

# Learning stimulus relationships increases control in the flanker task\*

Jiaying Zhao, Devin Karbowicz, Daniel Osherson  
Princeton University

May 19, 2011

## Abstract

In this study we examine whether learning the statistical structure of successive stimuli improves performance on the flanker task. In three experiments, sequences of flanker stimuli were segregated into pairs, with the second stimulus contingent on the first. RTs were lower for the second stimulus if its *congruence* tended to match the congruence of the preceding stimulus (Experiment 1). In contrast, performance was not enhanced if the congruence of the second stimuli tended to mismatch the congruence of the first stimulus (Experiment 2). The distinction appears to result from the difficulty of learning mismatch contingencies (Experiment 3). Our results suggest that implicit learning of inter-stimulus relationships can facilitate cognitive control of attention.

Keywords: flanker task, cognitive control, implicit learning

## Introduction

The Eriksen flanker task requires the identification of a central target in the presence of surrounding distractors (Eriksen and Eriksen, 1974). Arrowheads are typically used, yielding stimuli like these:

- (1)      < < < < <    (correct answer: “left”)  
         > > > > >    (correct answer: “right”)  
         < < > < <    (correct answer: “right”)  
         > > < > >    (correct answer: “left”)

---

\*The research reported herein was facilitated by a grant from the Henry Luce Foundation. Contact information: [jiayingz/dkarbowi/osherson@princeton.edu](mailto:jiayingz/dkarbowi/osherson@princeton.edu).

The first two stimuli in (1) are termed *congruent*, the last two *incongruent*. We will call two successive stimuli in the flanker task *concordant* if they are matched for congruence, that is, either each is drawn from the top two rows of (1), or each is drawn from the bottom two rows. Two successive stimuli are *discordant* if they are not concordant, that is, one is drawn from the top two rows of (1) and one from the bottom. Thus, congruence and incongruence are properties of individual stimuli whereas concordance and discordance are properties of pairs. Note that the two members of a concordant pair may or may not require the same answer, and likewise for discordance.

It is well documented that response times (RTs) are lower for congruent compared to incongruent stimuli (Eriksen and Eriksen, 1974; Gratton et al., 1992). It has also been found that RTs are lower for the second stimulus of concordant pairs compared to the second stimulus of discordant pairs (the *Gratton effect*, Gratton et al., 1992). One possible mechanism for the latter phenomenon is that congruent stimuli increase attention to surrounding flankers in the subsequent stimulus, thereby offering a more extended visual target in case of congruence but increasing interference in case of incongruence. Likewise, incongruent stimuli would draw attention away from flankers, thereby slowing the response to a following congruent stimulus but limiting interference in case of incongruence. Concordance would thus enhance performance in both situations, compared to discordance. In another version of the experiment (Gratton et al., 1992; Ghinescu et al., 2010), an explicit cue signaled the congruence/incongruence of subsequent stimuli. RTs were lower when cues predicted congruent stimuli, but no difference in RT was observed for cues predicting incongruent stimuli.

Recent evidence suggests that the Gratton effect hinges on concordant pairs with the same correct answer, that is, on successive stimuli that are *identical*. RT appears not to decrease for the second member of a concordant pair that requires a different answer than the first (Davelaar and Stevens, 2009; Mayr et al., 2003; Nieuwenhuis et al., 2006). The Gratton effect may thus reflect mere repetition priming rather than priming for the more abstract property of stimulus congruence or incongruence.

Perhaps a more robust Gratton effect can be achieved through learning the statistical structure of successive flanker stimuli, instead of relying on explicit cuing. This speculation is motivated by findings on preparatory control in task switching. In a predictable alternating-runs paradigm, participants are able to learn to prepare for the upcoming stimulus and reduce switch cost (see, for example, Rogers and Monsell, 1995, and Kiesel et al., 2010 for a review). In the first two experiments reported below, statistical regularities are implicitly embedded in the stimuli. Specifically, the congruency of the second member of a pair is contingent on that of the first, unbeknownst to the participants. In Experiment 1, the congruency of the second stimulus tends to remain the same as for the first. In Experiment 2, the congruency of the second stimulus tends to differ.

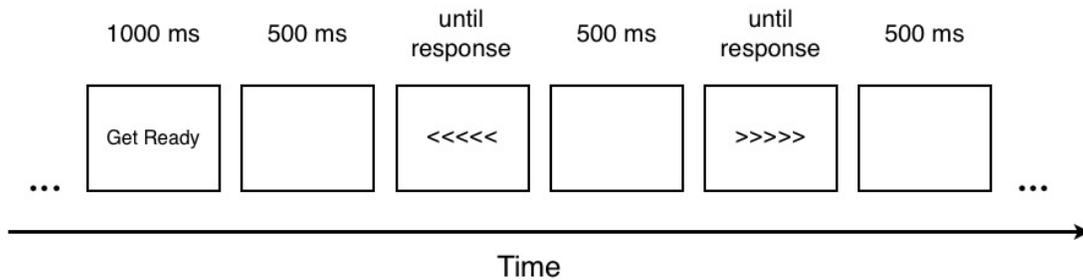


Figure 1: **Sample trial in Experiment 1.**

## Experiment 1

### Participants and materials

Sixty adults from Mercer County, New Jersey were tested individually in return for \$5 compensation (39 female, mean age 22.5 yrs, SD = 2.8). Stimuli were as shown in (1), presented at fixation on a computer monitor, occupying approximately two visual degrees.

### Procedure

Each trial consisted of a pair of stimuli presented sequentially. The trial began with the sign “Get Ready” displayed at the center of the screen for 1 second, followed by a blank screen for 500 ms. The first member in a pair was then presented at the center of the screen until the participant responded. After response, a blank screen appeared for 500 ms. followed by the second member which was presented until the participant responded again. Finally, a blank screen appeared for 500 ms. before the onset of the next trial. An example trial is shown in Figure 1.

There were two conditions in the experiment, called *concordant* versus *random*; they were performed by separate groups of thirty participants each (uninformed of the condition they were in). Each condition was composed of 200 trials, where each trial consisted of a pair of stimuli, as described above. In the concordant condition, 80% of the trials consisted of concordant pairs, 20% discordant. Half of the concordant trials involved congruent pairs, and the other half incongruent. Thus, if the first stimulus in a pair was congruent, there was an 80% probability that the second was also congruent. Likewise, if the first stimulus was incongruent, there was an 80% probability that the second was also incongruent. Within these constraints, all stimuli were chosen randomly. The first two columns of Table 1 lists

all concordant pairs. Crucially, although the congruency of the pairs was manipulated, the central arrow direction was always randomly determined for every stimulus. This implies that participants could learn to predict the congruency of the second stimulus of a pair based on the first, but they could not learn to predict the specific arrow direction of the second stimulus. In the random condition, the concordance of every pair was randomly determined. In other words, the congruency of the first stimulus in a pair was not predictive of the congruency of the second stimulus. Just as for the concordant condition, in the random condition the central arrow direction was randomly determined for every stimulus in every pair.

Participants performed five practice trials before starting the experiment. They were instructed to indicate the direction of the middle arrow by pressing the “1” key or the “0” key for left and right, respectively. Participants were required to respond as accurately and quickly as possible.

## Results and Discussion

If participants in the concordant condition learned to exploit its congruency structure then these participants would be better prepared for the second stimulus in a pair, compared to participants in the random condition. Since learning might require several trials, however, we examined performance only on trials 101 – 200 in each condition. Moreover, only a subset of these latter trials figured in the analysis. Specifically, in the concordant condition, we included only the 80% of trials that exhibited the same congruency for the two stimuli (both congruent or both incongruent). Likewise, in the random condition, only the concordant trials were selected (50% of trials). It was then possible to compare accuracy and RT between the two conditions with respect to the very same stimuli. For example, performance on the second stimulus of the concordant trial <<<<< followed by >>>>> was compared to performance on the second stimulus of the identical trial in the random condition. (Performance on the first stimulus in a pair was ignored.) Finally, for every participant trials with RT more than 2.5 standard deviations above her own mean were excluded from the analysis.

Average accuracy and RT for the second stimulus of concordant pairs in both the concordant and random conditions are presented in Table 1. For each row, the two conditions were compared via independent-sample *t*-tests. For all types of concordant trial, RT was reliably lower in the concordant condition than in the random condition whereas there were no reliable differences in accuracy. Despite the improvements in RT, only six of the 30 participants in the concordant condition were aware of the statistical relationship.

The results suggest that participants learned to exploit the partial predictability of congruence in the concordant condition, focussing attention adaptively for the second stimulus in a trial. The substantially lower RTs seen in Table 1 for congruent compared to incongruent

Table 1: Average accuracy (%) and RT (ms.) for the second stimulus in concordant pairs from Experiment 1. (Standard deviations are in parentheses)

Pair		Concordant		Random		Significance	
1st stim.	2nd stim.	Accu.	RT	Accu.	RT	Accu.	RT
>>>>>	<<<<<	95.0(8.1)	416.2(71.5)	97.7(6.3)	500.3(90.7)	$p = .16$	$p < .001$
<<<<<	>>>>>	97.1(5.2)	417.5(64.2)	93.6(11.7)	492.2(93.2)	$p = .14$	$p < .001$
<<<<<	<<<<<	99.6(2.3)	388.7(68.0)	100(0)	449.0(77.1)	$p = .32$	$p < .01$
>>>>>	>>>>>	99.3(2.7)	380.8(62.6)	98.9(6.1)	445.3(80.5)	$p = .74$	$p < .001$
<<<<<	>>>>>	95.4(7.5)	474.2(79.6)	89.8(19.5)	543.4(92.5)	$p = .39$	$p < .01$
>><<>	<<><<	94.5(10.5)	471.7(78.6)	91.0(13.7)	548.9(103.0)	$p = .94$	$p < .01$
>><<>	>><<>	94.7(8.0)	455.4(79.9)	93.6(8.8)	524.9(95.7)	$p = .30$	$p < .01$
<<><<	<<><<	94.8(7.1)	438.7(60.9)	92.6(8.8)	498.5(87.1)	$p = .57$	$p < .01$

trials may reflect the advantage accruing to spreading attention across multiple arrowheads with the same message.

## Experiment 2

Experiment 1 documents the ability to exploit concordance in sequential stimuli but leaves open the same question about discordance. In a discordant pair if the first stimulus is congruent then the second is incongruent, and vice versa. Experiment 2 was isomorphic to the first except that it involved a discordant condition in place of the original concordant condition. The discordant condition was composed of 200 trials, 80% of which were discordant pairs, 20% concordant. Half of the discordant trials involved a congruent stimulus followed by incongruent, and the reverse for the other half. For the random condition, the data from Experiment 1 were used again. Thirty new participants were recruited for Experiment 2, drawn from the same pool as before (21 female, mean age = 23.8 yrs, SD = 4.1).

We compared performance on matching second stimuli in the discordant versus random conditions, taking into account just trials 101 – 200. As before, trials with RTs beyond 2.5 standard deviations of the participant’s mean were excluded. Accuracy and RT for the second stimulus of discordant pairs in the two conditions are presented in Table 2.

It can be seen that for none of the eight types of discordant trials was RT reliably lower in the discordant compared to random condition; there were also no reliable differences in accuracy. Notice, however, that for all types of trials, the RTs were (non-significantly) lower in the discordant compared to random condition. Only four of the 30 participants in the discordant condition noticed the statistical relationship.

Comparison of the two experiments suggests that it is more difficult to learn discordant

Table 2: Average accuracy (%) and RT (ms.) for the second stimulus in discordant pairs from Experiment 2. (Standard deviations are in parentheses)

Pair		Discordant		Random		Significance	
1st stim.	2nd stim.	Accu.	RT	Accu.	RT	Accu.	RT
>>>>>	>><>>	95.6(6.0)	524.3(104.9)	95.3(12.1)	543.0(82.1)	$p = .90$	$p = .44$
<<<<<	>><>>	88.7(9.0)	524.1(102.7)	83.9(23.8)	538.5(85.0)	$p = .30$	$p = .56$
<<<<<	<<><<	91.2(11.2)	516.4(113.5)	89.2(18.8)	541.2(103.4)	$p = .63$	$p = .38$
>>>>>	<<><<	86.7(11.7)	534.3(123.6)	82.6(21.1)	545.3(80.2)	$p = .35$	$p = .69$
<<><<	<<<<<	99.0(3.1)	464.0(84.1)	98.7(3.9)	495.4(68.7)	$p = .78$	$p = .12$
>><>>	<<<<<	98.1(6.6)	443.3(82.1)	98.9(6.1)	473.6(74.1)	$p = .65$	$p = .14$
>><>>	>>>>>	98.1(4.5)	459.5(79.2)	96.8(7.8)	501.8(84.8)	$p = .43$	$p = .06$
<<><<	>>>>>	98.5(4.2)	442.0(86.3)	98.4(6.5)	469.2(74.0)	$p = .94$	$p = .19$

Table 3: Average accuracy (%) and RT (ms.) for the second stimulus in concordant and discordant pairs. (Standard deviations are in parentheses)

2nd stim.	Concordant		Discordant		Significance	
	Accu.	RT	Accu.	RT	Accu.	RT
<<<<<	97.2(4.8)	403.9(67.4)	98.8(3.2)	453.3(80.0)	$p = .14$	$p < .01$
>>>>>	98.2(2.8)	400.2(60.8)	98.2(3.6)	450.7(79.3)	$p = .96$	$p < .01$
>><>>	95.3(4.9)	464.1(76.4)	92.2(5.9)	526.9(99.6)	$p = .03$	$p < .01$
<<><<	94.4(7.4)	446.6(67.5)	89.2(8.6)	524.3(112.3)	$p = .01$	$p < .01$

relationships compared to concordant. To verify this, we contrasted performance on trials in which the second stimulus was matched between concordant and discordant conditions. For example, a concordant trial >>>>> followed by <<<<< from Experiment 1 was matched with the discordant trial >><>> followed by <<<<< from Experiment 2; performance on the second stimuli were then compared. As before, only trials 101 – 200 were used, and outliers were dropped. See Table 3, which reveals that for each of the four stimulus types there was a significant difference in RT between concordant and discordant trials. Participants responded faster to the second stimulus of a pair when the congruence of the first stimulus reliably matched the congruence of the second; in contrast, the second stimulus received no such performance boost when the congruence of the first stimulus reliably *mismatched* the congruence of the second. There was also reliably greater accuracy for concordant trials in which the second stimulus was incongruent.

Why did participants fail to show improved performance for discordant trials? Either they failed to learn the statistical relationship between the two stimuli in a pair, or they failed to exploit the relationship despite learning it. To clarify the matter, we performed a third experiment in which no learning was necessary.

Table 4: Average accuracy (%) and RT (ms.) for the second stimulus in discordant pairs in Experiment 3 compared to the random condition in Experiment 1. (Standard deviations are in parentheses)

Pair		Discordant		Random		Significance	
1st stim.	2nd stim.	Accu.	RT	Accu.	RT	Accu.	RT
>>>>>	>><>>	95.5(6.3)	478.6(144.4)	95.3(12.1)	543.0(82.1)	$p = .94$	$p = .04$
<<<<<	>><>>	89.9(14.9)	492.5(145.0)	83.9(23.8)	538.5(85.0)	$p = .25$	$p = .14$
<<<<<	<<><<	95.6(6.5)	480.6(151.2)	89.2(18.8)	541.2(103.4)	$p = .08$	$p = .07$
>>>>>	<<><<	84.8(15.1)	478.6(142.5)	82.6(21.1)	545.3(80.2)	$p = .64$	$p = .03$
<<><<	<<<<<	98.6(3.3)	429.4(135.9)	98.7(3.9)	495.4(68.7)	$p = .85$	$p = .02$
>><>>	<<<<<	99.1(3.8)	421.7(154.0)	98.9(6.1)	473.6(74.1)	$p = .86$	$p = .10$
>><>>	>>>>>	97.8(4.3)	430.9(157.9)	96.8(7.8)	501.8(84.8)	$p = .54$	$p = .04$
<<><<	>>>>>	98.7(4.1)	418.3(156.7)	98.4(6.5)	469.2(74.0)	$p = .85$	$p = .12$

### Experiment 3

The current procedure was like Experiment 2 except that participants were explicitly informed that every pair was discordant, that is, congruence was (invariably) followed by incongruence and vice versa. As before, half of the discordant trials involved a congruent stimulus followed by an incongruent stimulus, and the reverse for the other half. Thirty new participants completed Experiment 3 (20 female, mean age = 21.5 yrs, SD = 3.2).

To determine whether participants exploited discordance in the present procedure, we compared performance on the second stimuli with performance on matching stimuli in the random condition of Experiment 1. As before, only trials 101 – 200 were included and outliers were excluded. The results are presented in Table 4.

It can be seen that RTs in the present experiment were reliably lower for most stimulus types compared to the random condition of Experiment 1. The enhanced performance seems not to be due to delaying the response to first stimuli. The average RTs of the first stimuli in the present condition and in the random condition of Experiment 1 were 513.8 (SD = 167.3) and 571.0 (SD = 82.6), respectively, not reliably different [ $t(58) = 1.68$ ,  $p = .10$ ]. We also note that there was no reliable difference in accuracy between the two conditions for any type of discordant trial.

### General Discussion

Our first experiment documents the control over attention that observers can exercise when they learn that the congruency of one stimulus tends to match that of a successor. Presumably, the control is based on extending attention to the flankers for upcoming congruent stimuli and

restricting it for incongruent. The same type of control seems available when the congruency of the first stimulus invariably mismatches that of the second, and this contingency is noted explicitly (Experiment 3). In contrast, mismatch of congruency is difficult to learn implicitly, at least when the mismatch occurs only 80% of the time (Experiment 2)

Overall, our results confirm the existence of a robust Gratton effect (Gratton et al., 1992) inasmuch as RT declined for all types of trials when congruency was predicted implicitly in Experiment 1 and explicitly in Experiment 3. It remains to understand why implicit learning is impeded by mismatching congruency between stimuli whereas it is possible when congruency matches (Experiment 2 versus 1). The two situations, after all, convey equivalent information.

## References

- Davelaar, E. J. and Stevens, J. (2009). Sequential dependencies in the eriksen flanker task: A direct comparison of two competing accounts. *Psychonomic bulletin & review*, 16(1):121–126.
- Eriksen, B. A. and Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics*, 16(1):143–149.
- Ghinescu, R., Schachtman, T. R., Stadler, M. A., Fabiani, M., and Gratton, G. (2010). Strategic behavior without awareness? effects of implicit learning in the eriksen flanker paradigm. *Memory & Cognition*, 32(2):197–205.
- Gratton, G., Coles, M. G., and Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, 121(4):480–506.
- Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, Andrea, M., and Koch, I. (2010). Control and interference in task switching — a review. *Psychological Bulletin*, 136(5):849–874.
- Mayr, U., Awh, E., and Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature neuroscience*, 6(5):450–452.
- Nieuwenhuis, S., Stins, J. F., Posthuma, D., Polderman, T. J. C., Boomsma, D. I., and de Geus, E. J. (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory & cognition*, 34(6):1260–1272.
- Rogers, R. D. and Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, 124:207–231.