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The influence of unattended features on object processing depends on task demand

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ABSTRACT

Objects consist of features such as shape, motion and color, all of which can be selectively used for different object processing tasks. The present study investigated whether task demands influenced how well participants attended to features of novel colored dynamic objects that were task-relevant while ignoring those that were task-irrelevant. To address this, we used tasks which had different perceptual, learning and memory demands. The unattended features were systematically changed to measure their effects on how well participants could process the attended feature. In Experiment 1, participants discriminated simultaneously presented objects on the basis their shape or motion. We found that changes to unattended motion and color did not affect participants' sensitivity to discriminate the attended feature but changes to unattended shape did. We also found that changes to unattended motion impaired how quickly observers responded. In Experiment 2, participants identified learned objects at the individual level on the basis of their shape or motion. We found that changes to any unattended features affected accuracy and reaction times. Overall, these results point to an important role of task demands in object processing: Task demands can influence whether task-irrelevant features affect object-processing performance.

1. Introduction

Shape is the feature that is predominantly used for object recognition (Biederman, 1987; Tarr & Bulthoff, 1998). However, objects have other features, such as motion and color, which can also contribute to object recognition. Several studies using a wide range of recognition tasks and objects have shown that both motion (e.g., Knappmeyer, Thornton, & Bulthoff, 2003; Liu & Cooper, 2003; Newell, Wallraven, & Huber, 2004; Pyles et al., 2007; Spetch, Friedman, & Vuong, 2006; Stone, 1998; Vuong & Tarr, 2006) and color (e.g., Naor-Raz, Tarr, & Kersten, 2003; Price & Humphreys, 1989; Tanaka & Presnell, 1999) are used to varying degrees for object recognition, despite a bias to use shape in most recognition tasks. For example, motion may play an increasing role in the recognition process when shapes are visually similar, ambiguous or degraded (Knappmeyer, Thornton, & Bulthoff, 2003; Lander & Bruce, 2000; Vuong & Tarr, 2006). Similarly, color may play an increasing role if it is diagnostic of object identity (Naor-Raz, Tarr, & Kersten, 2003; Tanaka & Presnell, 1999).

Object recognition encompasses many different object-processing tasks, from discriminating between stimuli to identifying and categorizing individual objects. These different tasks may have different perceptual and cognitive demands. Therefore depending on the task, some features may be more useful than others (Schyns, 1998). To illustrate, visually discriminating ripe from unripe fruits may be more effective using color than shape information; conversely, discriminating different fruits may be more effective using shape than color information. It may further be the case that the relative contribution of shape, motion and color to object recognition and the shape bias that is often observed across different studies depend on attentional mechanisms that select features as a function of the perceptual and cognitive demands imposed by the task. Task demands have previously been shown to influence object priming, for example (Liu & Cooper, 2001).

In the present study, we combined a feature attention paradigm with either a discrimination or identification task to investigate the extent to which observers can attend to specific features of objects (e.g., their shape) while ignoring the remaining features (e.g., their motion or color). In both tasks, the attended features are made task-relevant whereas the ignored or unattended features are made task-irrelevant. Importantly, these tasks have different perceptual and cognitive demands which might influence whether observers can attend to a single feature that is relevant to the task or whether they attend to all features in an obligatory manner irrespective of whether or not the features are task-relevant or task-irrelevant. This distinction is similar to the one made between feature-based (Maunsell & Treue, 2006) and object-based attention (Scholl, 2001) proposed in the literature.

There is some indirect evidence that task demands can influence how successfully observers can filter out unattended features. On the one hand, studies that use relatively simple detection or

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binary-decision tasks showed that observers effectively filtered unattended features (e.g., Cant et al., 2008; Wegener et al., 2008). On the other hand, studies that use relatively more complex tasks or responses showed that observers could not effectively filter unattended features (e.g., Ling & Hurlbert, 2004; Melcher, Papathomas, & Vidnyanszky, 2005).

Cant et al. (2008) showed that color and shape are processed independently using a Garner paradigm (Garner, 1988; Gottwald & Garner, 1975). In this study, observers performed a speeded binary classification task of rectangular shapes, either by their size (e.g., small vs. large), surface color (e.g., red vs. yellow) or surface texture (e.g., brick texture vs. wood texture). When classifying surface properties, their classification times did not increase when size varied from trial to trial. Similarly, when classifying a rectangle's size, their classification times did not increase when color or texture varied from trial to trial. In terms of the logic of the Garner paradigm (Garner, 1988), these different features were separable (independent) rather than integral dimensions. For the purpose of the present study, these findings suggested that observers can filter out the unattended shape or color for the simple 2-choice classification task.

Similarly, Wegener et al. (2008) showed that observers were able to independently process motion and color, i.e., they could filter out the unattended motion or color. They presented observers with moving gratings in gray or pale yellow. The observers' task was to detect changes in the speed of two simultaneously presented gratings or changes in their color. They were either cued to the *feature* (i.e., color or speed) that would undergo a change next or to the *location* (i.e., the object presented to the left or the object presented to the right of the center of the screen) in which a change would occur next. Wegener et al. found that observers responded more quickly when they were correctly cued about which feature (i.e., speed or color) compared to which location would next undergo a change. The better performance for *feature* cuing compared to *location* cuing suggested a mechanism that was able to select the cued feature individually.

In contrast to Cant et al.'s (2008) and Wegener et al.'s (2008) results, Ling and Hurlbert (2004) found interference by unattended features on the processing of attended features when observers were tested with a more difficult comparison task. In their study, observers compared the size or color of two domes embedded in an array of several domes. When observers compared subtle differences between dome sizes, they judged domes with more saturated colors to be larger. Furthermore, their discrimination thresholds for both shape and color increased when the task-irrelevant feature was varied. Thus, with a more difficult comparison task relative to the classification task, observers were not able to completely filter out shape or color. That is on any given trial, the additional domes may increase the task load even though observers were instructed to ignore all domes except for the two they were to compare.

In line with Ling and Hurlbert's (2004) findings, Melcher, Papathomas, and Vidnyanszky (2005) found that observers automatically selected task-irrelevant features that co-occur in space and time throughout the visual field. Observers in their study performed a color discrimination task of random dots followed immediately by a motion discrimination task of red and green random dots. For the motion discrimination task, they were instructed to attend to one of the colors. Melcher et al. found that motion coherence thresholds for a given level of motion-discrimination performance were drastically reduced if the color of a sub-threshold motion prime matched the attended color. This finding suggests that observers automatically processed the color and motion simultaneously.

The studies reported above used different tasks and stimuli to test whether features are processed independently or not (Cant et al., 2008; Ling & Hurlbert, 2004; Melcher, Papathomas, & Vidnyanszky, 2005; Wegener et al., 2008). Thus, it is not clear whether task demands *per se* or stimulus properties gave rise to the different results concerning independent processing of features. To address this, observers in our study were shown the *same* novel objects across different tasks (see also Liu & Cooper, 2001). These objects had distinct basic shapes, non-rigid motions and colors. We used novel objects so that observers had no prior experiences or memory representations of the objects. Importantly, we designed our tasks to have different perceptual, learning and memory demands. For these tasks, observers were explicitly instructed to attend to either shape or motion to perform the task and to ignore the other features. We systematically changed the unattended features while observers responded on the basis of the attended one. The explicit attention instruction allowed us to measure how unattended features affected performance as a function of task.

In Experiment 1, we used a perceptual discrimination task in which observers were presented with pairs of objects at the same time and instructed to decide whether their shape or motion was the same or different. In Experiment 2, we used an identification task in which observers identified objects individually on the basis of their shape or motion. This task required observers to access prior object representations stored in memory. Therefore, the identification task included a learning component in which observers were first given the opportunity to form long-term representations of each target object. Importantly, observers learned specific combinations of shapes, motions and colors during the learning phase. For example, a specific shape (e.g., pyramid), non-rigid motion (e.g., bending) and color (e.g., blue) were always presented with each other during the learning phase (although observers may only be attending to shape, for instance). This additional learning phase emulates the natural situation in which observers learn representations of objects in which features co-occur.

There were thus several key differences between the perceptual discrimination task and the identification task for the purpose of the present study. These differences are summarized in Table 1. First, the discrimination task is easier than the identification task (50% chance level vs. 25% chance level). Second, the discrimination task minimizes the need to explicitly form and retrieve object representations by presenting the objects to be discriminated at the same time (Vuong, Friedman, & Plante, 2009). Importantly, the

Table 1
A comparison of the perceptual and cognitive demands for the perceptual discrimination and identification tasks used in the present study.

Task demand	Perceptual discrimination (Experiment 1)	Identification (Experiment 2)
Difficulty	2 Choices (chance = 50%)	4 Choices (chance = 25%)
Perceptual	Compare percepts shown simultaneously	Compare percept to stored representation
Memory	No prior associations of features; working memory; little memory retrieval	Prior associations of features in long-term memory formed during learning; memory retrieval
Learning	No opportunity to learn associations between specific shapes, motions and colors	Learning as a prerequisite to form object representations of targets; specific shapes, motions and colors are associated during learning

discrimination task does not rely on any pre-existing object representations stored in long-term visual memory. The identification task, on the other hand, required observers to retrieve prior object representations stored in long-term visual memory to identify the target objects at the individual level. Lastly for the discrimination task, there were no pre-existing associations between the three object features and little opportunity to form associations between specific shapes, motions and colors as the combination of the three features varied from trial to trial. By comparison for the identification task, the object representations formed during learning may have integrated specific combinations of shapes, motions and colors together. Importantly, these associations between features may make it more difficult to filter out task-irrelevant features that may have become associated with the task-relevant one (e.g., Newell, Wallraven, & Huber, 2004; Stone, 1998; Vuong & Tarr, 2006). Based on previous work (Cant et al., 2008; Ling & Hurlbert, 2004; Melcher, Papathomas, & Vidnyanszky, 2005; Wegener et al., 2008), we predicted that unattended features are more likely to affect performance when task demands are high.

2. Experiment 1

In Experiment 1, we tested whether participants can attend to an object's shape or motion independently of its other features when they perform a perceptual discrimination task (Vuong, Friedman, & Plante, 2009). If they can do so, we expect that their performance for the attended (task-relevant) feature would not be affected by changes to the unattended (task-irrelevant) features.

3. Method

3.1.1. Participants

Twenty-five volunteers participated in the experiment (23 females, 2 males; mean age = 20 yrs, SD = 2 yrs). One participant was excluded from the analyses due to a technical failure during the experiment. Most volunteers were undergraduate psychology students who participated for course credit. Other participants were reimbursed £5. All participants were naive to the purpose of the experiment and gave informed consent prior to starting the experiment. Ethics for both experiments reported in this study were approved by the local ethics committee of Newcastle University.

3.1.2. Stimuli

Fig. 1 shows four examples of the novel colored dynamic objects used in the present study. The stimuli consisted of 64 objects defined by the factorial combination of four volumetric shapes, four non-rigid motions and four colors. The stimuli were created using 3D Studio Max 9 (Autodesk, Montreal, Canada).

The four distinct volumetric shapes were a brick, a cylinder, a tapered version of the cylinder and a tapered version of the brick. These shapes were modeled after geons (Biederman, 1987). These shapes were easy to identify and discriminate even when they moved non-rigidly (which would necessarily deform their 3D geometry).

We created four distinct novel non-rigid motions from combinations of bending, twisting, stretching and skewing (i.e., motion of two parallel surfaces in opposite directions) movements. The motions were periodic so that they could be played in a 'loop' without any abrupt transitions. Each cycle took 3.37 s to complete. To create these motions, we varied different parameters of the volumetric shapes over time differently for each motion. These parameters included *bend angle*, *bend direction*, *twist angle*, *twist bias*, *stretch amount* and *skew amount* (Watt & Watt, 1992, chap. 15). The bend direction and twist bias control the direction of bending or twisting relative to an arbitrary initial direction. Thus, the same motion could be mapped onto any of the four shapes.

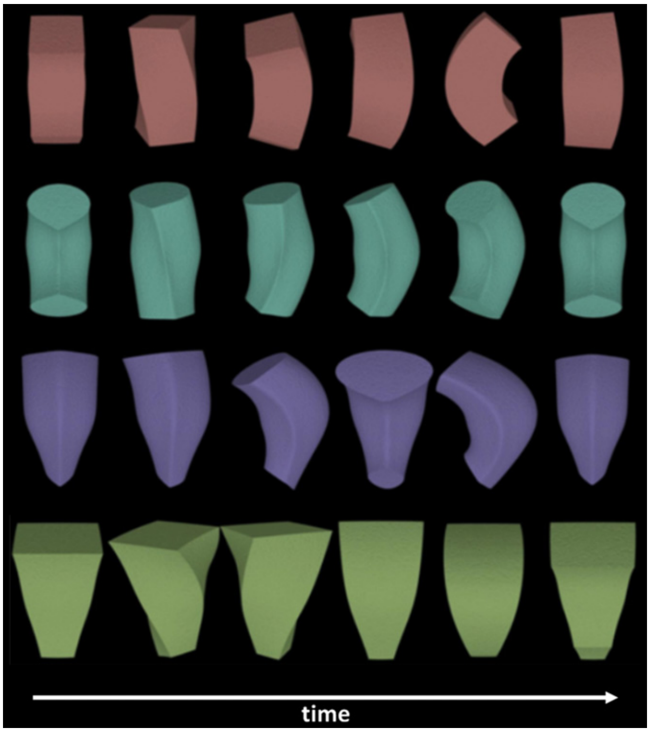

Fig. 1. Examples of the novel objects used in Experiments 1 and 2. Each object has a unique shape, non-rigid motion and color. The rows represent different objects and the columns represent single frames of an animation sequence of the objects' non-rigid motion. Note that these are the four target objects to be learned in Experiment 2. See www.staff.ncl.ac.uk/q.c.vuong/MayerVuong.html for dynamic examples of the four target objects. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Lastly, the four distinct colors were red (hue value = 0), green (hue value = 60), blue (hue = 120) and purple (hue value = 180). Luminance, saturation and blackness were the same values for all colors. As we were not interested in color perception *per se*, we did not calibrate the monitor for accurate color display. We also applied the same 'bumpy' surface texture to all objects to give them an elastic, deformable appearance.

The objects were rendered against a black background. Each object subtended approximately 7.6° of visual angle along the vertical axis and 3.8° of visual angle along the horizontal axis. Animations were saved in the QuickTime 7 format. The animations were played at 30 frames per second.

3.1.3. Design

Twelve participants attended to shape (attend-shape group) and 12 participants attended to motion (attend-motion group). These two groups differed for the non-color unattended feature. We refer to this unattended feature as the *complement* feature (i.e., *motion* for the attend-shape group and *shape* for the attend-motion group). We used a $2 \times 2 \times 2 \times 2$ factorial design with group (attend-shape, attend-motion) as a between-subjects factor and trial type (same, different), complement feature (same, different) and color (same, different) as within-subjects factors. In Experiments 1 and 2, we analyzed both accuracy and reaction times (RTs).

3.1.4. Procedure

Participants performed a same-different discrimination task in which they judged whether the attended feature of two objects (shape or motion) was the same or different, while ignoring the complement feature and color. Each trial started with a fixation cross which was shown for 0.5 s. The objects were presented for 6.74 s (two full cycles of the animation). The two objects were presented simultaneously; the center of each object was shifted by approximately 7° of visual angle horizontally to the left and right of the fixation cross. Participants were asked to respond as quickly and as accurately as possible any time after the onset of the objects. The screen turned black if no response was made after 6.74 s. Responses were made by pressing the ‘c’ or the ‘n’ key on a standard keyboard. The assignment of keys to ‘same’ and ‘different’ responses was counterbalanced across participants. The starting frame of the animation was randomized on each trial for both objects. Therefore, the objects were presented out of phase in their motion to control for differences in task difficulty between trials with same motion and trials with different motion.

Participants first completed 20–30 practice trials until they were confident that they had familiarized themselves with the stimuli and task. The experiment consisted of 480 trials, with a self-timed break after every 120 trials. Due to a technical error the number of trials per condition varied slightly for each participant (each condition was presented between 49 and 71 times). Overall, the experiment took approximately 1 h.

3.1.5. Data analysis

In Experiment 1, we analyzed sensitivity (d') as a bias-free measure of accuracy and correct RTs. For d' analyses, hits were defined as responding ‘same’ on *same* trials and false alarms were defined as responding ‘same’ on *different* trials. For the RT data, we removed outliers to reduce their influence on the means. We excluded responses that were shorter than 0.35 s and those that were longer than 6.0 s. Following this, RTs that were outside the interval of ±2.5 standard deviations of each participant’s mean RT of each condition were also removed from the analysis. These outliers accounted for 3.1% of correct RTs for the attend-shape group and for 4.8% of the data for the attend-motion group.

4. Results

The d' values and RTs were submitted to separate $2 \times 2 \times 2$ mixed ANOVAs with group (attend-shape, attend-motion) as the between-subjects factor and complement feature (same, different) and color (same, different) as within-subjects factors. Note that for RTs, we collapsed across trial type (same, different) for more direct comparisons with sensitivity. For both Experiments 1 and 2, we use $\alpha = .05$ as our statistical threshold for all analyses and partial-eta-squared (η_p^2) as our measure of effect size.

Fig. 2 shows the mean sensitivity as a function of group and complement feature, averaged across participants in each group. The two groups did not differ in sensitivity ($p = .56$). We found a main effect of complement feature ($F(1,22) = 4.95$; $p = .037$; $\eta_p^2 = .18$; same: $M = 2.99$, SEM = 0.19; different: $M = 2.79$, SEM = 0.21) but this effect was moderated by a significant interaction between group and complement feature ($F(1,22) = 4.45$; $p = .047$; $\eta_p^2 = .17$). Participants in the attend-motion group were less sensitive to motion changes when shape differed (Fig. 2; Tukey’s post hoc test: $p < .05$). By comparison, participants in the attend-shape group were equally sensitive to shape changes whether motion was the same or different (Tukey’s post hoc test: $p > .05$). There were no main effects of or interactions with unattended color.

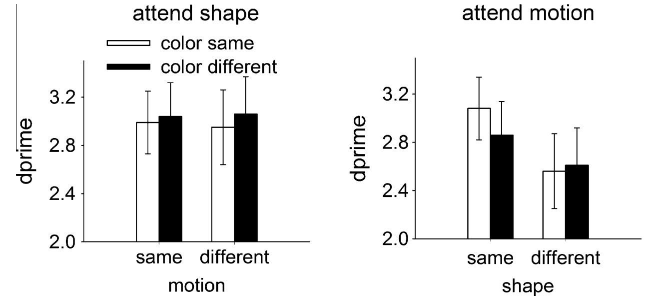

Fig. 2. The mean sensitivity (d') in Experiment 1 as a function of group, complement feature and color. For participants in the attend-shape group, the complement feature was motion; and for those in the attend-motion group, the complement feature was shape. Error bars in this and subsequent plots represent ±1 standard error of the mean (SEM).

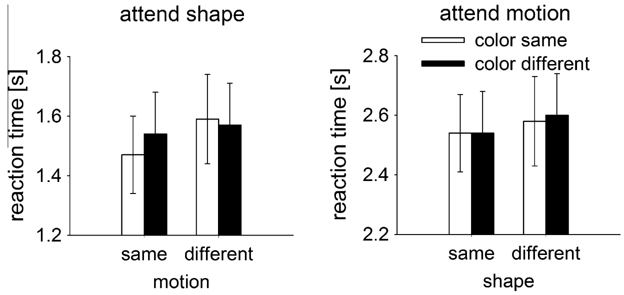

Fig. 3. The mean RTs in Experiment 1 as a function of group, complement feature and color. For participants in the attend-shape group, the complement feature was motion; and for those in the attend-motion group, the complement feature was shape.

Fig. 3 shows the mean correct RTs as a function of group and complement feature, averaged across participants in each group. For RTs, there were main effects of group ($F(1,22) = 27.39$; $p < .0001$; $\eta_p^2 = .56$; attend-shape: $M = 1.54$ s; SEM = 0.14 s; attend-motion: $M = 2.56$ s; SEM = 0.13 s) and complement feature ($F(1,22) = 8.32$; $p = .009$;$\eta_p^2 = .27$; same: $M = 2.02$ s; SEM = 0.09 s; different: $M = 2.08$ s; SEM = 0.10 s). In contrast to the sensitivity data, there was no significant interaction between group and complement feature.

5. Discussion

In Experiment 1, different groups of participants judged whether the shape or the motion of two objects was the same or different. This task can be performed on a perceptual basis with little memory and learning demands, as both objects were presented simultaneously (Vuong, Friedman, & Plante, 2009; see Table 1 in Section 1). There were three key findings. First, we found that participants in the attend-shape and attend-motion group were not adversely affected by changes to unattended color for both sensitivity and RTs. This finding is consistent with previous studies which showed that shape, motion and color can be processed independently when participants were tested with simple perceptual tasks (Cant et al., 2008; Wegener et al., 2008).

Although our results replicate previous studies (e.g., Cant et al., 2008; Wegener et al., 2008), our novel finding that participants in the attend-motion group were impaired by changes to unattended shape for both sensitivity and RTs presents an important constraint to the conclusion that participants automatically filter out unattended features for simple perceptual tasks. Because of the shape bias in object recognition (Biederman, 1987; Tarr & Bulthoff, 1998), participants in the attend-motion group may automatically attend to shape at least to some extent despite the instructions to ignore this feature and the low task demands. This shape bias has been shown for highly familiar non-rigidly deforming shapes such as faces (Knappmeyer, Thornton, & Bulthoff, 2003; Lander & Bruce, 2000) and for learned rigidly rotating objects (Spetch, Friedman, & Vuong, 2006; Vuong & Tarr, 2006). The current finding further helps to generalize this shape bias to novel non-rigidly moving objects and for perceptual discrimination.

Lastly, we found that participants in the attend-shape group were not impaired by changes to unattended motion in terms of their sensitivity. Such a finding is again consistent with the shape bias reported in the literature (e.g., Vuong & Tarr, 2006). However, participants were slower on the task when the unattended motion changed. Thus, the shape bias may have a stronger effect on the perceptual representations that are used for discrimination then for the time it takes to match these representations.

6. Experiment 2

The results from Experiment 1 suggest that observers can successfully filter task-irrelevant color but not shape for a simple perceptual discrimination task. Furthermore for this task, observers responded more slowly when task-irrelevant motion changed. In Experiment 2, we used an identification task which required observers to retrieve prior long-term object representations in which specific combinations of shape, motion and color were already associated together (see Table 1 in Section 1). As we used novel objects in this study, these prior representations were established during a learning phase which provided participants with the opportunity to form associations between specific shapes, motions and colors. We kept the unattended features during learning constant in order to create the more natural situation in which participants repeatedly encounter the same object with the same feature combination. Again, if participants can attend to an object's shape or motion independently of its other features under these new task demands, we expect that their performance for processing the attended (task-relevant) feature would not be affected by changes to the unattended (task-irrelevant) features.

7. Method

7.1. Participants

Twenty-five new volunteers participated in this experiment (12 female, 13 male; mean age = 29 yrs, SD = 10 yrs). Participants were undergraduate psychology students who received course credits and members of the Institute of Neuroscience of Newcastle University. One participant's data were removed from the attend-shape group for chance level performance. All participants were naive to the purpose of the study and gave informed consent.

7.1.1. Stimuli

The same set of objects from Experiment 1 was used in Experiment 2. Four of these objects served as the to-be-learned objects. These target objects are shown in Fig. 1.

7.1.2. Design

Twelve participants learned to identify the target objects on the basis of their shape (attend-shape group) and 12 participants learned to identify the target objects on the basis of their motion (attend-motion group). For each group, the unattended complement feature and color were manipulated with respect to the target objects (Fig. 1) during a test phase which followed learning. Thus, we had a $2 \times 2 \times 2$ factorial design with the between-subjects factor group (attend-shape, attend-motion) and complement feature (same, different) and color (same, different) as within-subjects factors. The dependent variables were accuracy (percent correct) and correct RTs.

7.2. Procedure

Participants first learned four of the 64 objects (Fig. 1). The four objects were chosen so that they differed from each other on the basis of all three features (shape, motion and color). The same target objects were used for all participants. As illustrated in Fig. 4, the experiment consisted of three phases: a learning phase, a practice phase and lastly, a test phase. In all three phases, the objects were presented in a randomized order and the starting frame for each animation was randomized.

In the learning phase, participants learned to associate a different key ('d', 'f', 'j' or 'k') with either the shape (attend-shape group) or the motion (attend-motion group) of each target object. On each trial, a fixation cross was shown at the center of the screen for 1 s, followed by the key associated with the target feature for 1 s, followed by the object for 6.74 s (two full cycles of the animation), followed by another fixation cross which remained on the screen until participants responded (Fig. 4, left panel). They were instructed to press the correct key to proceed to the next trial. Feedback was provided at the end of each trial in the form of a label ('correct' or 'wrong') shown for 1 s. The mapping of keys to objects was randomized across participants. Each object was presented eight times during this phase.

In the practice phase (Fig. 4, middle panel), participants were asked to identify the four learned objects by responding with the key associated with each. Each object was shown for 3.37 s (one full cycle of the animation). Otherwise, the trial sequence was identical to the learning phase. Each object was presented 10 times in this phase. It is important to note that in the learning and practice phases, although participants were explicitly associating each shape or motion to a key response, the unattended complement feature and color could implicitly be associated with the same key as well.

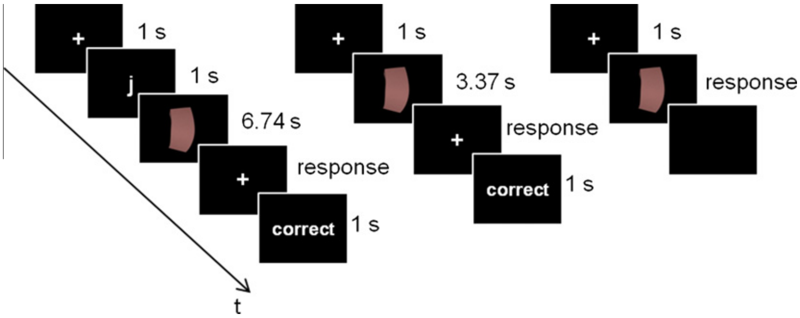

Fig. 4. Trial sequence for the three phases in Experiment 2. The left panel shows the learning phase; the middle panel shows the practice phase and the right panel shows the test phase. In the learning phase, the 'j' refers to the correct key associated with the attended feature of the subsequent object. For each panel, the duration of each trial event is illustrated along the diagonal time arrow (far left). 'Response' indicates that participants needed to respond to proceed to the next event.

The test phase was the critical phase for Experiment 1 (Fig. 4, right panel). In this phase, all 64 objects were presented. For the attend-shape group, the 60 unfamiliar objects could differ from the learned objects in their color, motion or color *and* motion. For the attend-motion group, on the other hand, the unfamiliar objects could differ from the learned ones in their color, shape or color *and* shape. On each trial, a fixation cross appeared for 1 s. Following that, a test object was shown. The objects were shown for 6.74 s or until participants responded. If they did not respond before 6.74 s, the objects disappeared from the screen. In contrast to the previous phases, participants were asked to respond as quickly and as accurately as possible as soon as they identified the learned shapes or learned motions. A correct response was entered when participants pressed the key associated with the shape or motion despite differences to the unattended features. No feedback was provided during this phase.

The test phase consisted of 240 trials. Each of the four learned objects (i.e., in which the unattended features did not change) was presented 30 times (120 trials). Each of the 60 unfamiliar objects was presented twice (120 trials). On 48 trials, unfamiliar objects were presented in which one unattended feature had changed (color or motion when participants attended to shape; color or shape when participants attended to motion). On 72 trials, unfamiliar objects were presented that differed in both unattended features from the target objects. There was a self-timed break every 60 trials. The experiment took approximately 1 h.

7.3. Data analysis

We used the same procedure as in Experiment 1 to remove outliers for the RT data. In the attend-motion group, 3.3% of the correct responses were removed as outliers. In the attend-shape group, 3.1% of the correct responses were removed as outliers.

8. Results

The accuracy data and correct RTs were submitted to separate 2 × 2 × 2 mixed ANOVAs with group as a between-subjects factor and complement feature and color as within-subjects factors. Fig. 5 shows the mean identification accuracy during the test phase for the participants in the attend-shape and attend-motion group as a function of the unattended complement feature and color. Overall, participants performed well above chance. There were no accuracy differences between participants in the attend-shape and attend-motion groups ($p > .24$). There were main effects of complement feature ($F(1,22) = 37.31$, $p < .0001$, $\eta_p^2 = 0.63$; same: $M = 98.5\%$, $SEM = 0.4\%$; different: $M = 89.3\%$, $SEM = 1.7\%$) and color ($F(1,22) = 11.87$, $p = .002$, $\eta_p^2 = 0.35$; same: $M = 94.8\%$, $SEM = 0.9\%$; different: $M = 92.9\%$, $SEM = 1.1\%$). However, these main effects should be considered in light of the significant interaction between complement feature and color ($F(1,22) = 6.70$, $p = .017$, $\eta_p^2 = 0.23$). There was no effect of color when the complement feature was the same (Tukey's post hoc test: $p > .05$). By comparison, when the complement feature was different, participants responded more accurately when color was the same than when it was different (Tukey's post hoc test: $p < .01$).

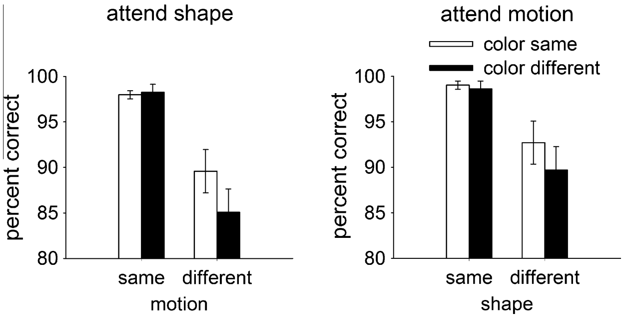

Fig. 5. The mean accuracy (percent correct) in Experiment 2 as a function of group, complement feature and color. For participants in the attend-shape group, the complement feature was motion; and for those in the attend-motion group, the complement feature was shape. Note that chance performance is 25%.

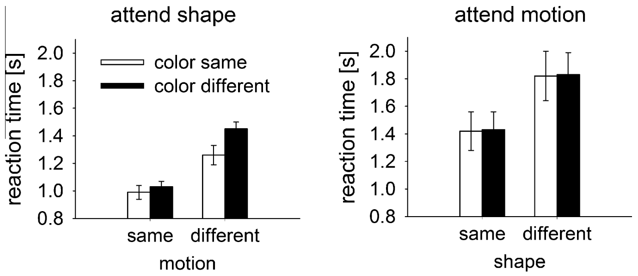

Fig. 6. The mean RTs in Experiment 2 as a function of group, complement feature and color. For participants in the attend-shape group, the complement feature was motion; and for those in the attend-motion group, the complement feature was shape.

Fig. 6 shows the mean correct RTs during the test phase for the participants in the attend-shape and attend-motion group as a function of the unattended complement feature and color. Participants in the attend-shape group responded significantly faster than those in the attend-motion group ($F(1,22) = 8.38$; $p < .0001$; $\eta_p^2 = .28$; attend-shape: $M = 1.18$ s; $SEM = 0.04$ s; attend-motion: $M = 1.63$ s; $SEM = 0.15$ s). Importantly, there were main effects of complement feature ($F(1,22) = 97.36$; $p < .0001$; $\eta_p^2 = .82$; same: $M = 1.22$ s, $SEM = 0.07$ s; different: $M = 1.59$ s, $SEM = 0.09$ s) and color ($F(1,22) = 4.80$; $p = .039$; $\eta_p^2 = .18$; same: $M = 1.37$ s, $SEM = 0.08$ s; different: $M = 1.44$ s, $SEM = 0.07$ s). However, in contrast to the accuracy data, there was no interaction between the two unattended features ($p > .13$).

9. Discussion

In Experiment 2, participants learned four novel colored dynamic objects on the basis of their shape or motion. They subsequently identified the target objects on the basis of the attended feature, while the unattended features were changed at test. In comparison to the perceptual discrimination task in Experiment 1, the identification task had more perceptual and cognitive demands (see Table 1 in Section 1). We found that changes to the unattended complement feature impaired participants' ability to accurately identify the target objects. Furthermore, we found that changes to unattended color impaired accuracy only when the complement feature also changed but not when the complement feature was the same. Similar to what we found in Experiment 1, RTs revealed that participants responded more slowly when unattended features were different at test. The current findings suggest that participants were generally unable to effectively filter out task-irrelevant features under tasks which required them to retrieve object representation from long-term memory (Newell, Wallraven, & Huber, 2004; Stone, 1998; Vuong & Tarr, 2006).

There was a learning phase in this experiment so that observers could form long-term representations of the four target objects and their features. The results from Experiment 2 further imply that participants automatically associated different combinations of shape, motion and color together during learning, consistent with previous work with rigid and non-rigid facial motion (e.g., Knappmeyer, Thornton, & Bulthoff, 2003; Lander & Bruce, 2000) and rigid object rotation (e.g., Liu & Cooper, 2003; Stone, 1998; Vuong & Tarr, 2006). This relatively automatic association was found despite our explicit instruction to only attend to shape (attend-shape group) or motion (attend-motion group) during learning. Thus, this finding allows us to generalize these previous results to non-rigid motion and non-face objects.

We did not find a shape bias in Experiment 2 as we did in Experiment 1. That is, changes to unattended shape or motion equally affected identification accuracy for participants in both groups (i.e., there was no main effect of group or interaction with group). Previous studies have found a shape bias when observers learned to identify faces and objects (Knappmeyer, Thornton, & Bulthoff, 2003; Lander & Bruce, 2000; Spetch, Friedman, & Vuong, 2006; Vuong & Tarr, 2006). Interestingly, there is evidence that the shape bias may be species-specific as we have shown a motion, rather than shape, bias for pigeons (Spetch, Friedman, & Vuong, 2006). The human studies used subtle facial motions or rigid rotations and did not use any additional salient features. In another human study, Newell, Wallraven, and Huber (2004) also did not find a shape bias in an object categorization task using objects which had distinct shapes, rigid motions and colors. The distinct motions and colors we used may allow observers to over-ride the shape bias during learning in our experiment, as in Newell et al.'s study. Further research is needed to clarify the generality of the shape bias. Again, the differences between the results of Experiments 1 and 2 may have emerged because the two tasks differed with respect to task difficulty, amount of memory load, role of learning and perceptual load (see Table 1 in Section 1). Further research will be necessary to tease apart the separate contributions of each of these components of task demand.

10. General discussion

In the present study, we combined a feature attention paradigm with different tasks to investigate how task demands affected visual attention for the purpose of object recognition (e.g., Cant et al., 2008; Garner, 1988; Gottwald & Garner, 1975; Ling & Hurlbert, 2004; Melcher, Papathomas, & Vidnyanszky, 2005; Wegener et al., 2008). In two experiments, observers attended to the shape or motion of colored, non-rigidly moving objects while ignoring the remaining features. Importantly, we used the same set of objects for tasks with different task demands. For perceptual tasks which have low memory and cognitive demands (Experiment 1), we found that unattended color did not affect task performance while unattended shape did. Unattended motion impaired processing speed but did not influence sensitivity. By comparison for identification tasks which required retrieving prior object representations stored in long-term visual memory (Experiment 2), we found that all unattended features affected performance when identifying learned objects.

Taken together, the results of Experiments 1 and 2 highlight the importance of task demands for affecting how successfully observers can select task-relevant features independently of an object's other features. This conclusion helps to generalize the findings from Liu and Cooper (2001), who found that object priming is also dependent on the judgements that observers need to make (e.g., symmetry judgements or possible/impossible-structure judgements) and not only on the objects themselves. In our study, observers always processed the attended feature but we varied the task demands.

Our study complements earlier findings on the role of shape and motion for recognition. In the face recognition literature, several studies have shown that non-rigid facial motions, such as facial expressions, can be used to identify people, particularly when facial shape is ambiguous or degraded (e.g., Knappmeyer, Thornton, & Bulthoff, 2003; Lander & Bruce, 2000). However, observers needed to be familiar with the individuals to learn their unique facial motions. Similar to studies using facial motion, previous research using novel rigidly rotating objects have shown that task-irrelevant motion affected object identification, particularly when shapes are visually similar or when there are many objects to learn (Liu & Cooper, 2003; Spetch, Friedman, & Vuong, 2006; Stone, 1998; Vuong & Tarr, 2006). It is interesting to note that in these studies, objects were implicitly associated with a particular rotation direction. Consistent with our study, these face and object recognition studies suggest that unattended motions can affect recognition performance if they have been associated with specific shapes, even if they are not relevant for the task. Concerning the specific role of shape for object recognition (Tarr & Bulthoff, 1998), we provide further evidence that the shape bias is also dependent on the task at hand (see also Newell, Wallraven, & Huber, 2004).

The learning procedure we used in Experiment 2 provided an opportunity to test whether observers automatically encoded unattended features in their long-term representation of the target objects. The results suggest that observers did automatically associate shape, motion and color in the object representation during learning, as changes to unattended features impaired recognition performance at test. However, our results also suggest that the strength of the association between features is not constant. In particular, color may be more weakly associated with the attended feature than the complement feature (motion for the attend-shape group and shape for the attend-motion group). That is, we found that the effect of color on accuracy only occurred when the complement feature also changed. More generally, the inability to filter out task-irrelevant features during learning might reflect mechanisms that form associations between different features as any of these features might be relevant for subsequent encounters with the objects. For example, Wallis and Bulthoff (2001) have shown that there is a mechanism that seems to automatically associate stimuli that occur in close temporal proximity. These mechanisms might be triggered by the repeated presentation of the same combination of shape, motion and color.

The present study was not specifically designed to address the role of learning in object recognition *per se* but rather to investigate the impact of different task demands on attentional mechanisms in object recognition. Learning and forming long-term object representations are part of these demands. Future research will be necessary to clarify more explicitly the role of learning for filtering unattended features.

The importance of task demands for filtering task-irrelevant features helps to reconcile the diverging findings from previous research on whether features are processed independently of each other. In particular, the question of whether shape and color are processed independently is an ongoing debate (Biederman, 1987; Biederman & Ju, 1988; Cant et al., 2008; Ling & Hurlbert, 2004; Price & Humphreys, 1989; Tanaka & Presnell, 1999; see Tanaka, Weiskopf, & Williams, 2001, for a review). Cant et al. demonstrated that shape and color were processed independently when observers made simple binary decisions (e.g., large or small for shape) in a speeded classification task (Garner, 1988; Gottwald & Garner, 1975). Like our perceptual discrimination task, this task does not necessarily require access to stored representations. Ling and Hurlbert, on the other hand, found that shape and color were both jointly processed when observers had to compare the size or the color of an array of domes of differing sizes and colors. Similarly, our results can help account for the diverging findings for the independence of motion and color (e.g., Melcher, Papathomas, & Vidnyanszky, 2005; Wegener et al., 2008).

Lastly, we note that we focused on shape and motion in this study and did not include a condition in which observers attended to color. Our primary goal was to determine how unattended features of objects may influence how attended features are processed. That said, the role of color in object recognition is less consistent than the roles of shape or motion even when similar tasks and stimuli are used. For example, Price and Humphreys (1989) and Tanaka and Presnell (1999) found that color facilitated how quickly and accurately observers named real-world objects (see also Naor-Raz, Tarr, & Kersten, 2003). By comparison, Biederman and Ju (1988) found no influence of color on naming times for real-world objects. All of these object-naming studies used objects with and without diagnostic color. Furthermore, Peuskens et al. (2004) reported that judgments of surface properties such as textures can be achieved by processing small surface patches whereas shape and motion judgments can be achieved by processing edges and larger portions of the objects. Their interpretation could apply to our stimuli as color is also a surface property (Tanaka, Weiskopf, & Williams, 2001).

In summary, the current study revealed important task and stimulus constraints which influence observers' ability to attend to features that are relevant for the task at hand while ignoring those that are not task-relevant. At the perceptual level, task-irrelevant features can be filtered out apart from a shape bias. In contrast at the identification level, task-irrelevant features are difficult to filter out particularly if these features have become associated with task-relevant features. We have coarsely defined our task demands in the present study to account for the broad range of tasks currently used in vision research. Despite this, the results across the two experiments already point to important and promising task variables (e.g., learning and memory demands) that need to be investigated more finely in future research.

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