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RESEARCH NOTE

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Sudden and gradual presentation of distractor objects: differential interference effects

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Abstract In solving the selection-for-action problem, it is believed that attentional mechanisms enable dominance of target over non-target objects. However, under some conditions, information from non-target objects "interferes" with the action to a relevant target. We investigated the possibility that this interference may result when the irrelevant object activates a specific subset of visuomotor pathways. Participants reached to grasp three-dimensional stimuli while actively attending to a nearby flanker object. The means by which the flanker was presented was manipulated. This relevant object was illuminated either abruptly or gradually. The parvocellular pathway in early visual processing is equally activated in both conditions. The magnocellular pathway is strongly activated by abrupt presentation and weakly activated with gradual presentation of the flanker object. Kinematics of the reach-to-grasp action to the target showed signs of interference only in the sudden illumination condition. This suggests a dissociation between dorsal and ventral cortical streams in terms of relevance for action. Our data suggests that this effect is not due to early visual-pathway differences, but instead reveals a property of a transient object-based visual attention mechanism.

Key words Selective attention · Kinematics · Human · Visual pathways

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Introduction

Perceptual events in visual space can "capture" attention so that processing efficiency is enhanced for characteristics related to the event (Yantis 1996). A potent feature for drawing attention to a target during a visual search task is its sudden appearance (Jonides and Yantis 1988). Much research has been directed at either confirming or disputing the unique status of abrupt onset for attentional capture. This event feature has been dissociated from a host of others such as luminosity (Hillstrom and Yantis 1994), item colour (Yantis 1993), attentional-control setting by the observer (Folk et al. 1992) and forward masking of stimuli that do not appear abruptly (Gibson 1996; Yantis and Jonides 1996).

One theory accounting for the salience effect of abrupt onset includes the concept that attention is captured by the introduction of a new perceptual object (Yantis and Jonides 1996). This concept is supported by the finding of no advantage in drawing attention by abrupt onsets over offsets when the item flashed is only part of an object (Watson and Humphreys 1995), selection being determined more by properties of featural singletons (Theeuwes 1994). Kahneman and Treisman (1984) term the new perceptual object an "object file", describing it as a temporary episodic representation for collecting, integrating and updating information about current characteristics of the object (Kahneman et al. 1992; Treisman 1992). This file is proposed to give preview benefits for visual identification (Henderson and Anes 1994) prior to slower access and processing within systems for existing object representations (Yantis and Jonides 1996).

Attentional capture by the abrupt onset of a new object occurs even when its appearance predicts neither location nor identity of the target in a visual-search task (Martin-Emerson and Kramer 1997). As such, the new object may act as an attentional distractor. Remington et al. (1992) demonstrated that response time to a letter target appearing in one of four boxes was increased if this target was preceded by distinct, abrupt-onset visual stimuli flashed briefly in another box, in all boxes or at fixation. This suggests that attention is captured involuntarily by abrupt onset. However, subsequent research has demonstrated that onsets do not necessarily override intention, and that goal-directed processes, such as expectancy, are critical to the degree to which attentional capture is elicited (Folk et al. 1992; Tepin and Dark 1992; Folk et al. 1994; Fournier 1994; Juola et al. 1995; Gibson and Kelsey 1998).

The reach-to-grasp action is a goal-directed action that requires some degree of attention to the stimulus to be grasped. This movement is performed regularly in the presence of task-irrelevant objects, and there is much debate as to whether the presence of such flanking objects influences organisation of the movement to the target (Jackson et al. 1995; Castiello 1996; Bonfiglioli and Castiello 1998). The degree to which attention is drawn towards the distracting object is one factor that may determine the strength of a distracting/facilitating effect of a flanker object upon the target action. Castiello (1996) required subjects to attend to a non-obstructing flanker object (by counting the number of times it was illuminated by a flashing spotlight) while reaching to grasp a target. Kinematics of the target action were compared with those from other situations in which the flanking object was simply presented in the same position. Interference effects, which reflected the physical characteristics of the flanker (such as its size), were only present under conditions where attention was directed to the flanking object.

If results from the computer-screen environment can be extrapolated to a three-dimensional world, it can be advanced that abrupt onset of a flanker object might act to capture attention in a more automatic manner than the voluntary deployment strategy used in the Castiello (1996) study. However, because action is goal-directed towards the target, voluntary intent may override any involuntary attraction to the flanker. The extent to which the flanker object, and its "object file", affect perceptuomotor processing for the target object should be evident in the kinematics of the target action. Successful overriding by voluntary intent would be indicated by the lack of interference effects under conditions of abrupt flanker onset.

Many theories have been raised to explain how prioritisation for targets over non-targets is achieved. Mordkoff and Yantis (1991) classify 3 model types: (1) independent race, (2) coactivation and (3) interactive. However, the distinction between these models can be ambiguous. With independent race models, only one winner activates the response following a competitive race between perceptual inputs. Tipper and colleagues (Tipper et al. 1992, 1997; Howard and Tipper 1997) suggest that competition exists between motor programs for the target and the distractor. If information related to the distractor is processed faster than the target, this needs to be inhibited and could influence movement to the target. Coactivation models assume activation-strength summation between perceptuomotor pathways, with joint contributions according to weighting. Lavie and Cox (1997) propose that processing order is ascertained according to each object's relevance, with processing capacity determining whether information from irrelevant items is acknowledged. Under certain conditions, this model would predict interference from abrupt flanker onset if perceptuomotor processing from its object file is "allowed" to interact with similar processing from the target object representation.

Interactive models are intermediate, examples being the "selective-attention" model of Castiello (1996) and the "integrated competition hypothesis" of Duncan and colleagues (Desimone and Duncan 1992; Duncan et al. 1997). With the selective model, attention is given to relevant and irrelevant visual stimuli, but, with task-related focusing of attention, only the relevant object is attended to and only the appropriate motor program is selected and performed (Castiello 1996). With the integrated competition hypothesis, a variety of brain systems are activated upon stimulation by visual input, integration occurs between activated systems and relevant object information biases the competition. Ascendancy of one object corresponds to a loss of relevance for other objects (Duncan et al. 1997). A number of experiments have demonstrated that interference occurs when features of different objects must be processed simultaneously (Duncan 1984; Vecera and Farah 1994; Duncan and Nimmo-Smith 1996).

One aim of the present study was to investigate whether the sudden presentation of a flanker non-obstacle object will affect kinematics of the reach to grasp movement to a target. The abrupt onset should trigger an object file representation providing temporary object-related information. If this flanker were the target, this object-related information would be of particular relevance to the task. As an irrelevant flanker, there is some question as to the extent to which the information contained within the object file integrates with that contained in the representation for the target object, and the weighting it might contribute to the target motor action. It is hypothesised that interference effects from the flanker should be evidenced as differences in the kinematics when comparing this abrupt onset condition with a condition in which a flanker is presented at the same time as the target. Because attention is said to be drawn almost automatically to the abrupt-onset flanker, it is also hypothesised that interference effects from an abrupt-onset flanker should be greater than interference effects to a flanker that is gradually illuminated during reach [reaching] to grasp a target. It is also important to distinguish between attentional effects of these manipulations and low-level sensory effects. Gradual onset and sudden onsets are both processed adequately by the parvocellular visual pathway, while sudden onsets strongly stimulate the magnocellular visual pathways (Tolhurst 1975; Breitmeyer 1984; Maunsell et al. 1990). Furthermore, the sudden onset of movement of a stimulus in the peripheral field reduces the sensitivity

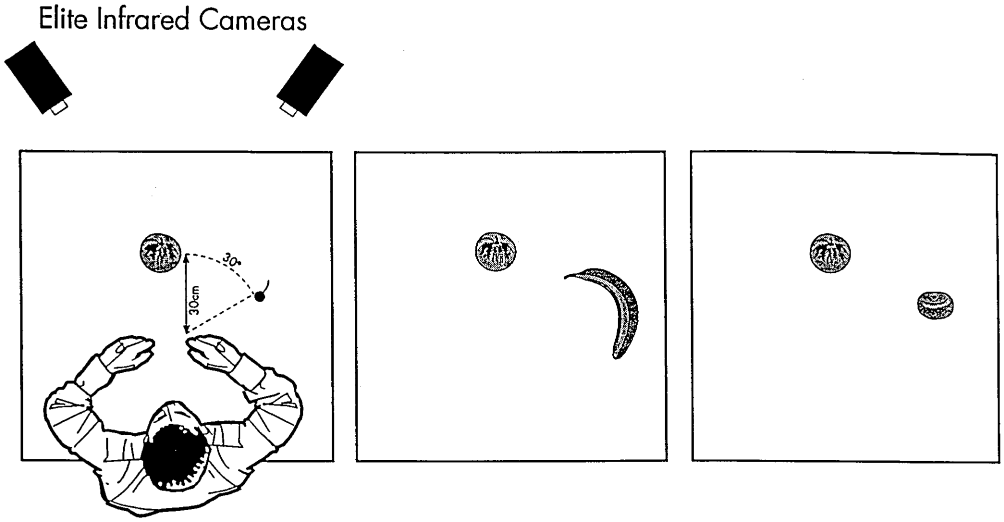

Fig. 1 The target was a three-dimensional apple presented 30 cm away from the subject along the mid-sagittal plane. The distractor could be another three-dimensional fruit (banana, cherry or mandarin). Please note that this figure is not to scale

to most natural targets in the central visual field (Kruger 1977; Derrington 1984; Mattingley and Badcock 1991). This peripheral shift effect is a property of the magnocellular pathways. In this experiment, we dissociate low-level sensory effects of illumination conditions from attentional effects by using the same illumination conditions with and without the presence of a flanking object.

Materials and methods

Thirty students (15 women and 15 men, aged 18–25 years) volunteered to participate in the experiment. All were right handed (Oldfield 1971), reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment. They attended one preliminary session of 0.5 h duration and one experimental session approximately 1 h duration, in which ten trials were performed. Both the preliminary and experimental sessions were conducted in a completely darkened room.

Subjects sat at a table (1 × 1 m) with their feet resting comfortably on the floor. Reflective passive markers (0.25 cm diameter) were attached with double-sided tape to: (1) the wrist, (2) the index finger and (3) the thumb. Movements of these markers were recorded with the ELITE three-dimensional motion-analysis system. This consisted of two infrared cameras (sampling rate 100 Hz) inclined at an angle of 30° to the vertical and placed 3 m in front of the table and 3 m apart. The spatial error measured from stationary and moving stimuli was 0.4 mm. Coordinates of the markers were reconstructed with an accuracy of 1/3000 of the field of view and sent to a host Pentium computer. The target object to be grasped was a red apple (~8 cm diameter, weight: ~100 g; see Fig. 1). The distractor object was another piece of fruit [cherry (~1.5 cm diameter, ~6 g in weight); banana (~4 cm diameter, 110 g in weight) or mandarin (~5 cm diameter, 50 g in weight); see Fig. 1]. Both target and distractor were positioned on an arc of radius 30 cm from the pressure-sensitive start switch positioned 20 cm in front of the subjects' midline thorax. The target was directly in front of the subject in the mid-sagittal plane and the distractor was 30° to the left or right (see Figure 1).

Two spotlights were positioned 0.8 m above the table. Onset time, light intensity and duration of illumination were controlled by an A/D input/output box time-locked to the ELITE recording system. One spotlight was positioned to optimise illumination of the target apple, the diameter of its beam exceeding the diameter of the apple by 0.2 cm. The other spotlight was positioned for illumination of the distractor fruit with the beam diameter adjusted according to fruit size. The distractor could not be seen via light scatter from the target spotlight before it was illuminated by the flanker spotlight.

In the preliminary session, the subject performed ten reach-to-grasp trials to the target apple. For this session, the conditions matched those of the experimental session, except that no distractor was presented. The subject was instructed to reach and grasp the apple as soon as it became illuminated by the spotlight. No emphasis was placed on speed of response, speed of movement or accuracy, and grip type was not specified. Once the apple had been grasped and lifted a short distance from the table surface, the light was extinguished and the subject returned his/her hand to the starting position. The subject was then blindfolded and one experimenter repositioned the apple in the correct location and a new trial was initiated (computer control) by a second experimenter. From these initial trials, the average movement duration from onset of reach movement, as determined from the wrist-marker velocity profile, to grasp of the object, as determined from the grip-aperture profile for each subject, was determined. This value was used for the timing of gradual illumination for one of the subsequent experimental conditions and ranged from 770–852 ms.

Five conditions were tested in the experimental session: (1) sudden illumination of distractor (SI); (2) gradually increasing illumination of distractor (GI); (3) continuous illumination of distractor (CI); (4) no distractor, but spotlight flashing (FC); (5) no distractor present (ND). For each of the conditions, ten trials were performed. This consisted of five trials with each type of distractor positioned on the right and five with each positioned on the left. Trial order was randomised. For all trials in which a distractor was present, the subject was instructed to pay attention to the distractor, without overt eye movement, and to name the fruit following completion of the trial.

These conditions were administered in a counterbalanced order. For all conditions, illumination of the target apple acted as the start signal for the reach to grasp movement. For the sudden illumination condition, the distractor was fully illuminated either 50 or 100 ms after target illumination. Time from computer-switching time to maximum illumination (1500 lux) was 10 ms. For the gradual illumination condition, the distractor was gradually illuminated over a time corresponding to the subjects average movement duration determined from the preliminary session. For one subject, movement durations during the experimental and preliminary sessions differed considerably. As a result, full illumination of the distractor occurred prior to completion of the action. Data from this subject were excluded from analysis.

For the continuous illumination condition, the distractor was fully illuminated 10 s prior to each trial and remained fully illumi-

Table 1 Movement duration and kinematic values for the different distractor illumination conditions. SD in *parenthesis*. Values which significantly differ from the others are denoted with an *asterisk*. *SI* Sudden illumination, *GI* gradual illumination, *CI* continuos illumination, *FC* flash condition, *ND* no distractor

	SI	GI	CI	ND	FC
Movement duration (ms)	830* (90)	710 (83)	732 (82)	725 (79)	718 (75)
Transport component					
Deceleration time (ms)	576* (64)	432 (54)	441 (48)	454 (53)	437 (46)
Amplitude peak velocity (mm/s)	654* (69)	821 (93)	800 (86)	795 (86)	769 (84)
Manipulation component					
Amplitude of maximum grip aperture (mm)	110 (7)	108 (4)	108 (4)	108 (3)	108 (6)
Time peak grip velocity opening (mm/s)	199* (21)	221 (25)	232 (21)	228 (27)	237 (31)
Time peak grip velocity closing (mm/s)	502* (56)	533 (54)	528 (53)	530 (60)	524 (55)
Time of maximum grip aperture (ms)	355* (36)	377 (40)	387 (42)	380 (41)	391 (42)

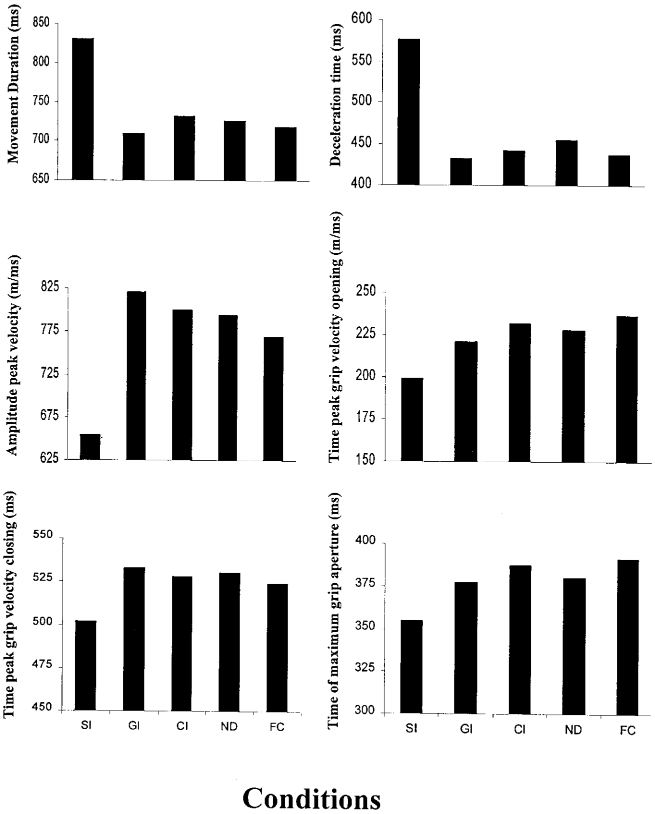

Fig. 2 Diagrammatic representation of the changes in movement duration and the kinematics of the reach and the grasp component for the different distractor conditions. *SI* Sudden illumination, *GI* gradual illumination, *CI* continuos illumination, *FC* flash condition, *ND* no distractor

nated throughout the trial. For the no distractor condition, no distractor was presented. In the "flash" condition, the spotlight flashed and remained on for the duration of the trial.

The ELIGRASP (BTS 1994) software package was used to analyse the data. This gave a three-dimensional reconstruction of the marker positions. The data were then filtered using finite-impulse-response (FIR) linear filtering with a transition band of 1 Hz (sharpening variable=2). The reach component was assessed by analysing the velocity profile of the wrist marker. The grasp component was assessed by analysing the distance between the index finger and thumb markers. Movement duration was taken as the time when the fingers closed on the target, and there was no further change in the distance between the index finger and the thumb. On the basis of previous literature on interference effects during the reach-to-grasp movement, dependent measures of particular relevance to the hypotheses were chosen for statistical analysis (Castiello 1996; Tipper et al. 1997). These dependent variables were: (1) movement duration; (2) reach component parameters: the time from peak velocity to the end of the movement (deceleration time), the amplitude of peak velocity; and (3) grasp component parameters: time to maximum grip aperture, amplitude of maximum finger aperture and the peaks of velocity for finger opening. The amplitude of maximum lateral and vertical deviations (X- and Z-coordinates, respectively) were also calculated from the trajectory profiles of the wrist marker. For each dependent variable, an analysis of variance (ANOVA) was performed with condition (SI, GI, CI, ND, FC) as a within-subjects factor. Post-hoc comparisons were conducted with the Newman-Keuls procedure.

Results

Mean values and standard deviations can be seen in Table 1. Movement duration and deceleration time were longer when the distractor was suddenly illuminated than for the other conditions [$F(4,116)=45.05$, $P<0.0001$; $F(4,116)=34.31$, $P<0.0001$, respectively; see Table 1]. The amplitude of peak velocity was also influenced by the type of condition. As shown in Table 1, it was lower when the distractor was presented suddenly than in the other conditions [$F(4,116)=9.05$, $P<0.001$]. Post-hoc comparisons revealed no differences between the GI, CI, ND and FC conditions for all the dependent measures described above.

For the manipulation component, the opening phase of the hand movement was affected by the type of illumination (see Fig. 2). The time of maximum grip aperture and that of maximum peak grip velocity were earlier for the sudden than for the gradual distractor illumination condition [maximum grip aperture: $F(4,116)=10.08$, $P<0.001$; peak grip velocity: $F(4,116)=27.34$, $P<0.0001$]. Post-hoc contrasts did not reveal significant differences between the GI, CI, ND and FC conditions. Spatial trajectories were not influenced by the presence of the distractor.

Discussion

The aim of the present study was to investigate whether kinematics of the reach-to-grasp movement towards an object were affected by the sudden or gradual illumination of a distractor object. It was found that interference was evident only when the distractor was suddenly illuminated.

Yantis and Jonides (1984) demonstrated that sudden visual onsets capture attention because attention is drawn by the appearance of a new perceptual object. The results of the present study suggest that sudden presentation of a distractor object led to interference effects; it competed with the action to a target. In this regard, Desimone and Duncan (1992) proposed a model to explain how only a small part of the total visual input can be used at any given time in the active control of behaviour. This idea is based on the assumption that activation from different objects competes within many cortical and subcortical systems in the brain. An increase in activity for one object determines a decrease in activity for others. As an object gains ascendancy in one system, it also tends to become dominant in others. For the sensorimotor network in its entirety, the tendency is to settle into a state in which different neural systems converge to work on the same dominant object analysing its multiple visual properties and implications for action. In general, it should be possible to select any kind of object for control of behaviour, depending upon the task demand.

Given the present results, the integrated competition hypothesis proposed by Desimone and Duncan (1992) cannot necessarily be taken as a rule. If a distractor object is suddenly illuminated, it appears to gain a level of ascendancy similar to that of the target. The result is competition between target and distractor, as revealed through the kinematic results. The objects compete for action, each generating parallel kinematic plans that would be required for grasping. Consequently, interference emerges given the conflict between the intended-but-not executed action towards the distractor and the intended-and-executed action towards the target. In other words, the interference effects determined by the distractor objects depend on the weight attached to them. Yet, this weight varies as a function of type of distractor presentation (Castiello 1996).

So, why do distractor objects produce interference only when suddenly illuminated? One possible response to this question considers the role of the magnocellular and the parvocellular pathways in guiding grasping behaviour. An abruptly presented object gives rise to a strong signal in the magnocellular stream (Breitmeyer and Ganz 1976; Badcock and Sevdalis 1987) This signal is rapidly processed by the dorsal stream of cortical processing (Maunsell 1987; Petersen et al. 1988), which provides strong input into cortical area 7 (De Yoe and Van Essen 1988; Grusser and Landis 1991), an area involved in the visual processing relevant to grasping (Graziano and Gross 1998). Conditions in which the stimuli are gradually illuminated minimize the contribution of the magnocellular pathway. One aspect of the current data favours the suggestion that the magnocellular system must be strongly stimulated to produce interference effects. We only obtained such interference with sudden illumination of the object.

However, the data do not support a purely low-level sensory effect. The same sudden onset of the spotlight when no object was present still produced a strong magnocellular system signal. Interference did not occur under these circumstances. This shows that the interference requires the presence of an object and suggests that we have instead demonstrated a property of a transient attentional system similar to that described by Nakayama and Mackeben (1989). This experiment extends their work by showing that the evocation of that transient attentional response requires a sudden onset for the object. It is still quite likely that these properties reflect processing in the higher levels of the dorsal stream, where object-based representations and attentional factors seem to be important (Lynch 1980).

Conclusions

The evidence presented here suggests that attentional mechanisms involved in selection have similar stimulus preference to the magnocellular pathway. When the appearance of a flanker object is characterised by an abrupt onset, a perceptual representation for the “distracting” object appears to be created, with attention being directed towards the new “object file”. It is proposed that this additional representation enters into conflict with that already active for the target object, and that the conflict between these two objects’ representations develops into a competition for access to higher levels of processing. The result is an alteration of the kinematics for the movement directed towards the target when the distractor is presented suddenly. In contrast, when the distractor is presented gradually, interference effects are not found.

Differences in results according to the manner in which the flanker is presented can be accounted by for the activation of different visual pathways. Specifically, the predominantly magnocellular pathway is probably activated when a flanker object is presented suddenly. Because the dorsal stream receives its main input from the magnocellular pathway and this stream is already processing target characteristics for motor processing, the additional demands imposed by the suddenly presented distractor led to competition (distractor) effects in target movement kinematics. Such effects are not elicited when a flanker activates the magnocellular pathway weakly, but leaves a strong parvocellular signal.

As a final point, it is relevant to mention that a possible limitation of the present study is concerned with two points that certainly deserve to be addressed with further investigations. The first point is that of the timing of events. The abrupt onset item was illuminated in full within 100 ms of the onset of the movement, while the gradual onset item was not fully illuminated until much later, say 750–900 ms. This could well explain some of the differences between the sudden and gradual illumination condition. However, this is mitigated to some extent by the fact that the continuously illuminated condition yielded little effect.

The second point is that subjects were instructed to deliberately attend to the flanker. The present instructions are likely to have evinced a top-down component to flanker selection. That is, the observed attentional capture might not be said to be purely bottom-up. Further studies should consider illuminating the abrupt onset item later in the trajectory to determine whether that changes its potential for influencing the trajectory and to instruct the subjects to ignore the distractor.

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