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Simultaneous stimulus preexposure enhances human tactile perceptual learning

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An experiment with human participants established a novel procedure to assess perceptual learning with tactile stimuli. Participants received unsupervised exposure to two sandpaper surfaces differing in roughness (A and B). The ability of the participants to discriminate between the stimuli was subsequently assessed on a same/different test. It was found that prior exposure to the stimuli led to more accurate judgements on the different-trials. Furthermore, simultaneous exposure to the stimuli enhanced this accuracy more than sequential exposure (A, B, A, B…). These findings extend recent results from visual studies to the tactile modality, confirming that simultaneous exposure produces a marked perceptual learning effect.

Exposure to two similar stimuli can facilitate subsequent discrimination between them (i.e., can reduce the extent to which generalization occurs between them). Examples of this *perceptual learning* effect have been extensively observed in a wide variety of procedures and species (see Mitchell & Hall, in press, for a recent review). In order to get a better understanding of the mechanisms involved in this phenomenon, researchers have attempted to determine which conditions of stimulus exposure are most optimal in generating perceptual learning. In this regard, several studies, with both human and nonhuman animals, have been specifically designed to test the notion that perceptual learning is more likely to occur under preexposure conditions that favour stimulus comparison (Gibson, 1969).

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Most of the human studies addressing this issue have involved visual stimuli, and have produced data that seem to confirm the beneficial effect of stimulus comparison in generating the perceptual learning effect. Perhaps the clearest effect supporting this notion is the finding that simultaneous presentation of two stimuli produces better discrimination than does sequential exposure (Angulo & Alonso, 2012; Mundy, Honey, & Dwyer, 2007; 2009). The generality of this effect has been well established across a variety of visual stimuli (e.g., Arabic symbols in the study by Angulo and Alonso, and morphed pictures of human faces and black-and-white checkerboard patterns in the studies by Mundy et al.). It is clear, however, that further research involving other sensory modalities in addition to vision is necessary to establish whether or not stimulus comparison has general relevance for human perceptual learning. The aim of the present experiment was to contribute to this issue, extending the study of this simultaneous-sequential preexposure effect to a human procedure using tactile stimuli.

The design and the logic of the experiment were very similar to that employed in previous studies with human (e.g., Mundy et al., 2009) and nonhuman animals (e.g., Rodríguez & Alonso, 2008; Rodríguez, Blair, & Hall, 2008). It consisted of two phases (see Table 1). In the first phase, the opportunity to compare two tactile stimuli was manipulated across conditions. Two sandpaper surfaces differing in roughness were used as the stimuli (A and B). Participants in Group SIM received simultaneous preexposure to both surfaces. On each preexposure trial, these participants were allowed to touch both A and B at the same time, each one with an index finger. Participants in Group SEQ received the same number of presentations of A and B, but sequentially rather than simultaneously. On each preexposure trial, these participants were allowed to touch only one surface (A or B) with the index finger of their dominant hand. Presentations of A and B were alternated across this sequential schedule (e.g., A, B, A, B…). Finally, Group CTRL provided a control condition for which there was no preexposure to the stimuli.

On the subsequent test phase, the ability of all the participants to discriminate between the stimuli was assessed with a same/different judgement task (e.g., Dwyer, Hodder, & Honey, 2004). Each test trial consisted of the sequential presentation of two surfaces. At the end of each test trial, participants were asked to judge whether or not the two surfaces which they had just touched, were the same or different. There were 4 test trials: 2 "same" trials (A-A, and B-B), and 2 "different" trials (A-B, and B-A). According to the hypothesis that stimulus comparison facilitates perceptual learning, and on the basis of previous studies using visual cues (e.g., Mundy et al., 2009), we expected to find that the groups that were allowed to compare the stimuli during preexposure, Groups SIM and SEQ, would perform better on the test (would discriminate between the stimuli) than the nonpreexposed control group. In addition, since it seems reasonable to assume that simultaneous exposure offers the most optimal conditions for stimulus comparison to occur (e.g., Gibson 1969, p.145; Mundy et al., 2007; 2009), we also expected to find better test performance in Group SIM than in Group SEQ.

METHOD

Participants. A total of 42 participants, 34 female and 8 male, were recruited from the School of Psychology at the University of the Basque Country. All were right-handed and ranged in age from 20 to 33 years. They were graduate students who did not receive any financial incentive to participate. Participants were randomly assigned, in equal numbers, to groups SIM, SEQ, and CTRL.

Stimuli. Squares of 10 x 10 cm made from commercially produced sandpapers (Debray, Barcelona, Spain) differing in roughness were used as the stimuli (grit grade "4" as the rougher surface, and grit grade "6" as the smoother surface). For half of the participants, the rougher surface served as stimulus A and the smoother surface as stimulus B. For the remainder this arrangement was reversed.

Procedure and instructions. Participants received all the preexposure and test trials in a single session. They were trained and tested individually. Prior to the beginning of the experiment, the participants were asked to sit comfortably at a table facing the experimenter. The experimenter then read the following instructions:

You are about to participate in an experiment concerning the sense of touch. Therefore, you will be blindfolded in order to eliminate any information coming from your sense of vision. In the experiment, you will use the index fingers of your hands only. I will guide your fingers toward some innocuous surfaces. I will allow you to touch them freely for some time. I will also indicate to you when you have to stop touching them, by lifting your fingers. This procedure will be repeated several times.

Once the experimenter had ensured that the participants had understood the instructions, the experiment began. Participants were blindfolded and rested their wrists on a desktop, with their fingers elevated. On each trial, the experimenter guided the corresponding finger of the participants to the corresponding surface. Once the distal segment of the finger made contact with the surface, the participants were allowed to freely touch the surface during a 5-second period. The interval between trials was 15 seconds. No explicit separation occurred between the preexposure and test phases. No feedback was provided during the experiment.

Preexposure. For Group SIM, this phase consisted of 4 trials. On each trial, participants in this group were allowed to touch simultaneously the A and B surfaces, each one with the index finger of each hand. The position of the surfaces for the left and right hands was counterbalanced. For Group SEQ, this phase consisted of 8 trials. On each trial, participants were allowed to touch one surface with the index finger of their dominant hand. Half of the participants in this group received the following sequence of surface presentations: A, B, A, B, A, B, A, B. The other half received the opposite sequence: B, A, B, A, B, A, B, A. Group CTRL did not receive any training prior to the test phase.

Test. For all of the groups, this phase consisted of 4 trials. Each trial consisted of the sequential presentation of two sandpaper surfaces. We chose the sequential procedure on test to help avoid trivial explanations for the superior performance of the simultaneous group. Participants in the sequential group should have an advantage because there was no change in procedure between training and testing. For that, superior performance on the test of the simultaneous group should not be due to the test procedure. As with the preexposure phase, the duration of the presentation of each surface was 5 seconds, and the interval between the first and the second presentation was 15 seconds. There were 4 test trials, 2 "same" trials (A-A, B-B), and 2 "different" trials (A-B, B-A). The order of presentation of these trials was randomized for each participant. At the end of each test trial, participants were asked to judge whether the two surfaces which they had just touched, were the same or different. The scores for the two "same" test trials and the two "different" test trials were combined to produce a mean score for the "same" and "different" conditions, respectively.

Table 1. Experimental Design

Preexposure	***Same-different test***	
SIM group		
A&B-A&B-A&B-A&B	A-A, B-B	A-B, B-A
SEQ group		
A-B-A-B-A-B-A-B	A-A, B-B	A-B, B-A
CTRL group	A-A, B-B	A-B, B-A

Note: A and B refer to sandpaper surfaces differing in roughness. Stimuli separated by an ampersand (&) were presented simultaneously within the same trial, and those separated by a dash (-) were presented sequentially, with an interval of 15 sec between them.

RESULTS

Figure 1 shows the mean proportions of correct responses on "same" and "different" test trials. Inspection of the figure suggests that accuracy on trials in which two surfaces with the same roughness were presented ("same" test trials) was higher than that on trials in which two different surfaces were presented. It is also apparent from the figure that on the "different" test trials, accuracy was higher in Group SIM than in Groups SEQ and CTRL, and higher in Group SEQ than in Group CTRL. However, there were no apparent differences among the groups on the "same" trials. A Group (SIM, SEQ, CTRL) by Trial type (different vs. same) analysis of variance (ANOVA) confirmed these impressions. It revealed a borderline effect of Group, $F(2, 39) = 2.78$, MSE = .084, and a significant effect of trial type, $F(1, 39) = 5.21$, MSE = .128 (here and elsewhere a significance level of $p < .05$ was adopted). The interaction between these variables was also significant, $F(2, 36) = 5.63$, MSE = .128. In order to explore the source of this interaction, a simple main effects analysis was conducted. It revealed a group effect on the "different" trials, $F(2, 39) = 7.1$, MSE = .125, but not on the “same” trials, $F(2, 39) < 1$, MSE =.088. Pairwise comparisons using Duncan tests showed that performance in the “different” trials was better in Group SIM than in Groups INT and CTRL, and better in Group INT than Group CTRL.

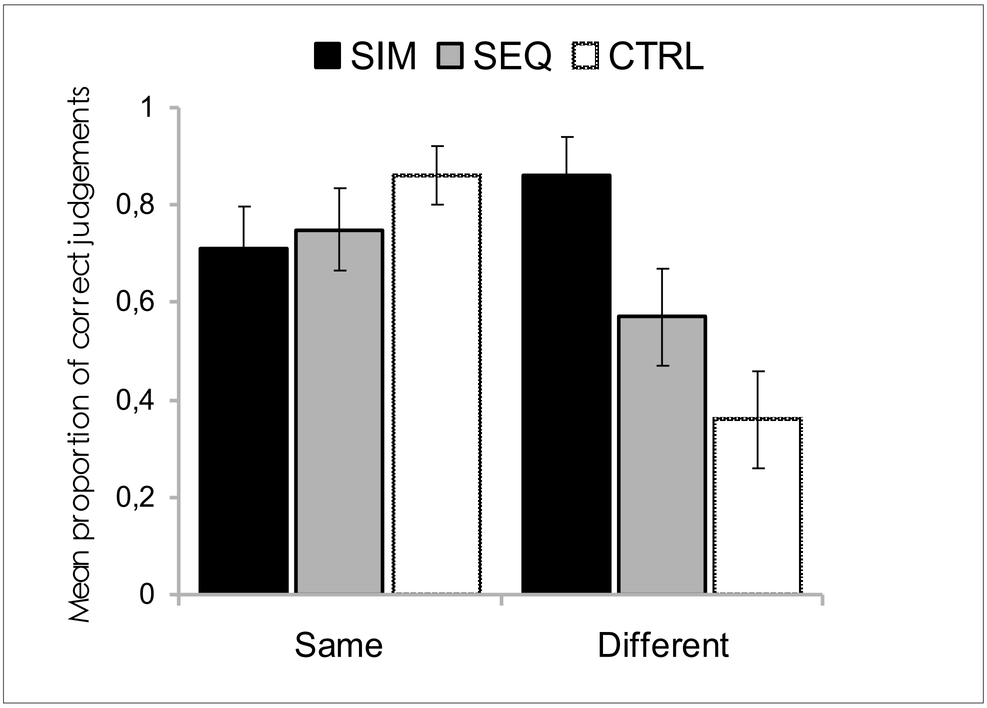

Figure 1. Mean proportion of correct responses on same and different test trials. Training conditions are illustrated in Table 1 and described in the text. Vertical bars represent the standard errors of the means (SEMs).

DISCUSSION

The present data provide clear evidence of a perceptual learning effect on a same-different test, using a novel procedure involving tactile stimuli differing in roughness. Stimuli A and B were judged to be different with more accuracy (i.e., were more easily discriminated) after brief preexposure to them. In addition, the schedule by which the stimuli were presented (simultaneous vs. sequential) influenced the degree to which preexposure facilitated discrimination. We found that discrimination was enhanced more by simultaneous preexposure than by sequential preexposure. These results thus seem to support the general relevance of the hypothesis that motivated the present study: perceptual learning is enhanced by preexposure conditions most favouring stimulus comparison. This hypothesis was first proposed by Gibson (1969), in her influential theory of perceptual learning. She suggested that stimulus comparison fosters a differentiation process, which increases the perceptual effectiveness or salience of the distinctive features of the stimuli (in our experiment, the roughness of the sandpaper surfaces), and reduces that of their common features (in our experiment, all the other characteristics shared by the sandpaper surfaces). This would allow one to detect and process the distinctive features more easily, thus enhancing the perceptual dissimilarity of the stimuli and reducing generalization between them. What Gibson did not specify, however, was the learning mechanism responsible for these changes in the stimulus salience.

In order to mend this lack of specification, several authors (e.g., Hall, 2001; Honey & Bateson, 1996; Mackintosh, 2009; Mitchell, 2010; Mitchell & Hall, in press; Mundy et al., 2007; 2009) have offered similar analyses appealing to the phenomenon of habituation. More specifically, they have taken into consideration the short-term habituation mechanism proposed by Wagner (1981).

According to Wagner (1981), presentation of a given stimulus results in habituation to its constituent elements, which makes them less likely to be fully processed when they are presented again after a relatively short interval. Any two similar stimuli, A and B, might be conceptualized as compound stimuli, *ax* and *bx*, where *x* represents those features that are common to both stimuli, and *a* and *b* represent the features that are unique to A and B, respectively. In our experiment, the two surfaces A and B can similarly be conceptualized as *ax* and *bx*, where *x* would represent all the features presented in both surfaces of sandpaper, and *a* and *b* would represent the unique roughness of each surface. Following this elemental approach, it has been noted that alternating preexposure to A and B (i.e., to *ax* and *bx*) results in the interval between presentations of the distinctive features being twice that of the interval between presentations of the common features. This difference would allow the short-term habituation mechanism to modulate differentially the salience of the distinctive and the common features. For example, the first presentation of stimulus A would produce short-term habituation to the *a* and the *x* features. Thus, when stimulus B is subsequently presented, the *x* features would still be habituated thus commanding relatively little processing, and the available (and supposedly limited) processing resources would tend to be fully devoted to the distinctive *b* features. This salience-modulation mechanism should be particularly effective in alternating preexposure schedules in which the interval between the stimulus presentations is very short. Under these conditions, the common features are highly preexposed and thus their habituation (and the related enhancement of the processing of the distinctive features) should be increased. It has been argued that simultaneous presentations of the stimuli are precisely the conditions under which this mechanism could most readily be engaged (e.g., Mundy et al., 2007; 2009). Simultaneous presence of the two stimuli would allow the participants to do a series of rapid alternations between them on each preexposure trial. For instance, participants in our simultaneous condition might alternate very rapidly between the stimuli, sampling one surface and then another on each preexposure trial. Clearly, this alternation would happen faster than in the case in which participants experience the stimuli sequentially with an interval of 15 seconds between them.

Short-term habituation would thus enhance the salience and consequently the processing of the differential roughness of A and B, and it would do so more efficiently during simultaneous than sequential preexposure. But how might this short-lived effect have an enduring impact on stimulus discriminability on the subsequent test? In answering this question, it has been suggested that short-term habituation must interact with some sort of higher-level process, the nature of which is still unclear. Different representational (e.g., Mundy et al., 2009), attentional (e.g., Mackintosh, 2009; Mundy et al., 2009) or mnemonic (e.g., Mitchell, 2010) processes have been proposed as candidates. Although these specific proposals differ in many ways, they share the central assumption that less short-term habituation to the distinguishing stimulus features results in a better representation of them, which will enhance stimulus discriminability. These accounts offer a satisfactory explanation for the simultaneous-sequential effect in humans. However, it is still unclear as to what aspect of the supposed interaction between low and high level processes is absent, and thus fails to generate the effect, in the case of the animal studies (for further discussion on this matter, see Mitchell & Hall, in press). Further research is required in order to specify the nature of this interaction. At the very least, the present study has established a simple and convenient procedure for addressing these and other issues using the tactile modality with humans. Moreover, the simplicity and brevity of this task makes it ideally suited to the use of, for example, neuroimaging techniques that could add to existing knowledge based on behavioural findings.

RESUMEN

La preexposición simultánea a los estímulos favorece el aprendizaje perceptivo táctil en humanos. Se validó un nuevo procedimiento para medir aprendizaje perceptivo con estímulos táctiles y participantes humanos. Los participantes recibieron exposición no supervisada a dos superficies de lija con diferente rugosidad (A y B). Posteriormente, a través de una prueba de juicios de igual-diferente se valoró la habilidad de los participantes para discriminar entre los estímulos. Se encontró que la exposición previa a los estímulos produjo un aumento en la exactitud de los juicios "diferentes". Además, este aumento fue mayor cuando los estímulos fueron expuestos de forma simutánea que cuando fueron expuestos de forma secuencial. Estos resultados extienden a la modalidad táctil otros resultados recientes con estímulos visuales y confirman que la exposoción simultánea aumenta los efectos de aprendizaje perceptivo.

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