Redundancy effects of a moving distractor generated by alerting and orienting

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Redundancy effects refer to improvement of performance in response to irrelevant stimulation, or distractors. Previously described redundancy effects have mainly been associated with relatively high-level perception. The present study examines whether redundancy effects exist in basic attentional and perceptual systems, such as alerting and orienting. Participants performed speeded detection of briefly presented targets while ignoring moving distractors. The presence/absence of distractors and their spatial relationships with targets were manipulated to dissociate possible alerting and orienting redundancies. The distractor pathway (straightforward vs. chaotic) and its motion predictability (blocked vs. intermixed sequences of straightforward and chaotic trials) were also manipulated. The presence of a distractor resulted in faster responses (alerting redundancy). Furthermore, participants responded faster to targets behind distractors (orienting redundancy). Orienting redundancy was found only in the straightforward condition. This indicates that generating an orienting redundancy effect is a relatively slow process based on continuous observation of motion. Lastly, a blocked sequence of trials improved the alerting redundancy effect in comparison with an intermixed sequence.

In perceptual and attentional tasks, a person often has to attend some stimuli or their features and to ignore other ones because they potentially disrupt performance or are simply irrelevant. Irrelevant stimuli or their ignorable features are usually called *distractors*. Distractors may affect task performance in three different ways. The first way is interference, when the presence of a distractor causes task performance to decrease because of involuntary re-allocation of attention to irrelevant stimuli. The second possible effect of a distractor is neutral influence, which takes place when there is successful ignoring of a distractor or highly automatized performance of a task. The third possible distractor effect can be termed a *redundancy effect*. In the latter case, a distractor improves performance.

Redundancy effects have mainly been studied in experiments investigating discrimination and recognition of objects and symbols. In such experiments, target stimuli are usually included in more complex irrelevant formations, such as “good” perceptual gestalts or words. Typically, this results in faster and/or more accurate responses to target stimuli than in isolated target conditions. This represents a typical redundancy effect. Depending on the field of study and the theoretical preferences of authors, such effects may be explained by perceptual organization laws (Pomerantz, 2003), automatic coactivation of recognition or response units of memory that correspond to irrelevant information (Eriksen, Goettl, St. James, & Fournier, 1989; Grice & Reed, 1992; Kahneman, 1973; Miller, 1982), and so on. Notably, most of the previous studies and theoretical frameworks of redundancy have

been concerned with relatively high-level categorical and semantic processes controlling perception and attention. Surprisingly, redundancy effects have hardly been explored in basic perceptual and attentional processes controlling relatively simple reactions, such as alerting and orienting. The present article follows definitions of these processes as stated in Posner’s framework for attentional research (Rueda, Posner, & Rothbart, 2004). *Alerting* refers to the system that provides nonspecific preparation for information input. *Orienting* refers to the system that provides selective preparation for a specific sensory input marked by corresponding physical parameters, such as the spatial location of stimuli.

Objectives

The present study is aimed at exploring whether redundancy effects actually exist in alerting and orienting systems. The typical paradigm for dissociating alerting and orienting effects is the attentional networks test (ANT) developed by Posner and colleagues (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Rueda et al., 2004). Nevertheless, the ANT does not completely satisfy the aim of the present research, since it is based on *task-relevant* warning signals, or cues, to test alerting and orienting. In contrast, distractors are always *task irrelevant*. Thus, the task used in this experiment was speeded detection of a briefly presented faint target in the presence of a concurrent salient distractor with the set of characteristics that elicit involuntary attentional capture: relatively large, bright, and moving over the screen.

A typical alerting effect as revealed by the foreperiod paradigm or ANT includes acceleration of response to a cued target, in comparison with the target-only condition. According to this rule, an *alerting redundancy effect* can be described as acceleration of response to a target in the presence of a distractor, in comparison with the target-only condition. In contrast, inhibition of response to a target in the presence of a distractor should indicate typical interference.

The *orienting redundancy effect* can be estimated by comparing reaction times (RTs) with targets presented at locations previously occupied by a distractor (cued locations) and targets presented in other locations (uncued locations). If a person tends to respond faster to targets in cued locations, it indicates that the orienting system controlling spatial distribution of attention has its redundancy effect on detection, which is called *retroactive orienting*. In contrast, a negative effect of a cue—that is, slower response to a cued target—implies ambiguous interpretation. On the one hand, it may be evidence for interference. On the other hand, it may reflect *inhibition of return* (IOR), a negative stage of involuntary attentional orienting (e.g., Klein, 2000; Lupiáñez, Klein, & Bartolomeo, 2006). If a negative effect of this sort is obtained in the present experiment, additional experiments will be necessary to clarify its true nature.

One must make a special distinction for uncued locations. For example, van Donkelaar and Drew (2002) found that in visual pursuit of a moving object, their participants tended to respond faster to probe stimuli that appeared at an anticipated location of a moving object. Such an effect may be termed *proactive orienting*. This is why it appears to be important to distinguish between uncued locations in front of and beside moving distractors. Notably, the critical difference between the present study and the experiment by van Donkelaar and Drew is that, here, the moving object is considered to be a distractor (i.e., one requiring that a person ignore it) rather than a pursued target (i.e., an attended object).

The possibility of proactive orienting provides additional direction for the investigation of redundancy effects. Proactive orienting implies that attentional shift to a location is controlled by an internal model of expectations related to a stimulus (endogenously), rather than being purely stimulus driven (exogenous). It seems reasonable (and, hence, requires empirical test) that the magnitude of the distractor redundancy effect may depend on the *predictability* of distractor motion over time and space. In the present study, predictability was manipulated in two ways. The first way was manipulating the character of distractor motion by varying its *pathway*. Thus, if a distractor is moving on a continuous predictable pathway (e.g., straightforwardly), it is expected to generate more pronounced redundancy effects than in chaotic movement. If redundancy effects in straightforward and chaotic motions do not differ (if they take place at all), this indicates a predominantly exogenous nature of orienting. The second way to manipulate predictability concerned the design of the trials sequence. It is supposed that redundancy effects increase if all straightforward trials are presented in a uni-

tary block, as opposed to a chaotic block, since this may aid the conscious or unconscious computation of the probability of target appearance at a specified location in the defined distractor pathway.

When redundancy effects refer to an influence of irrelevant (i.e., unattended) stimuli, it is critical that participants should remain ignorant about the relationship between the distractor and the target. Otherwise, they may consciously use the distractor as an informative cue—that is, attend it. Additional postexperimental self-report-based research would be necessary to find out whether participants were aware or unaware of relationships between the distractor and the target.

METHOD

Participants

A total of 28 psychology students at the Higher School of Economics (mean age, 18 years; 7 male) participated in the experiment for extra credit in general psychology lab classes. All of them reported having normal or corrected-to-normal vision. They were told that they were participating in “vigilance in distraction conditions” research. All of the participants were randomly assigned to one of two groups of motion predictability (see below for a description). The first group ($n = 15$) performed a *low motion predictability* task; the second group ($n = 13$) performed a *high motion predictability* task.

Apparatus and Stimuli

The stimuli were developed and presented with the help of the StimMake system (StimMake for Windows; authors, A. N. Gusev and A. E. Kremlev) and were presented on a standard VGA monitor with a refresh rate of 85 Hz. The stimuli were presented on a black background. The target stimulus was a small gray asterisk (visual angle about 1°) that could appear on any part of the screen. The distractor was a large white circle (visual angle about 2°). For manipulating the spatial positions of the targets and distractors, the whole screen was divided into 12×16 conditional squares, as shown in panel A of Figure 1. These squares were invisible to the participants, so they saw only a homogeneous field. Both the targets and the distractors were placed in the center of the conditional squares.

The participants responded by pressing the key on the parallel-port-compatible control panel that was designed for RT experiments. The construction of the control panel provided a short distance between the top (unpressed) and the bottom (pressed) positions of its keys. This provided measurement of RTs that was more precise than that provided by any key of a standard computer keyboard.

Procedure

The participants were seated 60 cm from the monitor. They were instructed to press the key as soon as they saw the briefly presented gray asterisk. They were also instructed to pay no attention to the moving white circle.

Distractor presentation. Typical distractor-and-target trials (except in the control condition) included a moving distractor. Perceived motion was achieved by a series of rapid shifts of a white circle to an adjacent spatial position (conditional square) (Figure 1B). The distractor duration in one spatial position was 100 msec. The whole pathway of a distractor within a trial could be either straightforward or chaotic. A straightforward pathway implied serial shifts of a distractor in only one linear direction per trial (Figure 1C)—that is, horizontally, vertically, or diagonally through the center of the screen, as shown in Figure 1A. A chaotic pathway implied four to five unpredictable, large-scale spatial skips and changes of linear direction per trial (Figure 1D).

Target presentation. Targets were presented briefly in only one unpredictable spatial and temporal position per trial. Target duration was 100 msec.

Figure 1. Stimulation and typical trials design: (A) Spatial division of a screen into conditional spatial positions, with gray fields indicating possible directions of distractor motion (the squares in fact remained invisible to the participants); (B) the time course of a typical distractor-and-target trial; (C) an example of a straightforward distractor pathway (the arrow indicates direction of motion); (D) an example of a chaotic distractor pathway (arrows indicate directions of motion; numbers indicate the order of direction change); (E) distractor–target spatial relation conditions (arrows indicate the direction of motion).

Spatiotemporal relations between distractor and target. In straightforward distractor-and-target trials, a target appeared at a random time, but not earlier than 300 msec after a distractor appearance. In chaotic distractor-and-target trials, a target also appeared not earlier than 300 msec after a large-scale spatial skip of a distractor. Target onset and offset coincided in time with spatial shifts of the distractor (Figure 1B). Target offsets always occurred at least 100 msec before distractor offset.

Target spatial position varied in relation to the current direction of distractor movement. Thus, a target could appear *in front* of, *be-*

hind, or *beside* a distractor (Figure 1E). The distance between the distractor and the target in the “in front” and “behind” conditions varied from four to six spatial positions. In the “beside” condition, the target appeared four to six positions from the current path of the distractor. There was also a control condition, in which only a target and no distractor appeared.

Sequence of trials. The experimental task consisted of 200 trials, differing in type. There were six types of distractor–target trials (25 trials per condition): straightforward–in front, straightforward–behind, straightforward–beside, chaotic–in front, chaotic–behind,

and chaotic–beside. Thus, “behind” trials corresponded to the cued condition in the ANT paradigm, whereas “in front” and “behind” trials corresponded to the uncued condition. There were also 25 control trials (containing only a target) and 25 empty trials (containing only a distractor), on which participants had to make no response. Empty trials were designed to avoid an automatic response on each trial.

Trials of all types were intermixed in two different ways depending on motion predictability. Thus, in the low motion predictability condition, trials of all types were intermixed in random order. In the high motion predictability condition, participants first received all of the straightforward trials with half of the control trials and then all of the chaotic trials with the other half of the control trials, or in the reverse order. The interval between trials varied from 0 to 500 msec. Participants could rest for 1 min after each 50 trials.

Self-report. In a postexperimental interview, the participants were asked whether the moving circle really distracted them from the target. They were also asked whether they noticed any systematic relationships between the distractor and the target during the experiment.

Independent variables. Within-subjects factors were distractor pathway (straightforward vs. chaotic) and distractor–target spatial relation (DTSR) (in front vs. behind vs. beside vs. control). The between-groups factor was motion predictability (low vs. high). Consequently, the experiment had a $2 \times 4 \times 2$ design.

The dependent variable was RT to a target.

RESULTS

The results of the experiment are summarized in Table 1 and are shown in Figure 2.

An ANOVA revealed a significant main effect of factor DTSR [$F(3,24) = 75.85, p < .001$] on RT, indicating that the participants tended to respond faster on all distractor–target trials than on control trials, but the fastest responses were obtained in the “behind” trials. The main effect of distractor pathway was also significant [$F(1,26) = 12.15, p < .01$], indicating that participants tended to respond faster in straightforward than in chaotic trials. The effect of the two-way DTSR $\times$ distractor pathway interaction on RT reached significance [$F(3,24) = 9.38, p < .001$]. This indicates that the previously revealed acceleration of response to the target in “behind” trials was due to the straightforward condition, whereas there was no acceleration in the chaotic condition.

The main effect of motion predictability on RT reached significance [$F(1,26) = 4.87, p < .05$], indicating that participants tended to respond faster with high than with low motion predictability. The effect of the two-way DTSR $\times$ motion predictability interaction was also significant [$F(3,24) = 3.06, p < .05$], indicating that participants in the high motion predictability group responded faster only to distractor-and-target trials but not on control trials. The effect of the two-way distractor pathway $\times$ motion predictability interaction failed to reach significance [$F(1,26) = 1.57, n.s.$]. The effect of the three-way DTSR $\times$ distractor pathway $\times$ motion predictability interaction also was not significant [$F(1,26) = 0.77, n.s.$], indicating that the effects of DTSR and distractor pathway on RT extended to both high- and low-motion predictabilities.

Self-Report Data

All of the participants reported that they successfully learned to ignore the white moving circle. Eight

Table 1
Mean Reaction Times in All Conditions
of the Experiment, in Milliseconds

Distractor– Target Spatial Relation	Low Motion Predictability ($n = 15$)				High Motion Predictability ($n = 13$)			
	Straight- forward Pathway		Chaotic Pathway		Straight- forward Pathway		Chaotic Pathway	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Control	420	41	418	41	413	53	410	51
In front	365	39	363	28	314	50	323	42
Behind	333	34	355	31	288	54	326	40
Beside	354	37	368	37	307	49	335	43

Figure 2. Effects of a moving distractor on reaction time (RT). Error bars denote $\pm SE$.

participants reported that they felt it was easier to respond to a target in the presence of the distractor. Three participants considered targets in front of and behind the straightforward distractor to be larger and brighter and, hence, easier to detect than “beside” targets. Only 1 participant (G.K.) reported that he deliberately used spatial relationships between the target and the distractor. He noticed that the appearance of a target was more probable in front of or behind than beside a distractor in the straightforward trials. So, G.K. tried to “catch” the direction of the circle motion and concentrate on that particular direction. Analysis of G.K.’s individual behavioral data in straightforward trials revealed that his mean RTs to “in front” and “behind” trials were 245 and 242 msec, respectively, whereas the RT for “beside” trials was 272 msec. Thus, G.K.’s result differed from the average sample result, since he responded faster to both “in front” and “behind” targets.

According to their reports, participants failed to discover any other systematic relationships between targets and distractors.

DISCUSSION

Self-Reports

As can be inferred from self-reports, most of the participants remained unaware of any relationships between the targets and the distractors. Thus, the observed distractor effects on RT are likely due to unconscious processes. None of the participants (except participant G.K.) tried to use distractor–target relationships in order to improve their performance. This observation allows the conclusion that the obtained behavioral data indicate involuntary distractor effects rather than reasonable and voluntary strategies that cannot be interpreted as redundancy effects. Although 3 participants claimed that the distractor improved detection by enhancing the apparent size or brightness of a target, this can hardly be considered evidence for conscious strategies. Rather, this might be considered to be a consequence of pronounced redundant distractor influences reflected not only in behavior—that is, RT—but also in some participants' conscious experience.

Redundancy Effects

Alerting redundancy effects. As can be seen from the results, distractor presentation appeared not to interfere with target detection. Moreover, it resulted in response acceleration by 60–100 msec in comparison with the control condition, regardless of the spatial relations between the distractor and the target. Presumably, the moving distractor with salient sensory characteristics activated an alerting system of attention. Alerting probably maintained activation at a high level during the whole period of distractor motion. Hence, alerting facilitated speeded detection of a target occurring during the same period. Such a facilitation can be referred to as an *alerting redundancy effect*. In Figure 3, where an idealized result of the experiment is presented, the alerting redundancy effect is illustrated by the area of the RT axis below the control condition RT and above the “in front” and “beside” condition RTs.

Orienting redundancy effect. It was determined from the experiment that such an effect did actually take

place when a target appeared behind a distractor moving straightforwardly. In terms introduced earlier, this can be referred to as *retroactive orienting*. The effect consists of response acceleration to targets presented in “behind” trials—that is, at locations previously cued by a distractor—by 25 msec, on average, in comparison with two other types of distractor-and-target trials. Notably, response acceleration may be unambiguously referred to as an *orienting redundancy effect*, in contrast with response inhibition, which might be interpreted as either an IOR stage of involuntary orienting (but nevertheless, a redundancy effect) or interference (i.e., an effect opposite to redundancy). In Figure 3, the orienting redundancy effect is shown as the area of RT axis below “in front” and “beside” trials and above “behind” trials.

The present experiment, however, revealed no *proactive orienting effect* such as van Donkelaar and Drew (2002) obtained using a similar paradigm. This is probably because of the difference between specific participants' sets in relation to moving stimuli in the present study and the study by van Donkelaar and Drew. For example, in their experiment, a moving stimulus was considered to be a tracked object (i.e., one of the attended stimuli). In contrast, in the present study, a moving stimulus was considered to be a distractor (i.e., an unattended stimulus). The individual case of participant G.K. is the one that favors this suggestion: G.K., who reported deliberately utilizing a moving distractor for voluntary orienting of attention, showed both retroactive and proactive orienting effects.

Predictability

Distractor pathway. Manipulating the character of distractor motion was aimed at establishing relationships between exogenous (i.e., stimulus-driven) and endogenous (i.e., associated with expectations) processes in generating redundancy effects.

In the present study, manipulating the distractor pathway influenced, presumably, only the orienting component of redundancy, since the RT difference in the straightforward and chaotic conditions differed only for “behind” trials (cued targets). Thus, a retroactive orienting effect was observed in the straightforward condition, whereas there was no orienting effect in the chaotic condition. Presumably, this result can be considered to be evidence that the orienting redundancy effect depends on generating a relatively stable and perhaps quite simple internal model of distractor spatial behavior. It is important to note that in the chaotic condition, targets appeared not earlier than 300 msec after large-scale skips of distractors (i.e., only after at least 300 msec in which smooth motion was observed). Hence, constructing such an internal model with the subsequent redundancy effect appears to take time. This may indicate the endogenous nature of the orienting redundancy effect, since the acceleration of response elicited by exogenous orienting of attention should typically begin earlier (Jonides, 1981).

Motion predictability. The results of the experiment indicate that motion predictability influenced the magnitude of the redundancy effect. Nevertheless, this influence concerned not orienting domain, as was presupposed in

Figure 3. A model of the contributions of alerting and orienting redundancy effects on RT changes with respect to the results of the experiment. DTSR, distractor–target spatial relation.

the Objectives section of this article, but alerting. Thus, participants from the high motion predictability group tended to respond faster to all distractor-and-target trials than did those from the low motion predictability group. The RT difference between the two groups was 40 msec, on average. It is difficult to come to any conclusion concerning an interpretation of this effect from the present experimental data. A series of additional experiments will probably be necessary to clarify this effect.

Independent (additive) contributions of alerting and orienting in generating redundancy effects. The present experimental design was based on the statement from Posner's attentional networks model (Posner & Fan, 2008; Rueda et al., 2004) that alerting and orienting are the two independent systems of attention. The results of the present study provided unexpected empirical support for this statement. Distractor pathway had a main effect on orienting alone, not on alerting. In contrast, motion predictability had a main effect on alerting alone, not on orienting. But the effect of interaction between these two factors was insignificant. In terms used by Sternberg (1969, 2001), these two factors are *additive*, so that the two systems that are affected by the factors (i.e., alerting and orienting) appear to be mutually independent—at least, in the control of redundancy effects.

AUTHOR NOTE

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