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Display symmetry affects positional specificity in *same–different* judgment of pairs of novel visual patterns

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Abstract

Deciding whether a novel visual pattern is the *same* as or *different* from a previously seen reference is easier if both stimuli are presented to the same rather than to different locations in the field of view (Foster & Kahn (1985). *Biological Cybernetics*, 51, 305–312; Dill & Fahle (1998). *Perception and Psychophysics*, 60, 65–81). We investigated whether pattern symmetry interacts with the effect of translation. Patterns were small dot-clouds which could be mirror-symmetric or asymmetric. Translations were displacements of the visual pattern symmetrically across the fovea, either left–right or above–below. We found that *same–different* discriminations were worse (less accurate and slower) for translated patterns, to an extent which in general was not influenced by pattern symmetry, or pattern orientation, or direction of displacement. However, if the displaced pattern was a mirror image of the original one (along the trajectory of the displacement), then performance was largely invariant to translation. Both positional specificity and its reduction in symmetric displays may be explained by location-specific pre-processing of the visual input. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

1.1. Complete translation-invariance?

When an object changes its position relative to the direction of gaze its projection on the retina is shifted to a new location. Recognizing an object despite its appearance at different locations is a fundamental problem of visual perception. Although our brain seems to be capable of tolerating shifts in the visual field at least to some extent, the limitations of translation invariance have only rarely been investigated. Experimental evidence is not only scarce, but also contradictory. While Biederman and Cooper (1991) reported complete *translation invariance* in priming studies, training experiments (Nazir & O'Regan, 1990; Dill & Fahle, 1997) uncovered considerable 'positional specificity' of pattern memory.

Studies by Foster and Kahn (1985) and Dill and Fahle (1998) have shown that *same–different* judgments for random-dot clouds are also sensitive to changes of visual field location. Both reports indicate that it is significantly easier to determine the identity of two sequentially displayed random patterns if both stimuli are presented to the same rather than to different positions in the visual field, hence there is no complete translation invariance. Control experiments have shown that retinal after-images, spatial attention, and eye movements cannot explain this *displacement effect*, i.e. the lack of translation invariance (Dill & Fahle, 1998). The displacement effect, or lack of translation invariance is: (a) specific for *same* trials; (b) equally large for horizontal and vertical translations; and (c) stronger for similar than for arbitrarily *different* patterns.

1.2. Previous models of positional specificity

Several explanations have been offered to account for positional specificity in *same–different* discrimination

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tasks. Biederman and Cooper (1992) suggested that pattern vision comprises at least two subsystems: Metric information about, for example, location and size of a stimulus is processed and stored independently of a second system that relies on the shape of an object. According to these authors, shape recognition itself is translation and scale invariant while the metric system is actually sensitive to changes of these two features. When taking a *same–different* decision, information on shape and metric properties cannot be separated. Presenting patterns to different locations may, therefore, bias decisions subconsciously even if subjects are instructed to ignore metric information (*metric bias hypothesis*). There is substantial evidence from a variety of *same–different* studies that task-irrelevant stimulus properties can indeed influence performance (Dixon & Just, 1978; Farell, 1985; Proctor, Van Zandt & Watson, 1990). Several findings, however, are difficult to explain by a simple metric bias. For example, the discrepancy between *same* and *different* trials decreases if control and displacement are tested in separate sessions, while the displacement effect itself retains its size (Dill & Fahle, 1998; see there for a detailed discussion of the *same–different* discrepancy).

Foster and Kahn (1985, Kahn & Foster, 1981, 1986; Foster, 1984, 1991) postulated mirror reflection and normalization operations that align the two successive visual inputs for comparison (*normalization hypothesis*). Mental transformation accounts of various types have been very popular for several decades. In general, they are relying on the frequent observation that response times and/or error rates in recognition tasks depend monotonically on the size of the difference between two transformed exemplars of the same stimulus (e.g. Arnoult, 1954; Shepard & Metzler, 1971; Rock, 1973; Bundesen & Larsen, 1975; Jolicoeur, 1985; Corballis, 1988).¹ A severe problem for normalization models is that in many *same–different* experiments performance in *different* trials is not affected by the size of the stimulus transformation. A normalization operation, therefore, cannot be performed before the actual stimulus comparison (Jolicoeur & Besner, 1987; Dill & Fahle, 1998).

Recently, Dill and Fahle (1998) explained the lack of complete translation invariance by assuming contributions of both position-sensitive and translation-invariant feature detectors to *same*-recognition (*local-feature hypothesis*). After translation of a stimulus, its re-detection is possible only for those features that are recognized by elements with larger receptive fields, while

more position-specific detectors no longer respond, thus reducing the available evidence for *same*. The local-feature hypothesis could account for a large number of data (Dill & Fahle, 1998). However, in order to explain the large size of the displacement effect even for translations as small as 2° across the visual field the position tuning of the local elements must be very precise, in a range that corresponds to early stages of visual processing such as the primary visual cortex (V1).²

1.3. Positional specificity: the influence of symmetry

All three models fail to explain a striking stimulus dependence of the displacement effect. In experiments with clouds of randomly distributed dots positional specificity was large and highly significant. However, only a small decrease of performance was detectable after translation of random black-and-white checkerboards (Dill & Fahle, 1998)³. The most obvious difference between the two pattern types seemed to be that we had introduced one non-random feature into checkerboards that was missing in dot clouds: each checkerboard was bilaterally symmetric with respect to its central midline whereas dot clouds were completely random and did not display any intended symmetry.

An influence of stimulus symmetry on pattern perception has been reported before. In studies on letter matching, Fox (1974) (see also, Egeth, Brownell & Geoffrion, 1976) had already found that letter pairs consisting of symmetrical letters are judged as *same* faster than are pairs of asymmetrical letters. He interpreted this finding as indicating that the visual system exploits symmetry as a structural diagnostic that is weighted as evidence for sameness. In terms of the local-feature model one might say that a high proportion of invariant detectors is specific to symmetrical features. Recognition of symmetrical patterns may, therefore, be less influenced by displacement. Such a specialization of the brain would not be surprising given the abundance of ecologically valid symmetrical stimuli that humans need to identify. The visual system may be especially equipped by nature or trained during early life to recognize symmetrical stimuli.

² Contributions from V1 have been hypothesised for a variety of perceptual learning phenomena (Poggio, Fahle & Edelman, 1992; Fahle & Edelman, 1993; Fahle, 1994; Sagi & Tanne, 1994; Gilbert, 1994; Fahle, Edelman & Poggio, 1995). However, involvement of the primary visual cortex in higher perceptual processes like shape discrimination is far from being established.

³ The latter finding is even more striking considering that matrix stimuli were displaced over a much larger range (4.8° compared to 2° for dot clouds). Both stimulus types differed in a number of parameters. For example, checkerboards were slightly larger (0.85° width compared to 0.5° for dot clouds).

¹ Based on anatomical observations and neural network modelling, Van Essen and co-workers (Anderson & Van Essen, 1987; Olshausen, Anderson & Van Essen, 1993; Van Essen, Anderson & Olshausen, 1994; cf., however, Fahle, 1995) designed circuits for cortical processing that could underlie normalization of size and position.

Richards (1978) reproduced these findings, but pointed to the confusion of two types of symmetry in Fox's experiments. When presenting pairs of symmetrical letters like, for example, AA, the local symmetry of each letter A is accompanied by global *display symmetry* that results from both As being mirror images of each other, relative to a vertical axis between them. Richards showed that when symmetrical letters are rotated in the image plane recognition is only speeded if display symmetry is preserved. Therefore, he attributed improved performance to display-symmetry effects rather than to the use of *letter symmetry* as a structural diagnostic. Richards extended these findings to random-dot clouds and found that symmetry facilitation was even more pronounced with these unfamiliar stimuli than with letters.

Effects of *display symmetry* have also been found by Kahn and Foster (1981, 1986; Foster, 1984, 1991). Two further studies, however, confirm Fox' (1974) interpretation that *stimulus symmetry* has direct impact on performance of pattern vision. Bagnara, Boles, Simion and Umiltà (1983) found that letter symmetry improves recognition in displays without a global symmetry axis. More recently, Quinlan (1995) confirmed both views by showing that for pairs of outline shapes both global and shape symmetry improve performance. However, like most of the above studies (except for Foster & Kahn, 1985, who did not test for pattern, but only for display symmetry) both Bagnara et al. (1983) and Quinlan (1995) tested matching only across different locations, i.e. they did not include control trials at constant location for comparison. Therefore, it cannot be decided whether an advantage of local shape-symmetry reflects better recognition in general of symmetric compared to asymmetric stimuli or whether shape symmetry directly interferes with mechanisms of translation invariance.

1.4. Pattern symmetry versus display symmetry

With the experiment presented in this paper we investigated whether, in addition to global display symmetry, properties of individual pattern stimuli can influence performance in *same-different* discrimination of symmetrical dot cloud stimuli. The symmetry axis in the stimuli (Fig. 1) could be oriented either vertically or horizontally yielding left-right (\Leftrightarrow) or top-bottom (\Updownarrow) bilateral symmetry. Both horizontal (HD) and vertical (VD) displacements across the fixation spot were tested. In separate control sessions performance with asymmetrical patterns was assessed in the same subjects.

Three different outcomes may be expected from this experiment. If only global display symmetry is responsible for a reduction of the displacement effect, then the orientation of the local symmetry axis relative to the point of fixation should be critical. Tangential orienta-

tion of the axis (conditions \Leftrightarrow HD and \Updownarrow VD) yields global display symmetry, while radial orientation (\Leftrightarrow VD and \Updownarrow HD) does not. If, on the other hand, intrinsic pattern symmetry affects positional specificity then performance should differ less between *same* and *different* locations for each of the symmetric conditions than for asymmetric dot clouds. Additionally, one may expect to find effects of absolute orientation of the symmetry axis, i.e. a general advantage of patterns with a vertical symmetry axis over other orientations (cf. Corballis & Roldan, 1975; Palmer & Hemenway, 1978; Fisher & Bornstein, 1982; Wenderoth, 1996; for a review see: Wagemans, 1995). All effects should be evident for both directions of displacement.

2. Methods

2.1. Subjects

Ten observers took part in the experiment. Except for one of the authors (MD) they were undergraduate students from Tübingen University being paid for their participation. Six subjects had already participated in similar psychophysical studies (Dill & Fahle, 1997, 1998). The remaining four had never been tested with this kind of stimulus or task. Each had normal (20/20) or corrected-to-be-normal visual acuity as assessed by Freiburg visual acuity tests (Bach, 1996). At the beginning of a session observers were informed about the design of the experiment (symmetry and location of stimuli; presentation sequence and task) and were instructed to maintain steady fixation throughout a trial. All subjects were explicitly told that their decisions on pattern identity in each trial should be independent of stimulus position and rely only on characteristics of the patterns themselves. It was emphasized that accuracy had to be considered as more important than speed, but that response times would also be recorded.

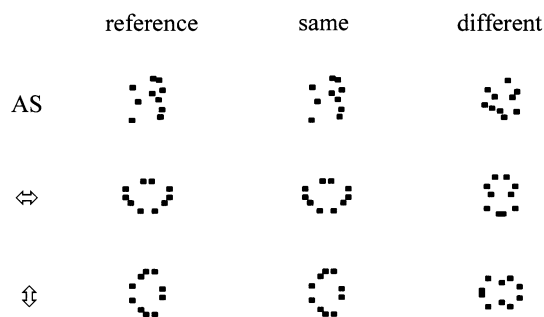


Fig. 1. Examples of dot cloud stimuli as they were used in the two experimental sessions. A reference dot cloud was presented at one of four positions in the visual field. One second later either the same or a different pattern appeared at either the same location or displaced to a new location. AS asymmetric dot clouds; \Leftrightarrow and \Updownarrow refer to dot clouds that display left-right and top-bottom bilateral symmetry, respectively.

2.2. Apparatus and stimuli

Stimuli were produced on a black and white raster monitor (refresh rate 75 Hz) controlled by a Macintosh Power PC. The display was viewed binocularly at a viewing distance of about 1 m. Stimuli consisted of 10 black dots (2×2 pixels each) randomly distributed in a square area of 28×28 pixels (about 0.5° side length). Dot clouds could be symmetrical relative to a horizontal (Fig. 1 \leftrightarrow) or to a vertical axis (\updownarrow), or they were asymmetrical (AS; cf. Dill & Fahle, 1998). Patterns were centered at 1° eccentricity on a uniform white background (mean luminance ca. 100 cd/m^2 ; total visual angle of the screen 12° width \times 16° height). Presentation time was short (96 ms) in order to prevent subjects from foveating a stimulus by a rapid saccade (Saslow, 1967). Since dot-cloud presentation was terminated by replacing the black dots with white background pixels, delayed stimulus offset due to phosphor decay can be excluded.

Fixation was aided by a black spot of about 0.13° diameter displayed throughout each trial at the middle of the monitor. Subjects communicated decisions by hand-held press buttons. A computer tone signaled the occurrence of incorrect responses to the subject directly after each trial.

2.3. Experimental design

The basic task of the experiment was to decide whether two sequentially presented dot clouds were identical (*same*) or *different*. The experiment was completed in two sessions on separate days, one testing recognition of asymmetric dot clouds and one involving symmetric dot clouds. Sessions consisted of five (asymmetric clouds) and ten (symmetric clouds) blocks, respectively, each block comprising 64 trials. Observers initiated a block by pressing either of the two buttons. Trials in each block were balanced for identity (*same* versus *different*), visual field (left, right, upper, lower), displacement conditions (0° [control] and 2° [displaced]) and—for the session with symmetrical clouds—orientation of the symmetry axis (\leftrightarrow versus \updownarrow). The order of trials in a block was randomized.

Individual trials started with the appearance of the fixation spot, followed 1 s later by the brief display of a reference dot cloud centered at 1° eccentricity in the parafoveal (left, right, upper, or lower) visual field (Fig. 2). After an interstimulus interval of 1 s the test stimulus appeared at either the same location or displaced by 2° across the fixation spot. In half of the trials the reference stimulus was presented above or below the fixation spot, in the remaining trials it appeared in the left or right visual field. Lateral stimuli were displaced horizontally into the opposite hemisphere (in 50% of the cases, the others being control trials with constant

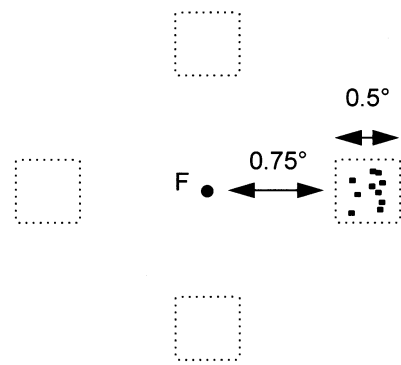


Fig. 2. The stimulus locations in the visual field. Subjects were instructed to fixate a dot in the center of the display (F). Dot clouds appeared at either of four locations centered 1° left, right, above, or below the fixation spot. Each pattern was randomly created within an area of 0.5° .

location). Patterns in the upper and lower visual field were displaced vertically.

Following the extinction of the second pattern, a question mark appeared requesting the observer's decision whether both stimuli were *same* or *different*. Patterns were not visually masked (cf. Dill & Fahle, 1998). The computer generated new reference and test patterns for each trial. In *different* trials reference and test clouds shared the type of pattern symmetry (\leftrightarrow , \updownarrow , AS), but were otherwise randomly different, i.e. not related by any kind of intended similarity. Two trials were separated by a 1-s break between the subject's response and the onset of the fixation spot for the next trial.

3. Results

Figs. 3 and 4 show mean accuracy (upper panels) and the mean RT over observers of median correct response times (RT; lower panels) for the two experimental sessions, respectively. RTs longer than 3 s were excluded from the analysis. To familiarize the reader with the major effects, we will first present results for asymmetric dot clouds (Fig. 3).

3.1. Asymmetric stimuli

The results of our new experiment confirm that *same-different* judgments are not completely translation invariant, and that the displacement effect is specific for *same* trials (filled squares in Fig. 3) and independent of the direction of displacement, i.e. present for both horizontal and vertical displacement (cf. Foster & Kahn, 1985; Dill & Fahle, 1998). While the number of correct responses is clearly lower for the displaced *same* trials (3°), the corresponding reaction times are strongly increased. Results for the *different*

trials (line symbols in Fig. 3), on the other hand, are very similar for both the same (0°) and displaced (3°) conditions.

To quantify these findings, data were subjected to three-way repeated-measures ANOVAs testing the influence of the main factors translation (control versus displaced), identity (*same* versus *different*), and direction of displacement (horizontal versus vertical). Observer decisions are more reliable if both stimuli are presented to the same (0° displacement) rather than to different (2° displacement) locations in the visual field ($F[1,9] = 45.18$; $P < 0.001$). The increase in error rate after displacement is accompanied by longer response times ($F[1,9] = 37.20$; $P < 0.001$), indicating that a speed-accuracy trade-off is not responsible for the displacement effect.

There is no significant overall difference in performance between *same* and *different* trials (accuracy: $F[1,9] = 2.20$; $P > 0.1$. RT: $F[1,9] = 1.47$; $P > 0.1$). However, displacements exert different effects on *same* versus *different* presentations as shown by strong interactions of the two factors translation and identity (accuracy: $F[1,9] = 17.03$; $P < 0.01$. RT: $F[1,9] = 21.43$; $P < 0.01$). *Same* detection is much impeded by translation (filled symbols in Fig. 3), while performance in *different* trials (open symbols) remains largely constant or even has a slight tendency to improve.

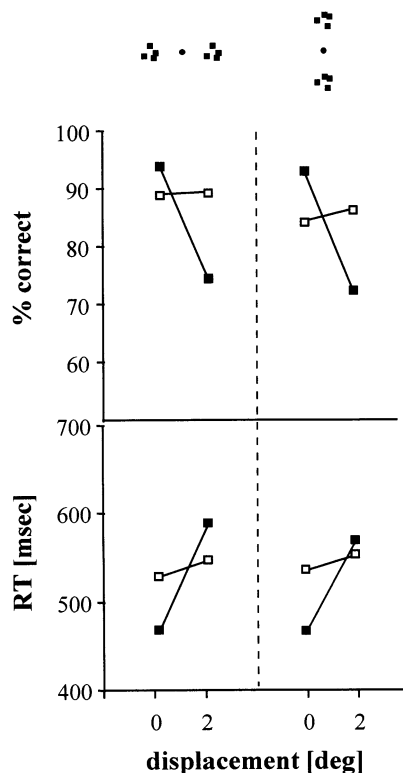


Fig. 3. Asymmetric dot clouds. Mean percentage of correct responses (upper panels) and mean of median RTs (lower panels). ■ *same* trials, □ *different* trials. $n = 10$ observers.

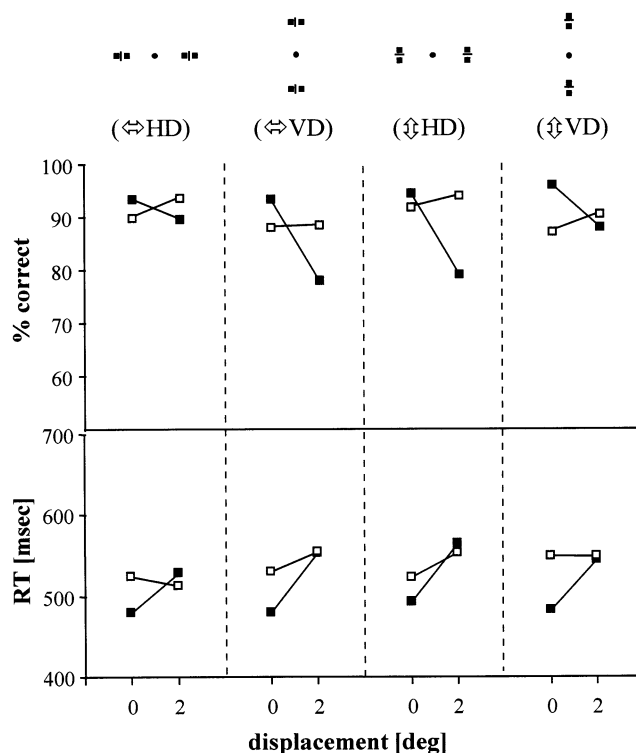


Fig. 4. Symmetric dot clouds. Mean percentage of correct responses (upper panels) and mean of median RTs (lower panels). ⇔HD left-right symmetric pattern, horizontal displacement; ⇕HD top-bottom symmetric pattern, horizontal displacement; ⇔VD left-right symmetric pattern, vertical displacement; ⇕VD top-bottom symmetric pattern, vertical displacement. ■ *same* trials, □ *different* trials. Same 10 observers as in Fig. 3.

While there is a minor advantage for laterally presented stimuli as compared to dot clouds above or below the fixation spot (accuracy: $F[1,9] = 7.35$; $P < 0.05$; RT: $F[1,9] = 0.03$; $P > 0.1$), direction of displacement has no influence on the size of the displacement effect or on its specificity for *same* trials as confirmed by insignificant two and three way interactions of direction of displacement with the other two factors ($P > 0.1$, respectively).

3.2. Symmetric stimuli

The two principal results with asymmetrical dot clouds are also found for symmetrical dot clouds (Fig. 4): a strong displacement effect (accuracy: $F[1,9] = 33.65$; $P < 0.001$; RT: $F[1,9] = 69.31$; $P < 0.001$) that is largely specific for *same* trials (accuracy: $F[1,9] = 17.81$; $P < 0.01$. RT: $F[1,9] = 16.40$; $P < 0.01$). Except for this interaction with translation there was again no overall difference between *same* and *different* trials (accuracy: $F[1,9] = 0.74$; $P > 0.1$. RT: $F[1,9] = 4.25$; $P < 0.1$).

The four experimental conditions (⇔HD, ⇕HD, ⇕VD, ⇔VD) are different concerning their overall performance (accuracy: $F[3,27] = 5.53$; $P < 0.01$. RT:

$F[3,27] = 4.02$; $P < 0.05$). In addition, they are not equally sensitive to translations (two-way interaction; accuracy: $F[3,27] = 4.20$; $P < 0.05$. RT: $F[3,27] = 2.43$; $P < 0.1$) and differ with respect to the results in *same* and *different* trials (two-way interaction; accuracy: $F[3,27] = 3.73$; $P < 0.05$. RT: $F[3,27] = 1.94$; $P > 0.1$). Three-way interactions, however, are not reliable (accuracy: $F[3,27] = 2.21$; $P > 0.1$. RT: $F[3,27] = 0.33$; $P > 0.1$).

To further specify the nature of these interactions, we grouped the four conditions according to: (a) the absolute orientation of the symmetry axis of the dot patterns (\Leftrightarrow versus \Uparrow); (b) global display symmetry, i.e. the orientation of the symmetry axis relative to the center of the display (radial versus tangential orientation); and (c) direction of displacement (HD versus VD).

3.2.1. Absolute orientation of the symmetry axis (\Leftrightarrow versus \Uparrow)

For both RT and error rates there is no indication of an influence of absolute axis orientation on the displacement effect. Although there may be a small overall difference between pooled \Leftrightarrow and \Uparrow conditions—at least for RT—(accuracy: $F[1,9] = 1.04$; $P > 0.1$; RT: $F[1,9] = 6.71$; $P < 0.05$), absolute orientation of the symmetry axis does not interact with translation (accuracy: $F[1,9] = 0.22$; $P > 0.1$; RT: $F[1,9] = 0.80$; $P > 0.1$).

3.2.2. Radial versus tangential orientation of the symmetry axis

The orientation of the symmetry axis relative to the fovea has critical influence on both general performance (accuracy: $F[1,9] = 40.45$; $P < 0.001$. RT: $F[1,9] = 18.34$; $P < 0.01$) and on the degree of translation invariance as judged by significant interactions between both factors (accuracy: $F[1,9] = 9.58$; $P < 0.05$. RT: $F[1,9] = 5.92$; $P < 0.05$). A three-way interaction for error rates (accuracy: $F[1,9] = 7.25$; $P < 0.05$; RT: $F[1,9] = 1.25$; $P > 0.1$) reflects the observation in Fig. 4 that the effect of display symmetry on the displacement effect is specific for *same* trials (filled symbols).

If data from conditions with tangential axis orientations (\Leftrightarrow HD and \Uparrow VD)—i.e. those that yield display symmetry—are subjected to separate analyses, a significant effect of translation can only be observed for RT (accuracy: $F[1,9] = 1.55$; $P > 0.1$. RT: $F[1,9] = 5.53$; $P < 0.05$). For conditions with radial axis orientations (\Leftrightarrow VD and \Uparrow HD), on the other hand, the displacement effect is clear-cut and very similar to the one for asymmetric patterns. Since the latter finding indicates that pattern symmetry itself does not lead to translation invariance of performance, we tried to quantify it by an additional comparison between these two conditions and performance with asymmetric stimuli. While both differ significantly in their overall level (accuracy:

$F[1,9] = 12.70$; $P < 0.01$. RT: $F[1,9] = 0.01$; $P > 0.1$), symmetry condition has no influence on the degree of positional specificity (accuracy: $F[1,9] = 1.50$; $P > 0.1$. RT: $F[1,9] = 2.70$; $P > 0.1$). The size of the displacement effect, therefore, is not influenced by pattern symmetry as such.

3.2.3. Direction of displacement

The direction of displacement has only minor general effects on performance (accuracy: $F[1,9] = 3.49$; $P < 0.1$. RT: $F[1,9] = 1.23$; $P > 0.1$) and does affect the size of the displacement effect (accuracy: $F[1,9] = 0.81$; $P > 0.1$. RT: $F[1,9] = 0.22$; $P > 0.1$).

4. Discussion

4.1. Further evidence for incomplete translation invariance

Our new experiments provide additional evidence that same-different judgments are partially specific to the location in the visual field (Foster & Kahn, 1985; Dill & Fahle, 1998). They further replicate that the displacement effect is specific for same trials and independent of the direction of displacement. Our analyses reveal that introducing symmetry into dot patterns can influence performance in this task. The higher degree of translation invariance does not result directly from pattern symmetry. If symmetry had this effect, one would expect the displacement effect for all symmetric conditions to be smaller than with asymmetric patterns. However, for locally symmetric, while globally asymmetric pattern pairs (conditions \Leftrightarrow VD and \Uparrow HD), translation invariance is similar as for asymmetric dot clouds. The information content of a shape comprising 10 asymmetrically arranged dots differs from that of a symmetric dot cloud where part of the information is theoretically redundant for recognition. Non display symmetric patterns are better recognized than asymmetric (AS) clouds—even without displacement. This finding may be explained by the difference in information content, while stimulus symmetry as such does not interfere with the mechanisms of translation invariance.

4.2. The influence of pattern symmetry

Earlier work (Barlow & Reeves, 1979; Saarinen, 1988; Herbert & Humphrey, 1996) has shown that detection of bilateral symmetry is less effective in parafoveal and peripheral as compared to foveal areas. However, even at 20° eccentricity perception of symmetry is possible (Saarinen, 1988). Given that dot clouds were presented with their center at only 1° distance from the center of the visual field, our subjects should have been able to perceive the symmetry of the dot

clouds. Nevertheless, this information did not help to reduce the displacement effect under conditions that did not yield display symmetry (\Leftrightarrow VD and \uparrow HD).

While intrinsic pattern symmetry seems to be of minor importance, symmetry relative to the fovea had a decisive impact; if the mirror axis of the dot clouds is oriented in a way yielding overall symmetry of the combined displays, performance is nearly translation invariant. The above results, therefore, confirm earlier studies by Kahn and Foster (1981, 1986, Foster, 1984, 1991). They are also in line with the Richards (1978) observation that the orientation of symmetric letter and dot stimuli relative to the fovea is crucial.

4.3. Implications for earlier models

In order to explain the influence of display symmetry on the degree of position invariance in terms of a biasing metric system (Biederman & Cooper, 1992) one has to assume the metric bias to disappear under conditions of display symmetry. Not only is there no obvious reason for a conditional bias, inspection of Fig. 4 also reveals that differences between *same* and *different* trials are still present for display symmetric conditions, while the displacement effect is strongly reduced.

The results of the above experiment are also difficult to understand in terms of normalization models. In addition to a continuous mental transformation one would have to postulate a second discrete operation that flips information between locations that are symmetrical with respect to the direction of gaze (cf. Kahn & Foster, 1981, 1986).

Similarly, the local-feature hypothesis (Dill & Fahle, 1998) has to incorporate additional assumptions if it is to account for the observation that the displacement effect disappears with display-symmetric stimuli. One such hypothesis could be that short-cut connections communicate information between local feature detectors from symmetrical locations, for example as part of a specialized mechanism to detect symmetry in displays. Alternatively, performance could be less sensitive to translation because position-invariant symmetry detectors are highly specific for detecting symmetry relative to the fovea.

4.4. A new model: location-specific preprocessing

We know of neither anatomical nor physiological evidence for any of these additional assumptions. All three accounts lose much of their original parsimony if they want to explain the disappearance of the displacement effect in symmetric displays. We, therefore, offer a further alternative. The central suggestion of this fourth account is that positional specificity is the result of differential processing of the incoming image. Visual input may be treated differently depending on the loca-

tion. Intra-pattern interactions comparable to the well-known phenomenon of lateral masking (Wolford & Hollingsworth, 1974; Banks, Bachrach & Larson, 1977) may distort visual input or ease perception of pattern parts at one location on the cost of other regions of a stimulus. After displacements in the visual field the information that is available for the actual form recognition system may differ because other preprocessing events take place. The result could be that a particular dot cloud may look different when presented left than when appearing right of the fixation spot. The form recognition system by itself may, nevertheless, be translation invariant.

But why should symmetric displays be less sensitive to these preprocessing effects? This would be the case if, for example, the same or similar preprocessing mechanisms work for symmetrical locations so that each stimulus feature would receive the same perceptual ‘treatment’ even after displacement. *Same-different* judgment after translation may then be more accurate than in asymmetric displays.

While this hypothesis has yet to be tested experimentally, a number of other experimental findings provide some evidence for our differential-preprocessing account. For example, lateral masking appears to be a radial effect that is most effective along the meridians of the visual field and less in tangential direction (Toet & Levi, 1992). Similar radial anisotropy has been reported for a variety of other spatial tasks (Rovamo, Virsu, Laurinen & Hyvärinen, 1982; Temme, Malcus & Noell, 1985; Fahle, 1986; Bennett & Banks, 1991; Bernardi & Fiorentini, 1991). Gradients of visual acuity—the decrease in resolution with increasing distance from the fovea—may well contribute to some of these phenomena (e.g. Rovamo et al., 1982). Others—like lateral masking—involve clearly more complex forms of processing.

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