Association of Haptic Trajectories to Takete and Maluma

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Abstract. An experiment has been made, in which participants grasping the stylus of a robotic arm were physically guided along a jagged or rounded trajectory, and then were asked to associate either trajectory to the word "takete" or "maluma". A significant preference (nine out of eleven participants) for associating the jagged trajectory to "takete" and the rounded trajectory to "maluma" has been found, indicating the existence of a connectivity between haptic trajectories and words. This result suggests to interaction designers to avoid the association of counter-intuitive labels or verbal meanings to (yet rarely used) structured synthetic kinesthetic messages ("haptons") that are perceived as jagged or rounded. The experiment complements existing research on cross-modal associations between stimuli belonging to other sensory channels, such as vision or taste, and words having demonstrated verbal equivalence to "takete" and "maluma". Furthermore, it raises interest on currently unanswered questions about the perceptual importance of temporal aspects in the haptic recognition of shapes by rectilinear or curvilinear contour patterns, and their higher-level decoding and connectivity at cortical level.

Keywords: takete and maluma, bouba and kiki, kinesthetic-verbal associations.

1 Introduction

In 1929, Wolfgang Köhler asked a group of Spanish speakers to make an association between the words "takete" or "maluma" and the images of two shapes, one jagged and the other rounded, like those in Figure 1. His results showed a significant preference of the speakers for associating "takete" with the jagged, and "maluma" with the rounded shape. The experiment has been repeated by several psychologists using different pairs of words, in particular "kiki" and "bouba", as well as involving speakers from different languages and levels of literacy. Apart from some specific exceptions reported for a population of Papua New Guinea, these experiments have all shown a general tendency of speakers, including young children aged 2.5 years old [1], to map rounded shapes on words containing the vowels "o" and "u", and, conversely, jagged shapes on words containing "e" and "i".

I. Oakley and S. Brewster (Eds.): HAID 2013, LNCS 7989, pp. 60–68, 2013.

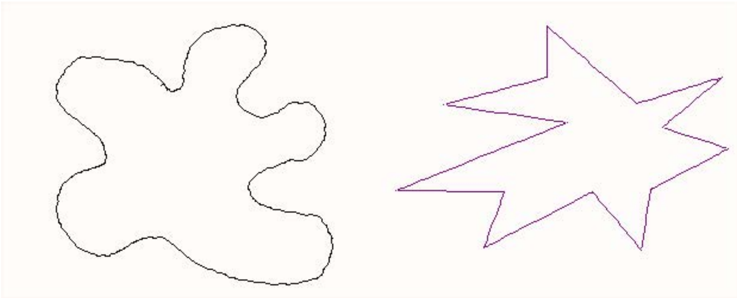

Fig. 1. Images similar to those used by Köhler in his experiments

Taken together, these results provide evidence of a powerful cross-modal effect, linking visual shapes to sounds of words. The existence of this effect in pre-literate children supports hypotheses on the existence of active connections among contiguous cortical areas, making possible for humans to link characteristic geometrical shape contours to similar geometries assumed by the speaker's lips. According to Ramachandran and Hubbard [2] such connections exist before language, hence they represent a general invariant influencing and constraining its development. Furthermore Ramachandran and Hubbard speculate that synesthesia, a phenomenon causing unusual, vivid cross-modal perceptions in a small percentage of the population, represents an amplified manifestation of the simultaneous activity occurring in connected cortical areas.

This body of research has been expanded by Spence and colleagues [3,4], who investigated on the existence of cross-modal associations between words and tastes. In evaluations where they asked subjects to associate perception of food and liquid tastes to takete/maluma or bouba/kiki, significant correlations emerged suggesting at least that counter-intuitive branding and labeling may be detrimental to the success of a food product. Besides its commercial implications, this investigation has demonstrated that the cross-modal associations of takete/maluma are not limited to visual shapes.

In this paper, a simple extension to the domain of non-visual shapes is presented. In particular, visual stimuli of shape contours such as those in Figure 1 have been substituted by kinesthetic feedback, providing cues of piece-wise rectilinear or curvilinear closed trajectories to blindfolded subjects. In the broader context of shape perception, haptic guidance has been mainly researched as a non-visual conveyor (often in connection with sound) of geometric and calligraphic information for training and teaching purposes, especially for enabling blind children to draw, to handwrite, and to perform collaborative explorations together with sighted users [5,6,7].

We avoided to investigate on the association of takete/maluma to tactile percepts of 3D shapes: this investigation would have represented a direct counterpart to the Köhler experiment once exposing two solids to the subjects' manipulation, respectively with rounded and piece-wise flat surfaces meanwhile having identical weight and texture; on the other hand, the use of 3D haptic trajectories as stimuli for the test restricts the displayed information to proprioceptive cues of contour, hence maintaining a clear parallelism with the original experiment. Furthermore, as we will see in the discussion, the employment of a simple robotic arm for the generation of kinesthetic feedback allows to link the experimental results directly to the design of haptic computer interfaces and virtual environments, especially concerning the realization of abstract haptic messages or "haptons" [8], as we may call them in analogy to tactons [9] to underline their kinesthetic nature, and in spite of the fact that their use in human-computer interaction has not been widely adopted yet [10].

2 Method

The experiment took place in a quiet room of the Department of Computer Science of the University of Verona, belonging to the Video, Image Processing and Sound Laboratory.

2.1 Participants

Eleven graduating students (six male and five female) participated to the test. All were Italian speakers, reporting normal proprioception and sight as well as no episodes of synesthesia. One subject had previous knowledge of the takete/maluma effect based on visual shapes, while the others were new about it. They were not economically rewarded, however upon individual request their participation to the experiment was acknowledged to the graduation course council of their Faculty.

2.2 Apparatus and Stimuli

A widely used robotic arm (Phantom Omni by SensAble Technologies) was programmed to draw a piece-wise rectilinear or curvilinear trajectory. This specific device has the advantage to expose a pen-like termination (called stylus) to the user's hand: this characteristic facilitated the simulation of an active pen, autonomously drawing rounded or jagged contours meanwhile being grasped by the subjects. Concerning the kinesthetic feedback,

– rectilinear movements reproduced a trajectory, whose projection on the subject's visual plane is illustrated in Figure 2 (below). This trajectory was framed within an ideal box sized approximately $10\times10\times4$ centimeters. The entire drawing was covered at approximately piece-wise constant speed in about two seconds, in absence of a resistive grasping of the robotic arm. Reactive forces were exerted by the device to keep the robotic arm on the right trajectory during the task;

– curvilinear movements were obtained by driving the robotic device with sinusoidal forces acting on the 3D spatial domain (x, y, z). With respect to the x direction, the force F_x in Newton at time t was given by

$$F_x(t) = 5 \cdot \sin\bigl[\pi S_x\bigl(x(t) + \mu_x(t)\bigr)\bigr],$$

with $S_x = 10\,\mathrm{m}^{-1}$, and μ_x, included to avoid stops of the robotic arm caused by incidental absence of force along the three directions simultaneously, randomly assuming values between $0.5 \cdot 10^{-3}$ and $5.5 \cdot 10^{-3}$ m across time. An identical relation governed the forces acting respectively on the y and z direction. The arm termination was initially set at the position $(0, 0, 0)$.

The net result was a rounded three-dimensional trajectory, again occupying a box sized approximately 10×10×4 centimeters. Figure 2 (above) illustrates a possible projection on the xy (corresponding to the visual) plane of these trajectories, whose final realization in any case depended on the force exerted by the user's hand: in particular, the smaller extension along the z direction was consequence of the larger inertia of subjects in following the movement of the robotic arm along depth[1]. Similarly to the rectilinear case, the quasi-periodic cycle was completed in approximately two seconds in presence of a gentle grasping of the robotic arm.

The psychophysics of tactile perception of 3D shapes essentially relies on studies of active exploration and manipulation, and has been extensively covered in the scientific literature. Conversely, the *haptic guidance* of subjects during passive motor tasks has been sparsely studied by psychologists. Feygin and colleagues [11] have measured the performance of subjects in manually reproducing, either with or without use of their vision, a 3D trajectory that had previously been learned under three different conditions: haptic, visual, haptic and visual. Results showed that visual training has an important role for learning the spatial development of a trajectory, while haptic training imprints the memory about its temporal development.

Besides the subjective performance in learning, and then reproducing a 3D trajectory through different modalities — an issue which is relatively important in the context of our experiment — two observations that have been reported as anecdotal by Feygin and colleagues are conversely worth mentioning here: i) among various learning strategies, subjects used verbalization and singing, and ii) under the visual learning condition, at least 7 out of 36 subjects mimicked the displayed trajectory with their hands. Together, these observations reveal the existence of a cross-modal association between the visual perception of a trajectory and the subjective production of movement, as well as words and structured (i.e., musical) sounds.

[1] The force feedback provided by the Phantom Omni amounts in any case to few Newtons, and can be easily overwhelmed by an intentional reaction of the user.

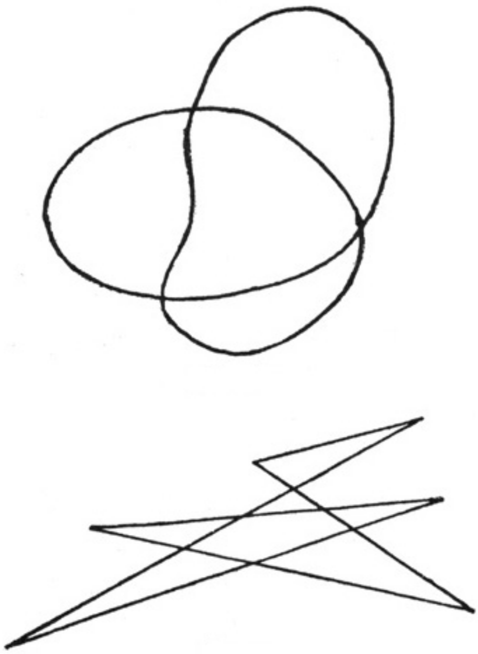

Fig. 2. Trajectories used in the experiment

2.3 Procedure

Subjects were asked to sit in front of the Phantom Omni, and to grasp the stylus with their preferred hand as if it were a normal pen. Then, they were suggested to keep their arm and wrist relaxed while holding it. At this point they were made aware of the gray and black buttons existing at finger reach on the stylus of the device, and were instructed to use them respectively to trigger the beginning of a motion pattern and to switch between two different trajectories of the robotic arm when the device was idle. Finally, subjects were blindfolded and the test started:

1. during the training phase, under the supervision of the experimenter subjects got accustomed with either trajectory by freely triggering as well as swapping them through the buttons. This phase took approximately two minutes;
2. once the training was over, before the evaluation task the experimenter asked them to remember the words “takete” and “maluma”.[2] Then, to autonomously repeat the previous phase and try to associate either word to the corresponding trajectory;

[2] In Italian, the vowel “e” sounds like in the English word “fence”; “maluma” sounds almost the same as in English.

3. during the evaluation task, subjects were left free to trigger and swap between as many instances of the two trajectories as they wished, until they came up with their decision. The decision concluded the test.

The time to perform the test (training plus evaluation) amounted to about five minutes.

2.4 Results

Table 1 lists the decisions, subject by subject. The polarization of the evaluation is evident. A two-tailed z-test of a single population proportion X, with $X \in \mathcal{N}(0.5, \sqrt{\frac{0.5 \cdot 0.5}{11}})$ the percentage of subjects associating the jagged trajectory to "takete", yields a p-value equal to 0.035.

Table 1. Subjects' decision

Subject no.	Sex	Previous knowledge	Decision on jagged trajectory
1	male	no	maluma
2	female	no	takete
3	female	no	maluma
4	male	no	takete
5	male	yes	takete
6	male	no	takete
7	male	no	takete
8	male	no	takete
9	female	no	takete
10	female	no	takete
11	female	no	takete

3 Discussion

The percentage of subjects associating the jagged trajectory to "takete" confirms the existence of a cross-modal effect between the haptic task and the words used in the experiment. However, its strength is less pronounced than the effect found by Köhler, or by Ramachandran and Hubbard using "kiki" and "bouba" in connection with visual shapes.

The decreased strength may be due to the minor sharpness of the angles displayed between two rectilinear movements by the haptic device at hand, due to its performance limits. These limits, in other words, may result in smoothed reproductions of the jagged trajectory compared to its geometrically ideal visual counterpart which, for instance, can be drawn on a piece of paper. As we mentioned before, it is easy to distort the haptic feedback provided by the Phantom Omni, just by forcing its arm to travel on a different trajectory. Conversely, the variability of the rounded trajectories should have no impact in the results, provided also the existence in the literature of successful studies making use of different types of rounded shapes [1].

Now, one may think to resort to more powerful robotic devices: on the one hand they guarantee increased robustness in reproducing a jagged trajectory; on the other hand, their motors are almost inevitably noisy. Specifically, their noise characterizes completely either trajectory: stationary when they reproduce rounded patterns and, conversely, spiky every time a piece of rectilinear trajectory is switched to another while reproducing a jagged pattern. The Phantom Omni in this sense is almost completely silent, and its residual noises should not have interfered with the task. Future experiments may opt for the use of more powerful robotic arms, once guaranteeing that subjects are not biased by the auditory feedback coming from the haptic device.

Alternatively to a robotic device, subjects during the task may have been guided by another person, or may have been asked to follow a contour by autonomously navigating around a path. By maximizing the potential of the temporal description of a shape, both such different user experiences might have led to stronger association effects in subjects: these and other alternatives to the proposed implementation are worth addressing in future experiments.

It would also be interesting to know if providing the words as printed, rather than verbally, would lead to different results. Such an experimental design, however, would significantly differ from the present one only if preliminary making sure that subjects are able to recall the words visually, and not verbally. Furthermore, the respective design should let the blindfolded subjects have a look to the printed words each time they need to recall them during the test, hence introducing an occasional visual component potentially lowering the level of control in the experiment.

The use of haptic instead of visual feedback opens an interesting question, which has been left aside by the previous discussions about the takete/maluma experiment based on vision: do subjects associate shapes or trajectories to words? In other words, do subjects reconduct visual contour patterns to the corresponding shapes that they delimit, or rather to an image of the motor activity producing the contours themselves? The latter hypothesis, which may be supported by the results of the proposed experiment and, at least partially, by the observations of Feygin and colleagues reported in Sec. 2.2, would require to extend the speculations of Ramachandran and Hubbard, who connect shapes to words mainly through a spatial analogy while giving less emphasis to the temporal aspects.

Recent studies reporting about fMRI-based analyses of the activity occurring in specific areas of the human brain, are progressively shedding light on the functional roles of the lateral occipital complex and the intraparietal sulcus of the brain, in decoding visual and haptic 3D shape information incoming from the periphery of the nervous system, and in the integration of this information with object representations stored in the frontoparietal regions [12]. In particular, spatial properties of objects such as size, shape, and relative position, seem to be encoded into the lateral occipital complex in a modality-independent format, as opposed to pictorial properties such as color and texture. The existence of a common representational system would find confirmation in the individual ability to explore objects either visually or haptically, with comparable spatial learning performances.

Specifically, the lateral occipito-temporal sulcus has been supposed to contain a spatial representation of objects, that is accessed from both the periphery and the memory. The former access occurs independently of the sensory modality. However, the process is modulated by the object familiarity: particularly during the haptic exploration of unfamiliar objects, the activity in the lateral occipito-temporal sulcus is largely disconnected from the frontoparietal regions, and the recognition is then mostly supported by local spatial imagery processes: in other words, the haptic recognition of unfamiliar objects would receive little or no support from visual-haptic analogies existing in the memory, until some spatial imagery is consolidated in the lateral occipital complex. Interestingly for our discussion around takete/maluma, these conclusions have been drawn in experiments where participants listened to pairs of words, and decided whether the objects designated by such words had similar shape or not; then, in a separate session the same participants performed a haptic discrimination task of familiar and unfamiliar objects [12].

Unfortunately, these functional experiments could not measure any temporal aspect of the decoding process taking place in the lateral occipito-temporal sulcus during the haptic recognition: especially in the case of the exploration of unfamiliar objects, any measure of this kind could have informed our discussion with substantial arguments. Precious information could have additionally been drawn from our experiment as well, had we recorded quantitative data about the temporal process (such as deviations from the desired trajectory and jitter on task completion times caused by reactive forces exerted by subjects) during the haptic recognition task. Especially for this reason, we hope to collect such data in a future instance of the experiment, as well as to repeat the task with congenitally blind participants: for these subjects, in fact, any mental imagery of spatial features of objects results exclusively by a haptic experience of 3D shapes.

As a final consideration, the proposed experiment is likely to target a subset of the existing connections between spatial ability and haptic feedback, and hence have limited scope. Words like "takete" and "maluma" may in fact be significantly associated to temporal cues going beyond their instantiation into simple geometrical shapes. Furthermore, as for any forced choice, the two words can probably be associated to different pairs of qualities using whatever modality: this fact calls for an even more cautious use of the results.

All this said, the outcome of the proposed experiment suggests the existence of a robust decoding of unfamiliar haptically-explored trajectories from users gifted with normal proprioception and sight. In absence of this decoding, any connectivity with words such as "takete" and "maluma" should in fact be absent. This conclusion implies that it is important, for interaction designers, to avoid counter-intuitive associations between haptically-displayed shapes and their labels: similarly to what has been recommended in the case of cross-modal associations between tastes and words [3], this concern may prevent from the design of "haptons" with an inherently odd verbal semantics and related meaning.

Acknowledgments. This research has been hosted and funded by the Department of Computer Science of the University of Verona. The author acknowledges the software implementation work of Davide Conigliaro, Marco Schivi and Pietro Lovato, attending the course of Non-visual interaction in the same Department at the time when this research was conducted. One anonymous manuscript reviewer has provided especially constructive criticism, that helped the author discuss better the limits of the hypothesis and consequent experimental design in the related section.

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