Sequential Effects in Spatial Exogenous Cueing: Theoretical and Methodological Issues

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Abstract

Spatial cueing is a largely used experimental paradigm to study exogenous attention orienting, both in behavioural and neurological research. In such a paradigm participants are presented a sequence of trials that are assumed to be independent from each other. In each trial a peripheral spatial cue is presented, followed by a target peripheral stimulus; subjects are required to respond as fast as possible to targets, attempting to ignore cues. In such experiments RTs are mainly dependent to trial type (valid vs invalid) and to Cue-target intervals (short vs long). The present study aims at investigating the hypothesis that facilitation and inhibition effects, observed in cueing experiments, can be considered analogous to sequential effects, usually observed in two-choice tasks, and then that all these effects can be explained by the very same cognitive mechanisms. Results from two cueing experiments support this theoretical explanation and highlight the relevance of taking into account sequential effects.

Introduction

In the study of visuospatial attention endogenous and exogenous control modalities are recognized. Probably, spatial cueing is the most used experimental paradigm to investigate the mechanisms and characteristics of both voluntary and automatic attention orienting (Posner, 1980). In such a simple paradigm a sequence of trials is administered to the subjects; each trial consists of two consecutive events: the presentation of a spatial cue followed by the presentation of a target stimulus, to which subjects are required to respond as fast as possible. To study the exogenous modality, usually cues are peripheral stimuli that are unpredictably presented on the same location of the following target or on a different location. While in the former case the trial is called "valid", in the latter case the trial is called "invalid". Typically, when the intervals between cues and targets (SOAs) are shorter than 200-300 ms, a facilitation effect is observed (performance on valid trials is better than performance on invalid trials); on the contrary, when the intervals between cues and targets (SOAs) are longer than 200-300 ms, an inhibition effect is observed (IOR; performance on invalid trials is better than performance on valid trials) (Posner & Cohen, 1984). Facilitation effects are often interpreted consistently with the hypothesis that on valid trials cues have involuntary captured attention and then targets appear on the location currently "illuminated" by the attentional spotlight. Differently, inhibition effects are explained consistently with the hypothesis that attentional focus is more probably located on locations that are not recently scanned (Klein, 2000).

Even though such effects are very often interpreted as caused by spatial orienting of attention, they seem to be analogous to first order sequential effects usually observed in two-choice tasks (Bertelson, 1961; Soetens, 1998). An extensive number of two-choice task experiments have showed that reaction time (RT) to a stimulus is dependent not only on that stimulus but also on the sequence of preceding stimuli. Influences caused by the previous stimulus-response cycle are called "first order sequential effects", while influences caused by earlier cycles are called "higher order sequential effects". Similarly to cueing experiments, in two-choice tasks the sequential effects mainly depend on response-stimulus intervals (RSI). Infact, first order repetition effects are usually observed with relatively short RSIs (less than 500 ms); whereas, first order alternation effects are observed with relatively long RSIs (i.e., RTs are faster to a different stimulus than to a repeated stimulus). While repetition effects are often explained in terms of an automatic facilitation caused by a residual activation of memory traces, alternation effects are associated to a kind of subjective expectancy. More specifically, in a series of binary stimuli subjects seem to expect more alternations than repetitions; this phenomenon is well known as "gambler's fallacy" and it is often explained in terms of an erroneous representation of randomness and probability (Nickerson, 2002) based on what Tversky and Kahneman (1971) called "law of small numbers" (which is the erroneous belief that proprieties of

large samples will also apply to very small samples). Moreover, as Roney and Trick (2003) show, gambler's fallacy occurs as a result of a natural tendency for people to organize separate and independent events into larger units.

The aim of the present study is to reconcile the two briefly outlined research traditions by investigating higher order effects in exogenous spatial cueing. Specifically, it is suggested that in spatial cueing trials can not be considered independent, and therefore facilitation and inhibition effects are influenced by trials sequences. Moreover, a possibility arises to consider such cueing effects as dued to automatic facilitation and subjective expectancy, respectively. Therefore, two exogenous spatial cueing experiments were run manipulating: a) cue-target intervals (SOAs); b) sequences of trials (as suggested by Soetens, Boer and Hueting, 1985).

Experiment 1

The present experiment aimed at investigating the effects of preceding trials in an exogenous spatial cueing paradigm in which the intervals between cues and targets (SOAs) were shorter than 200 msec. As the literature suggests, short SOAs tend to produce a facilitation effect for which RTs recorded on valid trials are faster than those recorded on invalid trials. As mentioned above, facilitation effect is usually explained in terms the capability of the cue to involuntary actract attentional focus.

Method

Subjects A total of 10 individuals were recruited to participate in the experiment. Their man age was 24.2, ranging from 22 to 28 years. All of them were undergraduate students and reported normal or corrected-to-normal vision. All participants reported to be right handed, and were naives to the purpose of the experiment.

Apparatus The experiment was conducted on 19'' SGI monitor controlled by a Windows compatible PC. Programming was done using SuperLab 2.01, which controlled display parameters and registered RTs. The screen resolution was 1024x768. Subjects responded via a one-button response pad connected to the Serial Port.

Stimuli The fixation point was a white cross subtending a visual angle of 0.8°, located at the center of the display. Spatial Cues were outlined grey circles (2.5°). Target stimuli were solid grey circles (1.5°). Cues and targets could appear either on the left or on the right of the fixation point at a distance of 5.2°. The background was black. The choice of the stimuli was made following the results of Pratt, Hillis and Gold (2001) on the effects of the physical characteristics of cues and targets on facilitation and inhibition.

Procedure Subjects were run individually in a silent and darkened room; they were seated about 40 cm in front of a computer monitor, placed straight ahead with its centre at the eyes level. Their head movements were minimized by an adjustable chin rest. Participants were instructed to maintain their gaze on the fixation point at all times during each experimental session. Moreover, they were required to press a button as rapidly as possible in response to each target, regardless of its location (detection task). They were also informed that the visual cue was not predictive of the location of the incoming target, so they had to try to ignore that kind of stimulus. After instructions, a practice session was run, that lasted until the subject had made 20 consecutive correct responses. The experiment consisted of 11 blocks of about 192 trials each, and a rest period was always offered between them. Each target-present trial began with a fixation display containing the central cross; after 500 ms a cue was superimposed for all the trial duration. After a variable time ranging from 50 to 150 ms (SOA), the target appeared until a response was given or for 800 ms. Catch trials were identical to previous ones, but no targets occurred. Sequences of three trials were randomized within each block by the computer.

Design In 960 trials cue appeared on the same location of the target (valid trials); more specifically, in 480 valid trials cue and target appeared on the left position and in 480 valid trials cue and target appeared on the right position. In 960 trials cue appeared on a location different from the target one (invalid trials); more specifically, in 480 invalid trials cue appeared on the left and target on the right of the fixation point and in 480 invalid trials cue appeared on the right and target on the left of the fixation point. Finally, in 192 trials target did not appear (Catch trials).

To study higher sequential effects in spatial cueing, valid and invalid trials were grouped in sequences of three. Since the inter-trial interval was always the same, subjects had no ways to perceive grouping. Considering the two possible locations of cues and targets there were 64 possible sequences. Consequently each sequence was presented 10 times in random order and only RTs recorded on the third trial were considered for the statistical analyses on sequential effects. Following Soetens, Boer and Hueting (1985), each sequence can be described in terms of Alternations (A) and Repetitions (R) of two consecutive stimuli. In the present experiment two consecutive stimuli can be either the cue and the target of a single trial (in this case an Alternation corresponds to an invalid trial and a Repetition corresponds to a valid trial) or the target and the cue of two consecutive trials. Therefore an Alternation consists of the presentation of two stimuli that differ for the spatial dimension (for example, the first stimulus is presented on the left location and the second one on the right location); differently, a Repetition consists of the presentation of two stimuli that do not differ for the spatial dimension (for example, both stimuli are presented on the left location). In table 1 all possible A/R sequences are presented; in table 2 the stimuli specifications for the two trial sequences that can be both described by the A/R sequence N. 7 are given. More in general, the sequences 1-

16 end with an invalid trial (as it is indicated by the last "A"), the sequences 17-32 end with a valid trial (as it is indicated by the last "R"). Statistical analyses are performed comparing RTs to last Alternation (Invalid trial) and RTs to last Repetition (Valid Trial) in function of all combinations of four previous As and Rs.

In general, it is expected that facilitation effect (RTs to valid trials faster than RTs to invalid trials) usually observed in spatial cueing at short SOAs is significantly modulated by trials sequences.

Table 1: Sequences of alternations and repetitions

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
A	R	A	R	A	R	A	R	A	R	A	R	A	R	A	R
A	A	R	R	A	A	R	R	A	A	R	R	A	A	R	R
A	A	A	A	R	R	R	R	A	A	A	A	R	R	R	R
A	A	A	A	A	A	A	A	R	R	R	R	R	R	R	R
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
A	R	A	R	A	R	A	R	A	R	A	R	A	R	A	R
A	A	R	R	A	A	R	R	A	A	R	R	A	A	R	R
A	A	A	A	R	R	R	R	A	A	A	A	R	R	R	R
A	A	A	A	A	A	A	A	R	R	R	R	R	R	R	R
R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Table 2: Stimuli specifications of the A/R sequence N. 7

	TRIAL 1		**TRIAL 2**		**TRIAL 3**	
	Cue	*Target*	*Cue*	*Target*	*Cue*	*Target*
SEQUENCE 1:	right	left	left	left	right	left
SEQUENCE 2:	left	right	right	right	left	right

Results

Subjects missed the targets on less than 1% of the target-present trials and made false alarms on less than 3% of the catch trials. RTs of less than 100 ms were excluded as anticipations and accounted for less than 1% of all observations. The mean RT for correct responses was calculated for each subject for each cell of the design. Preliminarily, mean RTs were analyzed with a 2 (trial type: valid, invalid) X 2 (target location: left, right) repeated measure analysis of variance. Only a main effect was found for location ($F_{1,9}$=5.485, $p<0.05$), with slower RTs in the right condition (see Table 3).

Table 3: Mean and standard deviations (in italics) for valid and invalid trials for each target location.

		TRIAL TYPE	
		Valid	Invalid
TARGET LOCATION	Left	481.58	489.14
		48.12	*58.13*
	Right	489.50	492.49
		53.30	*56.97*

In order to examine sequential effects RTs were submitted to a 2 (trial type: valid, invalid) X 16 (A/R sequence: AAAA, RAAA, ARAA, RRAA, AARA, RARA, ARRA, RRRA, AAAR, RAAR, ARAR, RRAR, AARR, RARR, ARRR, RRRR) repeated measure analysis of variance. Only the interaction trial type X A/R sequence was significant ($F_{15,135}$=8.731, $p<0.0001$).

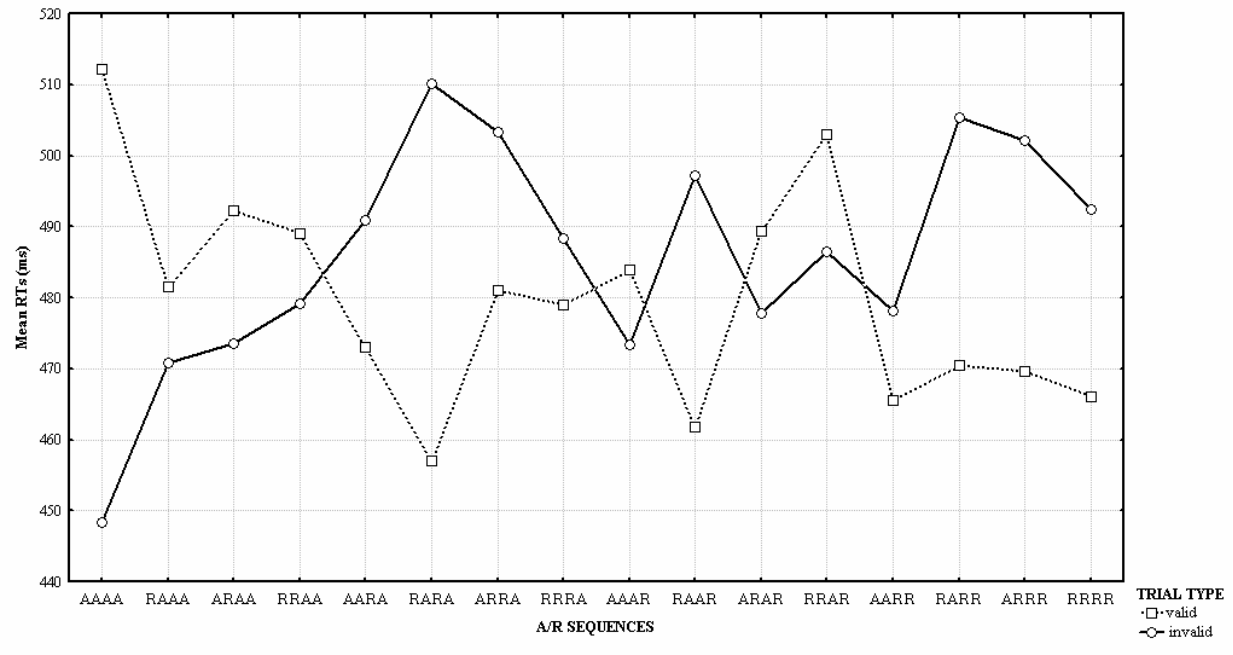

Figure 1: Mean RTs for valid and invalid trials for each A/R sequence.

In order to understand the interaction effect, a post-hoc test (Duncan) was performed. Results showed that the facilitation effect was significant only for some A/R sequences: RARA (p=.001), RAAR (p=.002), RARR (p=.003), ARRR (p=.006), RRRR (p=.030). Moreover, a significant inhibition effect (valid trials RTs slower than invalid trials RTs) was observed for the sequence AAAA (p=.001).Finally, considering separately valid and invalid trials, post-hoc comparisons showed that mean RTs were largely dependent to the specific A/R sequence considered. For example, RTs recorded on those valid trials preceded by the sequences RARA and RAAR, were significantly faster than RTs recorded on those valid trials preceded by the sequences AAAA, ARAA, RRAA ($p<.05$ for all cases). In a similar way, RTs recorded on those invalid trials preceded by the sequences RARA, ARRA, and RARR were significantly slower than RTs recorded on those invalid trials preceded by the sequences AAAA, RAAA, and ARAA ($p<.01$ for all cases). Figure 1 shows mean RTs to valid and invalid trials for each combination of four As and Rs.

Discussion

Results of the preliminary analysis of variance failed to show the typical facilitation effect, usually observed in such paradigms. There can be some reasons for it. One simple possibility is that the stimuli and/or the experimental procedure were not suitable to highlight that kind of attentional effect. This hypothesis can be discarded taking into account the results of the second analysis of variance, for which it is evident that facilitation effects exist, but only for specific sequences of preceding trials. Considering that this kind of effect is less stable than inhibition effect, that is it is not always observed (Samuel & Kat, 2003), it is possible to claim that facilitation effects, when observed, are just dued to the experimental arrangement of trials.

Moreover, results from the second analysis of variance demonstrated that even with short SOAs RTs in spatial cueing can depend on the subjective expectancies generated by preceding trials as it is highlighted by the inhibition effect observed with sequence AAAA.

Experiment 2

The second experiment aimed at investigating the effects of preceding trials in an exogenous spatial cueing paradigm in which the intervals between cues and targets (SOA) were longer than 200 msec. As the literature suggests, long SOAs tend to produce an inhibition effect, usually called Inhibition of Return (IOR), for which RTs recorded on valid trials are slower than those recorded on invalid trials.

Method

The apparatus, stimuli, procedure and design were almost identical to those for Experiment 1. The only difference concerned the stimuli presentation timing (see following Procedure sections).

Subjects A total of 10 undergraduate students were recruited to participate in the experiment. Their man age was 22.4, ranging from 20 to 25 years. All of them reported normal or corrected-to-normal vision. Moreover, all participants reported to be right handed, and were naives to the purpose of the experiment.

Procedure Each target-present trial began with a fixation display containing the central cross; after 500 ms a cue was superimposed for 100 ms. Then, the fixation display was presented again for a variable time, ranging from 500 ms to 1000 ms (SOA). After it, the target appeared for 30 ms. Finally, a third fixation display appeared until a response was given or for 800 ms.

Results

Subjects missed the targets on less than 2.5% of the target-present trials and made false alarms on less than 2% of the catch trials. RTs of less than 100 ms were excluded as anticipations and accounted for less than 2% of all observations. The mean RT for correct responses was calculated for each subject for each cell of the design. Preliminarily, mean RTs were analyzed with a 2 (trial type: valid, invalid) X 2 (target location: left, right) repeated measure analysis of variance. Only a main effect was found for type of trial ($F_{1,9}=131.44$; $p<0.0001$), with slower RTs for valid condition (see Table 4).

Table 4: Mean and standard deviations (in italics) for valid and invalid trials for each target location.

		TRIAL TYPE	
		Valid	Invalid
TARGET LOCATION	Left	286.80 *28,64*	236.49 *36,03*
	Right	283.85 *29.59*	240.47 *33.08*

In order to examine sequential effects RTs were submitted to a 2 (trial type: valid, invalid) X 16 (A/R sequence: AAAA, RAAA, ARAA, RRAA, AARA, RARA, ARRA, RRRA, AAAR, RAAR, ARAR, RRAR, AARR, RARR, ARRR, RRRR) repeated measure analysis of variance. Main effects were found for trial type ($F_{1,9}=89.038$, $p<.0001$), with faster RTs to invalid condition, and for A/R sequence ($F_{15,35}=2.331$, $p<.01$). Also the two-way interaction trial type X A/R sequence was significant ($F_{15,135}=3.945$, $p<.0001$). In order to understand the interaction effect, a post-hoc test (Duncan) was performed.

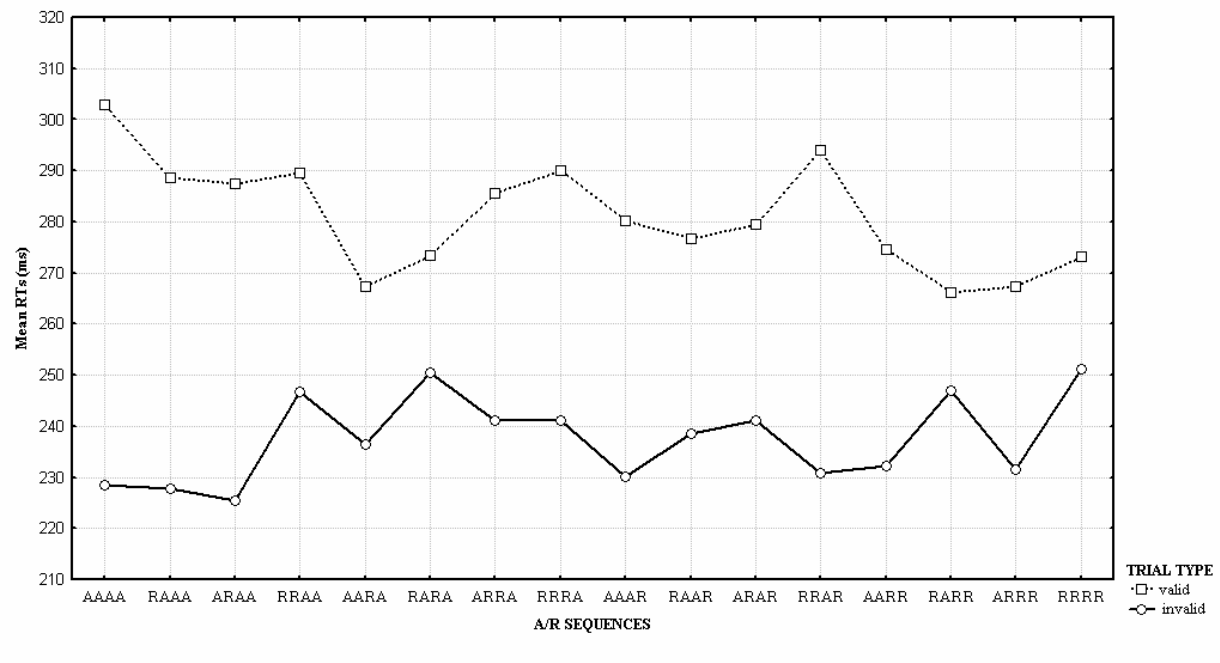

Figure 2: Mean RTs for valid and invalid trials for each A/R sequence.

Results showed that the conventional inhibition effect (IOR, valid trials RTs slower than invalid trials RTs), usually observed in exogenous spatial cueing at long SOA, was significant for all A/R sequences ($p<0.001$).

Finally, in order to examine a modulation of IOR in function of A/R sequences, mean Inhibition Effects (calculated by subtracting mean RTs to invalid trials from mean RTs to valid trials) were submitted to an unvariate repeated measure analysis of variance (A/R sequence: AAAA, RAAA, ARAA, RRAA, AARA, RARA, ARRA, RRRA, AAAR, RAAR, ARAR, RRAR, AARR, RARR, ARRR, RRRR). The effect was found significant ($F_{15,135}=3.945$, $p<.00001$) and the post-hoc test showed that some sequences produced larger IORs than others (for details see Table 5).

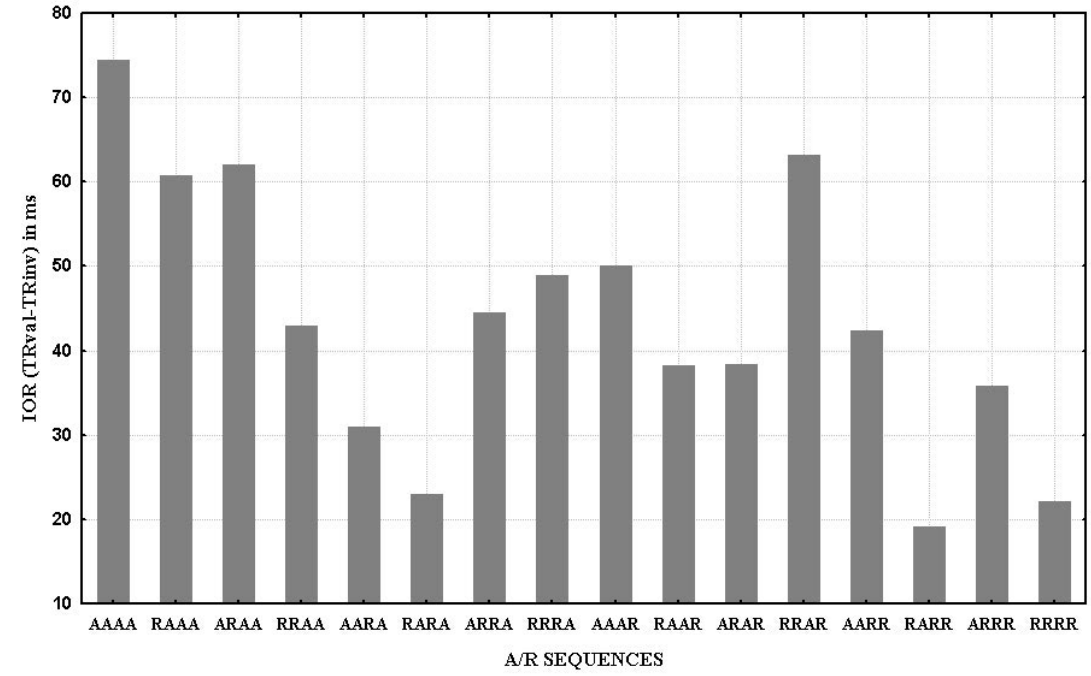

Figure 3: Mean IORs for each A/R sequence.

Table 5: Post-hoc results.

	AAAA	RAAA	ARAA	RRAA	AARA	RARA	ARRA	RRRA	AAAR	RAAR	ARAR	RRAR	AARR	RARR	ARRR
RAAA	0.28														
ARAA	0.30	0.92													
RRAA	**0.02**	0.17	0.15												
AARA	**0.01**	**0.02**	**0.02**	0.37											
RARA	**0.01**	**0.01**	**0.01**	0.13	0.48										
ARRA	**0.02**	0.19	0.17	0.89	0.31	0.11									
RRRA	**0.05**	0.33	0.30	0.62	0.18	**0.05**	0.69								
AAAR	**0.05**	0.35	0.33	0.57	0.16	**0.04**	0.64	0.92							
RAAR	**0.01**	0.09	0.08	0.71	0.55	0.23	0.63	0.42	0.38						
ARAR	**0.01**	0.09	0.08	0.70	0.56	0.23	0.63	0.41	0.37	0.99					
RRAR	0.32	0.84	0.92	0.13	**0.02**	**0.01**	0.15	0.27	0.30	0.06	0.06				
AARR	**0.01**	0.16	0.14	0.96	0.38	0.14	0.86	0.60	0.55	0.73	0.72	0.12			
RARR	**0.01**	**0.01**	**0.01**	0.08	0.35	0.76	0.06	**0.03**	**0.02**	0.15	0.15	**0.01**	0.08		
ARRR	**0.01**	0.06	**0.05**	0.58	0.67	0.29	0.51	0.33	0.29	0.83	0.84	0.04	0.61	0.20	
RRRR	**0.01**	**0.01**	**0.01**	0.12	0.47	0.94	0.10	**0.05**	**0.04**	0.21	0.22	0.01	0.13	0.79	0.28

Discussion

Results of the first analysis of variance showed as expected the inhibition effect (IOR), usually observed with long SOAs. The second and third analyses highlighted that even if IOR seems more strong than facilitation effect it is largely modulated by A/R sequences. Therefore, results of this experiments suggest that size of IOR can be modulated by subjective expectancies originating from preceding trials. Nevertheless, we can not conclude that IOR is exclusively dued to subjective expectancies related to representation of randomness and probability.

General Discussion

The present study was aimed at investigating higher order sequential effects in exogenous spatial cueing. The results of experiment 1 and 2 suggest that facilitation and inhibition effects can be significantly modulated by the specific sequence of preceding stimuli and trials. From a methodological point of view, the results suggest that the assumption that trials in cueing paradigms are independent it is not valid, and consequently that it is dangenorus to think that simply randomizing trials prevent sequential effects. It should be noted also that pseudo-random generators usually used to randomize trials often are be based on an implementation of the alternation bias.

From a theorethical point of view, it seems possible to conclude that facilitation effects in short SOAs cueing experiments can be more simply dued to higher order sequential effects. Differently, this conclusion seems it is not suitable for the inhibition effect (IOR) observed with long SOAs, as in the second experiment IOR it is observed for all the A/R sequences.

Future research should focus on a direct manipulation of first order sequential effects in spatial cueing.

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