Using morphs of familiar objects to examine how shape discriminability influences view sensitivity

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We investigated how the difficulty of detecting a shape change influenced the achievement of object constancy across depth rotation for object identification and categorisation tasks. In three sequential matching studies, people saw pictures of morphs between two everyday, nameable objects (e.g., bath-sink morphs along a continuum between bath and sink endpoint shapes). In each study, both view changes and shape changes influenced performance. Furthermore, the deleterious effects of view changes were strongest when shape discrimination was hardest. In our earlier research using morphs of novel objects we found a similar interaction between view-sensitivity and shape-sensitivity (Lawson, 2004a; Lawson & Bülthoff, 2006; Lawson, Bülthoff & Dumbell, 2003). The present results extend these findings to familiar object morphs. They suggest that recognition remains view-sensitive at the basic level of identification for everyday, nameable objects, and the difficulty of shape discrimination plays a critical role in determining the degree of this view sensitivity.

One of the most impressive achievements of our visual system is its ability to abstract away from task-irrelevant variation in the input in order to identify and categorise objects. Our object recognition system is usually both fast and accurate at recognising shapes across changes of retinal size, viewpoint and illumination (see Lawson, 1999, for a review). This achievement of object constancy often, though, comes at a measurable cost in terms of the speed or the accuracy of processing. For example, if a familiar object is first seen at one view in depth and is subsequently shown at a different view then its second identification is usually less efficient (so priming is reduced) compared to if the second view is identical or similar to the first view of that object (e.g., Hayward, 1998; Lawson & Humphreys, 1996, 1998, 1999; Lawson, Humphreys & Watson, 1994; Srinivas, 1995; Thoma & Davidoff, 2006; Vuilleumier, Henson, Driver & Dolan, 2002; see also Fang & He, 2005 for similar results with an adaptation paradigm).

There is still no consensus as to the theoretical interpretation of these empirical findings of view-sensitive (and sometime view-invariant) performance. However, the simplistic characterisation of this debate as being between those arguing that object recognition is subserved only by 2D representations finely tuned to viewpoint in depth versus those proposing fully view-invariant 3D representations of objects has gradually evolved into more complex and nuanced intermediate positions (e.g., Biederman, 1987; Biederman & Gerhardstein, 1993, 1995; Burgund & Marsolek, 2000; Bülthoff & Edelman, 1992; Demeyer, Zaenen & Wagemans, 2007; Foster & Gilson, 2002; Hayward, 2003; Hayward & Tarr, 1997; Hummel, 2001; Hummel & Stankiewicz, 1998; Marr, 1982; Tarr 1995; Tarr & Bülthoff, 1995, 1998; Tarr & Pinker, 1990; Thoma, Hummel & Davidoff, 2004; Tjan & Legge, 1998; Vanrie, Willems & Wagemans, 2001; Vuilleumier et al., 2002; Wilson & Farah, 2003).

One important obstacle to progress in understanding how our visual system achieves object constancy is that it is still unclear what factors are critical in determining the level of view-sensitivity in a given situation. Many factors are likely to play a significant role. These include the class and structure of the stimuli to be identified (compare the geometry of faces to animals to artefacts to the twisted wire or block stimuli often used in studies of novel object recognition), familiarity (whether people have experience with the stimuli prior to testing and the number of presentations of a given object within a study), task (performance may differ from initial recognition to short-term or long-term priming and across different tasks such as picture-picture matching and naming), the difficulty of discrimination between objects (usually harder for face and subordinate level object recognition and when many similarly shaped object must be distinguished relative to most instances of basic level object recognition) and stimulus presentation (for example, whether real objects are seen, either monocularly or binocularly, or whether objects are depicted on a computer monitor, and if these depictions include colour or shading or only show line drawings).

All of these factors have been investigated in previous research into the achievement of object constancy. However, usually only one or two factors have been included within a single set of studies. Furthermore progress in this area has been hampered by difficulties in making cross-study comparisons due to the diversity of both tasks and stimuli that have been used by different researchers. Few investigators have used a fixed task and manipulations with different stimuli or have used multiple tasks for a standard set of stimuli. This means that it has not been possible to detect systematic changes in view-sensitivity due to interactions between these factors (Tarr and Bülthoff (1998).

We believe that it is essential to explore the pattern of view-sensitivity across a wide set of conditions in order to be able to gain a broad-based understanding of the effects of depth rotation on object recognition. A unique strength of the present studies is the use of the same methodology as our earlier studies (Lawson, 2004a; Lawson & Bülthoff, 2006; Lawson, et al., 2003) in combination with a new set of stimuli. The results of the present studies testing familiar objects together with our previous studies testing novel objects have allowed us to map out variation in view-sensitivity across a wide set of conditions. Together these experiments have manipulated the class and structure of the stimuli tested (using a large and geometrically diverse set of 3D shapes from different superordinate categories), familiarity (testing novel and familiar, everyday objects), task (comparing two recognition tasks and a categorisation task) and, most importantly, varying the difficulty of shape discrimination within every study. Other differences between these studies were minimised: all the studies used the same stimulus presentation (shaded, grey-scale pictures of the objects were presented briefly on a computer screen) and the same general methodology (speeded responses were required in a sequential picture-picture matching task). Ongoing research presenting 3D versions of the familiar stimuli used in the current studies is extending the set of conditions tested (Lawson, 2008).

The role of shape discriminability in modulating the view-sensitivity of object recognition

The main aim of these six studies was to investigate how the cost of achieving object constancy over a rotation in depth is modulated by the difficulty of the shape discrimination required in the task across a wide range of conditions. In particular, we have probed whether view-sensitivity is eliminated when shape discrimination is relatively easy. In a series of recent studies we measured view-sensitivity when people had to detect shape changes to novel objects (Lawson, 2004a; Lawson & Bülthoff, 2006; Lawson et al., 2003). We found a striking interaction between view-sensitivity and shape discrimination difficulty. When subtle shape changes had to be detected, performance was highly view-sensitive. In contrast, if only large shape changes had to be detected, performance was much less view-sensitive and in some cases was even view-invariant. This pattern of performance generalised across three different experimental paradigms.

These findings support the claim that view-sensitivity increases as the shape similarity of objects that must be distinguished increases (Biederman & Gerhardstein, 1993; Hamm & McMullen, 1998; Tarr & Cheng, 2003). This first finding is relatively uncontroversial (but see

Hayward & Williams, 2000). In contrast, there is considerable disagreement about when object recognition becomes view-insensitive as shape discrimination becomes easier. For example, Biederman and Gerhardstein (1993, 1995) have argued that distinguishing between familiar objects at the basic level (e.g., identifying objects as exemplars of the categories of dog, table and apple) is largely view-invariant. In contrast, Tarr and colleagues (Tarr & Bülthoff, 1995; Tarr & Cheng, 2003) argue that it is usually view-sensitive. The results from our earlier studies (Lawson, 2004a; Lawson & Bülthoff, 2006; Lawson et al., 2003) led us to support the latter claim, since we found view-sensitivity even when shape discrimination seemed easier than that required for everyday object recognition. However, we wanted to test this claim more directly by using familiar rather than novel objects. This issue, namely how changes in shape discriminability modulate view-sensitivity for the identification of familiar objects, is the focus of the present article.

The role of familiarity in modulating the view-sensitivity of object recognition

We present results from three studies here in which we presented morphs of familiar objects (see Figures 1 and 2) and which replicate the design of three of our previous studies which used morphed versions of novel objects. The familiar objects varied in shape in a similar way to our novel object stimuli, allowing us to systematically manipulate shape discrimination difficulty in order to investigate its effect on view-sensitivity. The use of familiar objects was critical because it enabled us to deduce when object constancy over depth rotation can be achieved with minimal cost during our everyday experience with nameable objects and to contrast performance with that for novel objects. Specifically, there are three reasons why the present studies were necessary to extend our earlier findings.

First, our initial studies presented novel objects so we do not know how the difficulty of shape discrimination for these stimuli compares to that required in everyday object recognition. If a finer level of identification was necessary to discriminate the novel objects than is needed for the basic-level recognition of familiar objects then the discrimination of the novel objects may have been more like subordinate level recognition or face recognition. In this case, the view-sensitivity that we observed for the novel objects would be consistent with most current theories of visual object recognition. Furthermore, if the recognition of the novel objects was like subordinate or face recognition then no conclusions could be drawn from these results about the view-sensitivity of everyday, basic level object recognition. We do not believe that this was the case, since the novel objects were carefully selected to be similar to basic level objects (see Figure 1 of Lawson et al., 2003), but it was important to test this possibility.

Second, although the novel objects presented in our earlier studies were chosen to be physically similar to familiar objects, they may have differed on important shape dimensions. For example, the structure, symmetry and complexity of the novel objects may have differed from that of most familiar objects. Any such confounding factors could, in turn, have influenced the degree of view-sensitivity observed for these novel stimuli. For instance, view-sensitivity could have been greater for the novel objects because they were more complex or less symmetrical than most familiar objects.

Third, familiarity per se may influence view-sensitivity (for work on this topic with faces, see Eger, Schweinberger, Dolan & Henson, 2005; Jiang, Blanz & O'Toole, 2007; Pourtois, Schwartz, Seghier, Lazeyras & Vuilleumier 2005; Ryu & Chaudhuri, 2006; and summarised below). For example, view-sensitivity may be greater for novel than for familiar objects due to differences in their stored, visual representations. As we gain visual experience with a category of objects by seeing different views of multiple exemplars from it we may gradually acquire stored, view-invariant representations of that category. Alternatively, with experience we may acquire multiple, view-specific representations of objects from a given category, and all of those representations may be activated when an object from that category is encountered. A third possibility is that, relative to novel objects, view-sensitivity may be reduced for familiar objects because they can be named and have stored, semantic knowledge associated with them. The recognition of familiar objects may then be partly mediated by view-invariant, verbal or semantic processing. The present studies tested discrimination between different shaped morphs that would usually be given the same name (Experiment 5) and categorisation of pairs of morphs which would usually be given different names (e.g., baths and sinks, in Experiment 7).

Indirect evidence that familiarity may play an important role in the view-sensitivity of object recognition comes from a plethora of recent research with faces on this topic using both adaptation and imaging methodologies. These studies have reported a number of differences between performance with familiar versus unfamiliar faces. Their results are not fully consistent with each other and are open to different interpretations. Nonetheless they point to familiarity playing an important role in modulating view-sensitivity for faces.

Adaptation studies have demonstrated that face identification is highly sensitive to view in depth. Behavioural studies have reported decreased adaptation as the angle between the adapting and the test stimulus increases (e.g., Benton, Jennings & Chatting, 2006) and view-specific face adaptation has been reported in fMRI imaging studies (e.g., Grill-Spector, Kushnir, Edelman, Avidan, Itzchak & Malach, 1999; Andrews & Ewbank, 2004). Using an identity adaptation paradigm, Jiang, Blanz and O'Toole (2007) found that adaptation was greater across view changes for familiar compared to unfamiliar faces. They concluded that face familiarity enhanced the transferability of adaptation effects across view in depth (so familiar face recognition was less view-sensitive). However, adaptation effects were greater for familiar faces even when there was no view change, so their results showed more adaptation overall for familiar faces. Their findings could therefore be interpreted as demonstrating no benefit of familiarity in reducing view-sensitivity per se, but only in increasing adaptation in general. Ryu and Chaudhuri (2006) investigated orientation adaptation effects for faces. In their first study they found greater visual adaptation to the orientation of familiar compared to unfamiliar faces. This suggests that adaptation to familiar faces is more view-sensitive. In their second study they found very poor orientation discrimination for a familiar face following adaptation with a different familiar face whereas for unfamiliar faces between-face adaptation was similar to that for within-face adaptation. Here, showing one face for 5s disrupted people's ability to detect the orientation of a different face if both faces were familiar but produced orientation adaptation if both faces were unfamiliar. This surprising result is difficult to interpret and further research on this topic seems necessary before clear conclusions can be drawn.

Imaging studies have also provided evidence that face identification is influenced by both the view in depth at which a face is presented and the familiarity of that face. Eger, Schweinberger, Dolan and Henson (2005) investigated the effect of familiarity using a sex decision task. They reported similar levels of image-specific priming for familiar and unfamiliar faces in their behavioural data. In contrast, they found greater image specificity for familiar (but not unfamiliar) faces in activity in the anterior relative to the middle fusiform region. However, their visual change condition had an uncontrolled mix of changes, including some depth rotations but also alterations to lighting, facial expression, hairstyles, etc. This means that it is not possible to specify which changes produced the differences that they observed. A similar study was reported by Pourtois, Schwartz, Seghier, Lazeyras and Vuilleumier (2005). As in Eger et al.'s study, the differences between the two test images of a person's face were relatively unconstrained and included alterations to age and appearance as well as the view in depth. They found no behavioural effects in their sex decision task (unlike Eger et al., 2005), perhaps due to ceiling performance. In their imaging results they found evidence for repetition priming across visual changes for both familiar and unfamiliar faces but the location of these effects differed. Note, too, that unlike Eger et al. (2005) they did not test a control, same-view condition so the differences that they observed between familiar and unfamiliar faces may not have been specific to the achievement of object constancy.

Differences in the results and the designs of these studies make it difficult to draw strong conclusions about the view-sensitivity of familiar compared to unfamiliar face identification. However the overall pattern of findings demonstrates that familiarity may play a major role in modulating view-specificity for face recognition. Given this, it is clearly important to examine whether the view-sensitivity of object recognition is also influenced by familiarity. In particular, we wanted to investigate whether, when tested in comparable conditions, the recognition of familiar objects was much less view-sensitive than that of novel objects.

*** Insert Figures 1 and 2 ***

Stimulus selection

In order to draw valid conclusions about the recognition and categorisation of familiar objects, it was critical to select appropriate stimuli. We therefore conducted an initial series of four studies to allow us to choose suitable pairs of familiar objects (Experiments 1 and 2) and to select a range of morphs between those objects (Experiment 1) and to verify that the extremes of this range (the startpoint and endpoint morphs) were identified using the intended names (Experiment 4). We also collected typicality ratings for the names of the startpoint and endpoint morphs (Experiment 3) and we asked people whether they believed that objects inbetween these categories could exist and what common label could be applied to each pair of startpoint and endpoint names (Experiment 3).

Note that morphs between the startpoint and endpoint were not intended to be familiar to people. These morphs would rarely be similar to objects encountered in everyday life and people were not expected to be able to confidently or consistently name them. Instead they would often be torn between giving these inbetween morphs the labels of the startpoint and endpoint categories, with the object being a poor exemplar of both categories. These inbetween morphs were created because it is difficult to find sequences of familiar objects which vary systematically in shape and which have different startpoint and endpoint labels: one example would be a tadpole growing to an adult frog.

The initial studies ensured that the stimuli presented in the three final experiments comprised sets of morphs which spanned the shape space between fairly typical exemplars of two familiar, nameable categories of objects (e.g., bath-sink, see Figure 1). Within each of these morph sets the first, startpoint morph was usually given one name (e.g., 100% of naming responses were "bath"), the final, endpoint morph was normally given a different name (e.g., 84% "sink" responses) and the midpoint morph was identified using an approximately equal mix of the startpoint and the endpoint names (e.g., 66% "bath" and 32% "sink" responses). These were exacting conditions for stimulus selection so we began with a large set of 53 pairs of objects. From the 53 sets of morphs generated between each of these pairs, the 20 best morph sets were selected and the most suitable startpoint, midpoint and endpoint morphs within each sequence were chosen (see Figure 2). These stimuli were then presented in three sequential picture-picture matching studies which tested object recognition (Experiments 5 and 6) and categorisation (Experiment 7) whilst varying the difficulty of shape discrimination.

Experiment 1

Participants named depth-rotated views of morphs spanning the range of shapes between each of the 53 pairs of familiar objects. These results were used to select morph sets for which the startpoint and endpoint morphs were each named consistently and with different names.

Method

Participants Thirty-six undergraduate students from the University of Liverpool, U.K., took part in the study for course credit.

Materials for all experiments Fifty-three 3D models of familiar objects were selected: these were the S1 morphs. The shape of each S1 morph was then changed incrementally to produce a series of 12 more morphs labelled S2 to S13. The S13 morph had the least similar shape to S1 and was intended to resemble a different, familiar object. The 30° views for the bath-sink morph set are shown in Figure 1. Pictures of 12 different depth-rotated views of each of these 13 morphs were produced. The 0° view was assigned to be a foreshortened view if the object had an elongated shape and was otherwise arbitrarily assigned. Foreshortened views can be particularly difficult to identify (Lawson, 1999; Lawson & Humphreys, 1999) so we avoided presenting them. From the 0° view, each successive view was rotated by 30° about the vertical axis running through the midpoint of the morph. These views were labelled as 30°, 60°, 90° and so on up to 330°. Altogether there were 156 pictures (thirteen morphs, each shown from twelve views) of each of the 53 morph sets. Grey-scale images of the views of the morphs were generated using the SoftImage rendering software. The images were presented against a black background inside a window measuring 135mm by 110mm on a computer monitor at a viewing distance of approximately 50cm.

Design and Procedure The S1, S7 and S13 morphs from each morph set were used. Each morph was depicted from four views in depth, at 30°, 60°, 210° and 240°. Thus in total twelve pictures from each morph set were presented. All participants completed one block of 159 trials in which the S1, S7 and S13 morphs from all of the 53 morph sets were each seen once. Four groups of nine participants were shown different views of the morphs: two groups saw a mixture of 30° and 240° views and the other two groups saw a mixture of 60° and 210° views. Across the four groups, each of the views of all of the morphs were shown an equal number of times.

The experiment was run on a Macintosh PowerPC G4 computer using the Psyscope version 1.2.5 experimental presentation software. On each trial, a picture was presented centrally and participants were cued to type in the name of the object. They were not encouraged to make speeded responses. Trials were presented in a different, random order to each participant and the experiment lasted around 30 minutes.

Results and Discussion

Spelling mistakes were corrected, abbreviations were replaced with standardised responses (e.g., “bike” was changed to “bicycle”) and multi-word responses were reduced to a single word (e.g., “wide chair” was replaced by “chair”). If two alternative names were provided (e.g., “horse/giraffe”) the second was deleted. The percentage choice of the modal name for each S1, S7 and S13 morph (averaged over the four views tested) was calculated. The overall percentage of modal name choice was similar for each of the four separate views for the S1, S7 and S13 morphs.

Five of the 53 morph sets were eliminated at this stage because they were not named consistently. The remaining 48 sets of morphs were tested in a word-picture verification task in Experiment 2. In Experiment 2, people selected one of three alternative names for each picture of a morph from a given morph set. These names were chosen using the results of Experiment 1. They comprised the modal names given to the S1 and S13 morphs from that set (e.g., "key" and "sword" for the key-sword morph set) plus another common name given to pictures from that morph set ("saw" for the key-sword morph set). For the 20 morph sets selected to be stimuli in Experiments 5, 6 and 7, the overall accuracy of naming the S1 morphs was 86% (5% gave the S13 name and 10% gave another name) and 70% for the S13 morphs (5% gave the S1 name and 23% gave another name).

The results from Experiment 1 were also used to select which morphs were assigned to be the startpoint, midpoint and endpoint morphs for a given morph set in all the subsequent studies. The default assignment was S1 as the startpoint morph, S7 as the midpoint morph and S13 as the endpoint morph. This was used for five of the 20 morph sets which were chosen as the experimental stimuli. However, if the S1 (or S13) morph dominated naming in Experiment 1, different morphs were selected to try to equate the proportion of startpoint and endpoint names assigned to the midpoint morph, and to try to equate the accuracy of naming the startpoint and endpoint morphs. For 14 morph sets (including the bath-sink morph set illustrated in Figure 1), the S7 morphs were mostly given the startpoint name. For these morph sets, the revised startpoint morph was S5 and the revised midpoint morph was S9. For one morph set (the cup-jug), S7 morphs were mostly given the endpoint name so the revised endpoint morph was S9 and the revised midpoint morph was S5.

Experiment 2

In Experiment 2, a word-picture verification task was used to check the preferred names for the startpoint morphs (S1 or S5), midpoint morphs (S5, S7 or S9) and endpoint morphs (S13 or S9) for the 48 morph sets selected in Experiment 1. Experiment 1 placed a lower bound on the consistency of naming the morphs. However, in Experiment 1 people may have recognised a given object but have been unable to recall the most appropriate name for that object or they may have used different names to refer to identical or similar shapes (such as deer, stag, antelope and moose). In Experiment 2, the upper bound of naming consistency was tested by asking people to choose one label from just three alternative names with which to identify each morph. Experiment 2 also tested whether the midpoint morph was approximately at the category boundary (i.e. that it was labelled with a similar proportion of startpoint and endpoint names).

Method

Participants Thirty-two undergraduate students from the University of Liverpool, U.K., took part in the study for course credit.

Materials, Design and Procedure For each of the 48 morph sets selected from Experiment 1, the same three written names were shown with all of the morphs from a given set. These were the modal responses to the S1 and S13 morphs in Experiment 1 plus a common alternative response given to morphs from that morph set, see Table 1. In addition, participants could select "other" to indicate that they would label an object with a name that was not one of the three options provided. If they chose this response, they were asked to type in their preferred name. The startpoint, midpoint and endpoint morphs used were those selected for each morph set in Experiment 1. Each of these morphs was, in turn, depicted from 30°, 60°, 90° and 120° views.

Each participant completed two blocks of 144 trials. Across these trials, morphs from each of the 48 sets were presented six times: once from each of two views for each of the three morphs. For half the participants, the two views presented were 30° and 120° and for the remaining participants they were 60° and 90°. The six possible arrangements of positions (left, middle and right) of the startpoint, endpoint and alternative names was each used once for these six presentations of morphs from a given set for every participant. Across all participants, each view of all of the morphs was shown an equal number of times.

The experiment was run on a Macintosh PowerPC G4 computer using the Psyscope version 1.2.5 experimental presentation software. On each trial, a picture was presented centrally and three numbered names were presented below it plus a fourth "other name" option. Participants made an unspeeded keypress response to select one of the names or they pressed "4" to select "other name" and then typed in their preferred name. Trials were presented in a different, random order to each participant and the experiment lasted around 20 minutes.

*** Insert Table 1 ***

Results and Discussion

Reassuringly, the startpoint name dominated responses to the startpoint morph (92%) and the endpoint name dominated responses to the endpoint morph (68%). People chose the startpoint name (92%, 60% and 22% for the startpoint, midpoint and endpoint morphs respectively) more often than the endpoint name (5%, 32% and 68%). They rarely chose the alternative name (2%, 8% and 9%) and very few provided their own name for the stimuli (less than 1% for each morph).

Responses for each of the 48 morph sets were examined separately in order to select sets for which the startpoint morph was usually given the startpoint name, the endpoint morph was usually given the endpoint name and the midpoint morph was usually given a mixture of the startpoint and endpoint names. For 25 morph sets, both the startpoint and the endpoint morphs were assigned their modal name on at least 50% of trials. Twenty of these were chosen to be experimental morph sets by selecting sets to maximise object diversity, see Table 1. For these sets, 89% of people chose the startpoint name for the startpoint morph (minimum 69%; 7% chose the endpoint name and 3% chose the alternative name). For the endpoint morph, 83% chose the endpoint name (minimum 59%; 11% chose the startpoint name and 5% chose the alternative name). For the midpoint morph, 47% chose the startpoint name and 45% chose the endpoint name (minimum of 16% in both cases; 7% chose the alternative name).

Experiment 3

Rating data was collected from three groups of participants for the 20 experimental morph sets selected in Experiment 2. The first group rated the typicality of the startpoint and endpoint modal names for the startpoint and endpoint morphs. This was used to ensure that, for the startpoint morphs, the startpoint name was considered to be an appropriate label but the endpoint name was not, and vice versa for the endpoint morphs. This provided a final check of the appropriateness of the labels selected in Experiments 1 and 2 for these stimuli.

The second rating group decided whether an object could exist that was midway between the startpoint and the endpoint categories for a given morph set. This data was used to check if people thought that objects shaped like the midpoint morphs could (or already) existed in the world. If so, then the midpoint morph could either be considered to be a typical exemplar of the startpoint or the endpoint category or to have a different but appropriate label. In either case, the midpoint morph would itself be a familiar object, For example, people’s stored, visual representations of plates and bowls are likely to overlap with each other in shape space. If so, people might consider either plate or bowl to be acceptable labels for deep plates and shallow bowls. We instead intended the midmorph morphs to be sufficiently distinct from either its startpoint or its endpoint morph that it would be a poor exemplar of either category.

The third group provided a label which could apply to both the startpoint and endpoint categories for a given morph set (e.g., "animal" for the pig-dog set). Together with the results of Experiments 1 and 2, which investigated the preferred names given to the morphs, this provided evidence about the level of identification (basic or subordinate) of objects in a given morph set. The assignment of a given label for a category of objects to the superordinate, basic or subordinate level cannot be determined a priori and it appears to be knowledge-dependent (Medin & Atran, 2004). Few researchers have collected converging measures across different tests to establish the level of a given name (see Lawson & Jolicoeur, 2003; also Jolicoeur, Gluck & Kosslyn, 1984) so this information was not available for many of our startpoint and endpoint names. However, our population was similar to that tested by Rosch, Mervis, Gray, Johnson and Boyes-Braem (1976) so we could use the levels established by them for some items. We also reasoned that if the common label provided by raters was one which is generally agreed to be at the superordinate level (e.g., animal, furniture, vehicle), this would indicate that the separate startpoint and endpoint labels subsumed under it were basic level labels. However, if the common label was usually considered to be a basic level label by our undergraduate population (e.g., bird, boat, fish) then it would suggest that the startpoint and endpoint labels were at the subordinate level.

Method

Participants In the first, typicality rating group and the third, common label rating group there were 24 and 16 undergraduate students respectively from the University of Liverpool, U.K. who took part for course credit. In the second, existence rating group there were 61 prospective undergraduate students and their parents.

Materials, Design and Procedure Participants in the typicality rating group completed 80 trials in which they rated 30° views of morphs in terms of how good an example they were of a named category. The startpoint and endpoint morphs from the 20 experimental morph sets were each shown twice to a participant, once paired with the startpoint name and once paired with the endpoint name. The startpoint morph was shown before the endpoint morph for ten morph sets and vice versa for the other ten sets. For five of each of these ten morph sets, each morph was paired with the startpoint name before being paired with the endpoint name, and vice versa for the other five. Order of assignment of morph sets to these four presentation conditions was counterbalanced across four groups of six participants. Participants rated each morph for how good an example of the named category it was, using a scale from 1 (a very good example of their idea or image of the labelled category of objects) to 7 (a very poor example).

Participants in the existence rating group and the common label rating group each completed 20 trials. On each trial, pairs of words were shown comprising the startpoint and endpoint names for each of the 20 experimental morph sets. Note that no pictures of morphs were presented. For half of the word pairs, the startpoint name was presented to the left of the endpoint name and vice versa for the other half.

The existence rating group decided whether objects halfway between the two named categories could exist. They were told that, for example, if the two words were *trousers* and *shorts* then objects that were halfway between trousers and shorts almost certainly exist in the real world. However, if the two words were *bottle* and *sieve* then probably nothing that is half-bottle, half-sieve exists in the world. For each pair of labels, participants circled a number between 1 and 5 to indicate whether halfway objects: 1 - *probably* exist in the world right now; 2 - *possibly might* exist in the world right now; 3 - could never exist but I *can* imagine what it might look like; 4 - could never exist and I *cannot* even imagine what it might look like; 5 - *other*. If they selected 5 they were asked to write their own response.

The common label task was run after participants had completed Experiment 2, so these participants had seen pictures of the objects, though they were not told that the two studies were related. Participants were asked to provide a category label which included both the startpoint and the endpoint object categories for a given morph set such that these categories were both "kinds of" the label that they chose. As examples, they were told that stilton and brie were both kinds of cheese, cake and onion were both kinds of food, and oak tree and apple tree were both kinds of tree.

Results and Discussion

*** Insert Table 2 ***

1. Typicality rating group

Ratings ranged from 1 (for a prototypical exemplar of a category) to 7 (for a poor or non-member of a category). For startpoint morphs, the startpoint name was rated as more typical (2.4; range 1.5 - 3.9) than the endpoint name (5.1; range 3.3 - 6.4), see Table 2. For the endpoint morphs, the endpoint name was rated as more typical (2.9; range 1.4 - 4.4) than the startpoint name (5.1; range 3.3 - 6.5). This confirmed the results of Experiment 2: the startpoint morph was rated as a much better exemplar of the category labelled by the startpoint name than the endpoint name and vice versa for the endpoint morph.

2. Existence rating group

In most cases, people did not believe that an item midway between the startpoint and endpoint labels could ever exist (60% of responses were 3 or 4), though some midway items were thought to possibly exist (25%) or to already exist (14%), see Table 2. Participants were less likely to state that a midway item could exist for the eight animals (mean rating = 3.0) than for the twelve artefacts (2.2). This difference was significant in a by-items analysis of variance (ANOVA), $F(1, 18) = 13.936$, $p < .002$. This result is consistent with the claim that people believe that there are true, defining features which are necessary and sufficient for all members of a biological category to possess, but that this psychological essentialism does not extend to artefacts (Gelman, 2003; Keil, 1989, 2003; Murphy, 2002). Note, though, that even for the artefacts, in most cases people did not believe that objects labelled by the startpoint name were on a shape continuum with objects labelled by the endpoint name. Instead, these objects were generally believed to belong to distinct categories with no intermediate objects existing between them. This implies that the midmorphs for these morph sets would be unfamiliar and highly atypical exemplars of both the startpoint and the endpoint categories. The clearest exceptions were for the furniture (chair-bed, bench-chair and chair-stool), spoon-knife and car-van morph sets.

3. Common label rating group

There were five morph sets for which the superordinate label “animal” (or the less common alternative “mammal”) was provided consistently as the common label: giraffe-horse, pig-dog, lion-dog, camel-llama and dog-giraffe. The startpoint and endpoint names for these morph sets would therefore generally be agreed to be basic level labels. Other examples for which the modal common label seemed to be at the superordinate level were: cup-jug ("container" or "crockery"), chair-bed ("furniture"), stapler-holepunch ("stationery"), spoon-knife ("cutlery"), car-van ("vehicle") and bottle-wateringcan ("container"). For two further morph sets, bath-sink and key-sword, there was little agreement as to a suitable common label suggesting that these concepts are so distinct that they are not easily grouped into the same superordinate category. We therefore believe that these startpoint and endpoint names should also be considered to be at the basic level. Altogether there were therefore 13 morph sets that appeared to have basic level startpoint and endpoint names.

The remaining seven morph sets were mostly given basic level common labels so the startpoint and endpoint names for these sets would probably be considered to be subordinate level labels. However, in all cases the second most frequently provided label for these morph sets was at the superordinate level. These sets were shark-fish (the basic level label "fish" was the modal common label but the superordinate level label "animal" was the next most frequent response), lizard-frog ("reptile" then "animal"), duck-chicken ("bird" then "animal"), bench-chair ("seating" then "furniture"), chair-stool ("seating" then "furniture"), canoe-rowing-boat ("boat" then "transport") and submarine-boat ("boat" then "transport").

Overall these results suggest that most of the preferred startpoint and endpoint names for the 20 experimental morph sets were at the basic level, though around a third were at the subordinate level. Most importantly, there was no evidence that view effects were greater in Experiments 5 and 6 for the seven morph sets with subordinate labels (with a mean advantage for same-view over view-change trials of 145ms and 19% for errors) compared to the 14 morph sets with basic level labels (mean of 128ms and 18% errors, see Table 5). Indeed, the only morph set which produced no overall view effects (chair-stool) had startpoint and endpoint names that were subordinate level labels. There was therefore no evidence that the view effects that we observed in the subsequent studies were driven by the minority of items which were identified at the subordinate level (as opposed to the difficulty of shape discrimination).

Experiment 4

Experiment 4 provided a final confirmation of the choice of experimental stimuli. Three large groups of participants were tested with a free naming task. As in Experiment 1, we tested which labels were assigned to morphs. However, in Experiment 1 the S1, S7 and S13 morphs were shown whereas different morphs were presented in Experiment 4 for most morph sets (these were the morphs selected in Experiment 2). It was important to check the consistency and appropriateness of the labels given to these startpoint, midpoint and endpoint morphs for the experimental sets, since these were the stimuli that were presented in the subsequent studies. In addition the large numbers tested in Experiment 4 provided a good estimate of the proportion of startpoint and endpoint names used to label the midpoint morphs.

Method

Participants Three groups of 142, 133 and 175 prospective undergraduate students and their parents who were visiting the University of Liverpool, U.K. for an open day volunteered to take part.

Materials, Design and Procedure Two groups each completed two blocks of 20 trials. In each block people saw one morph from each of the 20 morph sets. In the first block they saw the startpoint morphs for ten morph sets and the endpoint morphs for the other ten, and the assignment of startpoint or endpoint morph for a given morph set was counterbalanced across the two groups. In the second block both groups saw the midpoint morphs of all 20 morph sets. The third group only completed this second block of 20 trials. Their results were used to check what names were given to these midpoint morphs when recognition had not been primed by seeing either the startpoint or endpoint morph, as was the case for the other two groups. All morphs were depicted from the 30° view and were projected onto a large screen in a lecture theatre. On each trial, a picture was presented for approximately five seconds and participants were asked to write down the name of that object in a booklet.

*** Insert Tables 3 and 4 ***

Results and Discussion

Spelling mistakes were corrected, abbreviations were replaced with standardised responses and multi-word responses were reduced to a single word. If two alternative names were provided the second was deleted. No response was made on 1.5% of trials and responses were indecipherable on 0.2% of trials.

The percentage choice of the modal name provided for the startpoint, midpoint and endpoint morphs was calculated separately for each morph set, see Table 3. Any alternative name given by more than 5% of participants is listed in Table 4, together with names which were considered as equivalent to another name, such as “pony” for horse. Averaged across all 20 sets, for the startpoint morph, 88% gave the startpoint name (minimum 45%; 5% gave the endpoint name and 6% gave other names). For the endpoint morph, 75% gave the endpoint name (minimum 17%; 7% gave the startpoint name and 13% gave another name). The low accuracy for a few objects appeared to be due to item-specific effects. For example, only 19% correctly named the llama with 46% preferring to label it as a horse. This was probably because "llama" is a low frequency word which is hard to recall. Supporting this suggestion, llama (92%) was clearly preferred as a label over horse (3%) when both were provided as options in the word-picture verification task tested in Experiment 2, see Table 1. In contrast, the low accuracy for naming the rowing boat (17%) was due to people preferring to use a more general label for this stimulus (boat, 80%; see also Experiment 3) rather than because it could not be distinguished from other boats at the subordinate level (accuracy was 84% for rowing boat in Experiment 2; see Table 1). Items such as the llama and rowing boat had a disproportionate effect on mean naming accuracy in Experiment 4: the median accuracy for naming the startpoint morph was 96% and for the endpoint morph was 83%.

For the midpoint morph, averaging over the three groups, 47% chose the startpoint name and 34% chose the endpoint name, with only 18% choosing another name. The midpoint morph was more frequently labelled with the startpoint name if participants had previously seen the startpoint morph (65%, compared to 44% if the midpoint morph was the first morph they had seen and 31% if they had initially seen the endpoint morph). Likewise, the midpoint morph was more likely to be labelled with the endpoint name if participants had previously seen the endpoint morph (49%, compared to 33% if the midpoint morph was the first morph they had seen and 20% if they had initially seen the startpoint morph). These results are not consistent with the similarity-based contrast effect (Hampton, Estes & Simmons, 2005). This would predict the opposite pattern, namely that the borderline, midpoint morph would be more likely to be given the endpoint name if the startpoint object had previously been labelled and vice versa. An alternative reason for the priming effect that we observed is that the recent production of the name given to the startpoint or endpoint morph could have increased its availability as a response to the midpoint morph.

These results demonstrate that most of the startpoint morphs were named consistently with the startpoint name, most of the endpoint morphs were named consistently with the endpoint name, and the midpoint morphs were named with a roughly equal mixture of the startpoint and endpoint names. This data therefore confirmed the appropriate selection of stimuli for the subsequent three studies.

Experiment 5

The twenty experimental sets of morphs of familiar objects selected from the first four studies were then used in three sequential picture-picture matching studies. These studies replicated the design of earlier experiments which we had conducted with novel, unfamiliar objects (Lawson, 2004a; Lawson & Bülthoff, 2006). The studies explored how view-sensitivity changed as the difficulty of shape discrimination was altered. This was investigated in two ways. First, shape discriminability was manipulated within each study by varying the size of the shape change that occurred on mismatch trials (in Experiments 5 and 6) and on match trials (in Experiment 7). Second, shape discriminability was varied across the studies by varying the task from identification (Experiments 5 and 6) to categorisation (Experiment 7).

As discussed in the introduction, there is a consensus amongst researchers that view-sensitivity will occur when shape discrimination is difficult - for example, for subordinate level recognition (Biederman & Gerhardstein, 1995; Hamm & McMullen, 1998; Lawson & Humphreys, 1996, 1998; Lawson & Jolicoeur, 2003; Lawson & Bülthoff, 2006; Tarr & Cheng, 2003). However, there is considerable disagreement about the point at which this view-sensitivity dissipates as shape discrimination becomes easier. Many of the studies that have investigated the view-sensitivity of recognition across rotations in depth have tested people's ability to identify novel objects (e.g., Bülthoff & Edelman, 1992; Lawson, 2004a; Lawson & Bülthoff, 2006; Rock & Di Vita, 1987; Tarr 1995; Vanrie et al., 2001; Vanrie, Beatse, Wagemans, Sunaert & Van Hecke, 2002). However, compared to the categories that people distinguish between in everyday, basic level object recognition, these novel stimuli probably differed in terms of their shape discriminability, level of recognition and shape properties such as complexity and symmetry, in addition to their reduced familiarity, semantic associations and nameability. Any such differences between novel and familiar objects could have independently influenced the view-sensitivity of novel stimuli leading to difficulties in drawing conclusions about the view-sensitivity of everyday object recognition.

In Experiment 5 we used a sequential picture-picture matching task to test people's ability to ignore view-changes whilst detecting shape-changes. Four shape-change and three view-change conditions were tested. These were equivalent to the conditions tested in Experiment 1 of Lawson and Bülthoff (2006). This similarity in experimental design allowed us to compare performance across familiar and unfamiliar objects. From the results of our previous studies with novel objects (Lawson, 2004a; Lawson et al., 2003; Lawson & Bülthoff, 2006), in Experiment 5 we expected that view changes would influence people's ability to detect shape changes even though variation in view in depth was irrelevant to the task (for contrasting predictions, see Stankiewicz, 2002). We further predicted that greater view sensitivity would be found on same-shape matches than on shape-change mismatches, supporting our hypothesis that view sensitivity increases as the difficulty of shape discrimination increases.

A methodological improvement was made in Experiments 5 relative to Experiment 1 of Lawson and Bülthoff (2006). The first picture presented on each trial in Experiment 5 was the startpoint morph for half the trials and the endpoint morph on the remaining trials. In our previous study, the first picture was always the startpoint morph. As a result, it was possible, though unlikely, that view-sensitivity for the startpoint morph was much greater than for the endpoint morph. If so, then the pattern of view-sensitivity that we reported could have been due to this systematic variation in the view-sensitivity of the different morphs per se, rather than to the difficulty of shape discrimination within the task. This alternative account could not explain any variation in view-sensitivity in Experiment 5.

Method

Participants Thirty undergraduate students from the University of Liverpool, U.K., took part in the study for course credit.

Materials Five morphs were presented from each of the 20 experimental morph sets. These were the startpoint, midpoint and endpoint morphs, the nearstart morph (the morph midway between the startpoint and the midpoint morph; this was S3, S4 or S7 depending on the morphs used as the startpoint and endpoint for a given morph set, see Experiment 2) and the nearend morph (the morph midway between the endpoint and the midpoint morph; this was S7, S10 or S11). Each morph was, in turn, depicted from three views in depth, at 30°, 60° and 240°. Thus in total there were fifteen stimuli for each morph set (five morphs by three views; see Figures 1 and 2 and Table 1). A subset of these pictures (which excluded the nearstart and nearend morphs) were shown in Experiments 6 and 7.

Design and Procedure All participants completed one block of 360 experimental trials. In this block, each of the 20 morph sets were presented on nine matches and nine mismatches. On all trials, both pictures showed morphs from the same morph set. One group of ten morph sets was presented on half the trials. Here, the first picture presented was always the 30° view of the startpoint morph. The second picture was the same startpoint morph on matches and it was the nearstart, midpoint or endpoint morph on easy, medium and hard to detect shape change mismatches respectively. The second group of ten morph sets was presented on the other half of the trials. Here, the first picture presented was always the 30° view of the endpoint morph. The second picture was the same endpoint morph on matches and it was the nearend, midpoint or startpoint morph on easy, medium and hard to detect shape change mismatches respectively. The assignment of morph set group to the first picture morph (whether startpoint or endpoint) was counterbalanced across two subgroups of fifteen participants.

Relative to the first picture, the second picture could show a given morph from the same, 30° view or from a 60° view or a 240° view. For each of the 20 morph sets, in each of these three view-change conditions (i.e. for 0°, 30° and 150° view changes) there were three matches (for which no shape change occurred since the second as well as the first picture depicted either the startpoint or the endpoint morph) and one each of the easy, medium and hard mismatches. For generality, we tested two different (30° and 150°) view changes. Note, though, that there is no straightforward relation between the size of a view change and its effect on the perception of a given stimulus. Some view changes, such as those resulting in foreshortening, make identification much harder. Often, though, there is little effect of increasing the size of the view change above around 30°-45° (Foster & Gilson, 2002; Lawson & Humphreys, 1996). We therefore did not necessarily expect any difference between the two view change conditions tested here.

The experiment was run on a Macintosh PowerPC G4 computer using the Psyscope version 1.2.5 experimental presentation software. On each trial, a written cue saying "Get ready for the next trial" appeared for 750ms then, after 500ms, the first picture was presented 50 pixels above and 50 pixels to the right of fixation for 500ms. After a blank interstimulus interval of 400ms the second picture was presented at fixation until the participant responded. On all trials there was thus a translation of the stimulus from the first to the second picture so performance could not be based on detecting low-level visual changes.

Participants decided whether the two successive pictures showed the same or different-shaped objects and responded with a speeded “m” or “z” keypress respectively. They were told to ignore any difference in the view depicted in the first and second pictures and they were warned that on mismatches the pictures might show two objects with very similar shapes. After they had responded the correct response was given as feedback for 500ms, by presenting the letter “m” or “z” at fixation. There was an intertrial interval of 750ms. Participants took a self-timed break after every 120 trials. Prior to starting the experimental block they completed a block of 20 practice trials which were selected at random from the experimental trials. Trials were presented in a different, random order for each participant.

*** Insert Figure 3 ***

Results

ANOVAs were conducted on the mean correct RTs and on the percentage of errors for matches and mismatches separately, see Figure 3. Here and in Experiments 6 and 7, the results for the *F*-value in the by-participants and by-items analyses are reported using subscripts F_p and F_i respectively. On matches, same-shape "m" responses were correct whilst on mismatches, shape-change "z" responses were correct. Response latencies less than 300ms or exceeding 2300ms were discarded as errors (less than 2% of trials). No participants were replaced. There were three empty cells in both the by-participants and the by-items ANOVAs. These were replaced by the mean for that condition.

All ANOVAs included the within-participants factors of View Change (0°, 30° or 150°) and the counterbalancing factor of First Picture Morph (startpoint or endpoint). In this study and Experiments 6 and 7, view-sensitivity was similar irrespective of whether the first picture showed a startpoint or an endpoint morph. The effects of view change that we report here were therefore not merely due to greater view sensitivity to certain morphs. Results involving the counterbalancing factor of First Picture Morph will not be reported further. Mismatch ANOVAs included a further within-participants factor of Shape Change (easy, medium or hard to detect). All pairwise differences noted below were significant ($p < .05$) in both by-participants and by-items post-hoc Newman-Keuls analyses, unless otherwise specified.

Same-shape matches

View Change was significant for both RTs [$F_p(2, 58) = 124.47$, $p < .001$, $F_i(2, 38) = 132.64$, $p < .001$] and errors [$F_p(2, 58) = 166.00$, $p < .001$, $F_i(2, 38) = 34.47$, $p < .001$], see Figure 3. Same-view matches (723ms, 6% errors) were much faster and more accurate than 30° view-changes (910ms, 34% errors) which, in turn, were faster, though no more accurate, than 150° view-changes

(954ms, 33% errors).

Shape-change mismatches

View Change was significant for both RTs [$F_p(2, 58) = 16.42$, $p < .001$, $F_i(2, 38) = 9.34$, $p < .001$] and errors [$F_p(2, 58) = 31.30$, $p < .001$, $F_i(2, 38) = 9.54$, $p < .001$]. In contrast to same-shape matches, 30° view-change mismatches (798ms, 24% errors) were actually more accurate, though no faster, than same-view mismatches (807ms, 31%) which, in turn, were both faster and more accurate than 150° view-change mismatches (858ms, 34%; not significant for items for errors in Newman-Keuls analyses).

Shape Change was significant for both RTs [$F_p(2, 58) = 38.19$, $p < .001$, $F_i(2, 38) = 37.60$, $p < .001$] and errors [$F_p(2, 58) = 862.04$, $p < .001$, $F_i(2, 38) = 151.04$, $p < .001$]. Large, easy to detect shape changes (747ms, 5% errors) were detected both faster and more accurately than medium shape changes (819ms, 26%) which, in turn, were detected both faster and more accurately than small, hard to detect shape changes (897ms, 58%).

Finally, the interaction of View Change x Shape Change was not significant for RTs [$F_p(4, 116) = 1.45$, $p > .2$, $F_i(4, 76) = 0.38$, $p > .8$] but it was for errors [$F_p(4, 116) = 10.69$, $p < .001$, $F_i(4, 76) = 8.06$, $p < .001$], see Figure 3. For errors on hard shape changes, 30° view-changes (48%) were more accurate than either same-view trials (65%) or 150° view-changes (60%). For medium shape change errors, 30° view-changes (20%) and same-view trials (24%) were more accurate than 150° view-changes (35%). Finally, View Change had no significant effect on errors in detecting easy shape changes, with similarly high accuracy on 30° view-changes (3%), same-view trials (4%) and 150° view-changes (7%).

Discussion

As predicted, there were strong view effects on matches, with same-view trials being much faster as well as much more accurate than view-change trials. In contrast, view-sensitivity was relatively weak on mismatches. This variation in the effects of view change for familiar objects dependent on the difficulty of shape discrimination was similar to that found in Experiment 1 of Lawson and Bülthoff (2006) for novel objects (see Figure 3). The pattern of view-sensitivity that we had previously observed for novel objects thus generalised to everyday, nameable objects. These results suggest that there is a substantial cost to the achievement of object constancy across depth rotation, even for morphs of familiar objects that we must distinguish between in everyday life.

Experiment 6

In Experiment 5, all participants had to respond to mismatches with a mixture of easy, medium and hard to detect shape changes in addition to matches. On every trial, people therefore had to be prepared to detect a small, subtle shape change. The highly view-sensitive performance that we observed on matches in Experiment 5 was probably influenced by this demanding context. When people are recognising familiar objects they may typically set more lax criteria for distinguishing between different shapes than was necessary to perform the task in Experiment 5. It is therefore important to determine whether view-sensitivity still occurs in a task which does not require difficult shape discrimination and which may be more similar to everyday object recognition.

To examine this issue, three groups were tested in Experiment 6. Each group differed only in the difficulty of shape discrimination required on mismatches, with all groups doing identical matches. View-sensitivity on matches could be compared directly across the groups since each differed only in the context provided by the mismatches. If performance on matches was view-sensitive even when shape changes on mismatches were always large and easy to detect, this would suggest that view-sensitivity is ubiquitous in everyday object recognition. However, if matches were view-sensitive only when shape discrimination was difficult, for the group who had to detect small shape changes on mismatches, this would instead indicate that view-sensitivity is confined to subordinate level object recognition.

A second reason for comparing view-sensitivity across matches rather than mismatches is that there are potential problems of interpretation of changes in view-sensitivity across mismatches with varying sizes of shape change (as was the case in Experiment 5). In particular, people are less able to detect the occurrence of a view change across pairs of more dissimilar objects (Lawson & Bülthoff, 2006). For objects with very different shapes (such as an umbrella and an elephant), it becomes almost meaningless to try to specify when views of these two objects are aligned. Note, though, that any effects of this confound would lead to an underestimation of view-sensitivity. This issue was avoided in Experiment 6 since our analysis focussed on comparing match trials which were identical across the three groups.

A similar design to that of Experiment 6 was used in Lawson (2004a). This study presented morphs of novel objects. The results revealed a strong interaction between view-sensitivity on matches and shape discrimination difficulty on mismatches: view-sensitivity was much greater when the shape discrimination task was harder. Nevertheless, importantly, view-sensitivity was still found when the shape discrimination context was easy, when all mismatches presented two completely different shapes. Everyday object recognition is probably much harder than this easy context since most familiar objects have similarly shaped neighbours (e.g., stool, bench and table for chair; cat, goat and sheep for dog). However, a similar study conducted by Hayward and Williams (2000) produced different results. Their experiment, which also presented novel objects in a sequential picture-matching task, found no change in view-sensitivity as the difficulty of shape discrimination increased. Given this discrepancy in the literature, it was important to try to replicate the results of Lawson (2004a) using a different set of stimuli.

Method

Participants Thirty-six undergraduate students from the University of Liverpool, U.K. took part in the study for course credit.

Design and Procedure All participants completed one block of 120 trials. Stimuli from each of the 20 morph sets were presented on three matches and three mismatches. Each of these three trials presented a different view condition: relative to the first picture, the second picture was rotated in depth by 0°, 30° or 150°. For the group shown easy to detect shape change mismatches, stimuli were selected from different morph sets on each of these three different view change conditions.

One group of ten morph sets was presented on half the trials. Here, the first picture shown was always the 30° view of a startpoint morph. On matches, the second picture depicted the same startpoint morph. On mismatches it showed the midpoint morph from the same morph set, the endpoint morph from the same morph set or the startpoint morph from a different morph set for the hard, medium and easy to detect shape change groups respectively. The second group of ten morph sets was presented on the other half of the trials. Here, the first picture shown was always the 30° view of an endpoint morph. On matches, the second picture depicted the same endpoint morph. On mismatches it showed the midpoint morph from the same morph set, the startpoint morph from the same morph set or the endpoint morph of a different morph set in the hard, medium and easy to detect shape change groups respectively.

Twelve participants were assigned to each mismatch shape change group. Only the mismatches differed across these three groups. The assignment of morph set to the first picture morph (whether startpoint or endpoint) was counterbalanced across two subgroups of six participants within each group. The experimental procedure was identical to Experiment 5.

*** Insert Figure 4 ***

Results

ANOVAs were conducted on the mean correct RTs and on the percentage of errors for matches and mismatches separately, see Figure 4. On matches, same-shape "m" responses were correct whilst on mismatches, shape-change "z" responses were correct. Response latencies less than 275ms or exceeding 2300ms were discarded as errors (less than 1% of trials). No participants were replaced. There were eight empty cells in the by-items analyses which were replaced by the mean for that condition.

There was one within-participants factor, View Change (0°, 30° or 150°) and one between-participants factor, Mismatch Shape Changes (hard, medium or easy to detect). There were also two counterbalancing factors, the within-participants factor of First Picture Morph (startpoint or endpoint) and the between-participants factor of First Picture Subset (which group of morph sets was assigned to be shown as startpoint morphs and as endpoint morphs for the first picture). All pairwise differences noted below were significant ($p<0.05$) in by-participants and by-items post-hoc Newman-Keuls analyses.

Same-shape matches

View Change was significant for both RTs [$F_p(2,60) = 60.96$, $p < .001$, $F_i(2,36) = 39.76$, $p < .001$] and errors [$F_p(2,60) = 57.85$, $p < .001$, $F_i(2,36) = 27.86$, $p < .001$]. Same-view matches (655ms, 4% errors) were much faster and more accurate than 30° view-change matches (744ms, 19%) which, in turn, were faster, though not significantly more accurate, than 150° view-change matches (800ms, 21%).

Mismatch Shape Change was significant for both RTs [$F_p(2,30) = 23.82$, $p < .001$, $F_i(2,36) = 264.40$, $p < .001$] and errors [$F_p(2,30) = 65.69$, $p < .001$, $F_i(2,36) = 84.24$, $p < .001$]. The easy mismatch group (550ms, 4%), who only had to detect large shape changes on mismatches, were much faster and more accurate than the medium mismatch group (731ms, 10%) who, in turn, were much faster and more accurate than the hard mismatch group (917ms, 29%), who had to detect small, subtle shape changes on mismatches. Note that these large differences between the three groups are solely due to the mismatch context since these results are for matches which were identical across all three groups.

Most importantly, the View Change x Mismatch Shape Change interaction was significant for both RTs [$F_p(4,60) = 6.21$, $p < .001$, $F_i(4,72) = 6.85$, $p < .001$] and errors [$F_p(4,60) = 17.96$, $p < .001$, $F_i(4,72) = 16.66$, $p < .001$], see Figure 4. For the easy mismatch group, the only significant difference was that same-view matches (517ms, 1% errors) were faster than 150° view-change matches (584ms, 5%). The speed of responses on 30° view-change matches fell inbetween (550ms, 5%). View-sensitivity was greater for the medium mismatch group. Same-view matches (650ms, 3%) were faster than 30° view-change matches (726ms, 11%) which, in turn, were faster than 150° view-change matches (818ms, 16%). Also, same-view matches were more accurate than 150° view-change matches. View-sensitivity was still larger for the hard mismatch group. Here, same-view matches (798ms, 7%) were both faster and more accurate than either 30° view-changes (957ms, 40%) or 150° view-changes (997ms, 40%).

Thus for the easy mismatch group, view change effects were significant, but only for RTs (not for errors), with a difference of just 67ms (and 4% errors) between same-view matches and 150° view-change matches. For the medium mismatch group, view-sensitivity was greater (168ms, 14%) and was significant for both RTs and errors. Finally, view-sensitivity increased still further for the hard mismatch group (199ms, 33%).

Shape-change mismatches

Mismatches were not the focus of this study since, unlike matches, different stimuli were presented to the three groups on these trials. Nevertheless, for completeness, the results are reported in brief. View Change was not significant for RTs [$F_p(2,60) = 2.27$, $p > .1$, $F_i(2,36) = 1.37$, $p > .2$] but it was for errors [$F_p(2,60) = 22.05$, $p < .001$, $F_i(2,36) = 15.80$, $p < .001$]. Same-view mismatches (732ms, 11% errors) and 30° view-change mismatches (738ms, 12%) were more accurate than 150° view-change mismatches (759ms, 22%). Mismatch Shape Change was significant for both RTs [$F_p(2,30) = 16.81$, $p < .001$, $F_i(2,36) = 105.11$, $p < .001$] and errors [$F_p(2,30) = 147.16$, $p < .001$, $F_i(2,36) = 24.11$, $p < .001$]. The easy mismatch group (570ms, 4%) responded faster and more accurately than the medium mismatch group (762ms, 12%) who, in turn, responded faster and more accurately than the hard mismatch group (896ms, 30%). Finally, the View Change x Mismatch Shape Change interaction was significant for both RTs [$F_p(4,60) = 3.82$, $p < .008$, $F_i(4,72) = 2.91$, $p < .03$] and errors [$F_p(4,60) = 6.04$, $p < .001$, $F_i(4,72) = 4.89$, $p < .002$]. This interaction revealed a similar, but weaker pattern of view-sensitivity to that reported above for matches. There were no view effects for the easy group. For the medium mismatch group, same-view mismatches (8%) and 30° view-change mismatches (9%) were more accurate than 150° view-change mismatches (20%). For the hard mismatch group, same-view matches (867ms, 23%) and 30° view-changes (879ms, 24%) were both faster and more accurate than 150° view-changes (942ms, 43%).

Object-specific effects of view changes in Experiments 5 and 6

It is important to establish the generality of the view-sensitive effects reported above across different items. The significant view effects in the by-items analyses of both Experiments 5 and 6 provided evidence that these effects were not just due to performance on a subset of highly view-sensitive objects. This issue was examined in greater detail using data from both studies. The average cost of compensating for 30° and 150° view-changes on all matches was calculated for each of the 20 morph sets individually for the participants in Experiment 5 and for each of the three groups separately in Experiment 6.

There was a striking consistency in the presence of view-sensitivity for items across these four groups, see Table 5. In Experiment 5, every one of the 20 morph sets produced better performance on same-view trials than on view-change trials for both RTs and errors. In Experiment 6, the only exception to this view-sensitivity for the hard mismatch group was for one item for errors only; for the medium mismatch group, the only exceptions were for three items for RTs only; for the easy mismatch group, the only exceptions were for one item for both RTs and errors, for one item for RTs only and for one item for errors only. This level of consistency is particularly impressive given that there were just twelve participants in each of the three groups in Experiment 6. Furthermore of these eight exceptions, four were for the chair-stool morph set which, overall, produced no consistent view-sensitive effects, probably in part because the symmetry of the stool meant that its appearance was similar for all views tested. Averaging over size of view change (30°

or 150°), first picture morph (startpoint or endpoint) and group (Experiment 5 and hard, medium or easy mismatch groups in Experiment 6), the difference between same-view and view-change trials for the remaining 19 morph sets ranged from 48-269ms for RTs and 8-42% for errors. Importantly, view-sensitivity was similar across morph sets belonging to different superordinate categories (such as animals and furniture) and for morph sets with startpoint and endpoint labels at the basic or at the subordinate level (see also Experiment 3). This demonstrates that the strong, consistent view-sensitivity that we observed in our studies was not confined to a narrow subset of our stimuli.

Discussion

View-sensitivity on matches was found for all three groups tested in Experiment 6, see Figure 4. It was relatively weak when shape discrimination was easy because mismatches always showed large, readily detected shape changes. It was much greater when shape change detection was more challenging, for the medium and, especially, the hard mismatch groups. This interaction between view-sensitivity and the difficulty of shape discrimination replicates that reported for novel objects by Lawson (2004a; but see Hayward & Williams, 2000) and extends it to familiar objects. These results also demonstrate that the pattern of view-sensitivity observed in Experiment 5 was not an artefact due to either the inclusion of unusually difficult shape change detection trials within the task or to the increased difficulty of determining whether dissimilarly shaped objects are being presented from the same view. Instead view-sensitivity was found even for the easy group, for whom shape discrimination was probably much easier than that required in everyday object recognition, and for match trials on which identical shapes were presented, so view changes were readily detected.

Experiment 7

In Experiments 5 and 6, shape changes only occurred on mismatches so people always had to respond “different object” when they detected a shape change. This task is unlike everyday object recognition where some shape variation must usually be ignored when we identify objects as exemplars of a given category. The extent to which exemplars vary in shape within a category differs markedly, but even some basic-level categories (e.g., dogs, chairs) and most superordinate-level categories include a wide range of shapes. In the final picture-matching study, we tested whether performance would still be view-sensitive when people had to do a categorisation task in which they had to generalise across shape changes on matches. This task is more like everyday object recognition in that people had to ignore shape variation on some match trials by responding “same category” even when the two pictures showed objects with different shapes (e.g., the startpoint and the midpoint morph from the same morph set).

We tested the ability of people to achieve view-constancy for three different levels of difficulty of generalisation over shape changes. The task for the first, easy categorisation group was most similar to that of everyday, basic-level object recognition. Here, same-category matches presented either two identical shapes (the same startpoint morph or the same endpoint morph) or two quite similarly shaped morphs (a startpoint and a midpoint morph from the same morph set or an endpoint and a midpoint morph from the same morph set). The second and third groups were tested on a more challenging task since some same-category matches showed two objects that would usually be given different basic-level names (e.g., a bath and a sink; see Experiment 4 and Table 3). This task required greater shape generalisation than basic-level categorisation. In the second, medium categorisation group, matches presented either two identical shapes or two dissimilar shapes (a startpoint and an endpoint morph from the same morph set). In the third, hard categorisation group there were no identical shape matches so people always had to generalise over shape changes on matches - either from startpoint or endpoint to midpoint morphs or from startpoint to endpoint morphs. For all three groups, mismatches always showed two morphs from different morph sets so the context of shape discrimination was easy, and was identical to that for the easy group in Experiment 6.

This experiment used the same design as Experiment 2 of Lawson and Bülthoff (2006) which presented pictures of novel objects. In this previous study, view-sensitivity was found for all three categorisation groups, with better performance on same-view than on view-change matches. However, this view-sensitivity was relatively weak compared to when the shape discrimination task was harder (e.g., in the study reported in Lawson, 2004a and in Experiments 5 and 6 here). Given this, we predicted that performance would be only weakly view-sensitive in Experiment 7.

Method

Participants Forty-eight undergraduate students from the University of Liverpool, U.K., took part in the study for course credit.

Design and Procedure The stimuli were identical to those used in Experiment 5. All participants completed one block of 240 experimental trials. One group of ten morph sets was presented on half the trials. Here, the first picture shown was the 30° view of a startpoint morph. On matches, the second picture depicted the startpoint, midpoint or endpoint morph from the same morph set on zero, medium and large shape change matches respectively. On mismatches, the second picture showed the startpoint morph from a different morph set. The second group of ten morph sets was presented on the other half of the trials. Here, the first picture shown was the 30° view of the endpoint morph. On matches, the second picture depicted the endpoint, midpoint or startpoint morph from that morph set on zero, medium and large shape change matches respectively. On mismatches the second picture showed the endpoint morph from a different morph set. The assignment of morph set group to the first picture morph (whether startpoint or endpoint) was counterbalanced across two subgroups of eight participants for each of the three categorisation groups.

There were three view conditions: relative to the first picture, the second picture was depth-rotated by 0°, 30° or 150°. Stimuli from each of the 20 morph sets were shown as the first picture on six matches and six mismatches. Each view condition was presented on two of these six trials and, for matches, of these two trials, one was assigned to the small shape change condition and the other to the large shape change condition. Six different morph sets provided the second picture for the six mismatches for which a given morph set was shown as the first picture.

Sixteen participants were assigned to each of three categorisation groups. Only the matches differed across these groups. For the six matches for which a given morph set was shown as the first picture, then for the second picture: for the easy categorisation group, three matches showed the same morph again (so there was zero shape change) and three showed a midpoint morph (producing a moderate shape change); for the medium categorisation group, three matches had zero shape change and three had a large shape change (in which a startpoint morph was followed by an endpoint morph from the same morph set or vice versa); finally, for the hard categorisation group, three matches had a moderate shape change and three had a large shape change. Note that the moderate and large shape change matches in Experiment 7 showed identical stimuli to, respectively, the medium and large shape change mismatches in Experiment 5 and also to, respectively, the small and medium shape change mismatches in Experiment 6. However, the correct response on these trials was "change" in the recognition task tested in Experiments 5 and 6 versus "same " in the categorisation task tested in Experiment 7. The procedure was identical to Experiments 5 and 6 except that participants were told to decide whether the two successive pictures showed objects from the same or different categories. The practise trials ensured that participants were aware of the extent of shape variation on matches before they began the experimental trials.

*** Insert Figure 5 ***

Results

ANOVAs were conducted on the mean correct RTs and on the percentage of errors for matches and mismatches separately, see Figure 5. On matches, same-category "m" responses were correct whilst on mismatches, category-change "z" responses were correct. Response latencies less than 275ms or exceeding 2000ms were discarded as errors (less than 1% of trials). Two participants were replaced because their overall errors exceeded 15%. There was one empty cell in the by-items analyses which was replaced by the mean for that condition.

There were two within-participants factors of View Change (0°, 30° or 150°) and Shape Change (zero or small shape changes versus larger shape changes; these were zero and medium, zero and large, and medium and large shape changes for the easy, medium and hard categorisation groups respectively). There were also two counterbalancing factors: the within-participants factor of

First Picture Morph (startpoint or endpoint) and the between-participants factor of First Picture Subset (which group of morph sets were shown as startpoint morphs and as endpoint morphs for the first picture). All pairwise differences noted below were significant (p<0.05) in both by-participants and by-items post-hoc Newman-Keuls analyses.

Same-category matches

1.Easy categorisation group View Change was significant for both RTs [$F_p(2,28) = 19.87$, $p < .001$, $F_i(2,36) = 38.48$, $p < .001$] and errors, though only marginally for participants [$F_p(2,28) = 2.51$, $p < .1$, $F_i(2,36) = 4.14$, $p < .03$]. Same-view trials (510ms; 4% errors) were more accurate than 30° view-changes (524ms; 7%; not significant for participants) and were faster than 150° view-changes (562ms; 6%). Shape Change was significant for RTs [$F_p(1,14) = 10.39$, $p < .007$, $F_i(1,18) = 10.85$, $p < .005$] but not for errors [$F_p(1,14) = 0.00$, $p = 1$, $F_i(1,18) = 0.00$, $p = 1$]. Zero shape changes (514ms) were categorised faster than medium shape changes (551ms). The interaction of View Change x Shape Change was not significant for either RTs [$F_p(2,28) = 1.78$, $p > .1$, $F_i(2,36) = 1.38$, $p > .2$] or for errors [$F_p(2,28) = 0.52$, $p > .6$, $F_i(2,36) = 1.03$, $p > .3$], see Figure 5.

For the easy categorisation group, same-view matches were easier than view-change matches: they were more accurate than 30° view-changes and faster than 150° view-changes. This view-sensitivity replicates the finding of view-sensitivity on zero shape change matches in Experiments 5 and 6. Furthermore, it extends this finding to object categorisation: the same pattern of view-sensitivity was found for the medium shape change matches. Here, shape generalisation was non-trivial, as indicated by the significantly slower responses on these trials compared to zero shape change matches.

2. Medium categorisation group View Change was significant for RTs [$F_p(2,28) = 9.52$, $p < .001$, $F_i(2,36) = 7.00$, $p < .003$] but not for errors [$F_p(2,28) = 0.10$, $p > .9$, $F_i(2,36) = 0.09$, $p > .9$]. Same-view trials (585ms; 9% errors) were faster than 30° view-changes (608ms; 9%; not significant for items) which, in turn, were faster than 150° view-changes (630ms; 8%). Shape Change was significant for both RTs [$F_p(1,14) = 41.81$, $p < .001$, $F_i(1,18) = 54.73$, $p < .001$] and errors [$F_p(1,14) = 60.93$, $p < .001$, $F_i(1,18) = 20.22$, $p < .001$]. Zero shape changes (552ms; 3% errors) were categorised faster and more accurately than large shape changes (664ms; 14%). The interaction of View Change x Shape Change was not significant for either RTs [$F_p(2,28) = 0.75$, $p > .4$, $F_i(2,36) = 0.54$, $p > .5$] or for errors [$F_p(2,28) = 1.11$, $p > .3$, $F_i(2,36) = 1.12$, $p > .3$], see Figure 5.

For the medium categorisation group, same-view matches were faster than view-change matches. These results replicated the view-sensitivity found for zero shape change trials in the easy categorisation group. More importantly, they extended this finding to large shape change matches. Here, shape generalisation was difficult, as indicated by the much slower and less accurate responses compared to responses on zero shape change matches.

3. Hard categorisation group View Change was marginally significant for RTs [$F_p(2,28) = 2.82$, $p < .08$, $F_i(2,36) = 2.51$, $p < .1$] and was significant for errors [$F_p(2,28) = 3.71$, $p < .04$, $F_i(2,36) = 3.44$, $p < .05$]. Same-view trials (559ms; 4% errors) were more accurate than 150° view-changes (573ms; 7%). There were no significant effects involving 30° view-changes (556ms; 6%). Shape Change was significant for both RTs [$F_p(1,14) = 41.89$, $p < .001$, $F_i(1,18) = 22.51$, $p < .001$] and errors [$F_p(1,14) = 35.25$, $p < .001$, $F_i(1,18) = 12.26$, $p < .003$]. Medium shape changes (543ms; 3% errors) were categorised faster and more accurately than large shape changes (583ms; 9%). The interaction of View Change x Shape Change was significant for RTs, though only marginally for participants [$F_p(2,28) = 3.07$, $p < .07$, $F_i(2,36) = 4.16$, $p < .03$] but it was not significant for errors [$F_p(2,28) = 0.21$, $p > .8$, $F_i(2,36) = 0.34$, $p > .7$], see Figure 5. For medium shape changes, same-view trials (534ms; 1% errors) and 30° view-changes (533ms, 3%) were faster than 150° view-changes (562ms, 5%). In contrast, for large shape changes there was no significant difference in the speed of same-view trials (585ms and 8% errors), 30° view-changes (578ms, 9%) and 150° view-changes (585ms, 10%).

For the hard categorisation group, same-view matches were more accurate (and, for medium shape changes, faster) than 150° view-change matches. This extended the finding of view-sensitivity for the easy and medium categorisation groups to a case in which shape generalisation was difficult and shape changes occurred on every trial (both matches and mismatches).

Category-change mismatches

Mismatch trials were not the focus of theoretical interest here, but are reported for completeness. There were no significant effects of View Change, Shape Change or View Change x Shape Change in either by-participants or by-items ANOVAs for RTs or for errors for any of the three groups. Mean RTs (and errors) were 567ms (6%) for the easy categorisation group, 635ms (6%) for the medium categorisation group and 588ms (5%) for the hard categorisation group.

Discussion

In Experiment 7, as in Experiments 5 and 6, people performed better on same-view compared to view-change trials. This was the case for all three categorisation groups. However, view-sensitivity was relatively weak. There was a maximum difference of around 50ms and 5% on errors between same-view and 150° view-change matches with similar levels of view-sensitivity across the easy, medium and hard groups. This may have been because shape discrimination was so easy for all three groups. The two objects shown on mismatches were selected at random and so were usually highly dissimilar in shape to each other. This was like the shape change discrimination task for the easy context group tested in Experiment 6 (see Figure 4). In contrast, in everyday object recognition, the visual system must usually distinguish a given object from all possible distractors. The closest of these distractors will often be highly similar in shape to the object. For example, the nearest neighbours in shape space to a goat are animals such as dogs, sheep, horses and deer. These objects are much more similar in shape to a goat than an object chosen at random so the criteria for detecting shape changes when categorising the goat may be more stringent.

In order to examine whether the choice of mismatch distractors influenced view-sensitivity in Experiment 7, we tested a final group of sixteen participants. This group saw the same matches as the easy categorisation group but the mismatches differed. On mismatches, two similarly shaped objects were presented, with different mismatch distractors being chosen to be paired with each morph set. We tried to choose distractors with similar shapes to the first object presented on mismatch trials. For example, the teapot-wateringcan morphs were used as distractors for the cup-jug morphs. The mismatch distractor manipulation was intended to increase the difficulty of shape discrimination for this group relative to the easy categorisation group. We predicted that, in turn, view-sensitivity would be greater for this final, similar distractor group if increasing the similarity of objects on mismatches made the task harder and more like everyday object recognition. This between-group manipulation was similar to that tested across the hard, medium and easy groups in Experiment 6. There we found a striking increase in view-sensitivity as the difficulty in detecting shape changes on mismatches increased from easy through to hard, see Figure 4.

4. Similar distractor group tested with the easy categorisation task

Sixteen extra participants were tested in the easy categorisation condition described above except that different distractors were presented on mismatches. On mismatches, the second, distractor object was selected to have a similar shape to the first object depicted. These distractors came from the full set of 53 morph sets used in Experiment 1. For example, the pig-dog morph set provided distractors for the giraffe-horse morph set. The data was analysed in the same way as for the other groups.

View Change was significant for RTs [$F_p(2,28) = 25.86$, $p < .001$, $F_i(2,36) = 32.42$, $p < .001$] but not for errors [$F_p(2,28) = 1.33$, $p > .2$, $F_i(2,36) = 1.87$, $p > .1$]. Same-view trials (518ms; 7% errors) were faster than 30° view-changes (544ms; 8%) which, in turn, were faster than 150° view-changes (579ms; 9%). Shape Change was significant for both RTs [$F_p(1,14) = 27.54$, $p < .001$, $F_i(1,18) = 13.30$, $p < .002$] and errors [$F_p(1,14) = 18.48$, $p < .001$, $F_i(1,18) = 15.78$, $p < .001$]. Zero shape changes (523ms; 4% errors) were categorised faster and more accurately than medium shape changes (571ms; 13%). The interaction of View Change x Shape Change was significant for RTs [$F_p(2,28) = 6.80$, $p < .004$, $F_i(2,36) = 7.43$, $p < .003$] but not for errors [$F_p(2,28) = 0.64$, $p > .5$, $F_i(2,36) = 1.56$, $p > .2$], see Figure 5. With zero shape change, same-view trials (488ms; 2% errors) were faster than 30° view-changes (510ms, 3%) which, in turn, were faster than 150° view-changes (570ms, 6%). With medium shape changes same-view trials (547ms; 12% errors) were again faster than 30° view-changes (578ms, 14%) but 30° view-changes were not significantly faster than 150° view-changes (588ms, 13%). For mismatches, mean RTs were 610ms and there were 8% errors.

Note that mismatches were therefore only 43ms slower and 2% less accurate than mismatches for the easy categorisation group.

As expected, matches were once again view-sensitive for the similar distractor group. However, their performance only improved modestly on same-view compared to view-change trials (44ms faster and 2% more accurate). In particular, contrary to our predictions, view-sensitivity for this group was not significantly greater than that observed for the easy categorisation group (33ms and 3%). There was no significant interaction of Group x View Change or of Group x View Change x Shape Change when data from both groups were analysed together.

This lack of difference in view-sensitivity between these two easy categorisation groups may have resulted from a failure to substantially increase the difficulty of shape discrimination in the similar distractor group. Here, the same morph set (e.g., teapot-wateringcan) provided all of the mismatch distractors for a given morph set (e.g., cup-jug). These mismatches were therefore less variable than those for the easy categorisation group in which morphs from six different sets appeared on each of the six mismatches for a given morph set. This increased predictability of mismatches for the similar distractor group could have made shape discrimination easier compared to the easy categorisation group. This might have offset any increase in the difficulty of shape discrimination produced by the greater similarity of the two objects shown on mismatches. A second reason is that it was not possible to pair all of the experimental morph sets with similarly shaped morph sets given that there were only 53 morph sets available for use as distractors. We have direct evidence that shape discrimination difficulty was not much greater for the similar distractor group: their overall performance was both fast and accurate and it was little worse than that for the easy categorisation group, both for matches (15ms slower and 2% more errors) and mismatches (40ms slower and 2% more errors). In contrast, in Experiment 6 the shape discrimination manipulation produced a much larger difference between the medium and easy mismatch shape change groups, for both matches (181ms and 6%) and mismatches (192ms and 8%).

The shape discrimination task tested in Experiment 7 was probably easier than everyday object recognition. For the easy, medium and hard categorisation groups, most mismatches involved a large shape change whilst for the similar distractor group the mismatches repeatedly presented the same distractor paired with a given object and this distractor was often not very similar in shape to that object. In contrast, most familiar objects that we have to recognise in our daily lives must be distinguished from a range of similarly shaped objects (e.g., chair from stool, table, sofa). Nevertheless, despite shape discrimination in this study being as easy or easier than that required for everyday recognition, all four groups still produced view-sensitive performance (see Figure 5), which suggests that basic level categorisation of familiar objects is view-sensitive.

GENERAL DISCUSSION

First, the results of the three sequential matching studies reported here suggest that the recognition and categorisation of familiar objects is normally sensitive to the view from which those objects are seen. The achievement of object constancy over depth rotation thus appears to incur a cost under most circumstances including, most importantly, when familiar objects are identified at the basic level used in everyday life. Second, the benefit from seeing an object from the same orientation in depth as it was previously identified is modulated by the overall difficulty of shape discrimination. The advantage for same-view over view-change matches was substantial when shape change detection was difficult but reduced when shape discrimination was easy. This was the case for matches relative to mismatches in Experiment 5 and for matches made in the context of small relative to large shape change mismatches in Experiment 6. Third, the magnitude and pattern of view-sensitivity was similar for the familiar objects tested here as for the novel objects that we tested in our earlier studies (see Figures 3, 4 and 5). In particular, we found no evidence that view-sensitive performance was restricted to the recognition and categorisation of novel objects. Together these results suggest that view-specific information is encoded as an integral part of the representations of a wide range of objects. These include familiar objects from a diverse range of superordinate categories (see Table 5), with similar view-sensitivity for subordinate as for basic level categories of objects (see Table 2). Our results also demonstrate systematic variation in the level of this view-sensitivity dependent on both the difficulty of shape discrimination and the task. These findings support the hypothesis that view-sensitive representations are typically used when recognising familiar objects at the basic level as well as at the subordinate level ((Tarr & Bülthoff, 1995; Tarr & Cheng, 2003; but see Biederman & Gerhardstein, 1993, 1995).

Our results are broadly consistent with recent theoretical accounts that propose that both view-specific and view-invariant representations play major roles in object recognition (Foster & Gilson, 2002; Hummel, 2001; Tarr & Bülthoff, 1995, 1998). For example, Hummel and colleagues have suggested that two types of shape representations can mediate object recognition. These representations work in parallel and comprise a view-specific, shape-specific, holistic representation that is sensitive to depth rotation and an analytic representation that can generalise over some view and shape changes (Hummel, 2001; Hummel & Stankiewicz, 1998; Thoma et al., 2004; Thoma, Davidoff & Hummel, 2007). The former representation can be activated automatically and may dominate when object recognition is easy whereas the latter representation requires attention and is slower to be activated but is necessary to generalise over either view or shape changes. The view-specific representation could mediate the same-view, same-shape matches in Experiments 5, 6 and 7, whereas only the analytic representation could support generalisation across view and shape changes on the remaining trials. This could account for the generally superior performance of people on same-view, same-shape matches in our research. However, it is not clear whether the view-specific representations could also mediate same-view, shape-change matches in Experiment 7. If not, this account would fail to explain why view-sensitivity was also found on these trials.

A potential critique of the present studies is the use of a sequential picture matching task. A particular issue with this task is that identical pictures were presented on same-view, same-shape trials. On such trials a simple similarity matching strategy might suffice to determine that a picture had been repeated but this strategy would be useless for everyday object recognition. Three points can be made regarding this concern. First, in Experiments 5, 6 and 7 the second picture was always presented at a different position to the first so the retinal input altered, preventing the use of very low-level matching strategies. Second, a simple matching strategy would fail for those same-view, same-category trials in Experiment 7 in which the first and second pictures showed different shapes. However, view-sensitivity was similar on these moderate and large shape-change matches as for the zero shape-change matches in which identical pictures were presented. This suggests that people did not benefit substantially from a simple matching strategy for the identical repetition trials. Third, in Experiment 6 there were striking differences in performance on the view-change matches across the three groups tested, see Figure 4. These trials were the same for all three groups and the differences cannot be due to low-level, simple similarity matching because there was always a view change, and hence a picture change, on these trials. This result demonstrates that shape discriminability influences view-sensitivity without needing to consider results from same-view (identical repetition) matches. Some researchers have argued that tasks such as sequential matching may be contaminated by familiarity effects and that naming is a better task with which to examine object recognition (e.g., Biederman & Gerhardstein, 1993). However, many would disagree (e.g., Tarr & Bülthoff, 1995). Furthermore, note that naming is a relatively noisy, unreliable task (Lawson, 2004b) making it a poor choice with which to examine the complex interactions investigated here. A final issue with the sequential matching task is that it does not necessitate the involvement of long term object representations. This is, in fact, a strength of the task since it can be used with novel as well as familiar objects. Furthermore, previous research has demonstrated that sequential matching tasks are sensitive to effects of object familiarity and perceptual training (e.g., Jiang, Bradley, Rini, Zeffiro, VanMeter & Reisenhuber, 2007; Lawson & Humphreys, 1996). Notwithstanding these points, it would be useful to extend the research reported here to a wider range of tasks.

The present results demonstrate the importance of shape discriminability and task in modulating view-sensitivity but current accounts of the achievement of object constancy pay little attention to these factors. In particular, we suggest that the difficulty of shape discrimination may be a much more important factor in determining whether performance is view-sensitive than the level of identification of a category (whether subordinate or basic; Rosch et al., 1978). However, most researchers have focussed on the latter factor. These two effects are often confounded: subordinate level distinctions (e.g., between different breeds of dog) usually require finer shape discriminations than basic level categorisation (e.g., between different animals). Nevertheless, it is possible to tease apart these two factors, as was done here.

An important benefit of manipulating shape discriminability directly is that it is relatively easy to specify objectively. In contrast, trying to determine whether a given category label is at the subordinate, basic or superordinate level can be time-consuming, subjective and contentious. For example, at what level are the following labels and to which superordinate category do they belong: telephone, stapler, vase, steering wheel, angel, pillow, tooth, brick, umbrella, leaf, feather, mould, ladder and button (see Lawson & Jolicoeur, 2003)? Consistent with this proposal is the finding that atypical exemplars of a category are often named not at the basic level at the subordinate level (e.g., “penguin” not “bird”; see Jolicoeur et al., 1984; Murphy & Brownell, 1985; Op de Beeck & Wagemans, 2001). It seems likely that one important reason why penguins are normally identified at the subordinate level is because they are dissimilar in shape to other exemplars from the category of birds and from other categories. Note, though, that this difference in 3D shape is often confounded with other, semantic factors (e.g., unlike most other birds, penguins swim, do not build nests and cannot fly) and people's knowledge and experience of a category (Medin & Atran, 2004).

In conclusion, the empirical findings presented here map out the variation in the difficulty the human visual system has in achieving object constancy across depth rotation over a wide range of conditions. Performance was superior on same-view relative to view-change trials across a diverse range of conditions. The factors manipulated included the superordinate category and geometry of objects, familiarity, shape discriminability and task. These results provide an important set of constraints on theoretical accounts of object recognition. In particular, they point to the crucial and underappreciated role of shape discriminability in modulating view-sensitivity in the recognition of both familiar and novel categories of objects.

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TABLES

Table 1. Percentage of selection of the startpoint, endpoint and third, alternative names for the startpoint, midpoint and endpoint morphs in the word-picture verification task in Experiment 2 plus the percentage of blank responses averaged across all three morphs, for the twenty experimental morph sets selected for use in subsequent studies.

		Startpoint morph			**Midpoint morph**			**Endpoint morph**					
Morph Group	**Startpoint name**	**Startpoint name**	**Other name**	**Endpoint name**	**Startpoint name**	**Other name**	**Endpoint name**	**Startpoint name**	**Other name**	**Endpoint name**	**Endpoint name**	**Other name**	**Blank responses**
1	**GIRAFFE**	95	2	3	52	2	45	6	6	84	**HORSE**	DOG	2
1	**SHARK**	97	2	2	72	0	28	31	3	66	**FISH**	DOLPHIN	0
1	**BATH**	97	0	3	75	2	23	5	0	95	**SINK**	SHOWER	0
1	**LIZARD**	89	3	5	59	2	38	39	2	59	**FROG**	CROCODILE	1
1	**CUP**	80	0	20	17	8	75	2	8	91	**JUG**	VASE	0
1	**PIG**	98	0	2	56	2	41	6	2	80	**DOG**	COW	3
1	**CHAIR**	86	6	6	47	9	41	2	2	95	**BED**	SOFA	2
1	**BENCH**	98	2	0	38	9	53	5	0	95	**CHAIR**	STOOL	0
1	**STAPLER**	81	0	17	47	0	53	19	2	80	**HOLEPUNCH**	LAMP	0
1	**LION**	83	3	14	56	6	36	17	5	78	**DOG**	CAT	0
2	**CHAIR**	69	2	30	38	2	61	14	6	78	**STOOL**	BENCH	0
2	**CAMEL**	83	0	17	33	0	67	5	3	92	**LLAMA**	HORSE	0
2	**SPOON**	75	25	0	19	38	42	0	13	88	**KNIFE**	TROWEL	0
2	**CANOE**	95	0	5	39	0	61	8	8	84	**ROWINGBOAT**	RAFT	0
2	**DOG**	95	2	2	64	0	36	2	2	97	**GIRAFFE**	HORSE	0
2	**CAR**	98	0	0	16	3	80	3	5	92	**VAN**	LORRY	1
2	**KEY**	84	16	0	47	36	16	3	2	94	**SWORD**	SAW	1
2	**SUBMARINE**	98	0	2	72	0	28	31	3	63	**BOAT**	YACHT	0
2	**DUCK**	95	0	3	50	13	36	14	23	63	**CHICKEN**	PIGEON	0
2	**BOTTLE**	95	0	2	28	3	66	2	0	97	**WATERINGCAN**	JUG	2
	Means	**89**	**3**	**7**	**47**	**7**	**45**	**11**	**5**	**83**			**1**

Table 2. Results for the typicality group, the existence group and the common label group in Experiment 3 for the twenty experimental morph sets. The typicality group rated 30° views of the startpoint and the endpoint morphs as to how good an example they were of the category labelled by the startpoint or the endpoint name. They used a scale from 1 (a very good example of their idea or image of the category) to 7 (a very poor example). The existence group decided whether an object midway between the stimuli labelled by the startpoint and endpoint names for a given object (such as giraffe and horse): 1 - probably already existed (mean of 14% of selections); 2 - might possibly exist (25%); 3 - could never exist but could be imagined (42%); 4 - could never exist and could not even be imagined (18%); or 5 - other (0.5%). The common label group were asked to provide a label that could be applied to objects from both the startpoint and the endpoint categories within each morph set.

		1. Typicality group				**2. Existence group**		**3. Common label group**	
Morph Group	**Morph Set**	**Startpoint Morph - Startpoint Name**	**Startpoint Morph - Endpoint Name**	**Endpoint Morph - Endpoint Name**	**Endpoint Morph - Startpoint Name**	**Mean rating**	**Modal rating**	**Modal response (and percentage choosing it)**	**Next most popular response (and percentage choosing it)**
1	**GIRAFFE-HORSE**	2.2	6.4	4.1	5.9	2.9	3	animal 63%	mammal 38%
1	**SHARK-FISH**	2.5	3.9	3.9	4.7	2.4	2	fish 38%	animal 19%
1	**BATH-SINK**	2.6	4.5	2.3	4.7	2.4	2	water container 19%	bathroom furniture 13%
1	**LIZARD-FROG**	3.3	4.2	3.7	3.3	3.0	3	reptile 44%	animal 25%
1	**CUP-JUG**	2.8	4.7	2.0	4.4	2.0	2	container 38%	crockery 19%
1	**PIG-DOG**	2.0	6.3	4.0	6.0	3.2	3	animal 81%	mammal 6%
1	**CHAIR-BED**	1.6	5.7	2.1	5.8	1.7	1	furniture 69%	seating 13%
1	**BENCH-CHAIR**	1.5	4.7	1.4	5.5	2.1	1	seating 75%	furniture 19%
1	**STAPLER-HOLEPUNCH**	2.9	4.5	2.6	5.1	2.7	3	stationary 88%	office equipment 13%
1	**LION-DOG**	3.9	5.3	4.4	5.4	3.3	3	animal 81%	mammal 19%
2	**CHAIR-STOOL**	2.0	4.8	2.7	4.8	1.7	1	seating 81%	furniture 13%
2	**CAMEL-LLAMA**	2.3	3.5	3.2	4.7	2.6	2	animal 50%	mammal 31%
2	**SPOON-KNIFE**	2.7	6.4	2.2	6.5	2.4	1	cutlery 81%	kitchen utensil 6%
2	**CANOE-ROWINGBOAT**	1.8	3.3	2.8	4.8	2.0	2	boat 81%	transport 6%
2	**DOG-GIRAFFE**	3.3	5.8	2.8	6.3	3.5	4	animal 81%	mammal 19%
2	**CAR-VAN**	1.5	5.6	2.5	4.2	1.4	1	vehicle 63%	transport 31%
2	**KEY-SWORD**	2.8	5.8	2.5	6.2	3.2	3	metal object 50%	tools 13%
2	**SUBMARINE-BOAT**	1.8	6.1	2.8	4.7	2.6	2	boat 69%	transport 19%
2	**DUCK-CHICKEN**	1.7	5.4	2.8	3.8	2.9	3	bird 56%	animal 25%
2	**BOTTLE-WATERINGCAN**	3.3	5.7	2.9	5.8	2.3	2	container 38%	water container 13%
	Means	**2.4**	**5.1**	**2.9**	**5.1**	**2.5**		**62%**	**18%**

Table 3. Percentage of startpoint and endpoint names provided for the startpoint, midpoint and endpoint morphs in the naming task in Experiment 4, plus the percentage of blank responses averaged across all three morphs, for the twenty experimental morph sets.

		Startpoint morph (both groups)		**Midpoint morph if startpoint named**		**Midpoint morph if named first**		**Midpoint morph if endpoint named**		**Endpoint morph (both groups)**			
Morph Group	**Startpoint name**	**Startpoint name**	**Endpoint name**	**Startpoint name**	**Endpoint name**	**Startpoint name**	**Endpoint name**	**Startpoint name**	**Endpoint name**	**Startpoint name**	**Endpoint name**	**Endpoint name**	**Blank responses**
1	**GIRAFFE**	**83**	1	47	14	41	24	33	20	1	**62**	**HORSE**	3
1	**SHARK**	**88**	10	71	26	51	48	15	79	6	**89**	**FISH**	0
1	**BATH**	**100**	0	84	16	70	27	44	54	15	**84**	**SINK**	0
1	**LIZARD**	**50**	44	49	47	9	90	14	82	11	**86**	**FROG**	0
1	**CUP**	**98**	2	49	48	25	73	6	89	1	**97**	**JUG**	1
1	**PIG**	**99**	0	95	3	97	2	95	4	11	**74**	**DOG**	0
1	**CHAIR**	**97**	0	74	5	46	18	22	68	1	**94**	**BED**	1
1	**BENCH**	**98**	0	55	33	50	48	36	57	0	**98**	**CHAIR**	0
1	**STAPLER**	**92**	4	71	23	14	62	7	63	2	**63**	**HOLEPUNCH**	6
1	**LION**	**45**	24	35	39	10	65	18	59	10	**66**	**DOG**	2
2	**CHAIR**	**89**	11	77	23	74	25	25	70	8	**75**	**STOOL**	0
2	**CAMEL**	**96**	0	84	7	54	31	61	23	7	**19**	**LLAMA**	1
2	**SPOON**	**87**	0	68	1	18	1	14	35	0	**85**	**KNIFE**	0
2	**CANOE**	**76**	3	44	9	22	16	17	13	2	**17**	**ROWINGBOAT**	0
2	**DOG**	**96**	0	68	15	66	11	45	21	2	**93**	**GIRAFFE**	4
2	**CAR**	**100**	0	33	51	46	44	18	77	17	**77**	**VAN**	0
2	**KEY**	**95**	1	70	16	50	24	44	32	0	**86**	**SWORD**	1
2	**SUBMARINE**	**97**	0	83	16	61	39	53	47	16	**82**	**BOAT**	0
2	**DUCK**	**99**	0	87	8	80	8	50	30	20	**53**	**CHICKEN**	0
2	**BOTTLE**	**70**	0	46	4	3	14	1	54	0	**91**	**WATERINGCAN**	4
	Means	**88**	**5**	**65**	**20**	**44**	**33**	**31**	**49**	**7**	**75**		**1**

Table 4. Any alternative names provided by at least 5% of participants for the startpoint, midpoint and endpoint morphs for the twenty experimental morph sets in Experiment 4.

Startpoint name	**Startpoint morph**	**Midpoint morphs if startpoint named**	**Midpoint morphs if named first**	**Midpoint morphs if endpoint named first**	**Endpoint morph**	**Endpoint name**
GIRAFFE	deer 10%	deer 24%	deer 33%	deer 27%, llama 6%	deer 14%, moose 6%	**HORSE**
PIG					fox 9%	**DOG**
CHAIR		seat 7%, couch 5%	couch 13%, seat 7%, sofa 7%			**BED**
BENCH		seat 10%		seat 6%		**CHAIR**
STAPLER			photocopier 5%	photocopier 6%		**HOLEPUNCH**
LION	leopard 7%, puma 5%	cat 8%		animal 6%		**DOG**
CHAIR					sink 7%	**STOOL**
CAMEL					horse 46%, deer 8%, dog 8%	**LLAMA**
SPOON	trowel 6%	trowel 18%, spade 8%	trowel 39%, spade 36%	trowel 26%, spade 17%	spade 5%	**KNIFE**
CANOE	boat 21%	boat 46%	boat 62%	boat 68%	boat 80%	**ROWINGBOAT**
DOG				deer 6%, llama 5%		**GIRAFFE**
KEY		saw 8%	saw 10%	saw 8%, knife 5%		**SWORD**
DUCK			bird 6%	bird 11%, pigeon 7%	bird 15%, pigeon 9%	**CHICKEN**
BOTTLE		container 7%, oilcan 6%	kettle 11%, oilcan 11%, jug 9%, can 7%, petrolcan 6%, container 5%	oilcan 18%, petrolcan 8%		**WATERINGCAN**

In Experiment 4, alternative names accepted as equivalent to the startpoint and endpoint names were:

Boat - ship or trawler
Camel - dromedary
Canoe - kayak
Chicken - hen
Cup - mug
Dog - wolf
Fish - piranha
Frog - toad
Horse - ass, donkey, mule or pony
Lion - lioness or tiger
Pig - boar
Sink - basin
Sword - dagger
Submarine - U-boat

In Experiment 4, alternative names accepted for other labels were:

Animal - mammal
Banjo - mandolin
Deer - stag or antelope
Moose - elk
Spade - shovel
Couch - sofa

Table 5. Mean cost of compensating for view changes on match trials (averaged over 30° and 150° view changes and averaged over first picture morph) for RTs (ms; left five columns of data) and errors (%; right five columns of data) for each of the twenty experimental morph sets, first for all participants in Experiment 5 (with a mix of hard and medium mismatches) and then for each of the three groups of participants in Experiment 6 and, finally, averaged over these four separate groups. The negative values indicate that same-view trials were either slower or less accurate than view-change trials. In the first column the Morph Group of each morph set is given together with the assumed level (basic or subordinate) of the labels for the startpoint and endpoint morphs in each morph set (see the typicality rating group in Experiment 3).

		Mean view effects on RTs (ms)							**Mean view effects on errors (%)**					
Morph group, level of labels, then startpoint then endpoint morph names		**Expt 5 Mixed mismatches**	**Expt 6 Hard mismatches**	**Expt 6 Medium mismatches**	**Expt 6 Easy mismatches**		**Mean for all groups**		**Expt 5 Mixed mismatches**	**Expt 6 Hard mismatches**	**Expt 6 Medium mismatches**	**Expt 6 Easy mismatches**		**Mean for all groups**
1-Basic	**GIRAFFE-HORSE**	295	145	176	60		**169**		29	54	17	0		**25**
1-Sub	**SHARK-FISH**	222	133	149	49		**138**		23	29	17	8		**19**
1-Basic	**BATH-SINK**	169	231	48	0		**112**		24	46	13	-8		**19**
1-Sub	**LIZARD-FROG**	338	389	237	112		**269**		48	58	29	8		**36**
1-Basic	**CUP-JUG**	198	169	87	130		**146**		39	50	12	0		**25**
1-Basic	**PIG-DOG**	267	269	214	48		**199**		27	17	4	8		**14**
1-Basic	**CHAIR-BED**	105	97	160	99		**115**		3	21	8	8		**10**
1-Sub	**BENCH-CHAIR**	158	187	189	81		**154**		15	8	8	0		**8**
1-Basic	**STAPLER-HOLEPUNCH**	256	151	-4	15		**104**		23	42	13	13		**23**
1-Basic	**LION-DOG**	175	235	100	85		**149**		34	13	21	0		**17**
2-Sub	**CHAIR-STOOL**	72	44	-17	-95		**1**		3	-17	4	-4		**-3**
2-Basic	**CAMEL-LLAMA**	235	31	115	22		**101**		23	46	13	0		**20**
2-Basic	**SPOON-KNIFE**	188	316	231	119		**213**		44	58	8	4		**29**
2-Sub	**CANOE-ROWINGBOAT**	160	184	-19	81		**102**		33	38	4	0		**19**
2-Basic	**DOG-GIRAFFE**	160	10	18	2		**48**		7	8	4	13		**8**
2-Basic	**CAR-VAN**	192	179	108	39		**129**		22	37	4	4		**17**
2-Basic	**KEY-SWORD**	153	85	51	58		**87**		24	8	0	4		**9**
2-Sub	**SUBMARINE-BOAT**	230	296	238	85		**212**		63	63	33	4		**41**
2-Sub	**DUCK-CHICKEN**	233	125	146	57		**140**		27	38	4	4		**18**
2-Basic	**BOTTLE-WATERINGCAN**	261	118	125	-88		**104**		37	54	4	13		**27**
	Means	**203**	**170**	**118**	**48**		**135**		**28**	**34**	**11**	**4**		**19**

Figure 1 The 60º view of all thirteen morphs of one of the 20 experimental morph sets, the bath-sink. The S1, S7 and S13 morphs were used in Experiment 1. In all subsequent studies, only morphs between the startpoint morph (here S5, "bath") and the endpoint morph (here S13, "sink") were presented. Startpoint and endpoint morphs were selected to try to equate their ease and consistency of identification and so that midpoint morphs (here S9) were identified about equally often using the startpoint name (e.g., "bath") and the endpoint name (e.g., "sink"). The startpoint, nearstart, midpoint, nearend and endpoint morphs were the S1, S4, S7, S10 and S13 morphs respectively for five objects, the S1, S3, S5, S7 and S9 morphs respectively for one object, and the S5, S7, S9, S11 and S13 morphs respectively for 14 objects including the bath-sink morph set illustrated here. See Experiments 1 and 5 for further details.

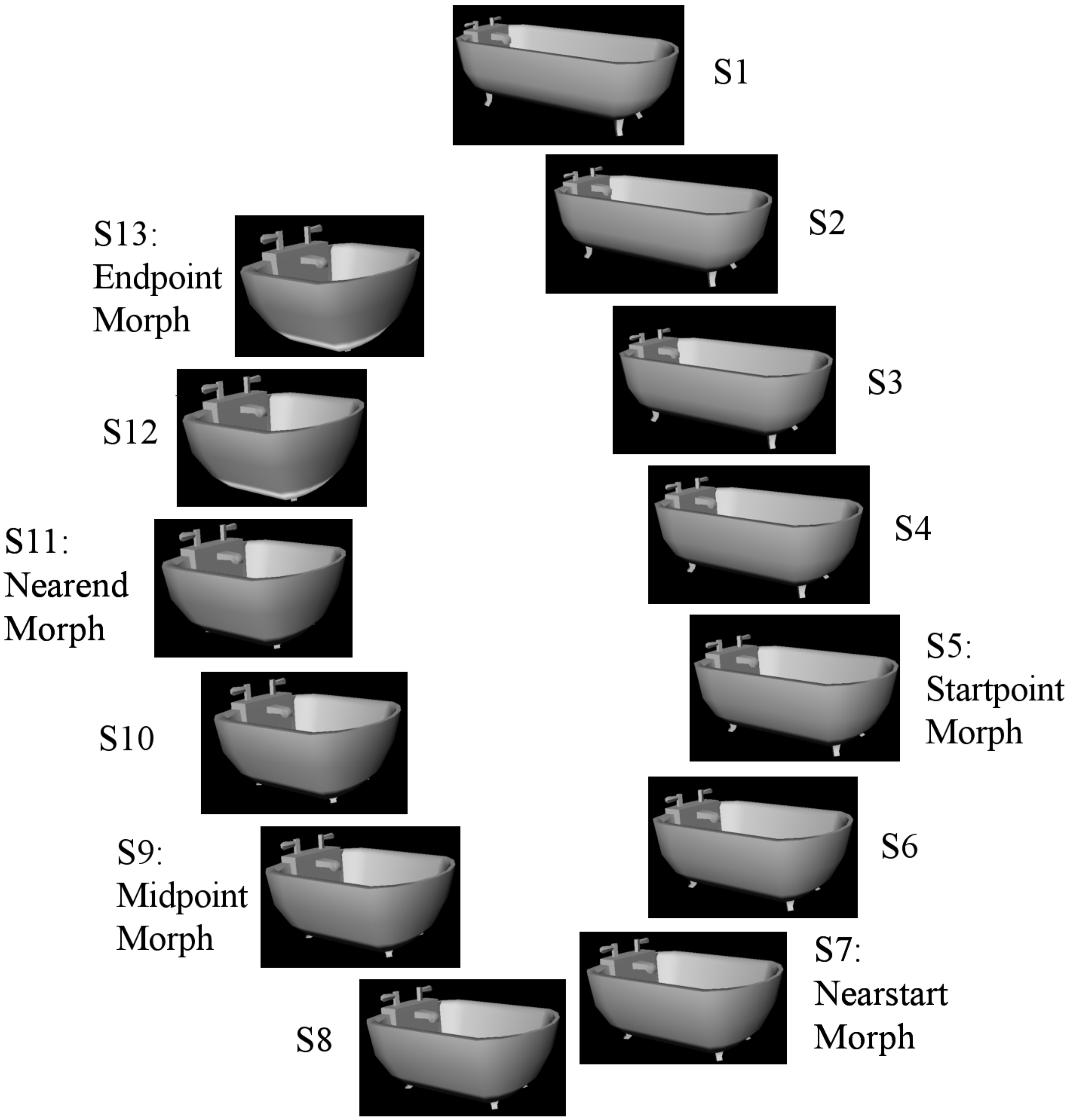
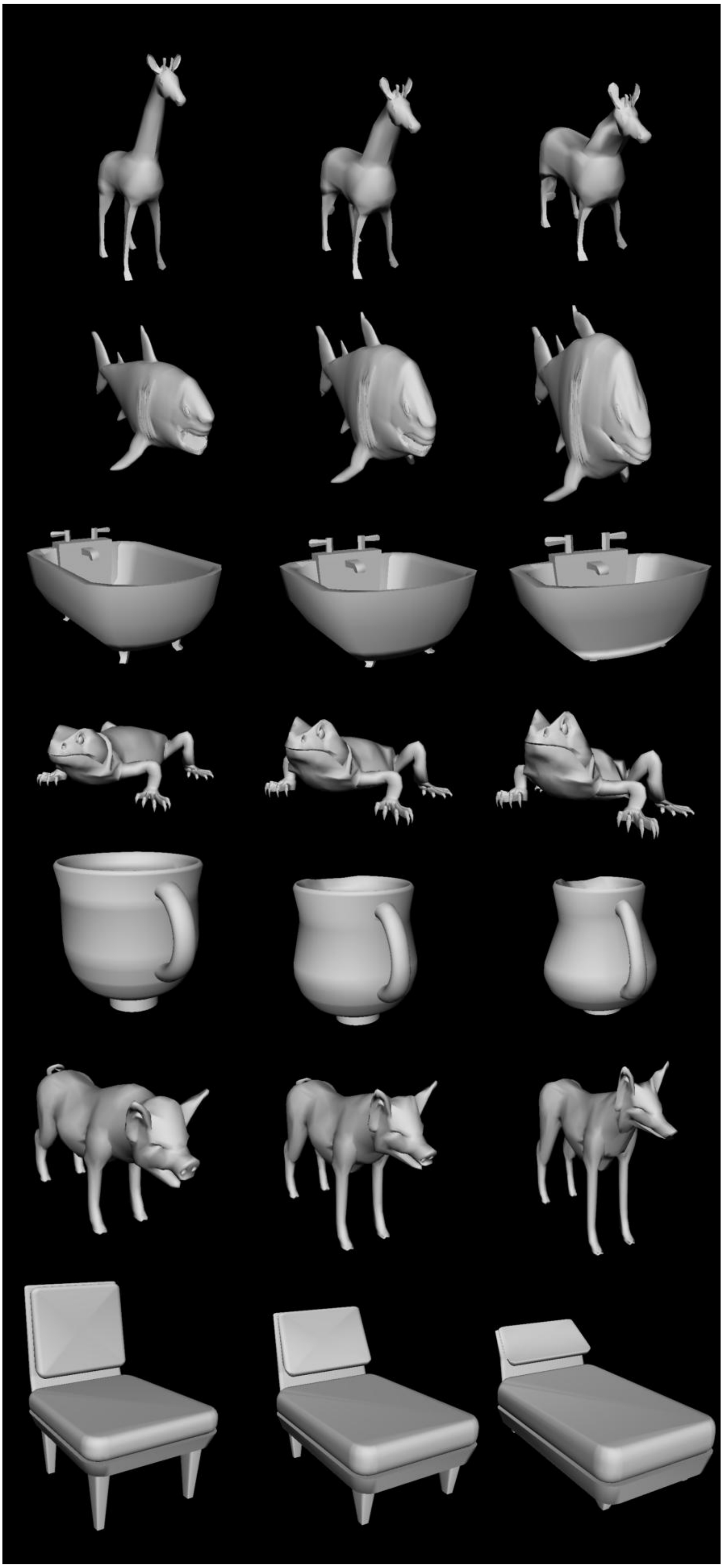


Figure 2 The 30^{o} view of the startpoint (left), midpoint and endpoint (right) morph from each of the twenty experimental morph sets used in Experiments 4, 5, 6 and 7 here. The modal names of the startpoint then the endpoint morphs are given on the right of each trio of pictures from each morph set.



Giraffe-Horse

Shark-Fish

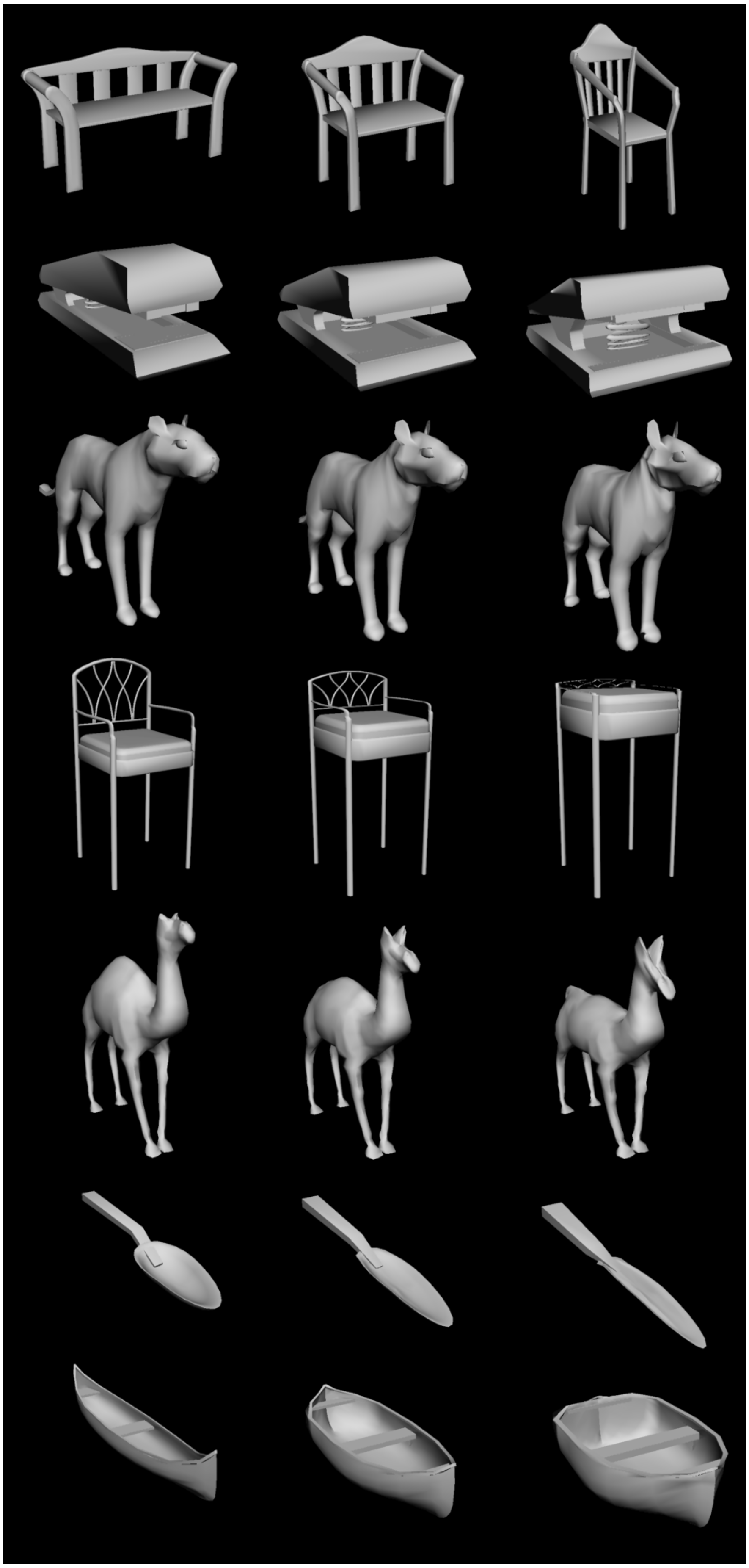
Bath-Sink

Lizard-Frog

Cup-Jug

Pig-Dog

Chair-Bed



Bench-Chair

Stapler-Holepunch

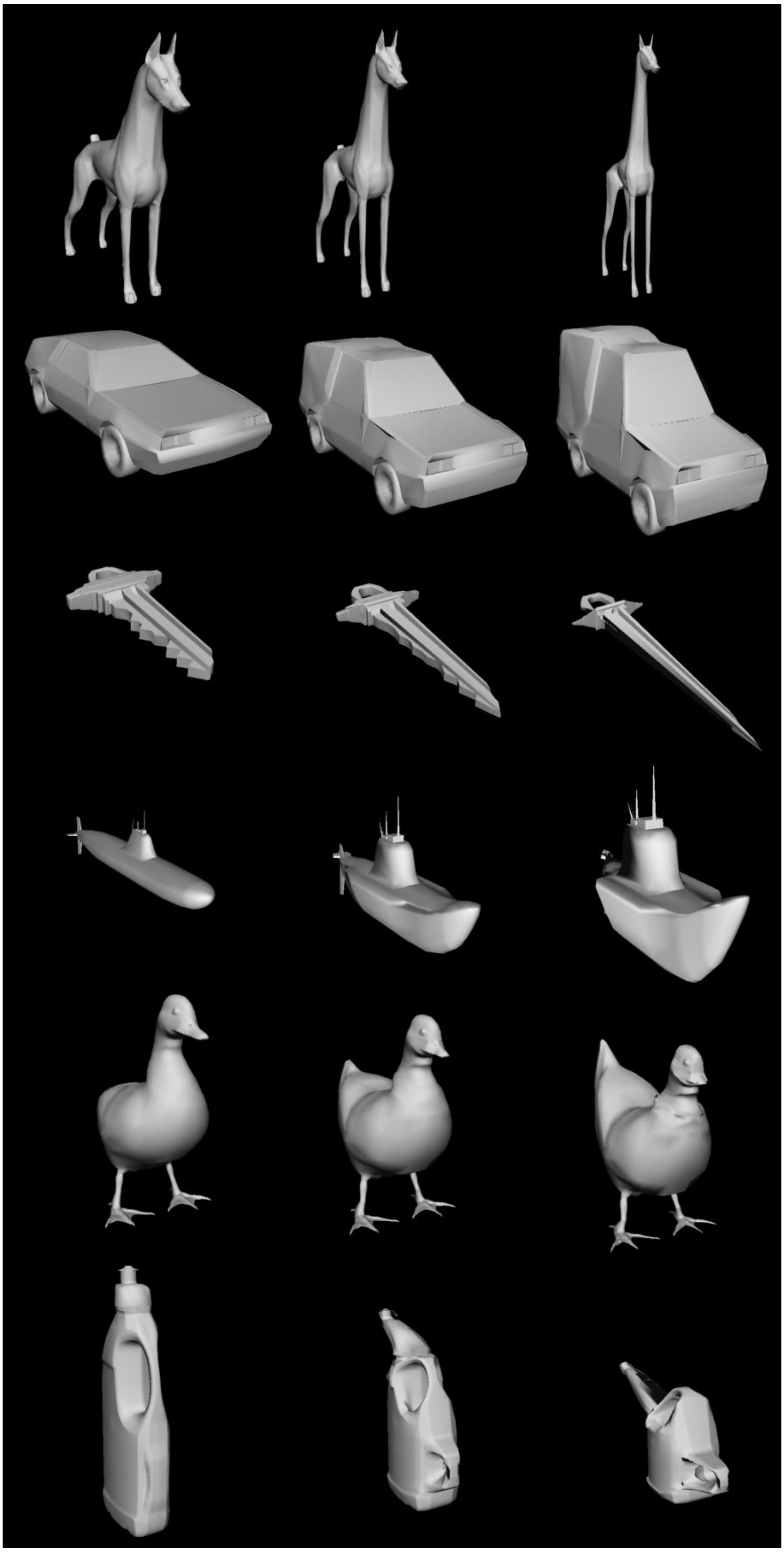
Lion-Dog

Chair-Stool

Camel-Llama

Spoon-Knife

Canoe-Rowingboat



Dog-Giraffe

Car-Van

Key-Sword

Submarine-Boat

Duck-Hen

Bottle-Wateringcan

Figure 3 (a) Mean correct RTs and (b) mean percentage errors in Experiment 5 and, below, (c) mean correct RTs and (d) mean percentage errors in Experiment 1 of Lawson and Bülthoff (2006) for view-same trials (0° view changes) and view-change trials (30° or 150° view changes). In Experiment 5, on half the trials, the first picture was a 30° view of a startpoint morph and the second picture showed the same startpoint morph on matches (where "shape change" was the wrong response) or the nearstartpoint, the midpoint or the endpoint morph from that morph set for mismatches with small, medium and large shape changes respectively (for these latter trials, "shape change" was the correct response). On the other half of the trials, the first picture was a 30° view of an endpoint morph and the second picture showed the same endpoint morph on matches or the nearendpoint, the midpoint or the startpoint morph from that morph set for mismatches with small, medium and large shape changes respectively. Experiment 1 of Lawson and Bülthoff (2006) was also a sequential picture-picture matching task with a similar design to Experiment 5.

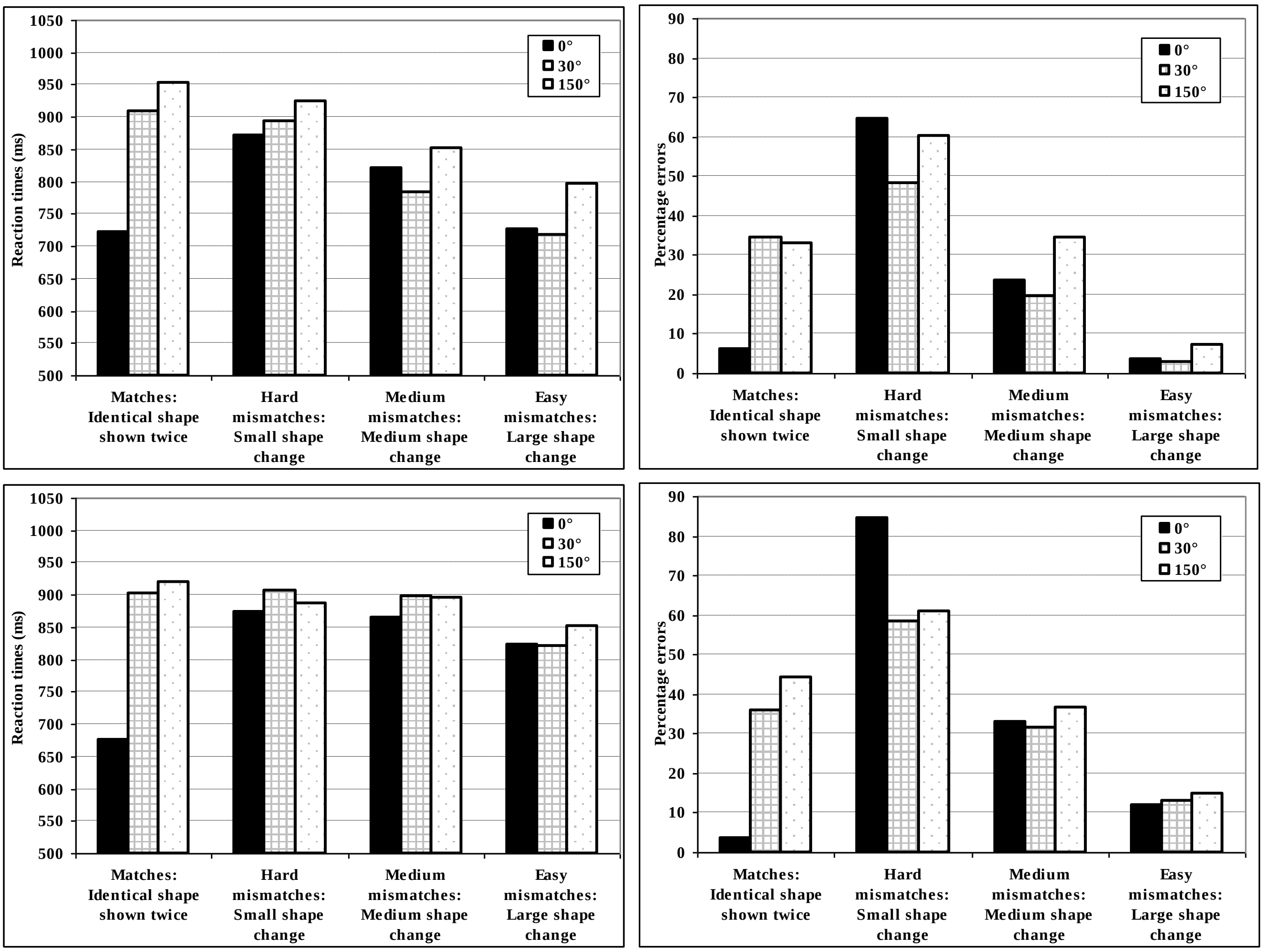


Figure 4 (a) Mean correct RTs and (b) mean percentage errors in Experiment 6 and, below, (c) mean correct RTs and (d) mean percentage errors in Lawson (2004). Results are shown for matches only for view-same trials (0° view changes) and view-change trials (30° or 150° view changes). These trials were identical across the three groups within each study, with only the difficulty of mismatches differing across the groups. In Experiment 6, the first picture was always a 30° view of a startpoint or an endpoint morph. For mismatches for the hard context group, the second picture showed the midpoint morph from the same morph set. For mismatches for the medium context group, the second picture showed the endpoint or the startpoint morph from the same morph set. For mismatches for the easy context group, the second picture showed the startpoint or the endpoint morph from a different morph set. The study reported by Lawson (2004) was also a sequential picture-picture matching task with a similar design to Experiment 6.

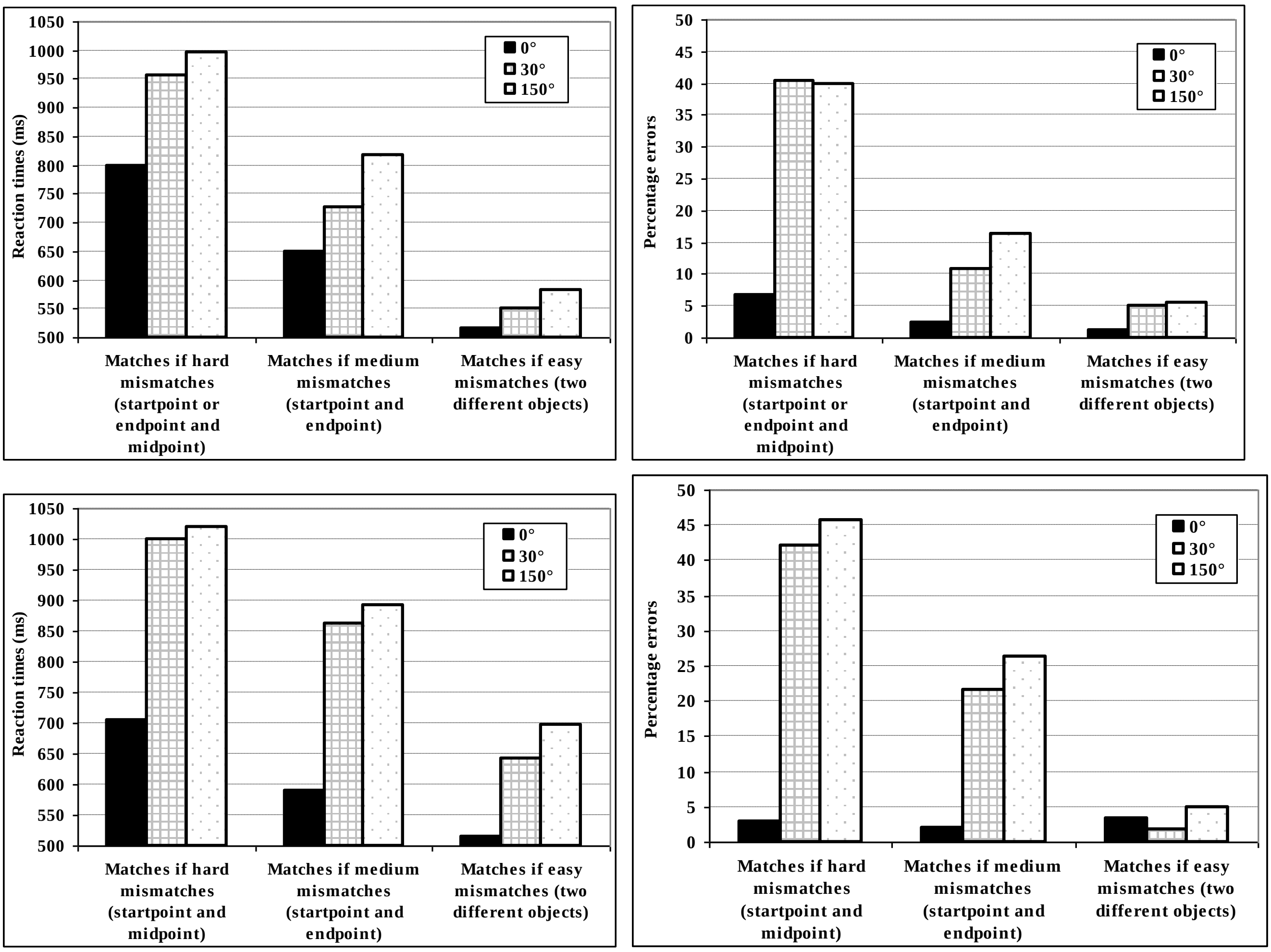
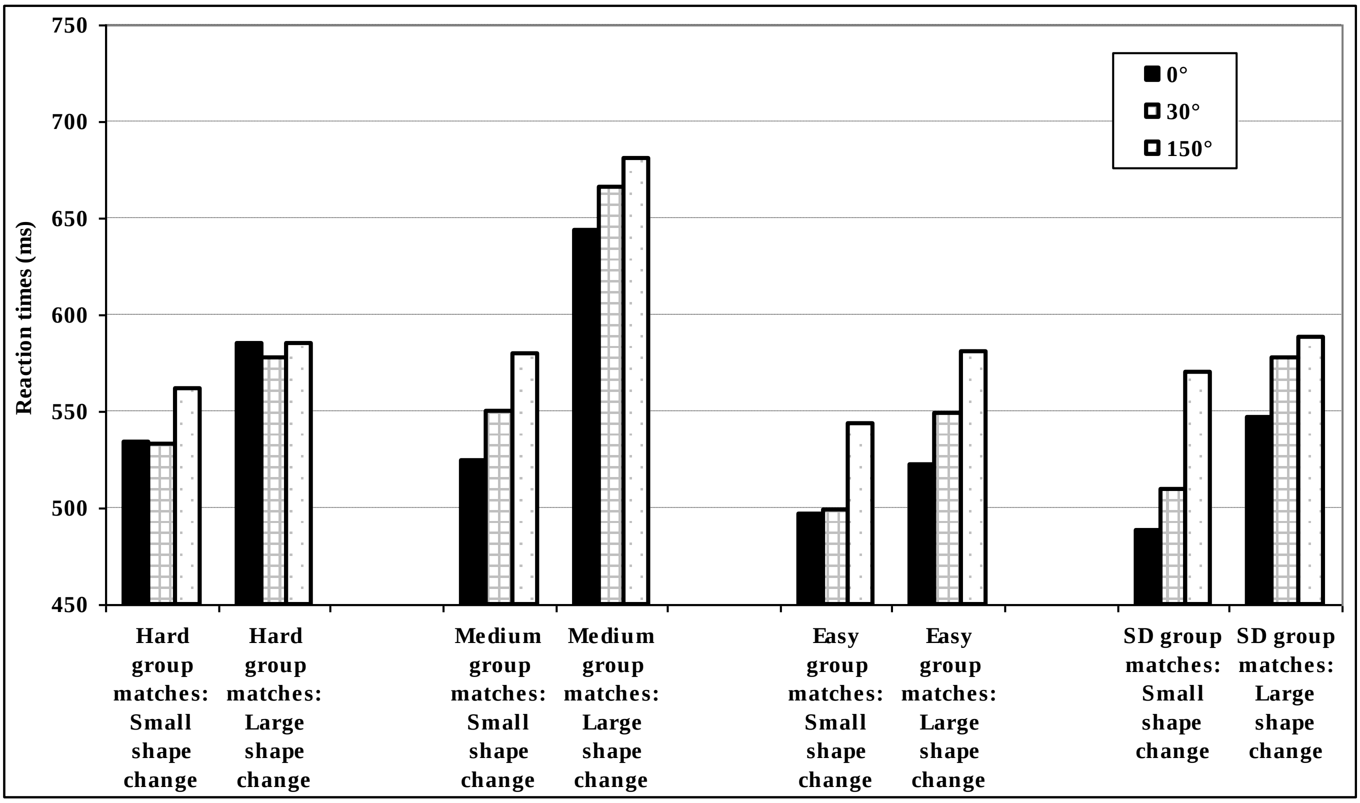
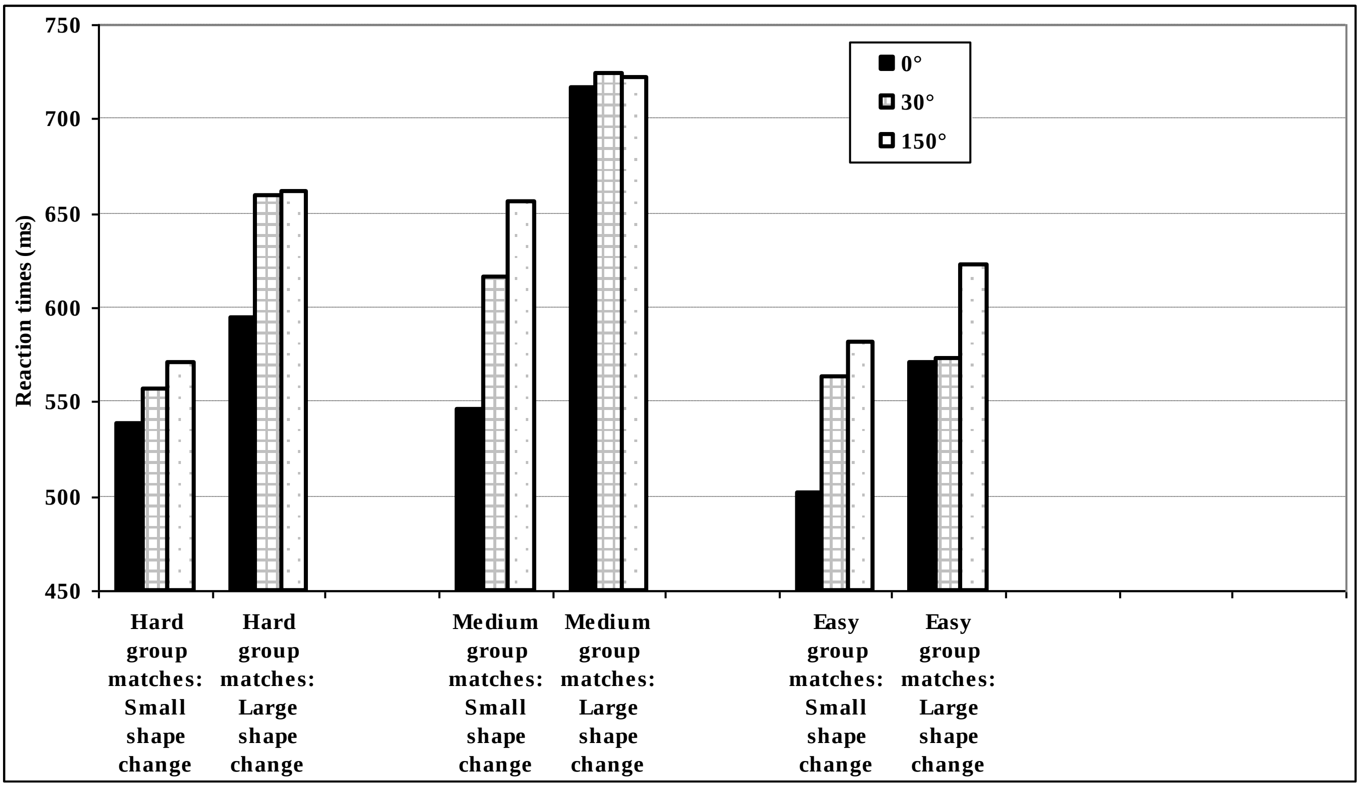


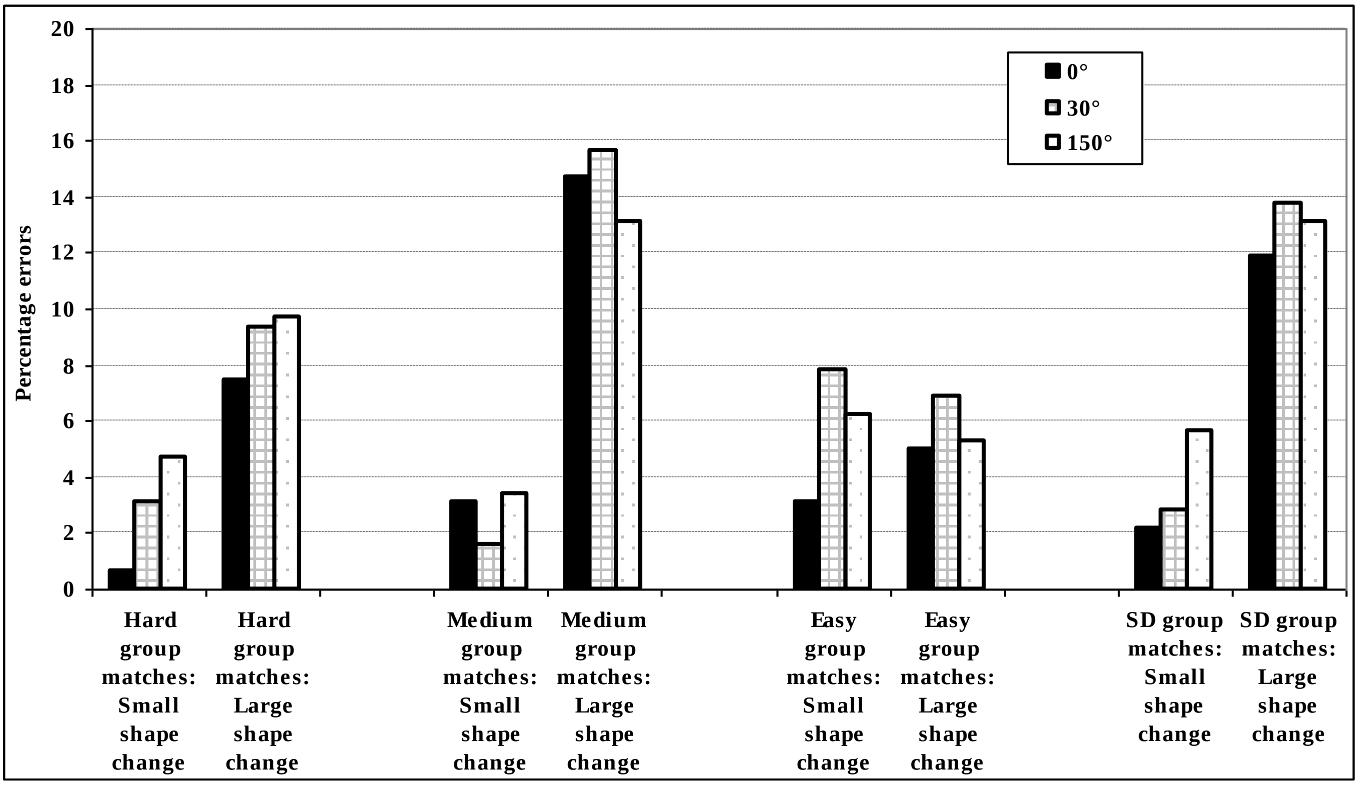
Figure 5 Mean correct RTs in (a) Experiment 7 and, below, (b) Experiment 3 of Lawson and Bülthoff (2006) and mean percentage errors in (c) Experiment 7 and, below, (d) Experiment 3 of Lawson and Bülthoff (2006) for the three comparable, easy, medium and hard categorisation groups in the two studies (not the S0-S3 group tested in Experiment 3 of Lawson & Bülthoff, 2006) and, for Experiment 7 only, for the final, similar distractor (SD) easy categorisation group. The SD group saw the same matches as the easy categorisation group but mismatches presented similar-shaped objects. Results are shown for matches only for view-same trials (0° view changes) and view-change trials (30° or 150° view changes). In Experiment 7 the first picture was always a 30° view of a startpoint or an endpoint morph. For matches for the easy categorisation group, the second picture showed the same startpoint or endpoint morph for small shape changes and the midpoint morph from that morph set for large shape changes. For matches for the medium categorisation group, the second picture showed the same startpoint or endpoint morph for small shape changes and the endpoint or the startpoint morph from that morph set for large shape changes. For matches for the hard categorisation group, the second picture showed the midpoint morph from the same morph set for small shape changes and the endpoint or the startpoint morph from the same morph set for large shape changes. Experiment 3 of Lawson and Bülthoff (2006) was also a sequential picture-picture matching task with a similar design to Experiment 7.



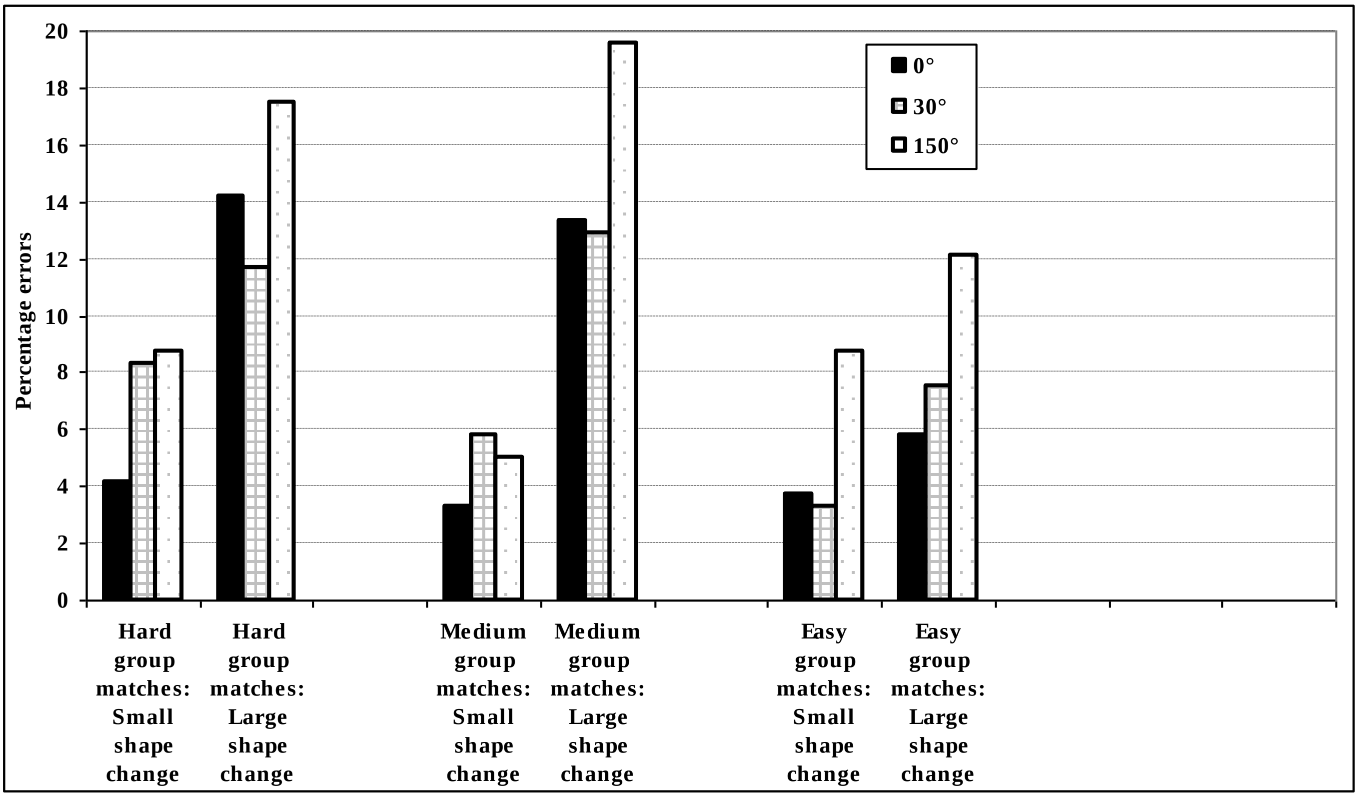
750
700
650
600
550
500
450
Reaction times (ms)
0°
30°
150°
Hard group matches: Small shape change
Hard group matches: Large shape change
Medium group matches: Small shape change
Medium group matches: Large shape change
Easy group matches: Small shape change
Easy group matches: Large shape change
SD group matches: Small shape change
SD group matches: Large shape change



750
700
650
600
550
500
450
Reaction times (ms)
0°
30°
150°
Hard group matches: Small shape change
Hard group matches: Large shape change
Medium group matches: Small shape change
Medium group matches: Large shape change
Easy group matches: Small shape change
Easy group matches: Large shape change



Percentage errors
0°
30°
150°
0
2
4
6
8
10
12
14
16
18
20
Hard group matches: Small shape change
Hard group matches: Large shape change
Medium group matches: Small shape change
Medium group matches: Large shape change
Easy group matches: Small shape change
Easy group matches: Large shape change
SD group matches: Small shape change
SD group matches: Large shape change



Percentage errors
0°
30°
150°
0
2
4
6
8
10
12
14
16
18
20
Hard group matches: Small shape change
Hard group matches: Large shape change
Medium group matches: Small shape change
Medium group matches: Large shape change
Easy group matches: Small shape change
Easy group matches: Large shape change