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Acta Psychologica 112 (2003) 17–41

acta psychologica

www.elsevier.com/locate/actpsy

Recognition thresholds for plane-rotated pictures of familiar objects

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Received 7 January 2002; received in revised form 28 June 2002; accepted 22 July 2002

Abstract

We investigated picture plane rotation effects on the minimum stimulus duration required to recognise pictures of familiar objects in a picture–word verification task. Participants made unspeeded responses, selecting from 126 written alternatives. Longer stimulus durations were needed to identify plane-misoriented views. These orientation effects were non-linear, arguing against a simple mental rotation account of compensation for plane misorientation in identification tasks. Orientation effects were found for almost all items, in particular including those labelled at the basic level (cf. Hamm, McMullen, 1998, *Journal of Experimental Psychology: Human Perception and Performance 24*, 413–426). We suggest that plane misorientation increases the difficulty of basic level as well as subordinate level identification unless only a small, visually dissimilar set of stimuli are presented. Errors in the task were analysed to provide an alternative, objective measure of perceived visual similarity, by assessing the number and nature of mistaken identifications made to a given target object. We propose that misorientation effects are best understood in terms of the effects of the perceived visual similarity of a target to its set of response alternatives rather than in terms of the level (basic or subordinate) at which the target is to be identified.

PsycINFO classification: 2323

Keywords: Object recognition; Similarity; Rotation

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0001-6918/03/$ - see front matter

PII: S0001-6918(02)00099-9

1. Introduction

In speeded naming tasks, misorientation in the picture plane generally increases the time taken to identify pictures of familiar objects (e.g., Jolicoeur, 1985; Jolicoeur & Milliken, 1989; McMullen & Jolicoeur, 1990; Murray, 1995a). Similarly, in an unspeeded picture–word verification task, plane misorientation decreases the accuracy of identification of briefly presented familiar objects (Lawson & Jolicoeur, 1998) and increases the minimum stimulus duration needed to identify those objects (Lawson & Jolicoeur, 1999). Thus in a variety of circumstances, plane misorientation reliably increases the difficulty of identifying pictures of familiar objects. It is, though, still not clear what causes misoriented views to be harder to identify and nor is it clear how the human visual system compensates for the effects of plane rotation.

One popular account of the effects of plane misorientation on object identification is that of mental rotation (e.g., Jolicoeur, 1990). Here, the increased latencies required to identify more misoriented stimuli are assumed to reflect the increased amount of mental rotation that an internal representation of the stimulus presented must undergo in order to align that internal input representation at a specific orientation with a stored representation of a familiar object at its canonical (environmentally predominant), upright orientation. The larger the initial difference in orientation between the input and the stored representation, the more time is needed for mental rotation to align the orientation of the two representations prior to matching. This then accounts for the broadly linear function relating degree of plane misorientation to performance reported in many studies of picture identification (see Lawson & Jolicoeur, 1999).

Recent studies have provided evidence against this mental rotation account for object identification. Neither a perceptual illusion of the rotation of the input stimulus nor the physical rotation of the stimulus influenced the speed of naming (an identification task), although both of these manipulations affected the ability to make left–right facing judgements (a mirror-image task) with the same pictures of familiar objects (Jolicoeur, Corballis, & Lawson, 1998). Mental rotation only seemed to be used for the left–right facing task. Here, participants were faster if the perceived direction of rotation of the picture (clockwise or anticlockwise) matched the best direction to mentally rotate the object to the upright and slower if the rotation was in the direction that would require the object to be mentally rotated by more than 180° to the upright. In contrast, the perceived direction of rotation of the object did not influence the speed of naming the object, suggesting that mental rotation is typically not involved in picture identification.

In addition, Willems and Wagemans (2001) found that the effects of depth rotation on the recognition of novel objects were not systematically related to the axis of rotation required to map between two views in a picture-matching task, contrary to the predictions of a mental rotation account. Instead they suggested that the effects could be explained by multiple views accounts of object recognition which incorporate normalisation processes such as interpolation or possibly linear combination.

Finally, we have reported non-linearities in the shape of the function relating orientation to identification performance (Lawson & Jolicoeur, 1999), whereas the simplest interpretation of the mental rotation hypothesis predicts a linear relation between the degree of misorientation and performance. We found that performance for 30°, 90°, 150°, and 180° views was better than would be predicted from a linear extrapolation of the results from 0°, 60°, and 120° views. Note that the latter three views are those which are typically tested in object naming experiments which present plane misoriented stimuli. With such coarse sampling, non-linear performance is difficult to detect. The identification of views rotated in steps of just 30° has rarely been investigated. The Lawson and Jolicoeur (1999) study tested just 14 participants and provided insufficient data for an items analysis. In the current paper, we tested two additional groups of participants under similar conditions as the participants tested in Lawson and Jolicoeur (1999). This enabled us to test the consistency of the non-linearities reported in that initial study in both by-participants and by-items analyses and to increase the statistical power to detect non-linearities. We also examined orientation effects item by item. We compared orientation effects for items identified using basic level labels (though note that we discuss further the problems in assigning labels to the basic or the subordinate level). In particular, we investigated a recent claim by Hamm and McMullen (1998) that plane misorientation effects are found only when subordinate level (and not when basic level) identification is required.

Hamm and McMullen (1998) employed a speeded word–picture verification task and presented plane-rotated views of familiar objects. They found that misoriented views of an object (e.g. of a collie or a yacht) were verified slower than upright views when the picture was preceded by a matching/mismatching label at the subordinate level (e.g. collie/alsation or yacht/trawler). In contrast, they found no effect of plane rotation when the picture was preceded by a matching/mismatching label at the basic level (e.g. dog/bird or boat/car). Hamm and McMullen (1998) hypothesised that basic level identification was orientation-invariant and that normalisation to the upright was only required for subordinate level identification. They suggested that the effects of misorientation that are reported reliably in speeded picture naming tasks are due to participants identifying some objects at the subordinate rather than at the basic level, and that contamination of means by such trials causes orientation-dependent performance (see also Vitkovitch & Tyrell, 1995).

Using a similar speeded word–picture verification task to Hamm and McMullen (1998), Murray (1998) reported that entry-level identification was slower for plane misoriented views relative to upright views. The term "entry level" describes the level of abstraction at which a given item is usually identified (Jolicoeur, Gluck, & Kosslyn, 1984; see also Murphy & Brownell, 1985; Op de Beeck & Wagemans, 2001). For typical members of a basic level category, the entry level is the basic level (a dove is named as a bird; a sailboat is named as a boat), but for atypical members the entry level is usually the subordinate level (a penguin is normally named as a penguin, not as a bird). Murray (1998) argued that plane misorientation disrupts entry-level identification, particularly if visually similar objects must be discriminated.

For word–picture verification at the basic level, Hamm and McMullen (1998) tested just six categories (dog, car, boat, aircraft, bird or bug). These basic-level items are visually dissimilar to each other, compared to if, for instance, dog, cat, horse, goat, sheep and pig had been tested. It would therefore be relatively easy to extract and use orientation-invariant features to distinguish between their six items. In contrast, for word–picture verification at the subordinate level, Hamm and McMullen's (1998) tested many more categories (both as word labels and as pictures) and many items from subordinate level categories were highly visually similar to each other (e.g., dachshund, sheepdog, dalmation, cocker spaniel and poodle). Orientation-invariant features would be difficult to find and use and so plane misorientation would be expected to have a large effect on performance. Level of identification and visual similarity were thus confounded across the stimuli tested by Hamm and McMullen—indeed, they noted that identification at the subordinate level often requires the discrimination of visually similar stimuli. However, a claim which they made strongly was that identification at the basic level was orientation-invariant. As Murray (1998) argued, this claim needs to be examined further, since Hamm and McMullen tested basic level identification under an unusually easy stimulus discrimination context, relative to both their own test of subordinate level identification and relative to basic level identification under normal viewing situations. We therefore re-examined Hamm and McMullen's (1998) claim in the current study.

A difficulty in testing this claim is that the assignment of a given category label to the superordinate, basic or subordinate level is often described as if it were clear and unambiguous yet this is not the case. For example, cat and dog are usually taken to be basic level labels—but at what level are the labels horse, pony, donkey or mule? These objects share many characteristics, both visually and semantically. Are some or all of these labels at the subordinate level? In addition, although trawler would usually be taken to be a subordinate level label (relative to boat), at what level are the labels canoe, submarine or windsurfer? The objects that these labels refer to have little in common with each other or with more typical boats (e.g., trawlers), either visually or semantically. Are some or all of these labels at the basic level? Even in Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976) there is ambiguity over this issue [1] and different researchers have disagreed over the level at which to assign the same object label (see below).

Introspection is insufficient to determine the level of a label—converging evidence from a number of measures is required. This has almost never been done. In the current studies the stimuli presented were taken from the Snodgrass and Vanderwart (1980) set, who suggested that all of their stimuli were represented at the basic level. They proposed that a "criterion for identifying whether a concept is at a basic level is whether its picture produces consensus in naming" (p. 181), and 116 of the 126 stimuli tested in the current study had a name agreement of at least 60%. However, atypical items with salient subordinate names such as penguin and submarine are consistently named at the subordinate rather than the basic level (Jolicoeur et al.,

[1] Rosch et al. (1976) initially classified tree, fish and bird as labels at the superordinate level and oak, trout, eagle, etc. as labels at the basic level (p. 388). These labels were subsequently assumed to be at the basic and subordinate level respectively, based on the results of their studies (see Table 10, p. 427). These latter levels are those used in Table 1 here.

1984). Even atypical items without salient subordinate names are often consistently distinguished from other category members by adding adjectives to the basic level name (Op de Beeck & Wagemans, 2001).

Finally, studies examining level of categorisation effects probably selected objects that seemed to fit neatly into the superordinate, basic, subordinate level hierarchy (e.g., animal, dog, labrador), but many other common objects do not fit well into this hierarchy. There are either no clear superordinate labels or are multiple possible superordinate labels for stimuli such as telephone, watering can, stapler, vase, steering wheel, angel, pillow, tooth, brick, umbrella, CD, leaf, feather, mould, ladder and button, and few of us could provide many subordinate labels for these same stimuli. Given the difficulties in determining whether a given label is subordinate, basic or superordinate and our concerns as to whether such an assignment would be meaningful, we concentrated on investigating individual orientation effects for a large and varied set of common objects. In a labelling study, we also examined people's consistency in providing superordinate and subordinate labels for the items tested.

The results of Hamm and McMullen (1998) and Murray (1998) do not allow us to decide whether the level of specificity of identification determines if object identification is orientation-invariant. In Hamm and McMullen (1998), the visual similarity of the distractors was unusually low for the basic level verification task (see above); if distractor similarity had been higher, orientation effects may well have been observed. In Murray (1998), the level of verification (basic versus subordinate) was not manipulated but probably did differ across stimuli. The orientation effects observed for entry level verification could then have been due to only the subordinate and not the basic level stimuli. Many of the entry-level items tested by Murray (1998) were included as subordinate level items in Hamm and McMullen's (1998) studies, e.g., swan, penguin, duck, owl, eagle, fly, ant, spider, grasshopper and helicopter. In addition, neither study reported by-items analyses of results and neither study examined orientation effects for individual items.

A major problem with investigating the role of visual similarity on object identification is that there is, as yet, no good measure of perceived similarity between different items. Some studies have tried to measure visual similarity directly from the stimulus, for instance by measuring the overlap in the outline of drawings or the numbers of pixels in common across drawings (e.g., Humphreys, Riddoch, & Quinlan, 1988; Rosch et al., 1976). Such crude techniques will be poor at measuring visual similarity as perceived by the human visual system. For example, the global shape of a triangle and a sitting dog will be more similar than the global shape of a running dog and a sitting dog, but the two dogs will be perceived as more similar by a human observer. Subjective ratings have also been used to measure visual similarity (e.g., Cutzu & Edelman, 1998; Humphreys, Lamote, & Lloyd-Jones, 1995; Op de Beeck, Wagemans, & Vogels, 2001). However such measures may be sensitive to the instructions given to participants and introspective reports may provide an inaccurate measure of perceived visual similarity, particularly for familiar stimuli. A promising alternative comes from examining task performance, for instance in same-different matching studies. The technique of multi-dimensional scaling can then be applied to this performance data (e.g., Cutzu & Edelman, 1998; Op de Beeck et al., 2001) and the results can be compared to those obtained using subjective ratings of similarity.

As an alternative to these measures, in the current study we analysed the number and the type of errors produced in a picture–word verification task on trials when participants incorrectly selected a distractor from a large set of alternatives. This allowed us to assess the visual similarity of a given item to other items in the response set. Objects are not visually similar or dissimilar per se, rather the context of identification is crucial. Visual similarity is high for dogs if they must be discriminated from goats and cats, but low if they only need to be discriminated from cars and boats. In the current study, the identification context was explicit in that participants were shown the list of all of the items which could appear in the study. In the context of most everyday viewing situations, a large and unspecified number of different objects might be presented.

In the current study, we used the method of ascending limits as an unspeeded response measure to test picture–word verification performance when even highly misoriented views of objects were identified accurately and specifically. Pictures were initially presented very briefly and were immediately masked. The stimulus duration of the picture was gradually increased until the participant identified the object. After each picture presentation, participants chose their response from a list of 126 written alternatives. There were usually several distractor objects which visually resembled any given target object, so participants typically could not identify a target from general properties (such as overall shape) or by using just a single distinguishing feature. Hence although we used a forced-choice verification task, there was only a low probability of guessing correctly which stimulus had been presented, making the task more like a typical naming task. In contrast, performance would be expected to be 50% correct by chance in the picture/word matching studies reported by Hamm and McMullen (1998) and Murray (1998), in which only a single word was paired with each picture.

2. Method

2.1. Participants

The 42 participants were from the University of Waterloo, Canada, and were native speakers of English with normal or corrected-to-normal vision. There were 14 participants in each of three subgroups, with those in Groups 1 and 2 being paid to participate whilst participants in Group 3 volunteered for course credit. Those in Group 1 were the participants reported in Lawson and Jolicoeur (1999). They completed two further blocks of 126 trials following the block of 63 experimental trials reported here, and the full experiment lasted around 2 h. Three participants in Group 2 were originally recruited for Group 1 but were excluded from it as they had progressed too slowly after the first block of trials to complete that study. No participants were excluded from Groups 2 or 3 and they took around 60 min to complete the study. There were no other major differences between the participants or the task completed across the three subgroups.

2.2. Materials

The stimuli were 126 line drawings of familiar objects taken from Snodgrass and Vanderwart (1980), see Table 1. All the objects had an environmentally predominant orientation which we labelled as 0°. Each drawing was rotated in the picture plane in steps of 30° to give seven views of each object, from 0° (upright) to 180° (inverted). A pattern mask was produced, which was composed of small overlapping sections of a large number of different objects, none of which were presented in the experiment.

2.3. Design

Participants completed one experimental block in which they saw one view of each of 63 objects. The 126 objects were divided into two equal sets by placing objects with alphabetically consecutive names into different sets. Seven participants in each of the three groups were randomly assigned to each set. In each set, 9 of the 63 objects were presented at each of the seven different rotations (0°, 30°, 60°, 90°, 120°, 150° and 180°). The orientation assigned to a given object was different for every participant. Across the 14 participants in each group, all items were depicted once at each orientation. The order of presentation of trials was random, and was different for every participant.

Participants were given a sheet which listed the names of all the 126 objects in alphabetical order together with a three digit number associated with each object. Participants responded by typing in the number corresponding to the object which they thought had been presented. Participants were instructed to guess the identity of the object if possible but to respond using the arrow keys if they had no idea what object had been presented. They were told that speed of response was irrelevant to the task. The same sheet was used throughout the experiment, and participants were not permitted to mark on it the objects which they had identified.

Each picture was initially displayed for 33 ms, and was then immediately pattern masked. From pilot studies, identification was rarely possible at this duration (less than 1% of trials). Stimulus duration was then increased in increments of the time taken to refresh the screen (16.7 ms) each time the stimulus was presented, so the second duration was 50 ms, then 67 ms, 83 ms, and so on. If the participant correctly identified the stimulus, they heard a triple beep, and a new object was presented on the next trial, initially for a duration of 33 ms. If the participant failed to type in the correct number for the object, there were no beeps, and the same object at the same orientation was presented again, for a slightly longer duration. The object was presented up to 14 times consecutively, giving a duration of 250 ms on the final presentation. If the participant still failed to recognise the object on the 14th presentation, the triple beep warning sounded and a different object was presented on the next trial. Participants were told that they would be automatically moved onto the next trial if they failed to identify the object on their 14th attempt, and they were not informed of the identity of objects which they so failed to identify.

Participants completed a practice block consisting of 10 trials before the experimental block. Practice trials were identical to experimental trials, except that different objects were presented, the experimenter helped the participant to complete the initial trials and participants used a different sheet that listed only 32 object names and their numbers (none of which appeared on the experimental sheet).

2.4. Apparatus and procedure

A PC-compatible 486 computer running the MEL Version 1.0 presentation package was used to display the stimuli. The procedure for each experimental trial was as follows: a fixation cross appeared on the screen until the participant pressed the space bar. The fixation cross was then immediately replaced by a picture of an object for the appropriate duration. The picture was replaced by a mask for 300 ms, which was in turn replaced by the sentence, "Enter the number of the object". Participants were required to type in a three digit number to identify the object which they believed had been presented, or to press the three arrow keys if they had no idea what the object was. The background screen was always white, the fixation cross and mask were black, and the picture was a low contrast, light grey.

3. Results

3.1. Subjects analysis

An ANOVA was conducted on the mean picture stimulus duration required for a correct response. There was one within-subjects factor, Orientation, the plane rotation of the object (0°, 30°, 60°, 90°, 120°, 150°, or 180°), and one between-subjects factor, Group (1, 2, or 3).

The main effect of Orientation was significant, $F(6,234) = 27.52$, $p < 0.001$, MSe = 235 (see Fig. 1). The main effect of Group was also significant, $F(2,39) = 5.97$, $p < 0.006$, MSe = 3164. Mean durations were 87, 105, and 114 ms for Groups 1, 2, and 3 respectively. Group 1 performance was probably better because the three slowest participants who were originally assigned to this group were replaced, and were put into Group 2 (see Section 2.1). The interaction of Orientation × Group was not significant, $F(12,234) = 0.45$, $p > 0.9$, MSe = 235 (see Fig. 1).

On 5.1% of trials, participants failed to identify the object even at the longest (250 ms) duration. The distribution of these trials was significantly influenced by Orientation, $F(6,234) = 6.11$, $p < 0.001$, MSe = 50 (see Fig. 2). There was no significant effect of Group, $F(2,39) = 2.17$, $p > 0.1$, MSe = 146. Mean error rates were 3.17%, 6.69% and 5.56% for Groups 1, 2, and 3 respectively. The interaction of Orientation × Group was not significant, $F(12,234) = 0.91$, $p > 0.5$, MSe = 50 (see Fig. 2).

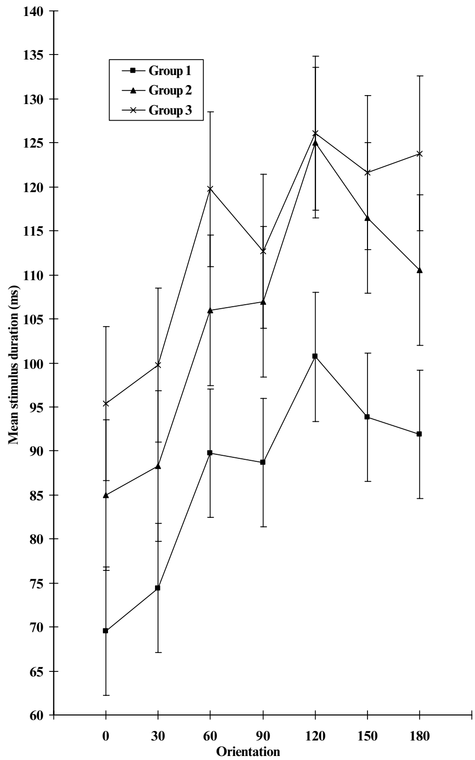

Fig. 1. Mean stimulus duration at each orientation for the participants tested in Groups 1, 2 and 3, along with 95% confidence intervals based on the error term for the main effect of orientation (Loftus & Masson, 1994).

3.2. Items analysis

An ANOVA was conducted on the mean stimulus duration required for a correct response. There was one within-items factor, Orientation, the plane rotation of the object (0°, 30°, 60°, 90°, 120°, 150°, or 180°). There were insufficient trials per object for the Group factor to be included in the items analysis.

The main effect of Orientation was significant, $F(6, 750) = 26.59$, $p < 0.001$, $\text{MSe} = 731$. The mean stimulus duration required to identify an object was 83, 87, 105, 103, 117, 111, and 109 ms for views from 0° to 180° respectively.

On 5.1% of trials, the object was not identified, even at the longest (250 ms) duration. The distribution of these trials was significantly influenced by Orientation, $F(6, 750) = 5.81$, $p < 0.001$, $\text{MSe} = 158$. There were 1.1%, 2.9%, 5.3%, 5.8%, 8.7%, 7.9%, and 4.2% of such trials occurring for views from 0° to 180° respectively.

These analyses indicated that there were reliable effects of orientation on both stimulus duration and error trials for items. We examined these effects further by

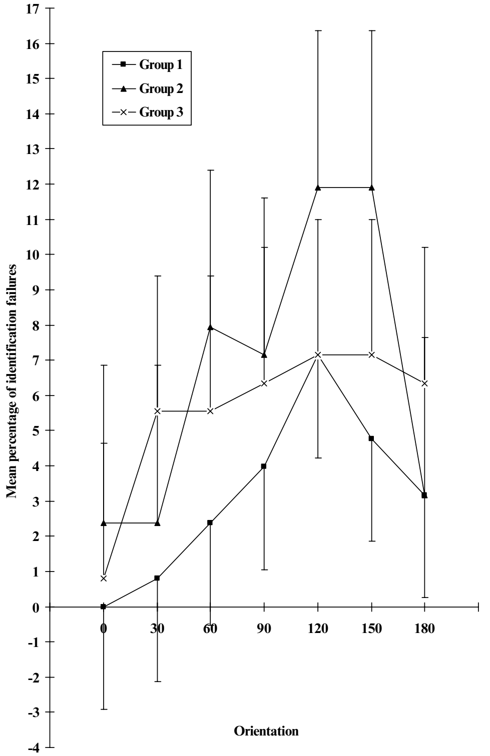

Fig. 2. Mean percentage of failures to identify the object at each orientation for the participants tested in Groups 1, 2 and 3, along with 95% confidence intervals (plotted in one direction only for clarity) based on the error term for the main effect of orientation (Loftus & Masson, 1994).

estimating the effects of orientation on identification performance for each item individually.

3.3. Item-specific orientation effects on stimulus duration

To test the claim of Hamm and McMullen (1998) that only subordinate level and not basic level identification is sensitive to plane-misorientation, we estimated the orientation effect for each individual object. To do this, we subtracted the mean stimulus duration required to identify upright (0°) and near-upright (30°) views of the object from the mean stimulus duration required to identify highly misoriented (60–150°) views of the object. We omitted results from 180° views in this analysis, since responses were more variable for these trials. This variability for upside-down views has also been reported consistently in speeded naming studies (see Jolicoeur, 1990; Murray, 1997).

The resultant estimated orientation effects ranged from a maximum for barn (109 ms, indicating that 0° and 30° views of the barn could be identified at much shorter stimulus durations than more misoriented views) to a minimum for blouse (−32 ms, indicating that highly misoriented views of the blouse required shorter stimulus durations to be identified than 0° and 30° views). Almost 90% of objects were identified less efficiently from highly misoriented views (see column 3 of Table 1), despite the paucity of data per item, with just three data points per view of a given object.

Given the difficulties in determining the level of identification of a given object label discussed in Section 1, we decided to use the assignments used by previous researchers. From the first column of Table 1, there were 32 object labels in our stimulus set which were considered to be basic level by Hamm and McMullen (1998), Jolicoeur et al. (1984), Markman and Wisniewski (1997), Rosch et al. (1976) or by Vitkovitch and Tyrell (1999), and for which none of these authors considered the label to be a superordinate or subordinate label. For these 32 basic level items, there was a mean orientation effect of +15 ms, with 27 of the 32 items having positive orientation effects. In an ANOVA for mean stimulus duration for only these items, the main effect of orientation was significant, $F(6, 186) = 4.514$, $p < 0.001$, MSe = 501. The mean stimulus duration required to identify these basic level stimuli was 77, 81, 89, 91, 103, 94, and 91 ms for views from 0° to 180° respectively. There was thus no indication that the clear and reliable effects of orientation for this subset of items were different in nature to those observed for the other items tested. Plane misorientation adversely affected the identification of most items with an environmentally predominant orientation which were labelled at the basic level (cf. Hamm & McMullen, 1998).

Similarly, from the first column of Table 1, all of the 13 objects which were consistently labelled at the subordinate level by one or more of the five papers listed above had positive orientation effects, with a mean orientation effect of +40 ms. In an ANOVA for mean stimulus duration for only these items, orientation was again significant, $F(6, 72) = 5.887$, $p < 0.001$, MSe = 986, with a mean stimulus durations of 88, 92, 124, 124, 146, 125, and 133 ms for views from 0° to 180° respectively.

A further four labels were considered to be subordinate level by Hamm and McMullen (1998) but basic level by Markman and Wisniewski (1997) or by Vitkovitch and Tyrell (1999). Of these, helicopter and duck had positive orientation effects whilst fly and ant had negative orientation effects. Finally, bird (with a positive orientation effect) was considered a superordinate level label by Markman and Wisniewski (1997) [1] but a basic level label in all the other studies. This inconsistency in the assignment of levels of categorisation across these researchers indicates that even for small sets of carefully selected objects it is not clear from introspection whether a given label is at the superordinate, basic or subordinate level. For the remaining 76 items which were not included in any of these five papers, the mean orientation effect was +25 ms.

The basic level items did show smaller orientation effects (15 ms) than the subordinate items (40 ms) and this interaction was significant, $F(6, 258) = 2.595$, $p < 0.02$, MSe = 5636. However, we do not think it meaningful to compare the magnitude of the orientation effects across these two small subsets. This study was not designed to make that comparison and we argued in Section 1 here that there are serious difficulties in assigning basic and subordinate labels.

The current results do not show that level of identification caused the increase in the orientation effects for subordinate items, because our items which previous researchers happened to believe had basic or subordinate labels had not been matched in any way, for instance on name frequency, semantic class or on ease of identification of upright views of the stimuli. The visual similarity between the 13 objects labelled at the subordinate level and other (potential distractor) objects in the set was probably greater than the similarity for the 32 basic level items, since the visual similarity of category exemplars is usually correlated to the level of specificity at which a category is labelled (Op de Beeck & Wagemans, 2001; Rosch et al., 1976). Also, all but one of the subordinate items were insects or birds, unlike most of the basic level items. Humphreys and colleagues (Humphreys et al., 1995, 1988; Riddoch & Humphreys, 1987) found that object identification is influenced by whether an item belongs to a category with visually similar exemplars (animals, birds, insects) or more dissimilar exemplars (e.g., clothing, tools, furniture).

Overall, we emphasise that the orientation effect was highly significant and similar in form across the 32 basic items, the 13 subordinate items and the remaining 76 items. There was considerable overlap in the orientation effects for the items labelled at the subordinate and at the basic level (see column 3 of Table 1). Plane misorientation adversely affects the identification of most items labelled at the basic level as well as at the subordinate level (cf. Hamm & McMullen, 1998).

3.4. Error analyses

On over 99% of trials, participants did not identify an object correctly on its initial presentation. These and subsequent error responses of participants were examined (10,784 responses across the 2646 experimental trials). Of these errors, 69% were due to the participant consistently making the same arrow key response when they had no idea what the object was. Such responses were excluded from the following analyses which only considered responses which were potentially correct (i.e. responses giving the number of one of the 126 stimuli on the participant's response sheet). These responses are termed viable error responses (3343 responses; 31% of the total error responses, with an average of 1.3 such responses per trial). These viable error responses indicate what object the participant thought had been presented. These confusions provide objective information about the perceived visual similarity of a given object to other stimuli in the response set. The number of trials on which at least one viable error response was made and the total number of viable error responses are plotted in Fig. 3, with these functions mirroring the relation between stimulus duration and orientation plotted in Fig. 1. There were 2.2, 2.4, 2.8, 2.8, 3.0, 3.1 and 2.7 viable error responses made per trial on which viable error responses occurred for views from 0° to 180° respectively (with 0.8, 0.9, 1.4, 1.4, 1.6, 1.5 and 1.3 viable error responses per trial overall).

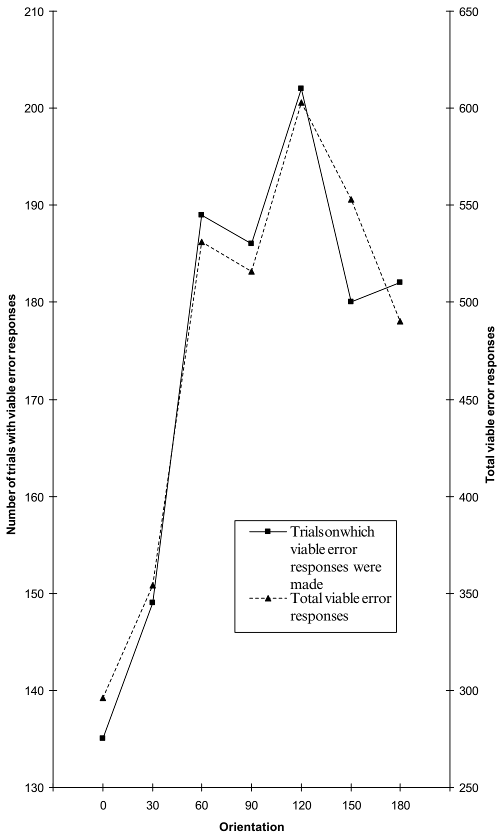

Fig. 3. The number of trials on which at least one viable error response was made (left axis) and the total number of viable error responses (right axis) at each orientation.

3.5. Item-specific orientation effects on viable error responses

For each item, we summed the total number of viable error responses made (column 5, Table 1) and the number of trials on which at least one viable error response occurred (column 6, Table 1). The overall number of viable error responses indicates the visual similarity of an object to the 126 objects in the response set. This was high (135) for sheep and low (3) for clock; the mean was 27. We also determined the most commonly occurring incorrect response (column 7 of Table 1). This indicates the most visually similar object to the target stimulus from a given set of distractors (cow for the target stimulus sheep and hat for the target stimulus mushroom). Note, though, that if few viable error response occur (see column 5 of Table 1), then this may produce spurious results. If there were few occurrences of even the most common viable error response (see column 8) for an object with many viable error responses altogether (see column 5), this indicates that there were a number of different visually similar alternatives to that object in the response set. For example, the target object mouse had a total of 35 viable error responses, yet no individual distractor response occurred more than three times.

In Section 1, we argued that is difficult to determine whether a given category label is at the subordinate or basic level. Instead visual similarity may provide a more accurate predictor of the effect of plane misorientation on recognition. More viable error responses were made to items with larger orientation effects (see Fig. 4). Stimuli presented at misoriented (rather than upright) views are presumably more difficult to identify because they are harder to discriminate from other stimuli in the response set. This causes participants to make more identification errors and to need longer stimulus durations to identify highly misoriented stimuli. The increase in stimulus duration required to identify misoriented views of objects was not, though, wholly due to more viable error responses being made to misoriented stimuli. In Fig. 5, we plot the increase in stimulus duration (relative to the 0° view stimulus duration) which was due to more viable error responses being made to misoriented views. Although this function has a similar shape to that for stimulus duration over orienta-

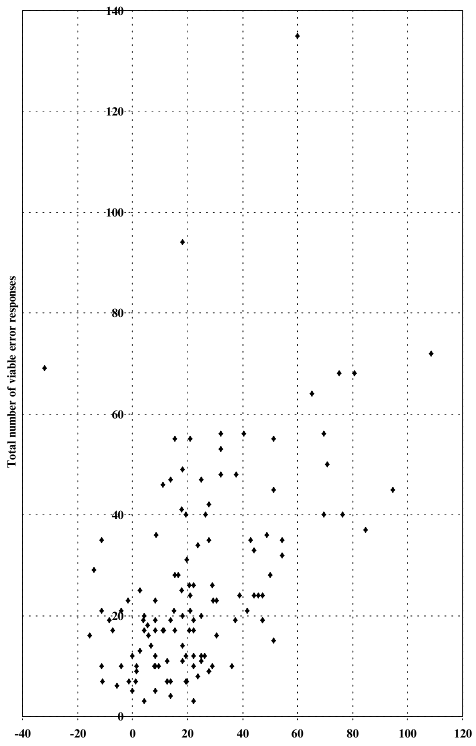

Fig. 4. A scatter plot of the orientation effect for each of the 126 experimental items against the total number of viable error responses for that item.

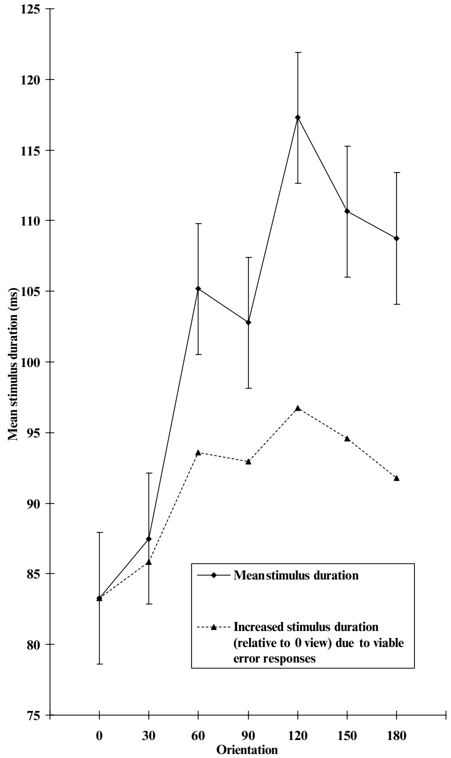

Fig. 5. Mean stimulus duration at each orientation for all 42 participants tested, along with 95% confidence intervals based on the error term for the main effect of orientation (Loftus & Masson, 1994) and the estimated increase in stimulus duration (relative to the 0° view) due to viable error responses at each orientation. The estimate was calculated by taking the mean extra viable error responses at a given orientation compared to that mean for the 0° view and then calculating the additional stimulus duration resulting from making those extra errors (where one extra error per trial would increase the overall stimulus duration by 16.7 ms). Note that since this latter measure is consistently lower than the plot of mean stimulus duration, this indicates that participants consistently made more "don't know" responses to misoriented (relative to 0° view) stimuli in addition to making more viable error responses to misoriented stimuli.

tion (also plotted in Fig. 5), it is consistently lower for each misoriented view. This indicates that, relative to upright views, participants made more "don't know" responses to misoriented stimuli as well as making more viable error responses. Participants do not just start guessing the identity of an object at a certain stimulus duration irrespective of stimulus orientation. The input representation of a very briefly presented, misoriented object may not match well enough to any stored object representation to allow participants to even hazard a guess as to the identity of the object. In this case, no viable error response would be made. In contrast, the same object presented for the same duration but upright might either be identified successfully or be misidentified as a visually similar object.

Table 1
The 126 stimuli, ordered by size of their orientation effect, which was calculated as the increase in stimulus duration required to identify 60°, 90°, 120° and 150° views relative to 0° and 30° views

1	2	3	4	5	6	7	8	9	10	11	12
S—Subordinate[a], B—Basic, SP—Superordinate	Target object	Orientation effect (ms)	Stimulus duration for 0° view (ms)	Total no. viable errors	No. viable errors trials	Most common viable error response[b]	% of Col 7/ Col 5 trials	Most common Superordinate Label	No. Col 9 trials/ 14 sjs	No. SB labels/ 14 sjs	No. types SB labels
	Barn	109	83	72	15	~~~	~~~	Building	11	10	5
	Record-Player	95	61	45	8	~~~	~~~	Hifi/Music Equipment	6	9	6
	Football-Helmet	85	72	37	10	Snail	11	Sports Gear	7	3	2
	Well	81	116	68	14	Record-Player	10	Water Supply	3	9	2
	Church	76	72	40	11	Wagon	10	Building	10	11	4
S—2a3	Peacock	75	100	68	14	~~~	~~~	Bird	13	4	1
B—5	Racoon	71	83	50	16	Dog	12	Animal	10	1	1
S—13	Eagle	70	67	40	15	Bird	25	Bird	14	8	2
S—3	Spider	70	94	56	8	~~~	~~~	Insect	10	12	3
B—5	Train	65	111	64	14	~~~	~~~	Vehicle/Transport	11	12	7
	Sheep	60	133	135	20	Cow	26	Animal	9	9	5
	Kettle	54	78	35	12	Watering-Can	17	Kitchen Appliance	4	13	8
	Spinning-Wheel	54	89	32	13	Bicycle	16	Machine	4	1	1
	Rocking-Chair	51	78	15	8	Chair	27	Furniture	10	3	2
	Bear	51	83	45	13	Rhinoceros	20	Animal	12	12	4
	Vest	51	100	55	15	Shirt	11	Clothing	12	4	3
S—3	Chicken	50	83	28	16	Rooster	14	Bird	6	11	4
	Camel	49	83	36	12	Giraffe	19	Animal	12	9	4
	Baby-Carriage	47	67	19	9	Wagon	21	Vehicle/Transport	9	12	4
	Lion	47	72	19	11	Tiger	32	Animal	11	8	5
S—3	Caterpillar	47	78	24	8	~~~	~~~	Insect	10	5	4
	Candle	46	83	24	10	Pipe	17	Light	8	11	6
	House	44	61	24	11	Dresser	17	Building	11	11	5
B—12t4	Couch	44	84	33	14	Desk	12	Furniture	9	7	6
	Glass	43	72	35	10	Cup	26	Material	5	13	7

SP—4; B—1235	Bird	42	67	21	8	Iron	14	Animal	11	14	8
	Seal	40	94	56	13	~~~	~~~	Animal	8	5	4
	Beetle	39	89	24	10	Grasshopper	21	Insect	13	9	6
	Jacket	38	78	48	15	Coat	19	Clothing	11	9	6
	Iron	37	78	19	6	Jacket	11	Appliance	6	10	4
S—3	Grasshopper	36	78	10	6	Bicycle	20	Insect	13	5	2
S—3	Owl	32	144	53	10	~~~	~~~	Bird	13	11	3
S—3	Rooster	32	111	48	17	Chicken	33	Bird	9	6	1
	Goat	32	128	56	16	Horse	18	Animal	14	10	3
B—14	Bed	31	61	16	10	Couch	13	Furniture	14	13	6
B—1	Motorcycle	31	72	23	9	Bicycle	13	Vehicle/Transport	12	13	4
	Watering-Can	29	72	23	8	Bicycle	13	Gardening Tool	4	1	1
	Saltshaker	29	67	26	10	Bottle	31	Container	2	1	1
B—145	Tree	29	72	10	10	Gorilla	30	Plant	8	14	4
	Skunk	28	89	42	16	Giraffe	12	Animal	11	1	1
B—15	Airplane	28	56	9	4	~~~	~~~	Vehicle/Transport	12	13	4
	Basket	28	78	9	5	Record-Player	22	Carrier	4	12	5
S—2a3	Penguin	28	83	35	12	Bird	11	Bird	10	9	2
	Gorilla	27	100	40	13	~~~	~~~	Animal	10	5	3
	Windmill	26	67	12	9	Sailboat	17	Building	12	4	4
S—2t3	Sailboat	25	61	20	7	Sled	10	Boat	12	5	5
B—14	Piano	25	56	11	6	~~~	~~~	Instrument	7	13	3
	Tiger	25	50	12	6	Zebra	33	Animal	11	6	4
	Pig	25	106	47	12	Rhinoceros	34	Animal	7	10	6
B—14	Lamp	24	67	8	6	Flower	25	Light	7	13	10
S—2a3	Ostrich	24	72	34	12	Peacock	12	Bird	11	0	0
B—2a	Stove	22	78	17	11	Desk	24	Kitchen Appliance	4	10	3
B—12t4	Chair	22	61	10	4	~~~	~~~	Furniture	13	12	5
	Dresser	22	61	3	3	~~~	~~~	Furniture	14	2	2
	Foot	22	72	12	6	Seal	25	Body Part	10	5	4
B—5; S—3	Duck	22	78	19	8	Bird	21	Bird	13	8	3
B—5; S—3	Helicopter	22	67	26	11	Harp	12	Vehicle/Transport	10	6	4

Table 1(*continued*)

1	2	3	4	5	6	7	8	9	10	11	12
S—Subordinate[a], B—Basic, SP—Superordinate	Target object	Orientation effect (ms)	Stimulus duration for 0° view (ms)	Total no. viable errors	No. viable errors trials	Most common viable error response[b]	% of Col 7/ Col 5 trials	Most common Superordinate Label	No. Col 9 trials/ 14 sjs	No. SB labels/ 14 sjs	No. types SB labels
B—15	Cat	21	56	21	9	Dog	19	Animal	11	12	4
	Coat	21	94	55	17	Shirt	20	Clothing	12	13	8
	Sweater	21	61	24	14	Shirt	42	Clothing	12	8	4
	Frog	21	89	17	8	Rabbit	12	Animal	7	12	5
S—3	Swan	21	94	26	12	Ostrich	15	Bird	12	6	2
	Sea-Horse	20	128	31	15	Snail	10	Fish	5	0	0
	Turtle	20	67	7	3	~~~	~~~	Animal	9	5	2
	Harp	19	67	7	6	~~~	~~~	Instrument	8	1	1
	Fox	19	111	40	17	Cat	25	Animal	11	8	4
	Kangaroo	19	61	12	6	Horse	17	Animal	11	11	4
	Strawberry	18	67	14	6	Apple	29	Fruit	11	3	1
	Giraffe	18	56	11	6	Peacock	18	Animal	14	0	0
	Roller-Skate	18	172	49	14	Wagon	14	Toy	7	11	2
	Pitcher	18	89	20	10	Cup	15	Container	2	7	4
	Swing	18	211	94	18	Bed	16	Toy	6	10	7
	Mushroom	18	89	25	11	Hat	32	Vegetable	5	11	7
B—4	Cow	18	117	41	14	Rhinoceros	15	Animal	10	11	5
	Monkey	17	111	28	13	Skunk	11	Animal	11	11	6
	Deer	16	105	28	10	Goat	14	Animal	13	11	7
	Garbage-Can	15	111	55	15	Cup	16	Container	3	11	6
	Rabbit	15	83	17	10	Mouse	18	Animal	9	9	4
	Rhinoceros	15	84	21	13	Elephant	19	Animal	12	2	1
	Donkey	14	83	47	18	Horse	34	Animal	10	8	2
	Squirrel	14	83	19	8	Racoon	16	Animal	10	9	2
B—4	Boot	14	78	7	3	Chair	43	Footwear	6	10	6
	Pipe	14	72	4	4	~~~	~~~	Smoking Instrument	3	11	9

B—14	Shoe	13	67	11	6	Chair	18	Footwear	9	12	4
B—5	Hat	13	55	7	4	~~~	~~~	Clothing	7	12	4
	Bowl	13	50	7	5	Cup	43	Crockery	5	9	6
	Crown	11	89	17	6	Cake	18	Headwear	4	6	3
	Cannon	11	117	46	12	Spinning-Wheel	17	Weapon	8	2	2
B—4	Horse	11	56	17	8	Giraffe	12	Animal	14	10	6
B—12t4	Apple	10	72	10	5	Pot	20	Fruit	13	12	5
B—12t4	Shirt	8	117	36	15	Coat	31	Clothing	14	11	5
B—45	Bicycle	8	50	5	4	~~~	~~~	Vehicle/Transport	12	12	8
	Doll	8	67	23	7	~~~	~~~	Toy	13	12	7
B—2t	Dress	8	78	12	7	House	17	Clothing	13	9	5
B—14	Bus	8	67	17	11	Car	24	Vehicle/Transport	14	12	6
	Zebra	8	56	10	4	Tiger	20	Animal	12	0	0
S—3	Bee	8	83	19	10	Fly	21	Insect	13	11	4
	Elephant	8	72	10	6	~~~	~~~	Animal	13	12	5
	Snail	7	61	14	9	~~~	~~~	Insect	7	5	2
	Wineglass	6	56	16	11	Glass	50	Glass	5	7	5
	Alligator	5	72	18	9	Sea-Horse	11	Animal	7	8	2
B—1245	Dog	4	67	20	10	Cat	25	Animal	8	12	7
	Clock	4	61	3	3	~~~	~~~	Timer	7	13	5
B—12t4	Pants	4	106	17	7	Desk	12	Clothing	13	10	5
B—14	Truck	4	83	19	10	Bus	21	Vehicle/Transport	11	6	3
	Desk	3	78	13	6	Dresser	23	Furniture	12	7	5
	Leopard	3	83	25	13	Tiger	28	Animal	10	1	1
B—4	Cup	2	61	10	6	Basket	30	Crockery	5	11	3
B—45	Flower	1	78	9	5	~~~	~~~	Plant	10	11	4
	Bottle	1	78	7	6	Pitcher	43	Container	7	11	5
	Wagon	0	72	12	7	~~~	~~~	Vehicle/Transport	12	5	4
	Stool	0	84	5	4	Glass	40	Furniture	7	4	2
	Pot	−1	67	7	5	Frying-Pan	29	Kitchen Utensil	3	11	4
	Cake	−2	67	23	9	Hat	22	Food	14	13	11
B—5; S—3	Fly	−4	89	21	10	Beetle	24	Insect	14	9	4
	Frying-Pan	−4	72	10	7	Pot	50	Pan	3	12	6

Table 1 (*continued*)

1	2	3	4	5	6	7	8	9	10	11	12
S—Subordinate[a], B—Basic, SP—Superordinate	Target object	Orientation effect (ms)	Stimulus duration for 0° view (ms)	Total no. viable errors	No. viable errors trials	Most common viable error response[b]	% of Col 7/ Col 5 trials	Most common Superordinate Label	No. Col 9 trials/ 14 sjs	No. SB labels/ 14 sjs	No. types SB labels
B—12345	Car	−6	72	6	5	Wagon	33	Vehicle/Transport	14	12	9
	Ironing-Board	−7	122	17	10	Sailboat	12	Household item	4	5	3
	Snowman	−8	67	19	7	Elephant	11	NA	0	0	0
B—45	Gun	−11	78	7	3	Elephant	29	Weapon	13	12	6
B—45	Tie	−11	61	21	8	Ostrich	10	Clothing	13	8	5
B—4	Mouse	−11	139	35	11	~~~	~~~	Rodent	6	9	6
	Telephone	−11	117	10	6	Saltshaker	20	Communication Device	10	11	1
B—4; S—3	Ant	−14	100	29	12	Spider	21	Insect	14	11	6
B—1	Sled	−15	117	16	8	Desk	25	Toy	6	7	2
	Blouse	−32	133	69	20	Jacket	23	Clothing	13	0	0
	Mean top 1/3	**49.9**	**84.3**	**37.9**	**11.4**		**18.5**		**9.3**	**8.5**	**3.9**
	Mean mid 1/3	**19.5**	**83.5**	**24.2**	**9.7**		**19.9**		**9.3**	**8.0**	**4.1**
	Mean bottom 1/3	**1.0**	**80.2**	**17.0**	**7.9**		**24.6**		**9.6**	**8.6**	**4.3**
	Mean overall	**23.4**	**82.7**	**26.4**	**9.7**		**21.0**		**9.4**	**8.3**	**4.1**

[a] In Column 1, S indicates a label at the subordinate level, B indicates a label at the basic level and SP indicates a label at the superordinate level. The level of these labels are taken from 1: Rosch et al. (1976)[1]; 2: Jolicoeur et al. (1984), where 2t indicates a typical exemplar whilst 2a indicates an atypical exemplar; 3: Hamm and McMullen (1998); 4: Markman and Wisniewski (1997); and 5: Vitkovitch and Tyrell (1999).

[b] In Column 7, ~~~ is given in this column if the most common viable error response only occurred once or if it occurred on less than 10% of viable error response trials. If more than one response occurred equally often, the first response alphabetically is given. For sheep and pig only, the most frequently occurring viable error response (cow and rhinoceros respectively) was made, on average, more than once per trial on which a viable error response was made. Here, some participants typed in the same incorrect response more than once, presumably when they forgot their previous guess or when they thought that they had mistyped their earlier guess.

3.6. Labelling study to determine superordinate and subordinate labels for the 126 items

This study was conducted to explore the position within the levels of categorisation of the labels which had been used for the experimental items. Fourteen undergraduates from the University of Liverpool volunteered to participate in the study which lasted around 30 min. They provided more general and more specific labels for each of the 126 written names of objects which had been used in Experiment 1. Eight participants began by providing more general, superordinate labels. They were given the example: "An oak—is a kind of—tree" and were asked to then fill in "A barn—is a kind of—?" etc., for the 126 experimental items. They then provided more specific, subordinate labels to the same set of 126 words. They were shown the example: "A sessile oak—is a kind of—oak" and were asked to fill in "?—is a kind of—barn", etc. A further six participants did the two tasks in the reverse order. The most commonly chosen superordinate label is given in Column 9 of Table 1 and the number of participants selecting this label is given in Column 10. The number of acceptable subordinate labels provided by participants is given in Column 11 and the number of different subordinate labels is given in Column 12.

The more general category allocated to an item appeared to have little influence on the orientation effect for that item. The mean orientation effect for living things ($n = 56$ items) was 25 ms compared to 22 ms for artefacts ($n = 70$). There were positive orientation effects for all categories with at least four members. This included those categories which are typically assumed to have basic level members: animals ($n = 31$), 25 ms; furniture ($n = 7$), 25 ms; vehicles/transport ($n = 10$), 21 ms; and clothing ($n = 10$), 12 ms; and categories which are usually assumed to have subordinate members: birds ($n = 9$), 39 ms; and insects ($n = 8$), 24 ms; as well as buildings ($n = 4$), 64 ms; containers ($n = 4$), 16 ms; toys ($n = 4$), 7 ms; and all other items ($n = 39$), 21 ms.

4. Discussion

The results of the study were clear-cut: longer stimulus durations were needed to identify plane misoriented compared to upright stimuli in an unspeeded, picture–word verification task that required discrimination between many response alternatives. This result was reliable across both subjects and items for analyses of both stimulus duration and errors.

In most studies testing the naming of familiar objects, increases in naming latency with misorientation have been reported to be almost linear, at least over the range 0°–120°. In contrast, in the current masking study, this function was consistently non-linear (see the upper line in Fig. 5). We sampled plane orientation more finely (every 30°) than most previous studies of plane rotation, which typically sample at most every 60° (e.g., Jolicoeur, 1985; Jolicoeur & Milliken, 1989; McMullen & Jolicoeur, 1992; Murray, 1995b). The 95% confidence intervals shown in Fig. 5 indicate that there was a large and reliable increase in the stimulus duration from 30° to 60°

views and again from 90° to 120° views, but that there was little difference between the stimulus duration required to identify 0° and 30° views, or 60° and 90° views, or 120° and 150° views. These step-like departures from linearity did not seem to be random fluctuations since the same pattern of performance was found for three groups of participants (see Fig. 1) and over items as well as over participants. The results argue against an account of plane misorientation effects in terms of just a single, simple analogue process of transformation or normalisation such as mental rotation, performed with an efficiency which is directly proportional to the degree of misorientation of a view. Such an account would predict a linear relation between identification performance and orientation.

A number of factors may contribute to the overall orientation function. For example, the cardinal axes of elongation and symmetry for upright, 0° views are generally either aligned with, or perpendicular to, the upright. The identification of other views with the same alignment of their principal axes (90°, 180°, and 270° views) may be privileged, since the orientation of their cardinal axes will be canonical, even if the top/bottom or left/right direction of these axes differs from the upright view. In addition, if the stored, orientation-sensitive representations accessed by upright, 0° views are rather broadly tuned, then views such as 30° and 330° which are close to the upright may be identified efficiently by being matched directly to stored, upright representations without needing image normalisation. Finally, variation in performance for 180° views is a widely observed phenomenon in speeded naming tasks, and Murray (1997) found that a "flipping" strategy involving rapid depth rotation may benefit the identification of 180° views only. Further careful investigation will be necessary to elucidate the factors underlying misorientation effects. For now we conclude that the non-linear orientation functions shown in Fig. 5 and converging evidence from other studies (e.g., Jolicoeur et al., 1998; for a review, see Lawson, 1999) point to the inadequacy of a simple mental rotation or normalisation account of plane misorientation effects on picture identification.

For most of the stimuli tested, performance was worse for highly misoriented views relative to upright and near-upright views (see column 3 of Table 1). Furthermore, significant orientation effects were found for the subset of 32 objects which were considered to be labelled at the basic level by Hamm and McMullen (1998), Jolicoeur et al. (1984), Markman and Wisniewski (1997), Rosch et al. (1976) or Vitkovitch and Tyrell (1999). These orientation effects were similar in form to those for the remaining items. This suggests that for verification tasks that include reasonably visually similar distractors as response alternatives, misorientation effects are found for most items with an environmentally predominant orientation, including those items labelled at the basic level (cf. Hamm & McMullen, 1998). In most everyday viewing situations, we believe that there will be such potential distractor alternatives.

In Section 1, we discussed why it is difficult to examine the effect of manipulating level of identification (whether superordinate, basic or subordinate) on orientation effects, and we questioned the theoretical usefulness of discussing level of identification. In summary, there is considerable disagreement about the level of identification of many commonly used labels. There does not seem to be a basic level at which all objects in a given superordinate category are usually initially identified, since atypical items (e.g., penguin) are usually first identified at the subordinate level (Jolicoeur et al., 1984; Murphy & Brownell, 1985). Worse still, for many items, there may be no clear subordinate or superordinate labels available (Op de Beeck & Wagemans, 2001). The labelling study conducted here indicated that there was considerable variation in the consistency with which an item was assigned to a given superordinate category. For example 13/14 raters agreed that a doll was a kind of toy whereas only 6/14 raters thought that a swing was a kind of toy and no raters could agree on the superordinate category of a snowman. Nevertheless, across different types of superordinate category the orientation effect was always positive and showed no consistent pattern, whether for living versus non-living categories or for categories with members which are usually taken to be basic level (such as animals) or subordinate level (such as insects).

Visual similarity probably plays a crucial role in determining the ease of identifying a given object and in mediating the effect of plane misorientation on object identification. To investigate this role, it is important to be able to accurately and meaningfully measure the perceived visual similarity of a given item within a set of stimuli. This, though, is difficult to achieve. In this study, we have described and used both quantitative and qualitative measures of visual similarity. We believe that these measures are more meaningful and ecologically valid than non-perceptual measures of visual similarity, such as numbers of pixels in common, or similarity in overall size, shape or orientation between two stimuli, whilst providing a more objective and dynamic measure than unspeeded, introspective rating measures. We examined the number and type of incorrect responses made by participants to each of the 126 objects (see Table 1) to produce a sparse confusion matrix. One problem with this measure is that it requires that the object is glimpsed only briefly (in order to generate sufficient errors) and so perceived visual similarity may depend mainly on coarse-grained, readily available information. The most common distractor response to a given target object provides evidence against this suggestion (see column 7 of Table 1). When the most common distractor response occurred frequently (see columns 5 and 8), the distractor item was usually visually similar to the target (target: sheep—distractor: cow; glass—cup; mushroom—hat; pig—rhinoceros, etc.). Another problem is that presenting the response alternatives as an alphabetical list of words may have caused participants to select distractors appearing more prominently in the list and may have encouraged strategic guessing if participants remembered which list items had already been presented. In subsequent studies we have minimised these problems by requiring participants to type in the name of the object directly.

The measure of the number of viable error responses is similar to the measure of errors made in a speeded naming task used by Vitkovitch and Tyrell (1995) and in a picture naming-to-deadline paradigm (Vitkovitch & Humphreys, 1991; Vitkovitch, Humphreys, & Lloyd-Jones, 1993). However in these studies errors were only analysed across superordinate categories of stimuli which were considered to have members which were either visually similar (fruit, vegetables, animals) or dissimilar (tools, furniture, clothing), whereas we analysed errors for each individual object. There are dissimilar members of similar superordinate categories (such as bananas in the category of fruit), similar members of dissimilar superordinate categories (such as shirt, blouse and jacket in the category of clothes) and items may be misidentified as an item from a different superordinate category (a glove is an item of clothing but it is more likely to be misidentified as a hand than as a jacket or a shirt). Finally, many common stimuli do not fit well into a single category—they may belong to multiple superordinate categories or are difficult to place in any category (such as spinning-wheel, well, saltshaker and snowman, see columns 9 and 10 of Table 1). We suggest that visual similarity should be assessed at the level at which discriminations are made in a given task rather than at the level of the superordinate category to which an exemplar belongs. We propose that the number and type of the viable error responses made when identifying a given object provides a quantitative and objective measure of the visual similarity of that object to other stimuli.

Acknowledgements

This research was supported by Grant LT-558/94 from the International Human Frontier Science Program and Grant RF & G/2/9900393 from the Leverhulme Trust to the first author. Requests for reprints should be sent to R. Lawson, Department of Psychology, University of Liverpool, Eleanor Rathbone Building, Bedford Street South, Liverpool, L69 7ZA, UK.

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