant main effect of cue axis repetition condition, F (1, 23) = 8.223, p = .009, η_p^2 = .263. Such result was also confirmed by paired-samples t-tests on sequence effects between axis repetition and switch conditions for arrow cues, t (23) = 3.506, p = .002. In addition, though the same comparison for gaze cues failed to reach significance (p = .247), the comparison between axis repetition condition of arrow cues and axis switch condition of gaze cues was significant, t(23) = 2.843, p = .009. No other comparisons were significant (ps > .246).

The other interactions in the ANOVA on RTs reached significance were cue categories × cue axis repetition condition × previous cue validity interaction, F (1, 23) = 11.718, p = .002, η_p^2 = .338. This interaction illustrated that in pre-invalid trials, RTs were facilitated when axis switched compared with when axis repeated for gaze cues, but this tendency was reversed for arrow cues. None of the other factors or interactions was significant (ps > .130). Furthermore, the ANOVA of the log-transformed RTs did not show any differences compared to the initial ANOVA.

Discussion

Finally, when cue categories are alternated along with the target identities and presentation axes, it is found that sequence effects are abolished. The results seem to support the feature-integration account, but after the inconsistency of this account of the findings of all three previous experiments, it is difficult to believe that the current findings are under the control of feature integration. There must be other mechanisms under the findings of the present study, some possible explanations are mentioned at the beginning of the experiment and will be further discussed in the following section.

General Discussion

The present experiments involved four possible target locations, which included locations within upper and lower visual fields. The asymmetrical allocation of the attention to upper and lower visual fields is known (e.g. He et al., 1996). However, several early studies have shown that the facilitation or inhibition effects in spatial cueing tasks are not influenced by the major horizontal and vertical visual meridians (e.g. Bennetts & Pratt, 2001; Henderson & Macquistan, 1993). In addition, different target locations, other than left and right, have been used and tested in many spatial cueing studies and no significant influence of layout has been reported (e.g. Kingstone et al., 2000; Langton & Bruce, 1999). Nevertheless, additional analyses considering the target locations are still being conducted on the current experimental results, but no significant influence of target locations on sequence effects have been found.

The findings of the present study expanded our knowledge about the sequence effect of symbolic cueing tasks. The feature-integration account that was proposed by previous researchers to explain the sequence effect of central cueing paradigm is not supported. Specifically, significant sequence effects were still found when the cue axis alternated between consecutive trials in the first two experiments. Because the exact cue directions and target locations always alternated under such experimental conditions, the observed sequence effects could not be attributed to the different performances between complete and partial repetition/alternation of the stimulus features. In addition, the feature-integration account was also not fully supported by the remainder of the results in Experiment 2. Indeed, the facilitated RTs between complete and partial alternation of stimulus features were only found for invalid-adjacent→valid trial sequences but not for both valid→invalid-adjacent and invalid-adjacent→invalid-adjacent trial sequences. The results of the first two experiments suggest that sequence effects of arrow cueing do not rely on the feature integration, such as the association between exact cue directions and target locations. In conclusion, the sequence effect of symbolic cueing found in the present experiments does not depend on associations of stimulus features, and it has probably originated from abstract relationships between stimulus features or even higher properties related to the task.

The results of Experiment 3 seem ambiguous. On the one hand, no significant influence of cue axis conditions on sequence effects were found according to the statistical analyses. On the other hand, as seen in Figure 4, when the cue axis was switched, the sequence effects seem to be abolished for horizontal arrows but not for vertical arrows. One possible explanation may be the atypical visual appearance of the horizontal arrows. Indeed, unlike the vertical arrows, the horizontal arrows are not the kind of arrows with classic visual forms. Although it is not statistically significant, the atypical appearance of the horizontal arrows may have hindered the sequential processes from other arrows. More investigations are needed to determine the extent to which the different visual features of arrows influence the sequence effects, but this topic is not a concern of the current study. Nevertheless, two conclusions can be made. First, sequence effects of arrow cueing can be found when both stimulus identities and cueing axes are manipulated simultaneously. Second, based on the first conclusion, feature integration cannot explain the whole story of the observed sequence effects that are generalized across different axes.

In Experiment 1 and Experiment 2, cue axes could alternate, but the same arrow cues (and the same targets) were presented; in the experiment of Qian, Wang, Song, and Wang (2017), cue categories (and target identities) could change, but the cue axis remained; in Experiment 3, both arrow cue identities (along with target identities) and cueing axes could alternate between trials. Significant sequence effects were found in all of these experiments. In contrast, when both cue categories (along with target identities) and cue axes were manipulated in Experiment 4, qualitatively different sequence effects were found for different conditions. Specifically, sequence effects were not significant when both cue categories (along with target identities) and presenting axes alternated between trials.

The current findings can be explained by the task-file theory (Schumacher & Hazeltine, 2016). According to this theory, learned associations within a task include not only associations between stimuli and responses, but also associations among abstract stimulus and response features, goals, and actions within the task representation. Such hierarchical associations lead to cognitive controls at multiple levels, which induce sequential processes between trials. This explanation may answer the question why the sequence effects happened between different central cues in previous and current studies. Particularly, even though stimulus features are changed, sequential processes can survive this change as long as the same task representation is preserved. Furthermore, when the difference becomes large enough to allow the two different conditions to be distinguished as two different (sub)tasks, the sequence effects will not be able to generalize between these two conditions, as found in Experiment 4 of the present study.

A more specific explanation is given by Gozli (2019). A concept of task organization is introduced to describe the hierarchical structure of an experimental task. Under this method of thinking, a task corresponds to multiple levels of goal hierarchy. The basic task goals may simply involve pressing specific buttons for specific stimuli, but the higher task goals, which may originate from experimental designs, task instructions, and even participants' own understanding of the task, will influence how participants are going to group stimulus-response events and perform the task. One useful prediction from a task organization hypothesis is that repetition of a motor response (a subordinate goal) is beneficial only when the task (a relatively superordinate goal) is also repeated. This prediction helps to explain why sequence effects survive some experimental manipulations, but not others. As an example, a possible task organization of current Experiment 1 can be seen in Figure 6 (exp.1). As we can see, corresponding stimuli, responses, and the relationship between them in the task form a hierarchical structure. In this structure, cue validity is a superordinate task selection factor, compared to the relatively subordinate cueing axes factor. The sequential control mechanisms could survive the change of cueing axes, since the cue validity factor as a superordinate factor could not change. Furthermore, only when the difference between experimental conditions is large enough to make the manipulations become a superordinate task selecting factor over the cue validity factor, as seen in Experiment 4 (see Figure 6, exp.4), is the sequence effect between the different conditions blocked. The current finding of a significant influence of experimental manipulations on the sequence effect is in line with the findings of some other studies, which are dedicated to finding the potential boundaries of sequential processes between tasks. For example, Kim and Cho (2014) found the congruency sequence effect between two color flanker tasks only when the tasks were performed by the same hand. Thus, the response mode (i.e. one hand or different hands) seems to be a candidate property for differentiating tasks. However, this finding was not replicated in the study of Weissman et al. (2015), which utilized a different stimulus set. Therefore, it seems that the boundary between tasks varies depending on the most salient task features at hand (Lim & Cho, 2018). In the present study, unlike that in the first three experiments, the change of both cue categories and cueing axes in Experiment 4 seems to be the most salient features for task selection, thus blocking the sequential processing between these manipulation conditions.

It is worth mentioning that the manipulations in present Experiments 3 and 4 also include alternation of target identities, but it is unlikely that this factor contributes to the current findings. There are two reasons for it. First, a detection task (i.e. pressing a button whenever a target appears) is utilized, so target identities are just an indifferent factor for participants' actions. Second, even if the target identity did play a role in the current task, it would be a subordinate factor below the target location factor, as illustrated in Figure 6 (exp.3 and exp.4), so as not to influence the results.

Current findings of a possible role of the task-file or task organization are not unique in the spatial cueing paradigm. Sequence effects have been found in the cueing studies with peripheral cues (Dodd & Pratt, 2007; Mordkoff et al., 2008), and in a recent study, Ansorge et al. (2019) investigated the origin of the effects by combining two tasks within one experiment. In their first two

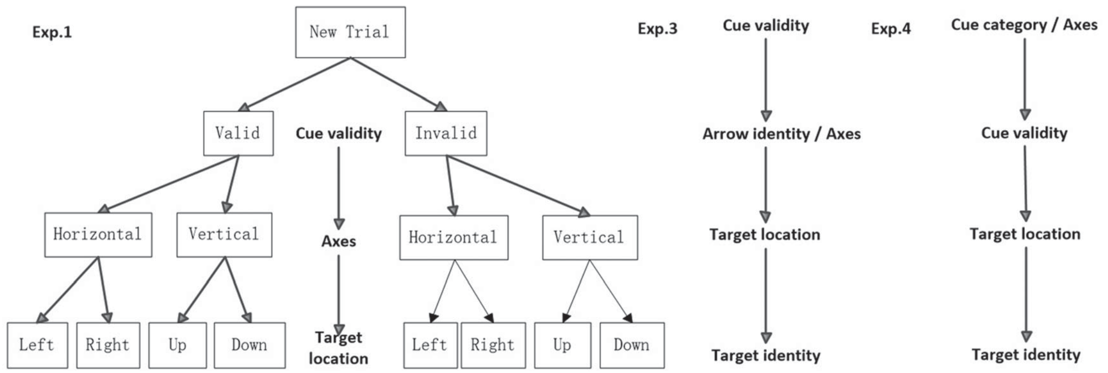

Figure 6. Possible task organization structures of current experiments. For simplification, only the structure of Experiment 1 is fully presented.

experiments, after perceiving a left/right white disk cue, participants needed to discriminate the color or the shape of the left/right disk targets, and these two tasks were repeated or switched from trial to trial. Similar to the findings of our first two experiments, significant sequence effects were still found when the tasks switched between trials. In their Experiment 3, Ansorge and his colleagues made further modifications to increase the difference between the two tasks: task requirements, stimulus-response mappings, responding hands, presenting axes, and colors of cues and targets. Under such experimental conditions, the sequence effects between tasks were abolished. This finding is in accordance with our findings from Experiment 4.

More importantly, the findings of the current study have several advantages in the following ways. First, since significant influences of task-file or task organization are found for both peripheral and central cueing tasks; now, we have reasons to believe that the sequence effects of all cueing tasks are probably under the control of the task-file or task organization theory. Second, the current findings reduce the requirements for setting boundaries between different conditions in cueing tasks. While the study of Ansorge and his colleagues included many manipulations, the current study manipulated only two factors: presenting axes and cue categories (along with target identities). Therefore, it seems that sequence effects of symbolic cueing can be significantly influenced when just two factors are changed simultaneously. In other words, the change of two factors sets up the distinction between the experimental conditions and provides a boundary for sequential modulations. Of course, the method of changing the factors is also important for bringing a salient boundary according to the results of the current study.

What is the possible cognitive mechanism under the current findings? One possible mechanism under the previous and current findings about the effect generalization between experimental conditions is the learning of more abstract properties, like abstract relationships between cues and targets or categorical stimulus features, rather than the learning of low-level stimulus characteristics. Under this learning mechanism, sequence effects can be generalized from the arrow cueing along the horizontal axis to the arrow cueing along the vertical axis in the first three experiments of the present study since the abstract relation of stimulus features and categorical information of cues remains the same; sequence effects can also be generalized from gaze cueing to arrow cueing or vice versa, since the cueing axes remain (Qian, Wang, Song, & Wang, 2017). However, sequential modulations are impossible when both cue categories and cueing axes are changed as that in the current Experiment 4. Another possible candidate is some cognitive control mechanisms related to the experimental designs. For example, participants may have more expectations of helpful information after a valid trial or have more inhibitions about irrelevant information (i.e. the cues) after an invalid trial, and such expectations or inhibitions will take effect despite of the change of stimulus features until the participants can explicitly distinguish the cueing processes. Nevertheless, the existing findings suggest that all of these possible learning or control mechanisms take effect in an implicit way and are restricted to a certain experimental design (Braem et al., 2014; Egner, 2017). Other explanations are also possible, but the topic is beyond the scope of the present study; what can be said now is that sequence effects of symbolic cueing are not limited by concrete stimulus features.

The current findings do not necessarily mean that feature integration cannot induce sequence effects. According to task-file or task organization theory, the sequential modulations of symbolic cueing may originate from many levels and factors. It is possible that the sequence effects of a typical cueing task are mainly attributed to feature integrations of stimuli and responses, as suggested by many previous studies. However, when feature integration is restricted by the experimental design (like that in the present study), higher level factors take control of the sequential modulations. Although the task organization theory has provided some progress, the extent to which different levels of control factors take effect under different conditions still needs more investigations.

In summary, the present study demonstrated that the observed sequence effects of symbolic cueing do not necessarily rely on complete versus partial repetition/alternation of stimulus features between trials. Instead, the relative significance of different task features in task representations or task organization structures may determine whether or not the sequence effects appear. Overall, our results suggest that the integration of stimulus features is not the only source of the sequential modulations of symbolic cueing tasks, some other high-level control mechanisms are involved.

Disclosure statement

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