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Similarity-based asymmetries in perceptual matching

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ABSTRACT

Asymmetries, where response times differ depending on the order of two stimuli, have been widely used to explore fundamental aspects of perceptual processing. Given how much is made of asymmetries in the study of perception there has been surprisingly little research into the cognitive mechanisms that may underlie why comparing two objects *in isolation* depends on the order of presentation. In visual search, for example, asymmetries are typically attributed to fundamental processing characteristics as opposed to the inherent relation between two stimuli. However, one possible explanation for asymmetries found in perceptual processing is that similarity is important in the task and it is similarity itself that is asymmetric. In the current paper, we use a stimulus set for which the transformational account of similarity predicts asymmetries based on differences in transformational complexity. Using the fine-grained measure of reaction time we show that directional differences in transformation distance successfully predict asymmetries in the speed of matching two stimuli in sequence. The results are discussed in relation to the role of transformations in perceptual identification more generally, and how transformations could be revealing about how objects are compared in other experimental contexts where objects are compared directionally (e.g., visual search).

1. Introduction

Asymmetries are often viewed as informative in the study of perception. A prime example of this is visual search; here, asymmetries in response times are observed depending on whether the task involves locating a target stimulus A among a homogeneous set of distractors, B, or vice versa, that is, target B among distractors A. Such asymmetries are assumed to be informative regarding the key characteristics of the underlying processes. As is well-known, Treisman and Souther (1985) used asymmetries in visual search to distinguish between competing accounts of early visual processing (e.g., parallel vs. serial search, or the existence of particular kinds of feature detectors). However, it is possible that such asymmetries arise not from structural aspects of the putative underlying process, which are taxed by different stimuli in different ways, but simply reflect a direct relationship between the two types of stimuli themselves. This latter possibility needs examination because asymmetries arise even in the minimal context of perceptual matching, that is, where two individual items are directly compared to one another (Op de Beeck, Wagemans, & Vogels, 2003; Rothkopf, 1957).

The perceptual matching task, where two presented stimuli must be judged as *same* or *different*, has been a valuable tool for assessing the cognitive and perceptual abilities of both human and animals. In particular, tasks of this type have been used to investigate categorization (Cohen & Nosofsky, 2000), visual object recognition (Bundesen & Larsen, 1975; Graf, 2002, 2006; Lamberts & Kent, 2008; Lawson, 1999; Lawson, Humphreys, & Jolicoeur, 2000; Panis, Vangeneugden, & Wagemans, 2008), phonological representation (Wicklegren, 1965, 1966), perceptual learning (Goldstone, 1998) and relational concept learning (Blaisdell & Cook, 2005; Wills & Mackintosh, 1999; Young & Wasserman, 1997, 2001). As the task requires online, rapid judgements, it is considered particularly useful for studying stimulus representation and the time course of stimulus processing (Goldstone & Medin, 1994; Lamberts & Kent, 2008).

One of the most counter-intuitive observations in perceptual matching is that the ease of detecting differences between two sequentially examined objects can vary systematically with the order in which they are viewed — even though the exact same objects are compared (Op de Beeck et al., 2003; Rothkopf, 1957; Tversky, 1977). Given the theoretical importance attached to asymmetries, it is perhaps surprising that these 'matching asymmetries' have not received more attention empirically.

1.1. Similarity and asymmetry

Overall, responding in perceptual matching is governed largely by the similarity between the stimuli being compared. In particular, previous research has confirmed consistently that the more similar two stimuli are, the longer it takes to correctly identify them as *different* in a speeded same-different task (Cohen & Nosofsky, 2000; Farrell, 1985; Goldstone & Medin, 1994; Posner & Mitchell, 1967; Takane & Sergent, 1983). Likewise, similarity is argued to affect accuracy: similarity between non-identical objects results in a response competition between *same* and

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different responses; consequently, greater similarity leads to higher error rates on *different* trials, prompting incorrect *same* responses (Gati & Tversky, 1984; Luce, 1986; Goldstone & Medin, 1994; Shepard, 1987; Tversky, 1977). Given the supposed role of similarity in this task, matching asymmetries could be taken to reflect the notion that similarity itself is an asymmetrical relationship, that is, SIM (A,B) ≠ SIM (B,A).

Indeed, Tversky (1977) argued that similarity could be asymmetric when stimuli are compared directionally, that is, when one is asking specifically "how similar is A *to* B?" as opposed to "how similar *are* A and B?". Specifically, Tversky's (1977) Contrast Model allows the unique features of one object to receive greater weight than the unique features of the other, depending on whether they occupy the role of *subject* (A) or *referent* (B) in the directional similarity comparison "how similar is A to B?". This differential weighting will give rise to asymmetries whenever the unique features of the two objects differ in salience. Tasks whereby participants must use one of the two objects as a referent when making a judgment or response are naturally directional, and sequential perceptual matching is a prime example. Hence, one of the sources of evidence Tversky cited for the existence of asymmetric similarities was data collected by Rothkopf (1957) that showed asymmetric confusions in a sequential auditory matching task.

However, is similarity really asymmetric, and, if so, does it underlie the asymmetries seen in perceptual matching? There are several reasons to doubt this. The first of these stems from the fact that evidence for asymmetric similarity in tasks *other* than perceptual matching is rather weak. The main evidence Tversky (1977) provided was based on explicit, verbal, directional statements such as "how similar is A to B?". For these experiments Tversky drew on an observation first made by Rosch (1975), whereby items varying in salience such as prototypical and atypical exemplars (for example, 'robins' and 'penguins') seem more natural in one of the positions of a directional comparison. Specifically, participants prefer the assertion that "penguins are similar to robins" over the assertion that "robins are similar to penguins". Furthermore, Tversky (1977) demonstrated that participants also give higher ratings of similarity to the first ordering than to the second. Such effects were shown not only with category exemplars, but also geometric shapes varying in complexity or goodness of form, and, subsequently, a variety of other stimulus materials (Bartlett & Dowling, 1988; Bowdle & Gentner, 1997; Catrambone, Bieke, & Niedenthal, 1996; see also see also Kayaert, Op de Beeck, & Wagemans, 2011; Panis, Wagemans, & Op de Beeck, 2011).

However, Gleitman, Gleitman, Miller, and Ostrin (1996) demonstrated that these seeming asymmetries need not reflect an asymmetry in the concept of similarity itself, but rather could be a function of the linguistic statement in which the word 'similarity' appears. Specifically, Gleitman et al. showed that 20 other, clearly symmetrical, predicates, such as 'equal' and 'identical' also gave rise to the same kind of 'evidence', namely preferences for one ordering over the other, and differences in the degree to which the relation in question is taken to apply. This, they argued, is based on general perceptions of figure and ground in language use. Consequently, there is no more reason to think that 'similar' expresses an asymmetric relationship, than do the predicates 'equal', 'identical', or any of the other linguistic terms they examined.

Gleitman et al.'s (1996) findings necessitate further research into asymmetry using non-linguistic, implicit similarity measures. Ironically, given the evidence for the general influence of similarity on task performance, perceptual matching could provide an ideal task for this. However, without independent evidence for asymmetric similarity the interpretation of results from perceptual matching remains tenuous.

It remains a serious empirical concern that alternative explanations may better account for observed asymmetries in perceptual matching. This can be seen from studies probing more closely the relationship between similarity and matching errors, that is, confusions. Confusability is often taken to be a more or less direct indicator of similarity, and confusability data has been the main source of similarity data that is not based on explicit ratings. However, confusion errors need not directly equate with similarity. Confusions, as 'errors', arise when performance breaks down, and different causes for this breakdown have been shown to affect directly the actual patterns of confusions observed (Garner & Haun, 1978). Furthermore, asymmetries in confusion data can arise from simple response biases toward one of the two stimuli, without reflecting asymmetric similarity at all (Garner & Haun, 1978). In fact, response bias is the mechanism by which asymmetries are incorporated into otherwise symmetric, spatial models of similarity (Nosofsky, 1991). One domain in which the nature of confusions has been studied in detail is phoneme similarity. Bailey and Hahn (2005) showed that confusion matrices were fairly poor predictors of phoneme similarity as measured in a range of tasks, including forced choice, ratings and even confusability data from other tasks. Errors were highly influenced by task idiosyncrasies and thus could not be taken to provide an unequivocal measure of stimulus similarity. To date, all previous studies that have observed asymmetries in perceptual matching have focussed exclusively on confusions, and these data consequently seem as readily open to alternative interpretation as the data in explicit, verbal contexts.

In summary, perceptual matching has, on occasion, been found to be asymmetric, and a similarity relationship that is itself asymmetric may provide a potential explanation for this finding. However, several requirements would need to be met for data on this issue to be readily interpretable, and none of these have been met in past research. Crucially, it has to be determined that it is similarity that is asymmetric and that it is the asymmetry of similarity itself that gives rise to the asymmetry in perceptual matching. In order to support such a conclusion, one requires independently motivated predictions of between-item similarity, of which asymmetric similarities are just one component; furthermore, one requires empirical evidence to validate the similarity predictions in general. Finally, then, evidence specifically for the predicted asymmetric similarities is required.

In the current experiment, therefore, we attempt to demonstrate asymmetries within a stimulus domain that has been used previously to test and compare a number of theories of similarity (Hodgetts, Hahn, & Chater, 2009). For this experiment we draw on the detailed predictions of the transformational approach to similarity, known as Representational Distortion (RD; Hahn, Chater, & Richardson, 2003; Hahn, Close, & Graf, 2009; Hodgetts et al., 2009; on the role of transformations in perception and cognition more generally see also e.g., Graf, 2002, 2006; Hendrickx & Wagemans, 1999; Imai, 1977; Leyton, 1992; Palmer, 1983; Wagemans, Lamote, & Van Gool, 1997; Wagemans, Vanden Bossche, Segers, & d'Ydewalle, 1994; for further references see Hahn et al., 2003). This account not only does very well in predicting similarity within this domain, it also specifically predicts asymmetric similarities across a large number of comparisons. These asymmetric predictions are tested using reaction times in perceptual matching.

1.2. Asymmetries and transformation

On the transformational approach, similarity is determined by the complexity of the transformation required to change one object representation into another. Hahn et al. (2009) were the first to exploit *directional* similarity judgements ('how similar is *A* to *B?*') in testing the transformational account. In everyday contexts, transformational complexity can differ depending on direction: spilling water from a cup, for example, is easier than gathering the spilled water back in. Any such directional difference should give rise to attendant differences in perceived similarity, and hence asymmetric similarity between the two comparison points. Hahn et al. (2009) tested whether an inherent sense of direction could be artificially induced. To this end, they showed participants short animations of one familiar basic-level, naturalistic object undergoing a shape-changing