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The Effects of View in Depth on the Identification of Line Drawings and Silhouettes of Familiar Objects: Normality and Pathology

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Three experiments are reported into the effects of viewpoint in depth, and of stimulus type (line drawings vs silhouettes) on picture identification. Clear effects of both factors were observed. Strongly foreshortened views were harder to identify than more canonical views, and silhouettes were harder to identify than line drawings. Furthermore, there was a strong interaction. The foreshortening disadvantage was greatly increased if silhouettes rather than line drawings were presented. Our results suggest that the internal information available in line drawings (but not silhouettes) is critical for identifying foreshortened views of objects. Additional results from an agnosic patient, HJA, suggest that certain forms of brain damage can disrupt the use of internal information for identification, reducing differences between performance with line drawings and silhouettes.

INTRODUCTION

A disadvantage in identifying foreshortened relative to more canonical views of objects has been widely reported, both for normal subjects (Humphrey & Jolicoeur, 1988, 1993; Lawson & Humphreys, 1996, 1998; Srinivas, 1993, 1995) and for neuropsychological patients (Humphreys & Riddoch, 1984; Warrington & Taylor, 1973, 1978). A number of different possibilities have

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been proposed to account for the foreshortening disadvantage in identification. For example, Marr (1982) suggested that the disadvantage may reflect difficulties in encoding useful image descriptions (see also Humphrey & Jolicoeur, 1993; Willats, 1992). Marr proposed that the main axis of an object provides the reference frame for an object-centred, view-invariant image description which is required for object identification. In foreshortened views, the main axis of the object may be difficult to extract from the image, since it is small in two-dimensional extent relative to the other views. Indeed, with foreshortening, the axis of maximum two-dimensional elongation in an image often differs from the main axis of three-dimensional elongation for the object; alternative cues may then be required to identify the main axis of the object from foreshortened views. Such cues might include axes of symmetry or the identification of component parts of the object, such as the head of an animal. Any difficulty in assigning the main axis of the object to a particular view would disrupt identification, because useful image descriptions would be derived more slowly, or less accurately.

In support of this account, Humphrey and Jolicoeur (1993) reported a foreshortening disadvantage for naming familiar objects even when care was taken to avoid occluding important parts in foreshortened views (cf. Biederman, 1987; Biederman & Gerhardstein, 1993). However, the foreshortening disadvantage was reduced (but not eliminated) when objects were depicted against a chequered background which provided perspective depth cues (see also Humphreys & Riddoch, 1984). Humphrey and Jolicoeur (1993) argued that the perspective background allowed subjects to extract information about the three-dimensional orientation of the object more efficiently.

An alternative account of the foreshortening disadvantage has been proposed by Warrington and James (1986). They have argued that foreshortened views often obscure distinctive features of an object, making such views difficult to identify. Their account was based on the results from a study in which subjects (both normal controls and right hemisphere lesioned patients) identified silhouettes of familiar objects. Warrington and James (1986) measured when subjects were first able to identify an object as it was rotated away from a fully foreshortened view. They concluded that manipulating the degree of foreshortening required for identification (as measured by the angle of rotation of an object) did not have any systematic effect on object recognition thresholds, either across different objects rotated about a particular axis or for a particular object rotated about different axes. In addition, although the brain-damaged subjects generally required a greater rotation to identify a given stimulus, there was no qualitative difference between their pattern of performance and that of normal subjects. Their results suggest that performance was not determined principally by the ease of assigning the main axis of an object for a given view of that object. Instead, ease of recognition appeared to be influenced by which features were visible for a given object undergoing rotation about a certain axis.

Warrington and James (1986) therefore proposed that identification was dependent on salient features of objects, and that foreshortening disrupts performance when these distinctive features are obscured or distorted. Similarly, Biederman and colleagues (Biederman 1987; Biederman & Gerhardstein, 1993) have suggested that foreshortened views of an object may occlude important parts of the object.

In the present study, we investigated the nature of the relation between the degree of foreshortening of the main axis of the object and the ease of identification of the object from that view. If the availability of the main axis is important for identification, then views of objects in which the main axis is more difficult to assign (specifically, more foreshortened views) should be harder to identify. This was tested by comparing the ease of identification of familiar objects across a range of depth-rotated views which were foreshortened to varying degrees. We further compared the ease of identification of pictures of objects when internal details were visible (line drawings) and when they were not (silhouettes), across different views. The occluding contour and the main axis of elongation in the image for a line drawing and its matched silhouette was identical (see Figure 1). If the main axis is assigned using image cues that are derived solely from the occluding contour of the object, then stimuli which differ only in the availability of internal detail should produce equivalent view effects (for example, an equal-sized foreshortening disadvantage).

Marr (1982) argued that silhouettes can usually be identified efficiently because they preserve sufficient image information to derive adequate axis-based image descriptions, based on the occluding contour of the shape. Within Marr's framework, he proposed that the occluding contour of a shape can generally be used to derive the main axis of the image description, irrespective of whether stimuli are presented as silhouettes, line drawings or real objects. Marr notes that, in Picasso's painting, "Rites of Spring", in which only the occluding contour of each object is provided, the silhouetted depictions of objects can readily be identified. Marr (1982) stated that, "when we look at the silhouettes ... we perceive them in terms of very particular three-dimensional shapes, some familiar, others less so. This is quite remarkable, because the silhouettes could, in theory, have been generated from an infinite variety of three-dimensional shapes, which, from other views, would have had no discernible similarities to the shapes that we perceive" (p. 218). Marr suggests that processing constraints limit our interpretation of a given image, such that even for a very sparse image, such as a silhouette, only one particular interpretation is achieved, from an inherently ambiguous occluding contour.

There has been surprisingly little research investigating the identification of silhouettes of object and, in particular, there have been few direct comparisons between the identification of comparable stimuli with and without internal detail. However, in apparent support of Marr's view, Hayward (1998) reported that silhouettes were identified only a little less efficiently than shaded and detailed stimuli, both in a sequential picture–picture matching task and in a naming task.

Three picture identification experiments are reported in this paper. Experiment 1 investigated the effect of view on the identification of silhouettes of familiar objects. The foreshortening disadvantage was found to be confined to the most foreshortened silhouettes. In addition, the foreshortening disadvantage was much greater for the silhouettes presented in Experiment 1 than for comparable line drawings presented in earlier picture naming studies (Lawson & Humphreys, 1998). Accordingly, Experiment 2 extended Experiment 1, to compare directly the effect of view in depth on the identification of comparable line drawings and silhouettes, in a word–picture verification task. The results replicated and extended the identification results from Experiment 1. First, there was a non-linear, non-monotonic relation between the depicted view of an object and the ease of verification. All views were identified equally efficiently, except the most foreshortened view, which was more difficult to identify. Second, the foreshortening disadvantage was much greater for silhouettes than for line drawings. In Experiment 3, a single case study of a visual agnosic patient, HJA, was undertaken (Humphreys & Riddoch, 1984; Humphreys, Riddoch, & Quinlan, 1985; Riddoch & Humphreys, 1986, 1987). HJA was tested using a similar task to that employed in Experiment 2. Like the non-brain-damaged subjects tested in Experiment 2, HJA revealed particular difficulties in identifying highly foreshortened views of objects, but unlike normal subjects, he was no worse at identifying silhouettes than line drawings. This was attributed to HJA failing to take advantage of internal details to aid his identification of line drawings.

EXPERIMENT 1

In Experiment 1, subjects named silhouettes of familiar objects depicted from a range of depth-rotated views. The study investigated the severity of any foreshortened view disadvantage, and the extent of any such disadvantage across different views which were foreshortened to varying degrees. The view in depth of each object was manipulated quantitatively across a full 360° depth rotation. The identification of many of the silhouettes was extremely difficult and so only identification accuracy was measured, and subjects were put under no time pressure to respond. The lack of time pressure in Experiment 1 would, if anything, be predicted to reduce view effects relative to a task such as speeded naming, since subjects could, if necessary, engage in time-consuming problem-solving strategies to identify the objects.

Methods

Subjects. Eighty-four subjects volunteered to participate without payment. All subjects in Experiments 1 and 2 were from the University of Birmingham. They were native speakers of English aged 18–35 years, with normal or corrected-to-normal vision.

Materials. A set of 12 views of each of 36 familiar objects was produced (see Appendix 1). All of the objects had a horizontal main axis of elongation. The views of each object ranged over a 360° rotation in depth, and each view was separated by a 30° horizontal rotation in depth. All objects possessed an unambiguous main axis of elongation, and objects were rotated about the vertical axis running through their centre point. The angle of view was defined with respect to the line of sight of the viewer relative to the main axis of elongation of the object. The 0° view revealed the main axis perpendicular to the line of sight of the viewer (see Figure 1). In the foreshortened, 90° and 270° views, the main axis of elongation pointed directly towards the viewer. The first author selected the 90° view to reveal the front of the object with the most important or familiar features to the fore.

The stimuli were produced by tracing and then scanning photographs of either the object or scale models of the object. Photographs were taken from a slightly elevated angle of between 15° and 30° above the horizontal plane on which the object rested. This angle was maintained constant during the depth rotation of each object. An elevated angle was used to ensure that the effects of foreshortening the main axis of the object were not too severe, so that the pictures presented should be representative of the range of views seen under typical viewing conditions. Each picture was scaled to occupy a square of 6 × 6 cm. The initial set of stimuli produced were line drawings. Silhouettes were derived from these line drawings by shading in black inside the occluding contour of each line drawing (see Figure 1). The occluding contour of each line drawing and its corresponding silhouette was thus identical; only internal details were lost for the silhouettes.

Design. On each trial, a silhouette of an object was presented at one of 12 possible views, from 0° to 330°. Each subject completed one block of trials only, consisting of a set of 36 silhouettes of different objects. There were 12 different sets of silhouettes. In each set, three of the 36 objects were shown at each of the 12 different views. The set of three objects shown at each view was rotated in a Latin Square design across the different sets, so that, over the 12 sets, each object was seen 12 times, once at each view. Seven subjects were assigned to each set of silhouettes. The order of presentation of trials was random and was different for each subject.

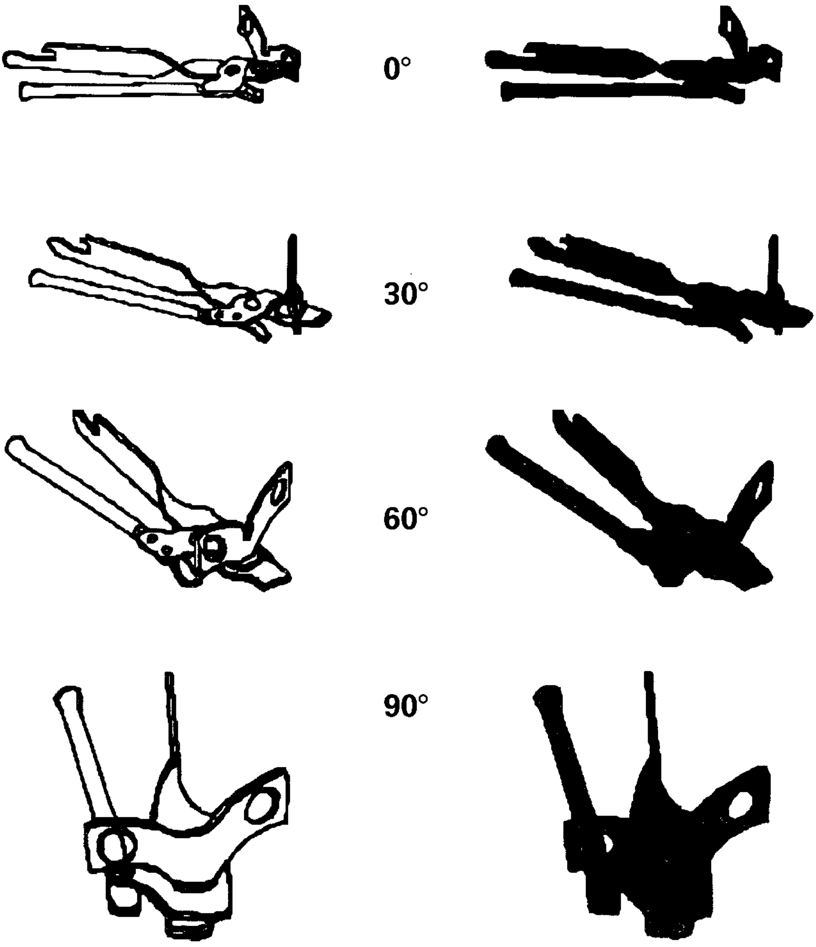

FIG. 1. Examples of the matched line drawings and silhouettes depicting 0°, 30°, 60° and 90° depth-rotated views of a can-opener.

Apparatus and Procedure. A Macintosh IIci computer running the Psychlab Version 8.5 presentation package was used to display the stimuli. The experiment lasted about 5 min.

The procedure for each trial was as follows: A fixation cross appeared on the screen for 500 msec, immediately followed by the picture, which was displayed until the subject named the object. Responses were recorded by the experimenter. Subjects were put under no time pressure to respond, and only errors were scored. Before the experimental block, subjects completed a block of 10 practice trials, which presented silhouettes of different objects to those depicted in the experimental trials.

Results

Mean percentage error rates over subjects are shown in Figure 2. In this and in the following experiments in this paper, the results for both by-subjects and by-items analyses are reported, using subscripts F_1 and F_2 respectively. The responses to the two views rotated 180° from each other were combined for analysis. The two views rotated by a full half-turn from each other had very similar correct response rates (see Figure 2) and so collapsing across the two views resulted in little loss of information. A log-linear transform was performed on the total number of correct responses for each combined view, for every subject or item. There was one within-subjects factor, "view" (the view of the silhouette: 0°/180°, 30°/210°, 60°/240°, 90°/270°, 120°/300° and 150°/330°).

The effect of view was significant, $F_1(5,415) = 62.9$, MSe = 0.563, $p < .001$, $F_2(5,175) = 19.8$, MSe = 1.288, $p < .001$. The 90° and 270° foreshortened views were named less accurately than any other views ($p < .01$; Newman-Keuls analysis). In addition, the 0° and 180° views were named less accurately than any other view, except the foreshortened, 90° and 270° views ($p < .05$ for subjects; not significant for items). There were no other significant effects.

Discussion

The results for Experiment 1 were clear. First, there was a strong foreshortening disadvantage for the identification of silhouettes. However, there was no monotonic relation between increasing error rates and increasing foreshortening of the main axis of the object. Increasingly foreshortened views were not increasingly difficult to identify, for instance across 0° to 30° to 60° views. Only

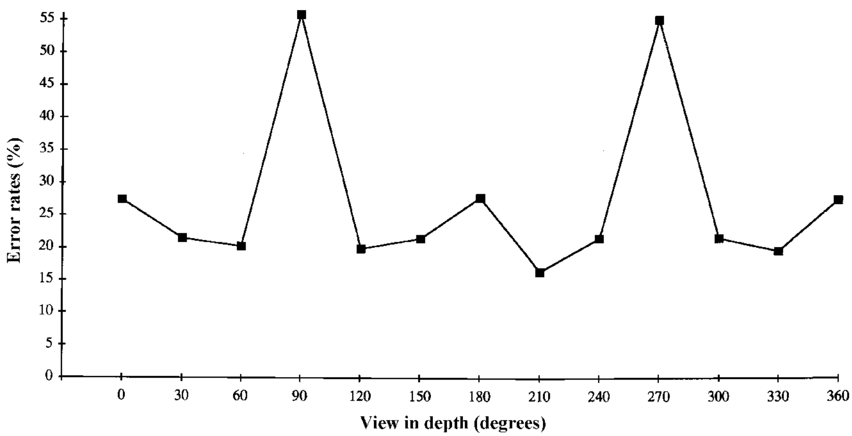

FIG. 2. Mean percentage error rates as a function of view in depth in Experiment 1.

the most foreshortened (90° and 270°) views were disadvantaged by foreshortening the main axis of the object.

Second, there was a weak disadvantage for identifying views which fully exposed the main axis of the object (the 0° and 180° views). On axis-based accounts of object recognition, an object-centred reference frame should be easy to assign to views of an object which fully expose the main axis of elongation. It follows that the 0° and 180° views should be identified efficiently. The results from Experiment 1 run counter to this prediction. However, the 0° and 180° view disadvantage here might have been an artefact of the stimuli used, since all views were scaled to occupy the same 6 × 6 cm square. This scaling resulted in the 0° and 180° views being disproportionately small in area. Some fine details were lost or were relatively small for these views, relative to other views.

Third, the foreshortening disadvantage in Experiment 1 appeared to be greater than that observed in a speeded naming task reported by Lawson and Humphreys (1998, experiment 1; see Table 1 here). This earlier experiment presented the line drawings from which the silhouettes presented in Experiment 1 here had been derived. The line drawings were depicted over a range of views from 0° to 150°. For the silhouettes presented in Experiment 1 here, there were 25.8% more errors to 90° compared to 60° views. However, for the line drawings presented by Lawson and Humphreys (1998; see Table 1 here), there were only 5.6% more errors to 90° compared to 60° views, despite the added time pressure in this speeded response task. This apparent increase in the foreshortening disadvantage for silhouettes suggests that internal details may be particularly important for the identification of foreshortened views.

The present results provide evidence against any axis-based account of the foreshortening disadvantage that might attribute effects of foreshortening solely to problems in assigning the main axis to foreshortened views of objects. First, as an object was depicted from an increasingly foreshortened viewpoint, identification did not become increasingly difficult. In Experiment 1 here (and

TABLE 1
Mean Reaction Times (msec) and Error Rates (%), as a Function of the View in Depth, for the First Block of Naming of Line Drawings in Lawson and Humphreys (1998, experiment 1) and, for Comparison, the Error Rates (%) for the Naming of the Same Range of Views of Silhouettes in Experiment 1 Here

	View in Depth					
	0°	*30°*	*60°*	*90°*	*120°*	*150°*
Lawson and Humphreys (1998, experiment 1), line drawings						
RTs (msec)	1006	974	939	1032	957	963
Error rates (%)	12.3	10.7	9.5	15.1	6.4	12.7
Experiment 1 here, silhouettes						
Error rates (%)	27.4	21.4	20.2	56.0	19.8	21.4

also in experiment 1 of Lawson & Humphreys, 1998), the identification of relatively foreshortened views (e.g. 60° and 120° views) was not more difficult than that of less foreshortened views (e.g. 0° and 30° views). We consider this issue further in the discussion of Experiment 2.

Second, as noted in the Introduction, if the ease of assigning the main axis is equated, then axis-based accounts of recognition would predict that view effects should be the same across different types of stimuli (for instance, across comparable line drawings and silhouettes). If (1) all view effects on identification are a result of variation in the ease of assigning the main axis to an image description, and (2) only information derived from the occluding contour of the object (and not from internal details) is used to assign the main axis, then axis-based accounts predict that the main axis should be assigned equally efficiently across comparable line drawings and silhouettes, and hence equal view effects should be observed. There might be a main effect of stimulus type, with the identification of silhouettes (which lack internal details) being generally more difficult than the identification of line drawings. However, any view effects should be the same across the two types of stimuli, and so should not interact with effects of stimulus type. Comparison of the present results with those of experiment 1 in Lawson and Humphreys (1998; see Table 1 here) seems to contradict this.

Overall, the results suggest that internal details are important cues to object identity, particularly when other types of information such as the occluding contour are uninformative, for example as a result of foreshortening. Internal details may either aid in the assignment of axes (as axis-based accounts would predict), or they may be used more directly, as important cues to object identity (as distinctive features accounts predict; see Warrington & James, 1986).

EXPERIMENT 2

The results of Experiment 1 suggested that there may be a greater foreshortening disadvantage for silhouettes than for line drawings. However, the identification of line drawings and matched silhouettes could not be compared directly, since the experimental conditions differed across the present and the earlier study (Lawson & Humphreys, 1988). Most importantly, only accuracy of identification was measured in Experiment 1 here, whereas previously speed of response was the primary measure.

Experiment 2 was designed to allow a direct comparison between the ease of identification of line drawings and silhouettes depicted at different depth rotations. The occluding contour was identical for the paired line drawings and silhouettes for each view of a given object, but internal details were lost for the silhouettes (see Figure 1). However, unlike Experiment 1, a word–picture verification task was employed, in which subjects saw a word followed by a picture of an object, and decided whether the word and the picture both represented the same object (match trials) or represented two different objects (mismatch trials). Verification rather than naming was employed in Experiment 2, since an unspeeded naming task would probably have resulted in near-ceiling performance for line drawings, while a speeded naming task would probably have produced unacceptably high error rates for silhouettes. Verification tasks typically produce faster, more accurate performance than naming tasks, and therefore it was chosen as a more suitable task.

Experiment 2 was designed to investigate whether increasing foreshortening of the main axis of the object would increase the difficulty of verification, and whether view effects on the identification of matched line drawings and silhouettes would be identical when the ease of assigning the main axis, based on information derived from the occluding contour, was equal across the stimuli.

On the basis of Experiment 1, we predicted (1) that the most foreshortened views would be verified more slowly than other views, (2) that silhouettes would be verified more slowly than line drawings and (3) that the foreshortened view disadvantage would be exacerbated for silhouettes relative to line drawings.

Methods

Subjects. Sixty-four subjects from the University of Birmingham were paid to participate. They were native speakers of English aged 18–35 years, with normal or corrected-to-normal vision.

Materials. For match trials, 0°, 30°, 60° and 90° views of each of the 36 familiar objects listed in Appendix 1 were presented. For mismatch trials, views of a different set of 36 familiar objects were produced, in the same way as the pictures produced for match trials. Each mismatch object was depicted at one angle only, but over the 36 mismatch objects, a range of different depth rotations was depicted. The names of the mismatch objects are listed in Appendix 2. For match and mismatch objects, each view of each object was depicted as both a line drawing and a silhouette.

Design. On each trial, a word was presented, followed by a picture of an object at one of four different possible views: 0°, 30°, 60° or 90°. On half the trials, the word named the object which was subsequently depicted (match trials). On the remaining mismatch trials, the word referred to an object which was visually similar to the depicted object, but which belonged to a different object category (see Appendix 2). Each subject completed a single block of experimental trials, consisting of 36 match and 36 mismatch trials, with only one view of each object being presented. All subjects saw the same views of the 36 mismatch pictures.

For match trials, there were four different picture sets. In each set, nine of the 36 objects were shown at each of the four different views: 0°, 30°, 60° and 90°. The nine objects depicted at each view were rotated in a Latin Square design across the four picture sets, so that over the four sets each object was seen four times, once at each view. Sixteen subjects were assigned to each set, of whom eight saw line drawings only and eight saw silhouettes only, for both match and mismatch trials. The order of presentation of trials within a block was random, and was different for each subject.

Apparatus and Procedure. A Macintosh IIci computer running the Psychlab Version 8.5 presentation package was used to display the stimuli. The experiment lasted about 10 min.

The procedure for each trial was as follows: a fixation cross appeared on the screen for 800 msec, followed by a blank screen for 300 msec. A word then appeared in the centre of the screen for 400 msec, in 7 mm high, upper-case letters. The word was immediately followed by a picture, which was displayed until the subject responded. Subjects responded with their preferred hand to match trials, and with their non-preferred hand to mismatch trials, by hitting either the "M" or "Z" key of the keyboard. Subjects decided whether the word and the picture both referred to the same object. They were encouraged to respond as rapidly and as accurately as possible. Before the start of the experiment, subjects completed a block of 14 practice trials of words and pictures which did not appear in the experimental trials.

Results

Mean correct reaction times (RTs) and percentage error rates over subjects are given in Figures 3a and 3b respectively. Reaction times less than 300 msec or exceeding 1500 msec were discarded as errors. All subjects scoring an average of over 20% errors in the experiment were replaced (eight subjects; one was presented with line drawings, seven were presented with silhouettes).

Match Trials. An analysis of variance was conducted on the mean correct RTs for match trials. There was one within-subjects factor, view (0°, 30°, 60° or 90°), and one between-subjects factor, stimulus (line drawings or silhouettes).

The main effect of view was significant, $F_1(3,186) = 18.1$, MSe = 3701, $p < .001$, $F_2(3,105) = 7.7$, MSe = 14515, $p < .001$. Foreshortened, 90° views were verified slower than 0°, 30° and 60° views ($p < .01$; Newman-Keuls analysis). There were no other significant differences. The main effect of stimulus was also significant, $F_1(1,62) = 6.9$, MSe = 37301, $p < .02$, $F_2(1,35) = 27.1$, MSe = 12628, $p < .001$. Silhouettes were verified more slowly than line drawings. Finally, there was a significant interaction of view × stimulus, $F_1(3,186) = 6.5$, MSe = 3701, $p < .001$, $F_2(3,105) = 6.3$, MSe = 7368,

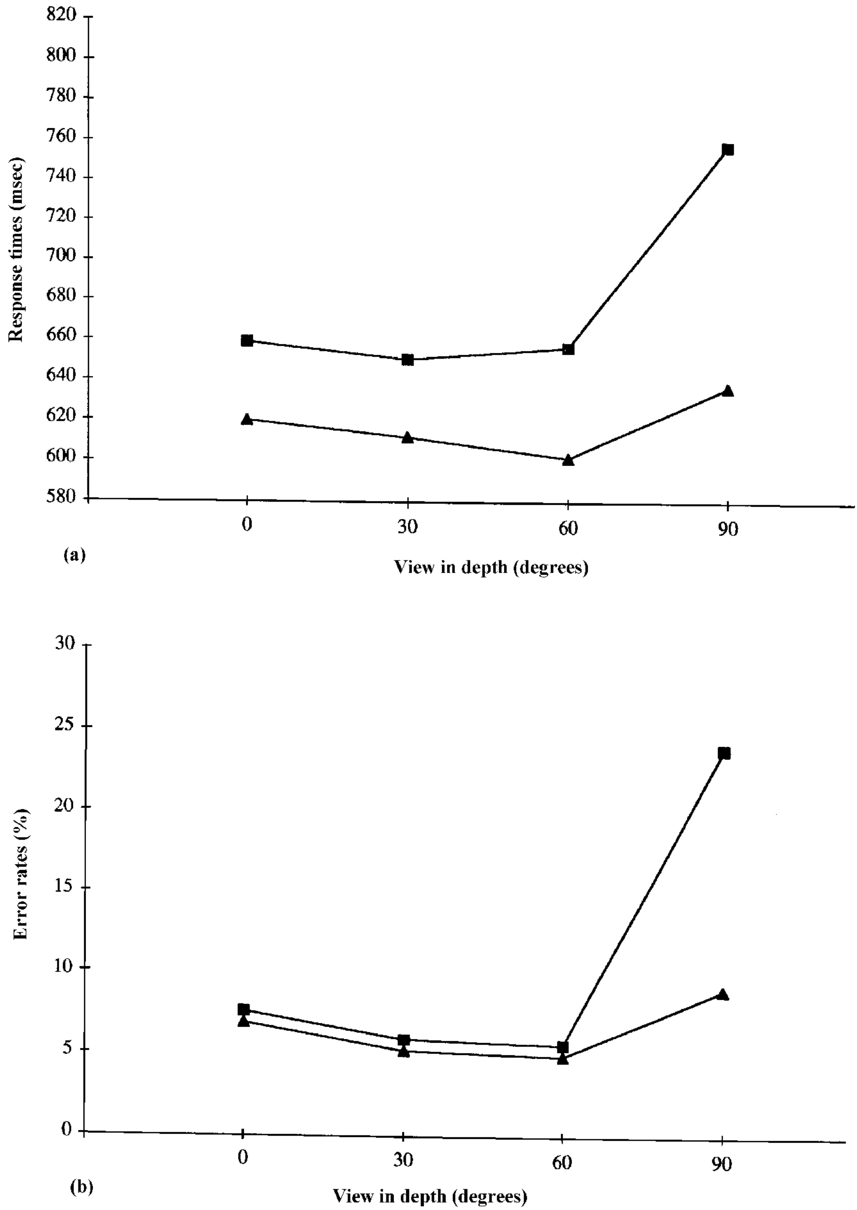

FIG. 3. Mean correct response times (a) and percentage error rates (b) for match trials for silhouettes (■) and line drawings (▲), as a function of view in depth, in Experiment 2.

$p < .001$. Foreshortened, 90° silhouettes were verified more slowly than any other stimulus ($p < .01$; Newman-Keuls analysis). In addition, 30° and 60° line drawings were verified faster than any silhouettes ($p < .05$ or above for subjects; for items, $p < .01$ for 90° silhouettes and $p < .05$ for 0° silhouettes compared to 60° line drawings only).

An analysis of variance was also performed on the log-linear transformed error scores. The main effect of view was significant, $F_1(3,186) = 18.7$, MSe = 0.511, $p < .001$, $F_2(3,105) = 9.4$, MSe = 0.728, $p < .001$. Foreshortened, 90° views were verified less accurately than 0°, 30° and 60° views ($p < .01$; Newman-Keuls analysis). There were no other significant differences. The main effect of stimulus was significant across subjects and marginally significant across items, $F_1(1,62) = 12.0$, MSe = 0.492, $p < .002$, $F_2(1,35) = 4.1$, MSe = 0.932, $p < .06$. Silhouettes were verified less accurately than line drawings. Finally, there was a significant interaction of view × stimulus, $F_1(3,186) = 6.5$, MSe = 0. 511, $p < .001$, $F_2(3,105) = 4.0$, MSe = 0.600, $p < .01$. Foreshortened, 90° silhouettes were verified less accurately than any other stimulus ($p < .0 1$; Newman-Keuls analysis). There were no other significant effects.

In further analyses, data from the verification of foreshortened, 90° views were excluded. For the analysis of RTs, the main effect of view was no longer significant, $F_1(2,124) = 0.6$, MSe = 3333, $p >.5$, $F_2(2,70) = 0.8$, MSe = 10863, $p > .04$. Stimulus was marginally significant across subjects and significant across items, $F_1(1,62) = 3.3$, MSe = 28494, $p > .07$, $F_2(1,35) = 9.9$, MSe = 10363, $p < .004$. Silhouettes were verified more slowly than line drawings. The interaction of view × stimulus was no longer significant, $F_1(2,124) = 0.4$, MSe = 3333, $p > .6$, $F_2(2,70) = 0.1$, MSe = 6169, $p > .9$. There were no significant effects in the error analysis.

These latter analyses reduced by one-quarter the amount of data analysed relative to the initial analyses reported above. To check whether the null results found when data from 90° views were excluded was simply due to the reduction in the amount of data analysed, additional analyses were conducted which excluded data from the verification of the 0° view rather than the 90° view. The results from these final analyses mirrored the initial analyses in which data from all four views had been included. Thus the lack of a main effect of view or of an interaction of view × stimulus when data from verifying the 90° view were removed from the analyses did not appear to be due simply to a reduction in the amount of data analysed.

Mismatch Trials. The mean correct RTs for mismatch trials were 716 and 813 msec, and the error rates were 16.7% and 29.7%, for the verification of line drawings and silhouettes respectively.

Discussion

The results clearly revealed a view effect on verification performance, with the most foreshortened, 90° views being more difficult to verify than other views. However, as in Experiment 1 here and in experiment 1 of Lawson and Humphreys (1998), there was no trend towards longer RTs or more errors as the object was depicted from increasingly foreshortened views (e.g. across 0°, 30° and 60° views). Thus, in Experiment 2, only the verification of the most foreshortened, 90° view was impaired; there was no evidence that increasingly foreshortened views became increasingly difficult to verify. If the depicted angle of these views provides a good measure of the availability of the main axis of the object (see Appendix 3), then the results of both Experiments 1 and 2 suggest that view effects are not caused solely by difficulties in assigning the main axis to the structural description of an image.

In addition, there was an effect of stimulus, with silhouettes being harder to verify than line drawings. This is not surprising, given that extra information (internal detail) was available in the line drawings but not the silhouettes, while other information (for instance, that available from the occluding contour of the stimulus) was identical across comparable line drawings and silhouettes. However, note that when the foreshortened, 90° views were removed from the analyses, this greatly reduced the difference between the ease of verification of line drawings and silhouettes.

Finally, the unique influence of 90° views resulted in a strong interaction between the stimulus and view factors. Foreshortened, 90° silhouettes were much harder to verify than foreshortened, 90° line drawings (121 msec slower and 15% less accurate), but 0°, 30° and 60° silhouettes were only a little harder to identify than 0°, 30° and 60° line drawings (on average only 44 msec slower and 0.7% less accurate). This interaction is difficult to explain on any account which posits (1) that the foreshortening disadvantage is due solely to the inefficient derivation of the main axis of an object from the foreshortened view, and (2) that the main axis is derived solely from the occluding contour of an image (so that internal details do not contribute to the assignment of the main axis). Note that, given these conditions, the derivation of the main axis of the object from the occluding contour should be equally difficult for comparable line drawings and silhouettes, and hence equal view effects should be observed across the different stimulus types.

Instead, it seems that the internal details of the objects (available only from line drawings) were generally not critical for the identification of 0°, 30° and 60° views, but were often vital for the identification of highly foreshortened, 90° views. As noted above, this suggests that internal details are essential in either assigning the main axis of the object to a foreshortened view, or in directly aiding identification of such views, regardless of axis factors.

A comparison of the present results from a verification task with those of similar naming experiments (Experiment 1 here with silhouettes, and experiment 1 of Lawson and Humphreys, 1998, with line drawings; see Table 1) reveals a very similar pattern. This is evidence against one possible account of the results of Experiment 2, namely, that the present verification task encouraged subjects to employ top-down imagery or guessing strategies. For example, subjects may have visualized a prototypical view of the object when presented with the written name of an object (Palmer, Rosch, & Chase, 1981). Matching to such an image might have disadvantaged the verification of non-canonical relative to canonical views of objects, not because non-canonical views were intrinsically difficult to identify, but because they did not provide a good match to the imagined view of the object. Since there was only a small disadvantage for the verification of foreshortened, 90° line drawings, such an account would have also had to assume that top-down matching only produces marked effects when verification is difficult (i.e. for silhouettes); when verification is efficient, as it is for line drawings, top-down strategies may usually be unnecessary. However, in the naming task employed in Experiment 1 here and in experiment 1 of Lawson and Humphreys (1998), stored knowledge could only be accessed following visual processing of the picture presented. Under these conditions, foreshortened, 90° views were still found to be more difficult to identify than other views, and foreshortened, 90° silhouettes were particularly difficult. This result counters the suggestion that the substantial foreshortening disadvantage for the verification of silhouettes found in Experiment 2 was due solely to top-down effects. Note further that, in an unpublished speeded naming study which the first author conducted, using the same stimuli as in Experiment 2 here, 60° and 90° views of matched line drawings and silhouettes were presented, and a strong interaction between stimulus and view was observed which mirrored the pattern of results reported in Experiment 2.

EXPERIMENT 3

Experiment 3 consisted of a single case study of a brain-damaged patient, HJA, whose visual identification problems have been investigated extensively by Humphreys and Riddoch (1984; Humphreys et al., 1985; Riddoch & Humphreys, 1986, 1987). HJA performs normally on many tasks which test relatively low-level visual performance, for example discrimination of line length, orientation and position. However, HJA has great difficulty in naming visually presented common objects, and when he cannot name an object, he cannot mime its use or identify it in any other way. HJA has virtually unimpaired semantic memory, with excellent recall of the visual attributes of objects (except colour), and good drawing from memory.

Humphreys et al. (1985) tested HJA on the Navon task, in which he was required to identify a large, global letter, composed of numerous smaller letters, or to identify small, local letters which were grouped into a large, global letter. HJA's speed of identification of global letters was within the normal range, suggesting that global information was rapidly made available to him (see also Boucart & Humphreys, 1992). However, when he was required to identify the local letters which made up a global letter, his responses were slower than those of normal controls (and much slower than his global letter identification). In addition, unlike normal subjects, HJA showed no effect of global-to-local (or of local-to-global) interference.

Humphreys and Riddoch proposed a new term, "integrative agnosia", to describe HJA's syndrome, that of a high-level visual deficit in grouping local form information, and integrating global and local levels of information, to provide a coherent, informative percept. Humphreys et al. (1985) suggested that HJA analysed local and global properties in parallel, and achieved independent local and global form descriptions. Hence, in the Navon task, HJA's performance was not affected by whether the identity of the local and global letters was congruent or not. For normal subjects, information derived from global and local processing is combined, to produce a single, coherent percept. This results in global-to-local interference in the Navon task, since subjects cannot selectively attend to local elements without concurrently activating information from the global letter.

HJA's well-documented difficulties in integrating form information indicated that he might reveal a different pattern of results to that of the normal subjects tested in Experiment 2. Specifically, HJA's performance on the Navon task (Humphreys et al., 1985) suggested that, with the present stimuli, he might not be able to integrate information from the occluding contour (which was equally available in the line drawings and silhouettes) with internal detail, on the assumption that the occluding contour and the internal detail provided most of the informative global and local information respectively. Indeed, for HJA, information from internal detail may be made available so slowly that it often fails to influence identification. Consistent with this, Riddoch and Humphreys (1987) found that HJA differed from normal subjects in being no worse with silhouettes than line drawings in an unspeeded object decision task, in which non-objects were produced by adding or substituting parts of a familiar object to a different familiar object.

From the above considerations, two predictions can be made. First, if HJA's performance is based primarily on global information derived from the occluding contour of an object, then he should reveal a strong foreshortening disadvantage, since the results of Experiments 1 and 2 indicate that the information available from the occluding contour is profoundly disrupted in foreshortened, 90° views. Second, if HJA's performance is based solely on global information derived from the occluding contour, he should be as good at identifying silhouettes as line drawings across all views (as the only difference between matched line drawings and silhouettes is the availability of internal details).

In Experiment 3, HJA and an age-matched control, IA, were tested in a similar word–picture verification task to that employed in Experiment 2, to investigate the ease with which they could verify the names of line drawings and silhouettes of different, depth-rotated views of familiar objects.

Methods

Subjects. Two subjects volunteered to participate without payment. At the start of testing, HJA was aged 71 years, and IA, an age-, IQ- and education-matched control, was aged 72 years. HJA suffered a stroke in 1981, subsequent to which he manifested severe object agnosia, prosopagnosia, topographical agnosia, letter-by-letter reading and achromotopsia. A computed tomographic scan in 1984 revealed bilateral infarcts in his occipital lobes, and magnetic resonance imaging in 1987 showed bilateral lesions of the lingual and fusiform gyri. Further details of HJA's case history are given in Humphreys and Riddoch (1984) and Riddoch and Humphreys (1987).

Materials. These were identical to those presented in Experiment 2.

Design. On each block of trials, one picture set was presented, consisting of 36 match and 36 mismatch trials, which were all either line drawings or silhouettes. The sets used were the same as those presented in Experiment 2. However, in Experiment 3, both subjects were presented with all eight sets used in Experiment 2 (four sets of line drawings and four sets of silhouettes), so both subjects completed eight blocks of trials in total. The blocks were presented in different sessions over a period of 18 months. Blocks of line drawings were alternated with blocks of silhouettes, and both subjects completed the blocks in the same order. The extended test period was employed to minimize carryover learning effects across blocks. The same objects were associated with either match or mismatch trials over the eight experimental blocks, and so subjects could have learnt which objects were associated with match and mismatch trials. Any such learning would be predicted to reduce view effects, since subjects could learn to respond correctly given the word alone, and this response would be independent of the view of the subsequent picture.

Apparatus and Procedure. These were identical to Experiment 2, except for the following points. To reduce possible errors or delays in reading or understanding the word, the word was displayed for 1500 msec, rather than 400 msec, and the experimenter (the first author) read the word aloud as it was displayed. The subject responded by saying “same” for match trials and “different” for mismatch trials, to which the experimenter immediately typed in “M” or “Z” respectively. Response latencies were measured as the keypress RTs. These changes relative to Experiment 2 were made to clarify and simplify the task for the subjects.

Results: Match Trials

Reaction times less than 300 msec or exceeding 5000 msec were discarded as errors. Mean correct RTs and percentage error rates are given in Figures 4a and 4b, respectively, for HJA (the visual agnosic) and IA (the age-matched control).

HJA. HJA's responses were quite rapid, but highly inaccurate. An analysis of variance was conducted on his mean correct RTs for match trials (treating each RT as a separate subject). There were two between-subjects factors, stimulus and view. No significant effects were found [for view: $F(3,179) = 1.7$, MSe = 226811, $p > .1$; for stimulus: $F(1,179) = 1.0$, MSe = 226811, $p > .3$; for the interaction of view and stimulus: $F(3,179) = 0.9$, MSe = 226811, $p > .4$].

There was a significant effect of view on HJA's accuracy of verification, for both silhouettes ($\chi^2 = 16.1$, d.f. = 3, $p < .01$) and for line drawings ($\chi^2 = 18.3$, d.f. = 3, $p < .001$). From an inspection of Figure 4b, it is clear that, like normals, HJA made more errors to foreshortened, 90° views than to other views. This is supported by the results of further analyses. If the foreshortened, 90° view was omitted from the χ^2 analysis, the effect of view was no longer significant ($\chi^2 = 2.7$, d.f. = 2, $p > .2$ for silhouettes; $\chi^2 = 0.3$, d.f. = 2, $p > .2$ for line drawings), whereas if the 0° view was omitted from the analysis, the effect of view remained significant ($\chi^2 = 16.2$, d.f. = 2, $p < .001$ for silhouettes; $\chi^2 = 15.6$, d.f. = 2, $p < .001$ for line drawings).

Unlike the age-matched control, IA, and the young controls tested in Experiment 2, HJA was equally inaccurate at verifying silhouettes and line drawings ($\chi^2 = 0.0$, d.f. = 1, $p > .9$, averaging over all views), and he showed no indication of an interaction between the effects of stimulus and view. There was no significant difference between HJA's accuracy of verification of silhouettes and line drawings at 0° views ($\chi^2 = 1.0$, d.f. = 1, $p > .3$), 30° views ($\chi^2 = 0.7$, d.f. = 1, $p > .4$), 60° views ($\chi^2 = 0.1$, d.f. = 1, $p > .7$) or, importantly, at 90° views ($\chi^2 = 0.1$, d.f. = 1, $p > .8$). Finally, HJA's responses to foreshortened, 90° views were found to be no different to his mismatch trial responses. There was no significant difference between the number of correct responses to foreshortened, 90° match trials and the number of errors to mismatch trials, for both silhouettes ($\chi^2 = 0.4$, d.f. = 1, $p > .5$) and for line drawings ($\chi^2 = 1.6$, d.f. = 1, $p > .2$). Note that since HJA's performance with foreshortened, 90° line drawings was so poor, there may have been a floor effect, making it difficult to detect any further drop in his performance for foreshortened, 90° silhouettes. However, there was no evidence from his pattern of means for any difference

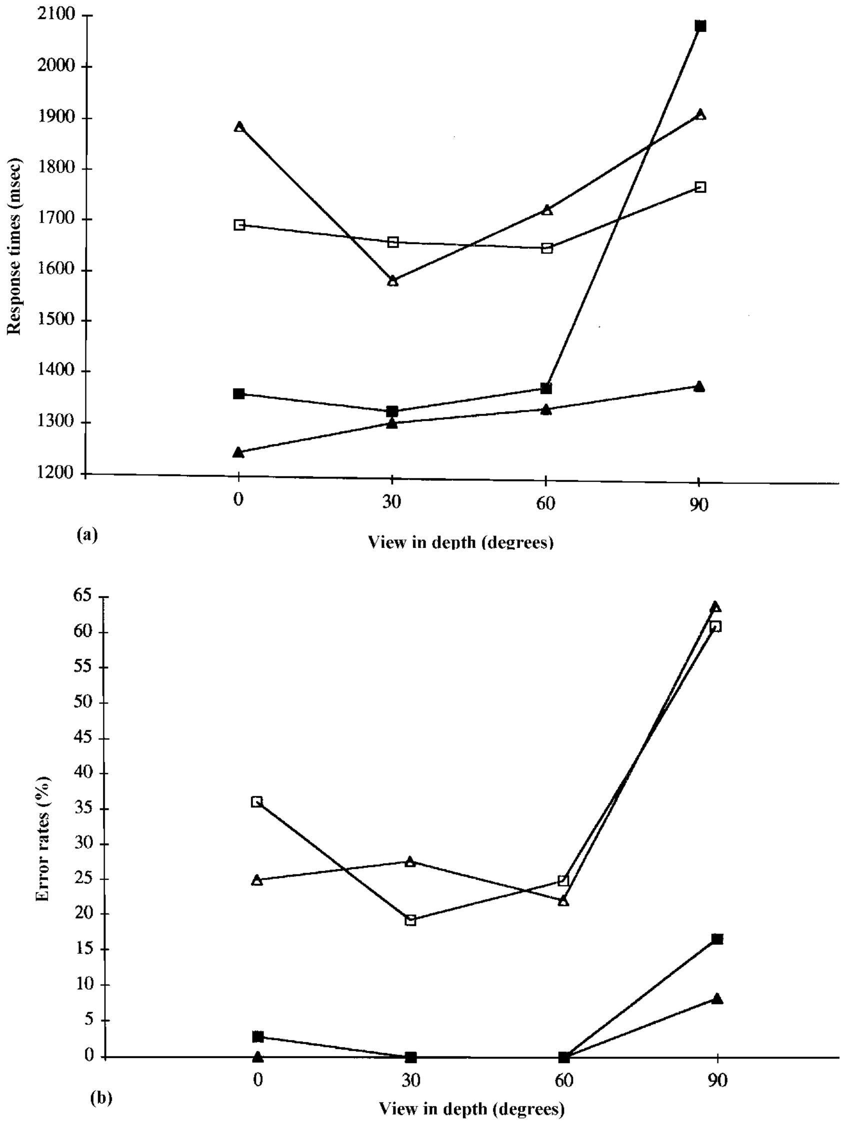

FIG. 4. Mean correct response times (a) and percentage errors rates (b) for match trials for silhouettes and line drawings, as a function of view in depth, for the visual agnosic, HJA, and the age-matched control, IA, in Experiment 3. □, silhouettes, HJA; △, line drawings, HJA; ■, silhouettes, IA; ▲, line drawings, IA.

between his accuracy of verification of line drawings and silhouettes, across the full range of views tested, and possible floor effects did not constrain the 0°, 30° and 60° view data.

Further support for the conclusion that HJA was equally impaired at identifying 90° line drawings and silhouettes, and that this result was not an artefact of a floor effect, comes from a subsequent unpublished study which we conducted with HJA alone. In this second study, a word was presented for 1500 msec followed by two pictures of different objects, displayed either side of fixation. The target picture depicted the object named by the word, whereas the other picture was a visually similar distractor item. HJA's task was to make a speeded keypress response to indicate whether the target picture was on the right or left side of the screen. Line drawings and silhouettes were presented separately, each in two blocks of trials, and target pictures were depicted at either 60° or 90° views within each block. This two alternative forced choice task was easier than the match/mismatch task employed in Experiment 3, and HJA was well above chance at discriminating 90° target objects from distractor items, making only 24 errors in 144 trials.

There were again no significant effects on RTs ($F < 1$ in all cases). However, replicating the results of the current study, there were significant effects of view on errors for silhouettes ($\chi^2 = 4.2$, d.f. = 1, $p < .05$), with 8/36 errors to 90° views but only 2/36 errors to 60° views, and, marginally, for line drawings ($\chi^2 = 3.2$, d.f. = 1, $p < .08$), with 10/36 errors to 90° views and 4/36 errors to 60° views. Once again, there was no evidence that silhouettes were identified less accurately than line drawings; in fact, any trend was in the opposite direction, with 10/72 errors to silhouettes and 14/72 errors to line drawings.

IA. An analysis of variance was conducted on the mean correct RTs for match trials for the age-matched control, IA, again treating each RT as a separate subject. There were two between-subjects factors, stimulus and view. The main effect of view was significant, $F(3,269) = 8.0$, MSe = 354024, $p < .001$. Foreshortened, 90° views were verified slower than all other views ($p < .01$, Newman-Keuls analysis). Stimulus was also significant, $F(1,269) = 10.0$, MSe = 354024, $p < .003$. Silhouettes were verified more slowly than line drawings. Finally, there was a significant interaction of view × stimulus, $F(3,269) = 5.0$, MSe = 354024, $p < .003$. Foreshortened, 90° silhouettes were verified more slowly than any other stimulus ($p < .01$; Newman-Keuls analysis). There were no other significant differences.

For errors, there was a significant effect of view for silhouettes ($\chi^2 = 8.9$, d.f. = 3, $p < .04$), but not for line drawings ($\chi^2 = 3.0$, d.f. = 3, $p > .3$). If the foreshortened, 90° view was omitted from the χ^2 analysis, the effect of view was no longer significant for silhouettes ($\chi^2 = 2.0$, d.f. = 2, $p > .3$) and there were no errors for line drawings. If the 0° view was omitted from the analysis, the effect of view was still significant for silhouettes ($\chi^2 = 8.3$, d.f. = 2, $p < .02$), but was again not significant for line drawings ($\chi^2 = 2.0$, d.f. = 2, $p > .3$).

Overall, like the young controls tested in Experiment 2, IA was less accurate at verifying silhouettes than line drawings ($\chi^2 = 5.1$, d.f. = 1, $p < .03$, averaging over all views). In addition, as for RTs, there was an interaction between the effects of stimulus and view on the accuracy of IA's performance. There was no significant difference between IA's accuracy at verifying line drawings and silhouettes at 0° views ($\chi^2 = 1.0$, d.f. = 1, $p > .3$), and there were no errors for 30° and 60° views. However, for 90° views, IA made more errors to silhouettes than to line drawings ($\chi^2 = 4.2$, d.f. = 1, $p < .04$).

Thus for both RTs and errors, IA's results mirrored those obtained for young normal subjects in Experiment 2, with a clear interaction between stimulus and view. No such interaction was observed in HJA's data.

Results: Mismatch Trials

For HJA the mean correct RT for mismatch trials was 1786 msec and 1736 msec, and the error rate was 26% and 33%, for line drawings and silhouettes respectively. For the age-matched control, IA, the mean correct RT for mismatch trials was 1565 msec and 1835 msec, and the error rate was 10% and 13%, for line drawings and silhouettes respectively.

Discussion

First, in the context of generally poor performance, HJA found the verification of foreshortened, 90° views particularly difficult, as do normals. Second, HJA differed from normals in that his verification of line drawings and silhouettes was very similar across all views, including 90° views. For foreshortened, 90° views, HJA actually made 3% fewer verification errors to silhouettes compared to line drawings, while for 0°, 30° and 60° views, he only made 2% more errors on average to silhouettes compared to line drawings. These results suggest that, for HJA, unlike IA and the subjects in Experiment 2, adding internal, local detail did not aid verification. HJA's results can be accounted for by assuming that he relied solely on global shape information derived from the occluding contour of the stimulus for identification, and hence he did not enjoy an advantage for line drawings over silhouettes, even for highly foreshortened, 90° views.

As described above, earlier studies with HJA had suggested that global shape information is more rapidly available to HJA than local feature information, and that HJA maintains global and local information independently, unlike normal subjects. In the present task, the occluding contour (from which, we assume, global shape information was principally derived) was identical across comparable line drawings and silhouettes. We propose that the foreshortening, 90° disadvantage for silhouettes found for non-brain-damaged subjects can be attributed to the relatively uninformative global shape information provided by the occluding contour of highly foreshortened, 90° views, compared to 0°, 30° and 60° views. If HJA could only use information derived from the occluding contour of stimuli, then identical performance across line drawings and silhouettes would be expected for all views, just as we found.

The results reported here for HJA—namely, a strong foreshortening disadvantage and equally poor identification of line drawings and silhouettes—might initially appear incompatible with two results reported from earlier studies. First, Humphreys and Riddoch (1984) reported that HJA was better at naming foreshortened, 90° views of objects compared to views which obscured important distinguishing features of objects, and that he was not significantly worse at naming foreshortened, 90° views, compared to more canonical views. Humphreys and Riddoch suggested that HJA relied primarily on local distinctive feature information to identify objects. When local features were less salient, in the minimal features condition, HJA was impaired. However, in these previous picture identification studies, HJA was not required to produce a speeded response (Humphreys & Riddoch, 1984; Riddoch & Humphreys, 1987). When he attempted to perform such tasks, he examined stimuli painstakingly, feature by feature. This strategy would be too slow to permit a speeded response, as was required here. Instead, in speeded tasks such as Experiment 3, HJA may have been forced to use only the more rapidly available global shape information (Humphreys et al., 1985), and so foreshortened, 90° views would be at a disadvantage relative to more canonical views.

Second, Riddoch and Humphreys (1987) reported that HJA actually responded more accurately to silhouettes than to line drawings in an object decision task. Riddoch and Humphreys (1987) argued that, due to HJA's problem in integrating local and global shape information, local detail sometimes led him to parse stimuli incorrectly. This caused more difficulties for line drawings than for silhouettes, since line drawings possessed more distracting, detailed information than silhouettes. However, if, as we have argued, HJA was not only poor at integrating local and global information, but was also slow to extract local information, then the disruptive effects of local detail should not have hindered his performance when he made a speeded response (just as incongruent local letters did not interfere with HJA's responses to global letters in the Navon task). Thus, we suggest that, in Experiment 3, HJA's performance was based primarily on global shape information derived from the occluding contour of the stimulus.

The control subject, IA, produced the same pattern of RT and error responses as the much younger subjects tested in Experiment 2. This suggests that it is unlikely that changes in the task (for instance, the increased number of blocks completed by each subject, and the within-subjects comparison of the verification of line drawings and silhouettes), or the age differences between the subjects, caused the qualitative change in the performance of HJA relative to the normal subjects tested in Experiment 2.

GENERAL DISCUSSION

The results of the three studies reported here revealed that highly foreshortened, 90° views were more difficult to identify than more canonical views of an object. Furthermore, for normal subjects, the foreshortening disadvantage was exacerbated when silhouettes rather than line drawings were presented, in both naming and verification tasks. However, this stimulus × view interaction was not observed for the visual agnosic patient, HJA, in a speeded verification task. We suggest that HJA could not take advantage of the additional local internal detail available in line drawings relative to otherwise comparable silhouettes, because he was abnormally slow to extract local information and to integrate it with global information. These results support and extend previous experimental and neuropsychological findings (Hayward, 1998; Humphrey & Jolicoeur, 1993; Humphreys & Riddoch, 1984; Lawson & Humphreys, 1996, 1998; Srinivas, 1993; Warrington & Taylor, 1973, 1978), and allow us to draw a number of conclusions about the effects of depth rotation on the efficiency of object identification.

One account of the effects of viewpoint on human visual object identification is that all view effects reflect variation in the ease of assigning the main axis of a stimulus, in order to derive an axis-based image description. This account predicts, first, that if foreshortening the main axis of an object makes the axis more difficult to derive from the image, then this should in turn make identification more difficult; and, second, if foreshortening has equal effects on the ease of assigning the main axis for line drawings and silhouettes, then the same pattern of view effects should be observed across the two types of stimuli. We tested this account, assuming, first, that the ease of assigning the main axis is directly related to the physical rotation of the object away from a fully foreshortened view (see also Appendix 3), and, second, that the main axis is assigned using information derived solely from the occluding contour of the image, and not from internal details. If these assumptions hold, then (1) increasingly foreshortened views should be harder to identify and (2) equal view effects should be observed for matched line drawings and silhouettes.

The results did not support these predictions. There was no trend towards more difficult identification of more foreshortened views. The foreshortening disadvantage was confined to the most foreshortened, 90° view (Experiments 1 and 2; although see also Lawson & Humphreys, 1998, experiment 2). In addition, this disadvantage was much greater for silhouettes than for line drawings, both for picture naming (compare Experiment 1 here with Lawson & Humphreys, 1998, experiment 1; see Table 1 here) and for word–picture verification (Experiment 2). We suggest that the occluding contour of an object generally provides sufficient information for identification if the object is depicted from a standard view, but not if it is depicted from a highly foreshortened, 90° view. For highly foreshortened line drawings, normal subjects can use internal details to aid identification. The loss of these details makes the identification of highly foreshortened silhouettes extremely difficult.

Converging evidence for this argument comes from the study of the agnosic patient, HJA. Previous evidence—for instance, from the Navon task—suggests that HJA can process global shape information relatively efficiently, but that he is impaired at rapidly detecting local information, and also at integrating it with global information (Boucart & Humphreys, 1992; Humphreys et al., 1985). Unlike neurologically intact subjects, HJA was no better at verifying line drawings than silhouettes, even for the most foreshortened, 90° views. This result is consistent with HJA failing to make efficient use of local internal details in line drawings, and with his performance being reliant solely on global shape information extracted from the occluding contour of stimuli. Moreover, HJA showed a strong foreshortening disadvantage for both line drawings and silhouettes. This last result suggests that one important effect of foreshortening, is to reduce the availability of useful global shape information from the occluding contour of stimuli, which causes a disruption of object identification.

We conclude that internal details can strongly benefit object identification, specifically for the identification of highly foreshortened, 90° views of objects.

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APPENDIX 1

The 36 objects presented in Experiments 1–3

BANANA	KANGAROO	SCREWDRIVER
BONE	KEY	SHOE
CAMEL	KNIFE	SPANNER
CAN-OPENER	LEEK	SPECTACLES
CAR	LOAF	SPOON
CLOTHES PEG	PAPERCLIP	STAPLER
COAT-HANGER	PEN	TELEPHONE
COMB	PENCIL	TENNIS RACQUET
CORKSCREW	RAZOR	TOOTHBRUSH
FORK	RULER	TORCH
HAMMER	SAW	TRAIN
IRON	SCISSORS	WHISK

APPENDIX 2

The 36 mismatch words and objects presented in Experiments 2 and 3

Word Presented	*Object Depicted*	*Word Presented*	*Object Depicted*
BATH-MAT	GRATER	ICE-LOLLY	PAINTBRUSH
BOOK	SUITCASE	JELLY	CAP
BOOMERANG	GUN	LADDER	CHAIR
BRACELET	WATCH	LADLE	SAUCEPAN
BUCKET	KETTLE	LEMON	MELON
CAKE	SANDWICH	MOTORBIKE	WHEELBARROW
CANDLE	CIGARETTE	NAIL	SCREW
COMPUTER	CALCULATOR	PARCEL	ENVELOPE
COOKER	RECORD PLAYER	ROCKET	AEROPLANE
CROWN	CANDELABRA	ROSE	CELERY
DINOSAUR	TORTOISE	RUCKSACK	HANDBAG
DOG	GOAT	SCORPION	LOBSTER
DUSTER	FLOWER	SOCK	RUBBER-BOOT
HAIR-DRYER	WHISTLE	TOASTER	BRUSH
HEAD-PHONES	LAMP	TONGS	COMPASSES
HELMET	CHAINSAW	TRACTOR	BINOCULARS
HIPPOPOTAMUS	RHINOCEROS	TRAM	BUS
HORN	PIPE	WHEEL	DARTBOARD

APPENDIX 3

Analyses of axis availability and data from Experiments 1 and 2

In Experiments 1 and 2, we assumed that the availability of the main axis of elongation of the object in a particular view depended on, or at least was strongly correlated to, the angle of view from which the object was depicted. We also suggested that, on axis-based accounts, axis availability should influence the ease of recognition of an object across the full range of viewpoints. However, both of these points must be considered further. First, image-based information must presumably determine the availability of the main axis of an object, but the ease with which the axis can be assigned from a given view may not correlate closely to the actual physical view from which the object is depicted. Second, axis availability may only be relevant across a restricted range of viewpoints; for instance just for those views where the main three-dimensional axis of elongation of the object does not coincide with the main two-dimensional axis of elongation of the image. It may be irrelevant if the main axis of the object is somewhat longer in certain views compared to other views (for instance, as is often true for 0° views relative to 30° views), so long as, *for a given view*, the main axis of the object still coincides with, or is similar to, the longest two-dimensional axis of elongation of the image (which was not always the case, especially for the 60°, 90° and 120° views).

To try to address these points, we used additional criteria to define four new measures of the availability of the main axis of the object in a particular image (in addition to the angle of view of the main axis of elongation of the object relative to the line of sight of the subject, which provided our original measure). We used several measures because we do not know how (if at all) our subjects assigned the main axis of the object to a given stimulus, and what information they used; note also that most theorists postulating axis-based accounts of view effects are not clear on this point (e.g. Marr, 1982).

1. The first additional measure was the aspect ratio of the depicted object. The aspect ratio was defined as the width-to-height ratio of the smallest rectangle which could enclose the stimulus (with the stipulation that the sides of the rectangle were parallel to the sides of the screen).
2. The second measure was the angle of the minimum perpendicular axis relative to the horizontal base of the screen. The minimum perpendicular axis was defined as the axis which minimized the length of the longest perpendicular from the axis to the edge of the stimulus (see Figure A1) Thus for a pencil, this axis would be in the position of the pencil lead, since the maximum length of a perpendicular from this axis would be just the radius of the cross-section of the pencil. Any other axis would increase the length of this maximum perpendicular. Similarly, for a bottle, the minimum perpendicular axis would pass from the centre of the top opening through to the centre of the base.

3, 4. The third and fourth measures were the angle and length of the assigned subjective axis, where the angle was measured relative to the horizontal base of the screen. The assigned subjective axis was defined by the first experimenter as the angle and two-dimensional extent of the main three-dimensional axis of elongation of the object in a given stimulus. The positions of the minimum perpendicular and the assigned subjective axes were usually very similar in a given stimulus.

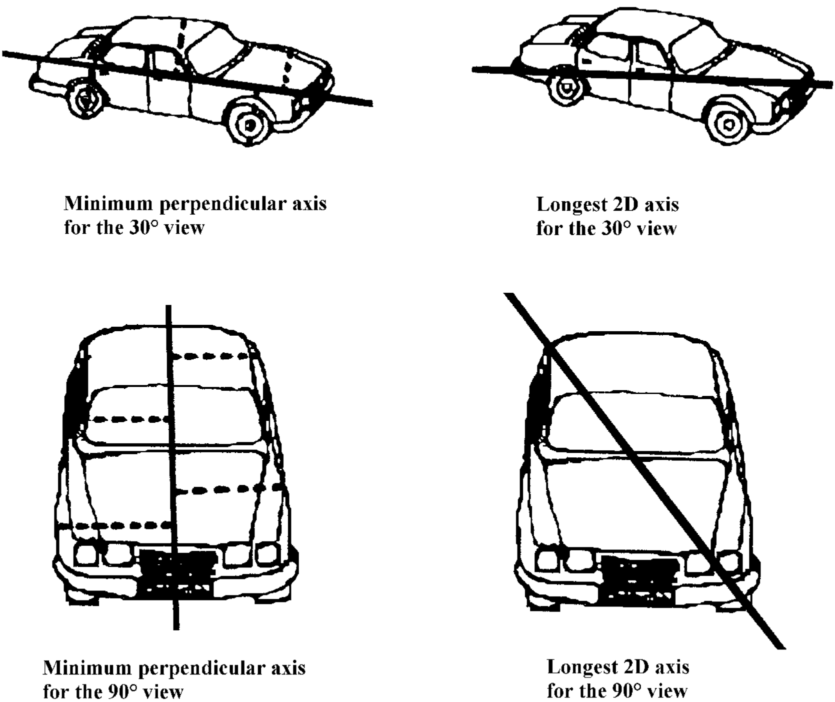


FIG. A1. On the left are two examples of the minimum perpendicular axis of the 30° view (top) and the 90° view (bottom) of the car, shown as a black solid line, together with four perpendiculars to this axis, shown as black dotted lines. The axis attempts to minimize the length of the longest perpendicular to the axis. On the right are two examples of the longest two-dimensional axis of the 30° view (top) and the 90° view (bottom) of the car, shown as a black solid line.

Note that we did not include a measure of axis availability which simply compared the longest available two-dimensional axis for different views of an object. Such a measure might initially appear the most appropriate measure of axis availability; however, such axes are usually psychologically implausible, since they disregard any object symmetry, and generally run across a diagonal of the stimulus (see Figure A1, especially for the 90° view). For instance, for a door seen face on, the longest two-dimensional axis would run obliquely between diagonally opposite corners, whereas both the minimum perpendicular and the assigned subjective axes would run vertically, passing midway horizontally between the top and the bottom pairs of corners.

Mean values for each of these four measures are plotted against the angle of view of the object in Figure A2. Note that there is a clear correlation between each measure and the angle of view, suggesting that all the new measures were strongly related to the angle of view. For each measure, the main axis becomes less available with increased foreshortening over 0°, 30° and 60° views, and is hardest to access in the 90° view. This contrasts to the naming and verification results from Experiments 1 and 2, which revealed no disadvantage in identifying 60° views relative to the less foreshortened, 0° and 30° views, with only 90° views being disadvantaged by foreshortening.

We then tested whether the foreshortened view disadvantage specifically reflected variation in any of our four measures of axis availability. For each measure in turn, the 36 objects tested in Experiments 1 and 2 were ordered with respect to that measure of axis availability for the 90° view. On the basis of this ordering, the objects were divided into six groups, each comprising six objects. The main axis of 90° views was assessed as being most available for the group 1 objects, and so these objects were predicted to show the smallest foreshortened, 90° view disadvantage, while the main axis of 90° views was measured as being hardest to access for the group 6 objects, which were therefore predicted to show the largest foreshortened, 90° view disadvantage. For instance, for assigned subjective axis length, the spoon (with an available axis length of 57 mm in the 90° view) was placed in group 1, whereas the iron (with an available axis length of 27 mm in the 90° view) was placed in group 6. We concentrated on axis availability for the 90° view because the results of Experiments 1 and 2 indicated that view effects were confined largely to the 90° view, and because axis availability may only be important when there are clear, alternative, competing axes in the stimulus, as appeared to be the case for many 90° views.

We repeated the analyses of variance for items for Experiment 1 (for errors only, with one within-items factor of view at 6 levels) and for Experiment 2 (for both RTs and errors, with two within-items factors of view at four levels and of stimulus at two levels), but in addition we included axis availability as a between-items factor with six levels. Each re-analysis was performed four times, using the four different measures of axis availability in turn (aspect ratio, angle of the minimum perpendicular axis, and angle and length of the assigned subjective axis).

For aspect ratio, angle of the minimum perpendicular axis and angle of the assigned subjective axis, there was no main effect of the axis availability factor and no interaction of this factor with any other factor in any of these analyses. Importantly, in addition, in no case was there a trend towards a greater foreshortened, 90° view disadvantage for those objects for which the main axis was measured to be less available in the 90° view, as one would predict if the availability of the main axis of the object in a given stimulus was an important factor determining view effects on object identification. The results for these additional analyses were, inevitably, rather noisy, since there was much variation in the size of view effects across individual items, and axis availability was arbitrarily divided into six levels, with just six items at each level. However, despite this, view effects were broadly similar and consistent across the different levels of axis availability for these three measures. Thus, from these analyses, there was no evidence that variation in our measures of aspect ratio, angle of the minimum perpendicular axis or angle of the assigned subjective axis related strongly to recognition performance.

In contrast, there did initially appear to be some, albeit weak, evidence that variation in the length of the assigned subjective axis might influence view effects on recognition. In Experiment 1, although there was no main effect of axis availability for the measure of subjective axis length ($F < 1$), there was a significant interaction of axis availability and view, $F_2(25,150) = 1.6$, MSe = 1.188, $p < .05$. There was a greater foreshortened, 90° view disadvantage for the six items at level 6 (shortest assigned subjective axis length for the 90° view) than for the items at the other, easier levels. Note that the interaction was no longer significant if the level 6 items were removed from the analysis. Similarly, in Experiment 2, there were no significant effects, but for both RTs and errors there was a trend towards an interaction between axis availability and view (but with $F < 2$, $p > .1$ in both cases) which mirrored that obtained in Experiment 1. Overall, for both Experiments 1 and 2, the influence of axis availability (as measured by the length of the assigned subjective axis) on performance was relatively small and was largely confined to the six level 6 items.

Nevertheless, to investigate this further, we repeated the initial items analyses for Experiments 1 and 2 (i.e. only including view and stimulus, not axis availability, as factors), but now omitting the six level 6 items (for axis availability as measured by the length of the assigned subjective axis, these were camel, iron, kangaroo, telephone, torch and train). We found the same pattern of significant effects as we reported in our initial analyses above, except that in Experiment 2 the interaction of view and stimulus for errors was no longer significant. Thus the results originally reported for Experiments 1 and 2 still largely held, even without the level 6 items which were primarily responsible for the effects of axis availability as measured by the length of the assigned subjective axis.

Finally, all the above analyses for each of the four measures of axis availability were repeated, but now items were allocated to the six axis availability groups based upon the size of the *difference* in a given measure of axis availability for 60° views relative to 90° views. This reallocation of objects to axis availability groups allowed us to investigate whether the change in axis availability from 60° views to 90° views could be the cause of the large change in object identification performance from 60° views (which were recognized efficiently) to 90° views (which were strongly disadvantaged). However, there were no significant interactions which included axis availability for the measures of angle of the minimum perpendicular axis, and angle and length of the assigned subjective axis. For the aspect ratio measure, there was a significant interaction between view and axis availability in both Experiments 1 (for errors) and Experiment 2 (for reaction times only). However, this interaction was in the opposite direction to that predicted by the axis availability hypothesis. The objects with the smallest change in aspect ratio from the 60° view to the 90° view revealed the largest foreshortened, 90° view disadvantage. Thus, the four measures of axis availability again did not appear to relate strongly to identification performance following this reallocation of objects to axis availability groups, based now on the difference in axis availability from 60° views to 90° views, rather than based simply on axis availability for the 90° view, as in the initial analyses.

In conclusion, our four different measures of the availability of the main axis of an object all related in a similar way to the angle of view of the object (see Figure A2), which was our original measure of axis availability used in Experiments 1–3. Our subsequent analyses of the results of Experiments 1 and 2 described in this Appendix indicated that none of these four, additional measures of axis availability was a strong predictor of variation in view effects across different objects, suggesting that the availability of the main axis of the object is not a major determinant of the strength of view effects. Nevertheless, we obviously cannot rule out the possibility that a different measure of axis availability might be a more efficient predictor of identification performance.

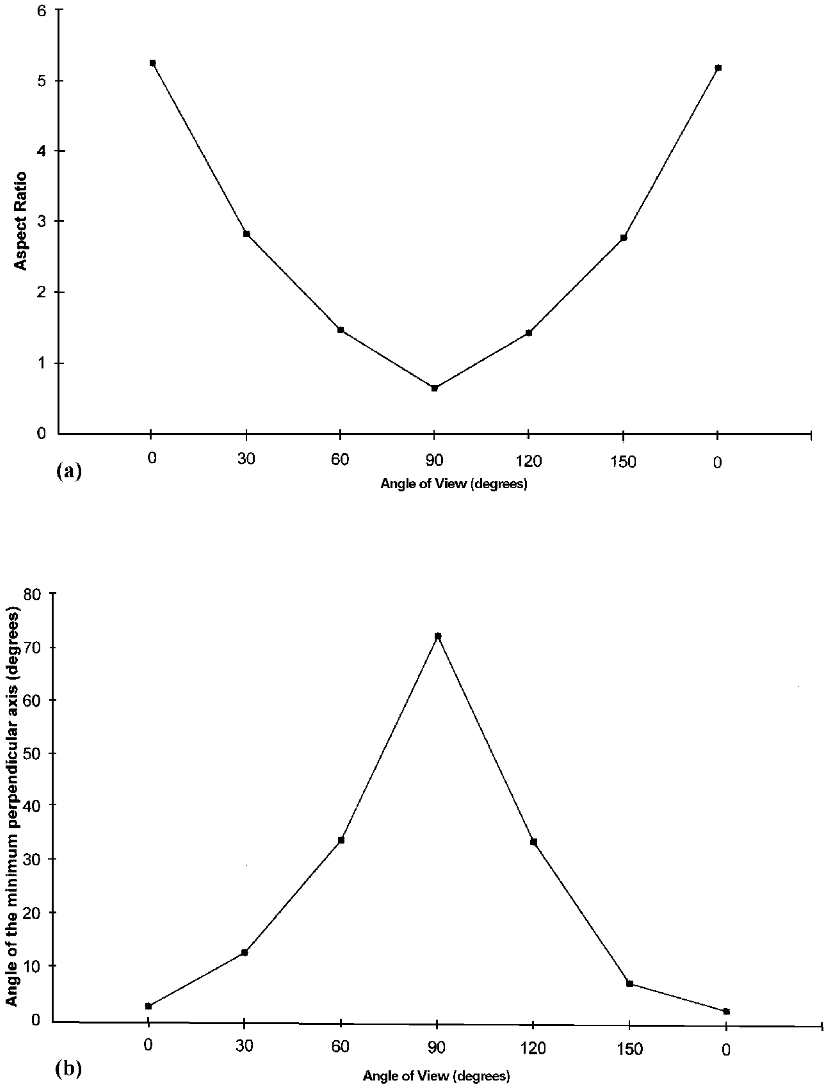
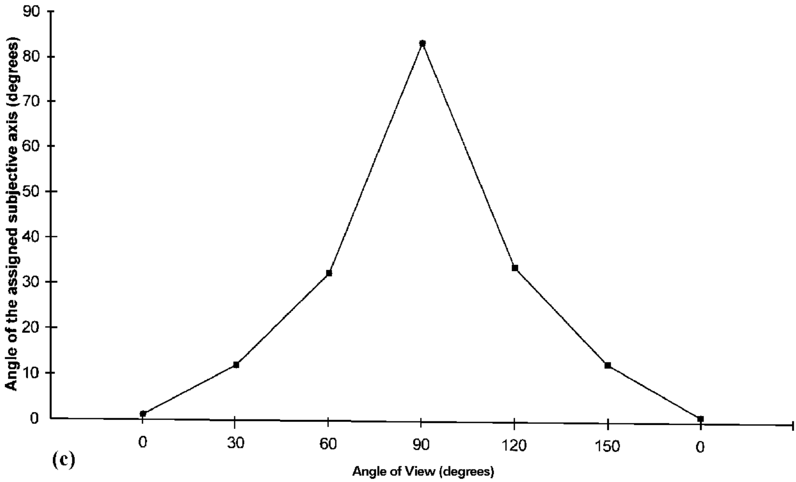
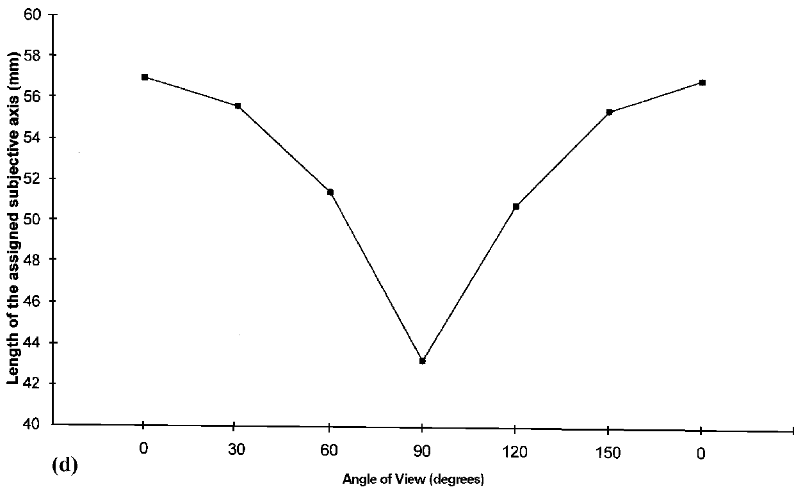


FIG. A2. Mean values for the measures of (a) aspect ratio, (b) angle of the minimum perpendicular axis (c) angle of the assigned subjective axis and (d) length of the assigned subjective axis, as a function



(c)



(d)

of the angle of view in depth of an object. See Appendix 3 for further details on the definition and measurement of these measures. Note that values for 0° views are plotted twice, so that the graphs are symmetrical; however, data for 0° views were only entered once in the analyses.