Short Report

Action Can Affect Auditory Perception

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According to *common-coding theory* (Hommel, Müsseler, Aschersleben, & Prinz, 2001), actions are coded in terms of their perceptual effects. The related theory of internal models (e.g., Wolpert & Kawato, 1998) assumes that forward models automatically generate predictions of the sensory consequences of actions and compare them with the actual sensory input. Both theories predict not only effects of perception on action, but also effects of action on perception.

Influences of action on visual perception have indeed been found (Hamilton, Wolpert, & Frith, 2004; Miall et al., 2006; Schubö, Aschersleben, & Prinz, 2001; Wühr & Müsseler, 2001). For example, Wohlschläger (2000) required participants to turn a knob or to press keys in a left-to-right (L-R) or right-to-left (R-L) order while observing perceptually bistable rotating visual displays. The direction of the manual action significantly biased the perceived direction of rotation: It made participants *see* the display differently.

Can action also influence auditory perception? We used tone pairs (derived from research on the *tritone paradox*; see Deutsch, Kuyper, & Fisher, 1987) that were perceptually bistable with regard to the direction of the pitch change between the two tones. Skilled pianists were required to play these tone pairs by depressing keys on a keyboard and to judge whether the pitch went up or down. We predicted that they would hear the pitch more often as rising with an L-R key-press order than with an R-L key-press order.

METHOD

Subjects

Twelve pianists with more than 11 years of training, all undergraduates at Yale University, participated. Twelve randomly selected undergraduates at Rutgers University served as a control group; 6 had had some piano instruction but no longer played.

Materials

The tones consisted of six octave-spaced partials whose relative amplitudes were governed by a fixed convex function centered on 261 Hz (see Deutsch et al., 1987). From tones representing the 12 musical pitch classes, we formed 12 pairs whose members were always separated by the interval of a tritone (e.g., A-D#). Each such tone pair is in theory equally likely to be perceived as going up or down in pitch (Shepard, 1964), although listeners perceive some pairs more often as going up in pitch, and others more often as going down (Deutsch, 1986). Twelve blocks of 24 semirandomly ordered pairs were formed, with half the pairs in each block assigned to the L-R key-press direction, and the other half assigned to the R-L direction.

Procedure

Each pianist performed the task in two conditions, whose order was counterbalanced: the piano-keyboard condition, in which a silent MIDI controller was used, and the computer-keyboard condition. The control group performed the task only in the piano-keyboard condition. In the piano-keyboard condition, numbers were employed as prompts for action, and the keys were labeled with ascending numbers (for half the participants in each group) or descending numbers. The horizontal separation of piano keys for a tone pair ranged from 7 cm (B-F) to 9.5 cm (F-B). In the computer-keyboard condition, letters served as prompts, and the pitch classes were mapped arbitrarily onto keys in the same row; the horizontal separation between keys was 7.5 cm.

On each trial, the computer monitor displayed two prompts (two two-digit numbers or letters) simultaneously. The participants' task was to press the corresponding keys in the proper order, using the index finger of their preferred hand, and to report whether the pitch went up or down between the two tones. Responses were made using the up-arrow and down-arrow keys on the computer keyboard. A tone was heard over earphones as long as a prompted key was held down.

RESULTS

Figure 1 summarizes the results in terms of the difference in the mean percentage of "up" responses between L-R and R-L key-press sequences (the *action effect*). Among the pianists, the overall percentages of "up" responses were 56.9 (L-R) and 39.4

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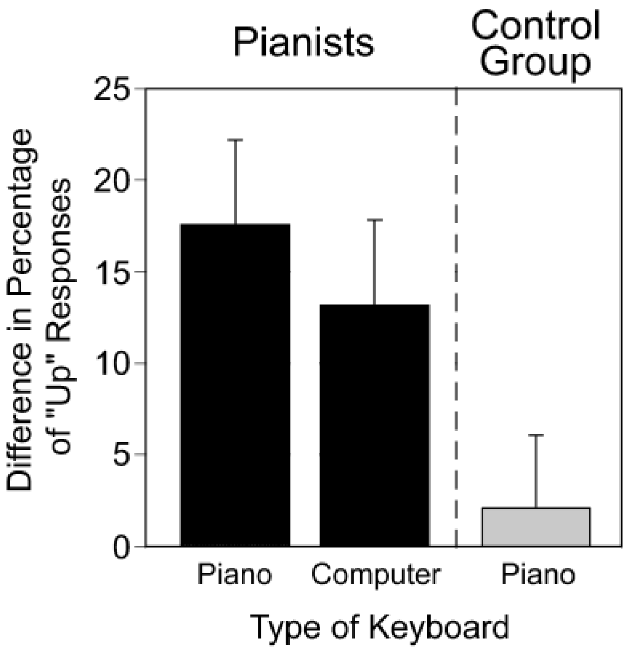

Fig. 1. Effect of action on perception. The graph shows the difference in the percentage of ''up'' responses for left-to-right versus right-to-left key presses for pianists in two keyboard conditions and for a control group using the piano keyboard only. Standard error bars are included.

(R-L) in the piano-keyboard condition and 51.0 (L-R) and 37.8 (R-L) in the computer-keyboard condition. The corresponding action effects were significant, $t(11) = 3.77$, $p < .003$ (two-tailed), $d = 1.1$, $p_{rep} = .99$, and $t(11) = 3.49$, $p < .005$, $d = 1.0$, $p_{rep} = .98$, respectively. The difference between the action effects in the two conditions just reached significance, $t(11) = 2.32$, $p < .05$, $d = 0.64$, $p_{rep} = .92$. Order of conditions and numbering of piano keys had no significant impact on the action effect.

For the control group, the mean percentages of "up" responses were 48.1 (L-R) and 46.0 (R-L). The mean action effect was not significant. The absence of this effect was not due to an inability to make consistent relative-pitch judgments. For each participant, we calculated the circular statistic of *mean resultant length* (Fisher, 1993) as an index of consistency in the piano-keyboard condition (maximum = .64). The means of this statistic did not differ significantly between the pianists (.41) and the control group (.35).

DISCUSSION

The results show that action can affect not only visual perception, but also auditory perception. Because an action effect was obtained for skilled pianists, but not for individuals with little or no piano experience, it seems that this effect does not reflect a general cognitive association between lateral movement and relative pitch height (Rusconi, Kwan, Giordano, Umiltá, & Butterworth, 2006), but rather reflects extensive active experience with such a mapping. That experience, we suggest, led to the automatic generation of specific pitch expectations when keys were depressed (i.e., auditory images were generated by an internal forward model), and those expectations in turn biased the perception of the bistable tone pairs.

The finding that the action effect in pianists was almost as large on a computer keyboard as on a piano keyboard suggests that the computer keyboard effectively functioned as a musical instrument with some similarities to a piano and thus activated the same movement-pitch associations. The finding that the action effect was somewhat weaker on the computer keyboard could have been due to the different appearance and feel of the keyboard, as well as to the arbitrary mapping of pitches to keys. In conclusion, the present study suggests that manual actions can make pianists *hear* tones differently.

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