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Analytic processing of distance

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ABSTRACT

How does a human observer extract from the distance between two frontal points the component corresponding to an axis of a rectangular reference frame? To find out we had participants classify pairs of small circles, varying on the horizontal and vertical axes of a computer screen, in terms of the horizontal distance between them. A response signal controlled response time. The error rate depended on the irrelevant vertical as well as the relevant horizontal distance between the test circles with the relevant distance effect being larger than the irrelevant distance effect. The results implied that the horizontal distance between the test circles was imperfectly extracted from the overall distance between them. The results supported an account, derived from the Exemplar Based Random Walk model (Nosofsky & Palmieri, 1997), under which distance classification is based on the overall distance between the test circles, with relevant distance being extracted from overall distance to the extent that the relevant and irrelevant axes are differentially weighted so as to reduce the contribution of irrelevant distance to overall distance. The results did not support an account, derived from the General Recognition Theory (Ashby & Maddox, 1994), under which distance classification is based on the relevant distance between the test circles, with the irrelevant distance effect arising because a test circle's perceived location on the relevant axis depends on its location on the irrelevant axis, and with relevant distance being extracted from overall distance to the extent that this dependency is absent.

To facilitate interaction with the world a human observer registers spatial relationships among perceived stimuli. Preservation of these relationships supports the assessment of distances between pairs of stimuli. We focus here on distances between stimuli in a frontal plane. An observer is capable of great accuracy in assessing the distance between two frontal stimuli (Klein & Levi, 1985; Stevens, 1975; Wilson, 1986). But how does an observer extract from such a distance the component corresponding to an axis of a rectangular reference frame? Consider two points varying on the horizontal and vertical axes of a computer screen. How does an observer assess the horizontal or vertical distance between these points? The question is of practical interest because the allocentric representations of many domains are thought to be organized in terms of rectangular reference frames. Encoding the locations of objects relative to such reference frames can require extracting horizontal and vertical components from the inter-object distances (Mou & McNamara, 2002; Mou, McNamara, Valiquiette, & Rump, 2004).

Perceptual analysis such as this has attracted interest because observers often do not perform it cleanly (Maddox & Dodd, 2003; Melara & Algom, 2003). Such analysis has been studied with speeded classification tasks (Garner, 1974; Kemler Nelson, 1993; Melara, Marks, & Potts, 1993). The stimuli for such tasks typically vary on two perceptual dimensions. At issue is whether classification of the stimuli on one of the dimensions depends on the values of the stimuli on the other dimension. Such dependency is called dimensional interaction. Pairs of dimensions that show dimensional interaction are called integral; pairs of dimensions that do not show dimensional interaction are called separable[1] (Algom & Fitousi, 2016).

Previous classification research has explored the analysis of spatial position into horizontal and vertical components (Garner & Felfoldy, 1970) and the analysis of rectangles in terms of width and height (Dykes, 1979; Macmillan & Ornstein, 1998; Monahan & Lockhead, 1977). This previous research does not directly generalize to the analysis of distance, however, because position and distance may dissociate (Abrams & Landgraf, 1990) and because rectangles may be perceived in terms of higher-order dimensions such as size and shape (Krantz & Tversky, 1975).

The present study used a speeded classification task to explore the perceptual analysis of frontal distances. On each trial of this task two small circles appear on a computer screen. Across trials, circles appear

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[1] The terms ‘integral’ and ‘separable’ have sometimes been given more technical meanings (Algom & Fitousi, 2016; Maddox, 1992). We use the terms in their earlier more informal sense.

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in an array of locations, with adjacent locations being separated by the same distance on the horizontal and vertical axes of the screen. On each trial the participant indicates whether the test circles are less than a critical horizontal or vertical distance apart. Thus the participant classifies on the basis of horizontal or vertical distance pairs of circles that vary in terms of horizontal and vertical distance. A response signal controls response time.

In previous work with this distance classification task the error rate has been found to increase and decrease, respectively, with the distance between the circles on the axis of comparison when this *relevant* distance is and is not less than the critical distance. Thus, the error rate has been found to increase, unremarkably, as relevant distance approaches the critical distance. Of greater interest, the error rate has been found to increase and decrease, respectively, with the distance between the circles on the axis orthogonal to the axis of comparison when this *irrelevant* distance is and is not less than the critical distance (Dopkins, 2005; Dopkins & Sargent, 2014). This has been shown for judgments of horizontal and vertical distance. By implication, the horizontal and vertical axes of space are integral for the purposes of distance assessment.

When compared in previous speeded classification studies the relevant and irrelevant distance effects have been found to be equivalent in size (Dopkins, 2005). By implication participants in these studies have not analyzed frontal distance; that is, they have not extracted the relevant distance between the test circles from the overall distance between them. In the present study we explored two sets of conditions in which *differential* (larger relevant than irrelevant) distance effects were observed in speeded classification. By implication participants in the present study were partially successful in analyzing frontal distance; they imperfectly extracted relevant from overall distance. We sought to understand the conditions promoting such analysis of frontal distance and the mechanism by which it occurs.

1. Experiment 1

As has been noted previous speeded distance classification studies have found equivalent effects of relevant and irrelevant distance (Dopkins, 2005). By implication relevant distance has not been extracted in these studies. This is remarkable given the importance of distance information for function in the world. Perhaps the conditions in these studies have not been sufficient to induce the extraction of relevant distance. Can specialized feedback induce such extraction? Experiment 1 sought to find out. Participants performed the version of the distance classification task in which equivalent effects of relevant and irrelevant distance have previously been observed. Across trials the test circles articulated a 3 row by 7 column array of locations. Participants were required to distinguish pairs of circles that were less than 3 horizontal positions apart (< **3** pairs) from pairs that were not less than 3 horizontal positions apart (∼ < **3** pairs) with position being defined in terms of the location array. The response interval was 400 ms. Participants in the Control condition received standard feedback following incorrect responses. Participants in the Focused Feedback condition received additional specialized feedback when they made errors on < **3** pairs with vertical distance 2 (*vertical 2 pairs*) – that is, when they indicated that the test circles for these pairs were not less than 3 horizontal positions apart. The feedback was designed to call attention to distance on the vertical axis without actually instructing participants to give this distance less consideration. On the basis of past results we expected equivalent effects of relevant and irrelevant distance in the Control condition (Dopkins, 2005; Dopkins & Sargent, 2014). The critical question was whether differential distance effects would occur in the Focused Feedback condition, implying the extraction of relevant distance.

1.1. Method

1.1.1. Participants

The participants were 52 undergraduate students who participated in fulfillment of a course requirement. The average ages in the Control and Focused Feedback conditions were 20.8 and 20.2 respectively. Ten males and sixteen females were run in each of these two conditions. All participants had normal or corrected-to-normal vision. Informed consent was obtained from all participants prior to their participation.

1.1.2. Stimuli

Each test circle was 3 mm in diameter. Pairs of adjacent test circles were separated by 8 mm on the horizontal and vertical axes of the computer screen. The participant sat approximately 60 cm from the screen. Thus each test circle subtended a visual angle of approximately 0.30° and pairs of adjacent test circles were separated by visual angles of approximately 0.76°.

1.1.3. Design

Twenty-six participants apiece were run in the Control and the Focused Feedback conditions. Because the feedback in the Focused Feedback condition emphasized test pairs of a particular vertical distance, the design sought to equate the numbers of pairs for the different combinations of vertical and horizontal distance. Each of the 20 types of pair that could be distinguished on the basis of the horizontal and vertical distance between the test circles was presented 25 times. The particular locations used for a given test pair were sampled randomly from those that were consistent with the values of horizontal and vertical distance in place for the pair. Under this design the horizontal distance between the test circles had a correlation of 0 with the horizontal positions of the circles. The test pairs were presented in a random order, grouped in blocks of 20, with the complete location array being presented at the beginning of each block.

1.1.4. Procedure

At the beginning of each trial, "Ready" appeared in the center of the computer screen. The participant then fixated the "Ready" stimulus and pressed the space bar of the computer. "Ready" then disappeared and a pair of circles appeared. Four hundred millisecond after the circles appeared, four asterisks appeared at the bottom of the screen. The participant was instructed a) to indicate whether or not the test circles were less than 3 positions apart in terms of the horizontal axis of the location array, b) to use the "B" and "N" keys of the computer keyboard to indicate 'less than 3′ and 'not less than 3′ responses respectively, and c) to respond concurrently with the appearance of the asterisks. If the participant's response occurred before the appearance of the asterisks, the message "TOO FAST" appeared at the bottom of the screen after the participant's response and remained there until the participant pressed the space bar. If the participant's response occurred > 250 ms after the appearance of the asterisks, the message "TOO SLOW" appeared in the same manner.

When the participant made an error in the Control condition, a message appeared to that effect, after the message, if any, regarding response speed. We will call this message the standard error message. The procedure in the Focused Feedback condition was the same as in the Control condition except in the following respects: a) If the participant made an error on a < **3** pair with vertical distance 2, a message appeared, after the standard error message, indicating that the participant had made a Vertical No Error. This message remained on the screen for 5000 ms. b) If the participant accumulated more than 4 but less than 11 Vertical No Errors a message appeared, at the end of each block following this accumulation, asking the participant to avoid making further Vertical No Errors. c) If the participant accumulated 11 or more Vertical No Errors, a message appeared, at the end of each block following this accumulation, indicating that the experiment would be extended if the participant made further Vertical No Errors.