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TITLE:

Investigating the Effect of Visual Imagery and Learning Shape-Audio Regularities on Bouba and Kiki

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KEYWORDS:

Bouba/kiki-effect; crossmodal; haptic touch; hearing; learning effect; mental image; multimodal; sensory regularities; shape recognition; shape-audio regularities; vision; visual imagery

SUMMARY:

The aim of the presented protocol is to investigate the role of visual imagery in the bouba/kiki-effect, whether training in noticing the bouba/kiki shape-audio regularities affects the bouba/kiki-effect and the recognition of individual bouba and kiki shapes, and finally the production of mental images with these regularities.

ABSTRACT:

This article presents a protocol for investigating the role of visual imagery in the bouba/kiki-effect, whether training in noticing the bouba/kiki shape-audio regularities affects the recognition of individual bouba and kiki shapes, the bouba/kiki-effect and finally the production of mental images with these regularities. To generate bouba/kiki shape-audio regularities, there were two types of shapes (filled; outlined) and two types of audio (word; non-word sound). Three groups of individuals participated in three experiments-Blind, blindfold, and vision. The experiments were conducted in fixed order across participants, with no break between them. In Experiment 1 (pre-test-post-test design with three repeated within-group measures) the participants were asked to associate a shape with the auditory bouba/kiki; in Experiment 2 (within-subject design), to name some audio (sometimes congruous; sometimes incongruous) and one shape as 'bouba' or 'kiki;' and in Experiment 3 (post-test only design), to draw the shape they associated with the auditory bouba/kiki. The results suggest that the blindfold-group draw upon visual imagery to solve new problems, but not long term; that training in noticing bouba/kiki shape-audio regularities affects the bouba/kiki-effect and the recognition of individual bouba and kiki shapes, but differently in each experimental group; and that all experimental groups create mental images of the shape feature of bouba (curve) and kiki (angle). In fact, the effect of visual imagery is robust across tasks, but not long term; the effect of learning shape-audio regularities is robust long term, but not across tasks. The presented protocol is appropriate for investigating

the effect of visual imagery and learning shape-audio regularities, when they occur and how robust they are; in specific individuals and groups of individuals. This protocol is unique in that it keeps under control both the visual imagery and the sensory information during training and testing.

INTRODUCTION:

95% of the world's population shows an auditory-visual bouba/kiki-effect, associating the visually rounded shape with the word, 'bouba;' and an angular shape with the word 'kiki;' and they do this even when they have not had any experience with either the shape or the word[1]. The language learning is preceded by the bouba/kiki-effect; it occurs across languages[1-5], with both bouba and kiki (i.e., people prefer visual curves over visual angles[6-9]), and it depends on the combination of consonants and vowels (e.g., it does not occur with 'bibi' and 'kuku'.)[1,5,10-12] This shape-word association occurs with other shapes and word pairs as well, as long as they are mainly curved, as bouba, and mainly angular, as kiki[11,13]; and/or they have the same combinations of vowels and consonants as 'bouba' and 'kiki,' for example: 'Baluma' and 'takete,' 'maluma' and 'takete,' 'uloomo' and 'takete,' 'maa-boo-maa' and 'tuh-kee-tee'[1,3-4,10-12,14]. In fact, people associate the rounded visual shapes with the spoken words containing continuant consonants (such as /l/ and /m/) and open back vowels (such as /ɑ:/, and /ɔ:/), and the visual angular shapes with the spoken words containing plosive consonants (such as /k/ and /t/) and close front vowels (such as (/ɛ/ and /I/)[11-12,15-16]. They are influenced more by the consonants than the vowels, especially by the voiceless ones (e.g., /k/ and /t/)[11-12,15-16]. Indeed, it seems the features of the global shapes – their curves and angles[17] – and the sound of the spoken words – their melody[17] – are the most crucial, as opposed to the global shapes and words themselves.

One study has investigated the bouba/kiki-effect with tactile bouba and kiki instead of the visual bouba/kiki shapes and found that bouba/kiki-effect in the visually impaired participants showed significantly less robustness (~64%) than the fully sighted (~90%)[18]. The authors argued that this effect was caused by a lack of visual imagery amongst the blind and partially sighted participants. The fully sighted participants had noticed regularities in their environment that are not easily accessed when vision is impaired[18]. It is not clear from this study, however, whether the visual imagery is necessary for the bouba/kiki-effect to occur. Only six of the 42 participants with a visual impairment were congenitally totally blind[18], thus had no visual imagery at all. Furthermore, the other participants, none of them blindfolded, may have observed the lip movements of the experimenter when announcing the word bouba or kiki. Rounded lip movements are seen when announcing 'bouba' while angular lip movements are seen when announcing 'kiki'[1,18]. This shows a tactile-visual-auditory bouba/kiki-effect instead of drawing upon any visual imagery. Additionally, any effect of noticing tactile-auditory regularities was not investigated, for example, by comparing the bouba/kiki-effect on trial one and trial four instead of calculating the effect across all four trials. Moreover, the tactile bouba and kiki were rather different across trials: In trials one and two they were 3D and 2D shapes (curved v angular); in trials three and four, identical in shape (circle) and dissimilar in texture (smooth v rough; smooth v spiky)[18]. In a related vein, one study has investigated a kinesthetic-auditory bouba/kiki-effect in blindfolded (fully sighted) individuals and found that 82% showed the bouba/kiki-effect[19]. This was observed after a 2-min of training to hold a robotic stylus programmed to draw trajectories

of the bouba and kiki shapes. However, since this study did not include a control or a pre-test group, whether the bouba/kiki-effect occurred because of the training period, is not clear from this study.

To this end, we have investigated the role of visual imagery in the bouba/kiki-effect, whether the bouba/kiki-effect and the recognition of individual tactile/visual bouba and kiki shapes were affected by the training in noticing tactile/visual-auditory bouba and kiki regularities, and finally what mental images these shape-audio regularities produced[17]. To generate bouba/kiki shape-audio regularities – not merely, for example, kiki-shape/kiki-word particularities[1] – this study included two types of bouba/kiki shapes (filled; outlined) and two types of bouba/kiki audio (word; non-word sound)[17]. Three groups of individuals participated in three experiments: Blind (N = 12), blindfold (N = 12), and vision (N = 12). The experiments were conducted without any breaks and in fixed order across all participants. This helped to keep the participants' type and amount of experience with bouba and kiki under control. The participants were asked to pick out the shape they associated with the auditory bouba/kiki in Experiment 1 (pre-test-post-test design with three repeated within-group measures); in Experiment 2 (within-subject design), to name one shape and some audio (sometimes congruous; sometimes incongruous) as 'bouba' or 'kiki;' and in Experiment 3, (post-test only design) they were asked to draw the shape they associated with the auditory bouba/kiki[17]. Overall, this study suggested that the effect of visual imagery is robust across tasks, but not long term within each task, whereas the effect of learning shape-audio regularities is robust long term within each task, but not across tasks[17]. This article presents the protocol from this study[17]. The protocol is appropriate for investigating the effect of visual imagery and learning shape-audio regularities, when they occur and how robust they are; in specific individuals and groups of individuals. This protocol is unique in that it keeps under control both the visual imagery and the sensory information during training and testing.

PROTOCOL:

The Medical Sciences Inter-Divisional Research Ethics Committee (IDREC) University of Oxford provided approval for this protocol (Ref No: MS-IDREC-C1-2015-200, R46287/RE002, and R42687/RE004).

1. Design and conditions

1.1. Conduct three experiments in the following fixed order with all participants: Experiment 1, Experiment 2, and Experiment 3, with no break between them. Make sure that all participants in Experiment 2 participated in Experiment 1 and all participants in Experiment 3 also in Experiment 2 (and Experiment 1).

1.2. Conduct Experiment 1, a pre-test-post-test design, with three groups of participants i.e., Blind, blindfold, and vision; and three repeated within-group measures. Present the trials in a fixed order to all participants. (Total number of trials: 8.)

1.2.1. Conduct the pre-test (Trial 1) to test the instant bouba/kiki-effect.

1.2.2. Conduct the first repeated within-group measure (Trial 4) to test the effect of repeated tactile/visual shape (either filled or outlined) and varied audio (word and non-word sound).

1.2.3. Conduct the second within-group measure (Trial 5) to test the effect of new tactile/visual shape (either outlined or filled) and varied audio (word and non-word sound).

1.2.4. Conduct the third within-group measure and post-test (Trial 8) to test the effect of varied tactile/visual shape (filled and outlined) and varied audio (word and non-word sound).

1.2.5. Randomly assign which type of tactile/visual bouba/kiki shapes to present in trials 1-4 (either filled or outlined). Present the other type in trials 4-8. Then, randomly assign which auditory word (either bouba or kiki) to present in Trial 1, and which auditory bouba/kiki (either bouba or kiki and either word or non-word sound) to present in each one of Trials 2-8.

NOTE: Make sure that in total, there are 4 bouba and 4 kiki trials; 4 filled and 4 outlined tactile/visual shape trials; 4 auditory word and 4 auditory non-word sound trials.

1.3. Conduct Experiment 2, a within-subject design, with 3 groups of participants i.e., blind, blindfold, and vision; and two within-group measures. Present the trials in a fixed order to all participants. (Total number of trials: 8)

1.3.1. Test the instant recognition of congruous (bouba/kiki + bouba/kiki) shape-audio (Trial 1).

1.3.2. Test the recognition of (1) congruous (bouba/kiki + bouba/kiki), and (2) incongruous (bouba/kiki + kiki/bouba) shape-audio [across 4 trials per type of congruousness (Trials 1-8)].

1.3.3. Randomly assign which type of tactile/visual bouba/kiki shape (either filled or outlined) to present in trials 1-8. Then, randomly assign which congruous tactile/visual shape and auditory non-word sound (either bouba + bouba or kiki + kiki) to present in Trial 1, and finally which type of congruousness (either congruous or incongruous tactile/visual bouba/kiki shape + auditory bouba/kiki non-word sound) to present in each one of Trials 2-8.

NOTE: Make sure that in total, there are 4 tactile/visual bouba and 4 tactile/visual kiki trials; 4 filled and 4 outlined tactile/visual trials; four congruous and four incongruous (shape + non-word sound) trials. The auditory bouba/kiki word is not included in this experiment.

1.4. Conduct Experiment 3, a post-test only design, with 3 groups of participants i.e., blind, blindfold, and vision. Present the trials in a fixed order to all participants. (Total number of trials: 4).

1.4.1. Test what mental images have been produced by the training in noticing shape-audio regularities (i.e., Experiment 1 and Experiment 2), in four separate trials: Bouba word, bouba non-word sound, kiki word, and kiki non-word sound.

1.4.2. Randomly assign which type of auditory bouba/kiki (either bouba or kiki and either word or non-word sound) to present in each one of Trials 1-4.

NOTE: Make sure that in total, there is one auditory bouba word trial, one auditory bouba non-word sound trial, one auditory kiki word trial, and one auditory kiki non-word sound trial.

2. Participants

2.1. Recruit one group of participants who are congenitally blind; that is, blinded less than 4 months after birth[20-22]: Categories 5: total blindness; and 4: Light perception (perceiving a light source) and light projection (perceiving where a light source is situated)[22]. Make sure they are all braille readers.

2.2. Recruit one group of fully sighted participants, at twice the size of the group of participants who are congenitally blind. Make sure they all have normal/corrected to normal vision.

NOTE: Make sure that all participants are between 18 and 70 years of age, with no cognitive delay or impairment, no physical disabilities, normal/corrected to normal hearing, and that they are all naïve to the bouba/kiki-effect.

2.3. Randomly assign half the group of the fully sighted participants to the blindfold-group and the other half to the vision-group.

NOTE: Participants, type of tactile/visual bouba/kiki shape(s), type of auditory bouba/kiki, and congruousness are all randomly assigned to one of two categories: Blindfold or vision; filled or outlined; word or non-word sound; bouba or kiki; congruous or incongruous. Thus the random assignment can be done either by a computer program or manually (e.g., by tossing a coin).

3. Materials

3.1. Produce the tactile/visual test materials

3.1.1. Transfer the visual bouba/kiki shapes (30 x 23 mm) to swell paper, either by printing them from a personal computer or by photocopying from a picture. Make sure to transfer two types of bouba/kiki shapes: One filled and one outlined [(1.5 pt. line). Cf. **Figure 1**].

3.1.2. Pass the swell paper through a heat fuser. Make sure the bouba/kiki shapes rise to ~0.5 mm height. Alternatively, order the tactile/visual bouba/kiki shapes from a transcription service for people who are visually impaired (with a PDF file attached).

3.1.3. Glue the swell paper onto foam board [white (5 mm thick)]. Use spray glue.

3.1.4. Cut the swell paper and foam board into size (50 x 50 mm), that is, to create tactile/visual picture cards. Use a knife for cutting wallpaper.

3.1.5. Cut a carton plate/foam board for covering the bouba/kiki shapes into size (297 x 210 mm). Use a knife for cutting wallpaper.

3.1.6. Cut copy paper/plastic embossing film into size (210 x 148 mm). Use a guillotine. Alternatively, order the A5 format.

3.1.7. Cut a rubber mat into size (230 x 150 mm). Use a knife or pair of scissors. Alternatively, order the Moon hand frame and take it apart to uncover the rubber mat.

[Place **Figure 1** here]

3.2. Produce the auditory test materials.

3.2.1. Record the spoken bouba (**Audio 1**) and kiki words. Save in the MP3 format: One file for the bouba word and one for the kiki word.

3.2.2. Create the bouba and kiki non-word sounds of the spoken words 'bouba' and 'kiki' by mimicking the duration and frequency (i.e., melody). Use a sound wave generator and pitch bend. Save in the MP3 format: One file for the bouba sound (**Audio 2**) and one for the kiki sound.

3.2.3. Install the VLC app for iOS on a smartphone. Transfer the MP3 files for bouba and kiki to the VLC app. Save them as four separate files: Bouba sound, bouba word, kiki sound, and kiki word.

[Place **Audio 1** and **Audio 2** here]

[Place **Table of Materials** here]

4. Procedure and scoring

4.1. Set up the test session

4.1.1. Conduct the three experiments in a room that is neutral in color and quiet, and with all participants individually. Ask the participants in the blindfold-group to put on their blindfold, before setting up the test materials, and make sure they keep their blindfold on throughout and between all three experiments.

4.2. Set up the tactile/visual test materials.

4.2.1. Place the rubber mat directly in front of the participant. Then, place (Experiment 1) the two tactile/visual bouba and kiki shapes (Experiment 2), the one tactile/visual bouba or kiki shape and (Experiment 3), the copy paper/plastic embossing film on top of the rubber mat. In

Experiment 1, make sure to always present bouba on the left and kiki on the right; and in both Experiment 1 and Experiment 2, to always present them in the same orientation (cf. **Figure 1**):

4.2.1.1. Enhance the participants' ability to form mental images by making sure not to inform the participants about this fixed presentation of the tactile/visual bouba and kiki shapes without interference from their position and/or orientation on the rubber mat. In the vision-group, always set up the test material behind a carton plate/foam board, to prevent these participants from taking a sneak peek at what is in store.

4.3. Set up the auditory test materials

4.3.1. Place the MP3 player directly in front of the participant (on the other side of the rubber mat), and with the loudspeaker closest to the participant. Do not repeat the auditory information from the MP3 player, to prevent the vision-group participants observing the lip movements on the bouba/kiki word-trials[1], and thus keep under control across all experimental groups the amount and type of auditory information.

4.4. Conduct Experiment 1, Experiment 2, and Experiment 3

4.4.1. Invite the participants who will be exploring and drawing the tactile shapes (i.e. the blind and blindfold-group) to explore the rubber mat (by touch). For example, for size and texture, without any of the picture cards and/or copy paper or plastic embossing film placed on top.

4.5. Conduct Experiment 1

4.5.1. Explain that two picture cards will be presented on the rubber mat, each one picturing a tactile/visual shape. Then, explain that some audio will appear from the MP3 player and that this audio will correspond to one of the tactile/visual shapes.

NOTE: Do not inform the participants about the two types of tactile/visual bouba/kiki (filled and outlined) and the two types of auditory bouba/kiki (sound and word).

4.5.2. Place the two picture cards on the rubber mat (cf. **Figure 1**).

4.5.3. In the blind and blindfold-group, ask the participant to make a fist using both hands. Next, ask the participant to place their fists on the top of the picture cards presented (and guide them if needed). Place the left hand on top of the participant's fists.

4.5.4. Ask the participant to explore the two tactile/visual shapes, the blind and blindfold-group by touch and the vision-group by vision. Ask them to say 'yes' when they have finished their exploring.

4.5.5. Remove the left hand from the participant's fists (in the blind and blindfold-group) / the carton plate or foam board (in the vision-group).

4.5.6. As soon as the participant says 'yes,' cover the picture cards.

4.5.7. Play the audio.

4.5.8. Ask the participant to signal which tactile/visual shape they associate with the audio, for example, by saying 'left/right,' 'curvy/angular' or 'flower/star'. Do not respond to the participant's answer.

4.5.9. Score whether the participant's answer is correct or incorrect.

NOTE: Repeat 4.5.2–4.5.9 for all eight trials.

4.6. Conduct Experiment 2

4.6.1. Explain that some audio will appear from the MP3 player and one picture card (tactile/visual) will be presented on the rubber mat.

4.6.2. Explain that the audio will appear once per picture card, as soon as they start exploring the tactile/visual shape.

NOTE: Do not inform the participants about the two types of tactile/visual bouba/kiki (filled and outlined), the one type of auditory bouba/kiki (sound), and the two types of congruousness (congruous and incongruous).

4.6.3. Place the picture card on the rubber mat.

4.6.4. In the blind and blindfold-group, ask the participant to make a fist using both hands. Next, ask the participant to place their fists on top of the presented picture card (and guide them if needed). Place the left hand on top of the participant's fists.

4.6.5. Ask the participant to explore the shape (tactile/visual), the blind and blindfold-group by touch and the vision-group by vision, and to listen to the audio. Then, ask them to name the tactile/visual shape and the audio as either 'bouba' or 'kiki': One name only[23-25], when they have finished their exploring.

4.6.6. Remove the left hand from the participant's fists (in the blind and blindfold-group) / the carton plate or foam board (in the vision-group) and play the audio.

4.6.7. Once the participant names the tactile/visual shape and the audio, cover the picture card. Do not respond to the participant's answer.

4.6.8. Score whether the participant's answer is correct or incorrect.

NOTE: Repeat 4.6.3–4.6.8 for all eight trials.

4.6.9. Across the congruous and incongruous trials, count a participant as 'correct' when they have recognized ≥75% of the tactile/visual bouba and kiki shapes.

4.7. Conduct Experiment 3

4.7.1. Explain that some copy paper/plastic embossing film will be placed on top of the rubber mat, instead of the picture card(s), and that the participant will be asked to draw on it.

4.7.2. In the blind and blindfold-group, invite the participant to try out the different drawing equipment, then to decide for themselves which ones they prefer: Plastic embossing film or copy paper and rollerball pen or saddleback style.

4.7.3. Explain that some audio will appear from the MP3 player and that the participant will be drawing the shape they associate with this audio, one shape per segment of audio when asked.

NOTE: Do not inform the participants about the auditory information (bouba and kiki), nor the two types of auditory bouba/kiki (sound and word).

4.7.4. Place the copy paper/plastic embossing film on the rubber mat.

4.7.5. In all three experimental groups (blind; blindfold; vision), ask the participant to make a fist using both hands, holding the rollerball pen/saddleback style. Then, ask the participant to place their fists on top of the copy paper/plastic embossing film (and guide them if needed). Place the left hand on top of the participant's fists.

4.7.6. Ask the participant to draw the shape that they associate with the audio presented. In the blind and blindfold-group, ask the participant to draw a tactile shape; and in the vision-group, a visual shape. Ask the participant to say 'yes' when they have finished their drawing.

4.7.7. Remove the left hand from the participant's fists.

4.7.8. Play the audio.

4.7.9. When the participant has said 'yes,' remove their drawing from the rubber mat and label it in the bottom right corner with the correct trial number. Do not respond to or provide any comments on the participant's answer/drawn shape.

NOTE: Repeat 4.7.4–4.7.9 for all four trials.

4.7.10 Scan all tactile/visual drawings (1:1 size) into the jpg format immediately after each test session.

NOTE: Experiment 3 is scored by a group of scorers after all drawing data have been collected.

4.7.11 Produce a questionnaire for scoring the drawing data (cf. **Figure 2**):

4.7.11.1. Scale down all scanned drawings to include 12 pictures per page in the landscape A4 format.

4.7.11.2. Randomly assign bouba/kiki trials, sound/word trials, and blind/blindfold/vision drawers.

4.7.11.3. Add trial number in the upper left corner of each picture.

4.7.11.4. Add 'bouba' and 'kiki,' and 'blind,' 'blindfolded' and 'sighted' under each picture.

[Place **Figure 2** here]

4.7.12. Recruit a group scorer, above 18 years of age; with normal/corrected to normal hearing and vision; with no cognitive delay or impairment, nor any physical disabilities; that are all naïve to this study, and that show a visual shape-printed word bouba/kiki-effect.

4.7.13. Ask the scorers to answer two multiple-choice questions per picture in the questionnaire: (1) 'Is the pictured shape "bouba" or "kiki;"' and (2) 'Is the pictured shape drawn by someone who is blind (since birth), blindfolded, or fully sighted?'[17]

4.7.14. Depending on the number of pictures in the questionnaire, ask half of the group of scorers to score half the questionnaire, and the other half to score the rest.

4.7.15. For each trial, count 'correspond,' 'not correspond,' and 'inconclusive,' as detailed below.

4.7.15.1. 'Correspond' when (I) ≥75% of the scorers agreed on which tactile/visual shape (bouba or kiki) was pictured, and (II) this shape corresponded to the presented auditory bouba/kiki in this trial.

4.7.15.2. 'Not correspond' when (I) ≥75% of the scorers agreed on which tactile/visual shape (bouba or kiki) was pictured, and (II) this shape did not correspond to the presented auditory bouba/kiki in this trial.

4.7.15.3. 'Inconclusive' when <75% of the scorers agreed on which tactile/visual shape (bouba or kiki) was pictured. Remove the 'inconclusive' pictures/participant drawings from the statistical analyses.

4.7.16. Across trials, count a participant as 'correspond' when ≥75% of their drawn mental images: That is, that tactile/visual shapes correspond to the presented auditory bouba/kiki.

4.7.17. For each trial, count 'recognized,' 'not recognized,' and 'inconclusive,' that is:

4.7.17.1. 'Recognized' when (I) ≥66.6% of the scorers agreed on which experimental group (blind, blindfold or vision) had drawn the pictured shape, and (II) this was correct in this trial.

4.7.17.2. 'Not recognized' when (I) ≥66.6% of the scorers agreed on which experimental group (blind, blindfold or vision) had drawn the pictured shape, and (II) this was not correct in this trial.

4.7.17.3. 'Inconclusive' when <66.6% of the scorers agreed on which experimental group (blind, blindfold or vision) had drawn the pictured shape. Exclude the 'inconclusive' participant recognitions from the statistical analyses.

4.7.18. Across trials (and with 'inconclusive' participant recognitions removed), count a participant as 'recognized' when recognized in ≥75% of all trials.

REPRESENTATIVE RESULTS:

The bouba/kiki-effect

An instant bouba/kiki-effect was observed in 6 of the 12 participants congenitally blind (50%), 9 of the 12 blindfolded (75%), and 10 of the 12 fully sighted (~83%) participants. That is, both the blindfold and vision-group were significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 3.00$, $p = 0.08$ and $\chi^2(1. N = 12) = 5.33$, $p = 0.02$ (Experiment 1, Trial 1)[17]. No significant difference was observed by Fisher's exact test between the three experimental groups (Experiment 1, pre-test)[17]. (Cf. **Table 1**.)

When it comes to the long term bouba/kiki-effect, on the first repeated within-group measure, 9 of the congenitally blind participants showed the bouba/kiki-effect along with 9 of those who were fully sighted. Both experimental groups were significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 3.00$, $p = 0.08$ and $\chi^2(1. N = 12) = 3.00$, $p = 0.08$, and 7 of those were blindfolded (Experiment 1, Trial 4)[17]. On the second repeated within-group measure, 11 blind and vision-group participants showed the bouba/kiki-effect. Both experimental groups were again significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 8.33$, $p = 0.00$ and $\chi^2(1. N = 12) = 8.33$, $p = 0.00$; and 7 were in the blindfold-group (Experiment 1, Trial 5)[17]. Finally, on the third repeated within-group measure and post-test, 9 of the 12 congenitally blind participants (75%), 6 of the 12 blindfolded (50%), and all of the 12 fully sighted participants (100%) showed the bouba/kiki-effect; both the blind and vision-group were again significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 3.00$, $p = 0.08$ and $\chi^2(1. N = 12) = 12.00$, $p = 0.00$ (Experiment 1, Trial 8)[17]. Fisher's exact test found a significant difference between the blindfold and vision-group [$p = 0.01$. (Experiment 1, post-test)][17]. (Cf. **Table 1**.)

[Place **Table 1** here]

The recognition of bouba and kiki shapes

11 of the 12 congenitally blind (~92%), 9 of the 12 blindfolded (75%), and all of the 12 fully sighted (100%) participants instantly recognized the congruous tactile/visual and auditory bouba/kiki; all

three experimental groups were significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 8.33$, $p = 0.00$, $\chi^2(1. N = 12) = 3.00$, $p = 0.08$, and $\chi^2(1. N = 12) = 12.00$, $p = 0.00$ (Experiment 2, Trial 1)[17]. (Cf. **Table 2**.)

Long term, 11 blind-group participants recognized the tactile bouba/kiki shapes together with congruous audio and 10 participants with incongruous audio: Both types of congruousness recognized significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 8.33$, $p = 0.00$ and $\chi^2(1. N = 12) = 5.33$, $p = 0.02$ (Experiment 2, Trial 1-8)[17]. 9 blindfold-group participants recognized the tactile shapes together with congruous audio and 8 participants together with incongruous audio; in other words, the congruous shape and audio were significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 3.00$, $p = 0.08$ (Experiment 2, Trial 1-8)[17]. All 12 participants in the vision-group recognized the visual bouba/kiki shapes together with congruous audio and six participants with incongruous audio: The congruous shape and audio recognized significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 12.00$, $p = 0.00$ (Experiment 2, Trial 1-8)[17]. (Cf. **Table 2**.)

[Place **Table 2** here]

The mental images of bouba and kiki

8 of the 12 participants who were congenitally blind [~73% (with one 'inconclusive' participant drawing removed)], eight of the 12 who were blindfolded [~90% (with three 'inconclusive' participant drawings removed)], and eight of the 12 who were fully sighted [80% (with two 'inconclusive' participant drawings removed)] instantly drew a mental image. This was a tactile/visual shape that corresponded to the presented auditory bouba/kiki. Both the blindfold and vision-group were significantly above the chance level (of 50%): $\chi^2(1. N = 9) = 5.44$, $p = 0.02$ and $\chi^2(1. N = 10) = 3.60$, $p = 0.06$ (Experiment 3, Trial 1)[17]. (Cf. **Table 3**.)

Regarding the long-term mental images of bouba and kiki, 11 participants in the blind-group, 8 in the blindfold-group, and 12 in the vision-group drew tactile/visual bouba/kiki shapes that corresponded to the presented auditory bouba/kiki. Both the blind and vision-group were significantly above the chance level (of 50%): $\chi^2(1. N = 12) = 8.33$, $p = 0.00$ and $\chi^2(1. N = 12) = 12.00$, $p = 0.00$ (Experiment 3, Trial 1-4)[17]. Fisher's exact test found a significant difference between the blindfold-group and the vision-group [$p = 0.09$ (Experiment 3, Trial 1-4)][17]. (Cf. **Table 3**.)

[Place **Table 3** here]

Furthermore, ~83% of all participant drawings included the most characteristic shape feature of the global bouba and kiki shapes, curve and angle, respectively (Experiment 3, Trial 1-4)[17]. The participant drawings differed in the quantity of curves/angles (e.g., one and five angles for the kiki word: cf. **Figure 2**, Trials 1, 6, and 9), and in the direction of the curves/angles [i.e. horizontal, vertical or diagonal: cf. **Figure 2**, Trials 2, 5, and 8 (bouba sound)], but typically did not include the global bouba/kiki shape [Experiment 3, Trials 1-4 (cf. **Figure 1; Figure 2**)][17]. Finally, the experimental group was recognized in ~43% of the scores' answers: Five participants in the blind-group, three in the blindfold-group, and five in the vision-group; no experimental group was

significantly above the chance level [of 33.3% (Experiment 3, Trial 1-4)][17].

The effect of visual imagery and learning

The presented protocol succeeded in investigating the role of visual imagery in the bouba/kiki-effect, whether training in noticing the bouba/kiki shape-audio regularities affects the bouba/kiki-effect and the recognition of individual bouba and kiki shapes, and finally what mental images these regularities produce. By including one group of participants with no visual experience (i.e. the blind-group) and two experimental groups with visual experience (i.e. the blindfold and vision-group), it was possible to test the effect of visual imagery; and by including one group of participants with no visual experience and extensive tactile experience (i.e. the blind-group) and one experimental group with extensive visual experience and no tactile experience (i.e. the blindfold-group), it was possible to test the effect of the training in noticing tactile-auditory regularities. The results clearly suggest that the blindfold-group drew upon visual imagery to solve new problems, but not long term (Experiments 1–3); that training in noticing bouba/kiki shape-audio regularities affected the bouba/kiki-effect (Experiment 1) and the recognition of individual bouba and kiki shapes (Experiment 2), but differently in each experimental group (Experiment 1-2), and that all experimental groups created mental images of the most characteristic shape feature of bouba (curve) and kiki [(angle) Experiment 3. Cf. **Table 1; Table 2; Table 3**][17]. Moreover, by including repeated within-group measures of instant and long term effect (Experiment 1-3), it was possible to test when the effect of visual imagery and learning shape audio-regularities actually occurred; and by including three different tasks (i.e. the bouba/kiki-effect in Experiment 1, recognizing individual tactile/visual bouba/kiki shapes together with congruous and incongruous bouba/kiki audio in Experiment 2, and drawing mental images of bouba/kiki audio in Experiment 3), to test how robust these effects were. The results clearly suggest that the effect of visual imagery was not robust long term within each task, especially when using haptic touch [cf. the blindfold-group (Experiment 1-3)]; whereas the effect of learning shape-audio regularities was, but not across tasks [cf. the blind and vision-group (Experiment 1-3). Cf. **Table 1; Table 2; Table 3**.][17]

FIGURE LEGENDS:

Audio 1: Bouba word

Audio 2: Bouba sound

Figure 1: Two types of bouba/kiki shapes: Filled and outlined

Figure 2: Examples from the questionnaire for scoring the drawing data

Table 1: The instant and long term bouba/kiki-effect

Table 2: The instant and long term recognition of bouba and kiki shapes

Table 3: The instant and long term mental images of bouba and kiki

DISCUSSION:

The presented protocol is appropriate for investigating the effect of visual imagery and learning shape-audio regularities, when they occur and how robust they are; in specific individuals and groups of individuals.

This protocol would be appropriate for testing not only the accuracy but also the exploration time, from when the experimenter removes their left hand from the participant's fists (in the blind and blindfold-group) / the carton plate or foam board (in the vision-group) to when the participant says 'yes.' In the statistical analyses, the longest exploration time per trial per experimental group would be divided into four and the number of 'fast,' 'medium' and 'slow' participants in each experimental group counted: 'Fast' using ≤25% of this exploration time, 'medium' using 26-75%, and 'slow' using ≥75%. Across trials, the participants would be counted as in Experiment 2: That is, as 'fast' if counted as 'fast' in ≥66.6% of all trials, as 'medium' if counted as 'medium' in ≥66.6% of all trials, and so on. (For 'inconclusive', i.e. the participant cannot be counted as 'fast,' 'medium' or 'slow', cf. Experiment 3.) It would be possible to test the exploration time for correct and incorrect answers separately, depending on the sample size and/or the number of correct and incorrect answers. Whether testing accuracy, exploration time or both, this protocol has one critical step: In Experiment 2, it is crucial to present the auditory bouba/kiki as soon as the participant starts exploring the tactile/visual shape, to ensure the presentation of multimodal (congruous or incongruous) information. Moreover, this protocol would be appropriate for testing other groups of individuals as well. These participant groups would be added as separate experimental groups: For example, a color perception-group and a shape perception-group;[22] a sudden vision loss-group and a progressive vision loss-group;[20-21] and/or specific groups of individuals with a hearing impairment and/or an Autism Spectrum Disorder[13].

With this protocol, it would be possible to establish a group norm (for accuracy and/or exploration time) for specific groups on each instant and long term effect, including each repeated within-group measure, and/or task; then to test individuals against their group norm: Whether any particular individual or the entire group is in need of further training in noticing the shape-audio regularities. A group norm for each instant and long term effect, including each repeated within-group measure, and/or task would also make it possible to determine what kind of training is needed to notice the shape-audio regularities: For example, more trials with the bouba/kiki-effect (Experiment 1) and/or more trials with congruous and incongruous shape and audio (Experiment 2). Indeed, it would be possible to increase both the number of trials and the number of repeated within-group measures in each task as well as altering the time between them, thereby allowing more individualized training and testing.

However, this protocol would need modifying if testing what type of materials (e.g., bouba or kiki, filled or outlined, and/or sound or word) best ensures the learning of shape-audio regularities. A possible way of modifying this protocol could involve presenting the different materials in blocks: For example, filled shape(s) and sound and/or outlined shape(s) and word (Experiment 1). These blocks could be presented in random order to all the participants in one

experimental group; or alternatively, each one of the four blocks to separate experimental groups (Experiment 1). The protocol would also need modifying if testing even further the robustness of the visual imagery and/or learned shape-audio regularities within and across tasks. This modification could involve adding repeated within-group measures with different shape and/or audio than those included in the training; for example, with the sound for 'maa-boo-maa' and 'tuh-kee-tee' after training with bouba and kiki shapes and words (Experiment 1)[1,3-4,10-16]. Another option could involve presenting a third tactile/visual shape which is not mainly curved/angular together with the bouba and kiki shapes in Experiment 1[10-16]. A spoken nonsense word and a sound could be created for this tactile/visual shape to produce a third shape-word pair[14-16] and a third shape-sound pair[17] (Experiment 1). The shape-sound pair could then be included in Experiment 2 as catch-trials or alternatively as regular congruous trials and with corresponding incongruous trials. Finally, the sound (from Experiment 2 and Experiment 1) and/or the nonsense word (from Experiment 1) could be presented in Experiment 3. A third option could involve not conducting Experiment 2 and Experiment 3 at all, but rather including them as tasks in the repeated within-group measures in Experiment 1, in random order.

The presented protocol is unique in that it keeps under control both the visual imagery and the sensory information during training and testing. It is flexible: Large and small samples and specific individuals can be tested against themselves (cf. the within-group testing) and/or other groups of individuals (cf. the between-group testing). It is possible to test both accuracy and exploration time, change the number of trials and repeated within-group measures in each experiment and the time between them, and change or even collapse the order of trials and/or experiments.

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DISCLOSURES:
The authors have nothing to disclose.

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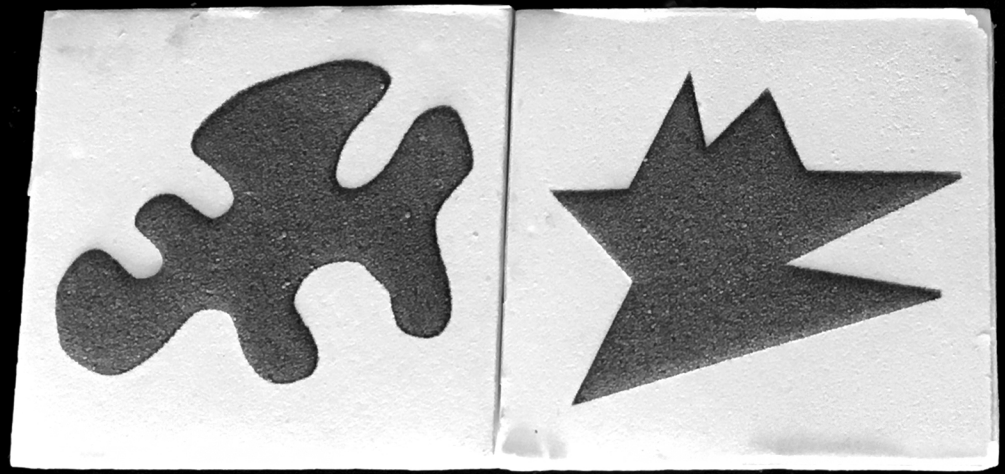


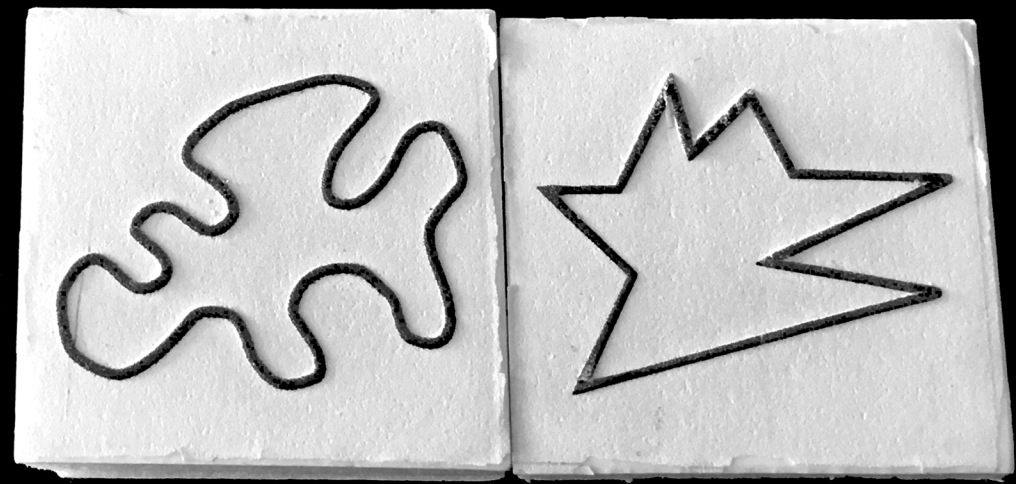


Figure 2

Reg. no: _____

Trial 1

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 2

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 3

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 4

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 5

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 6

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 7

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 8

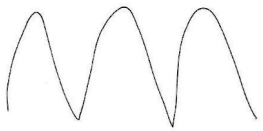
Bouba **Kiki**
Blind Blindfolded Sighted

Trial 9

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 10

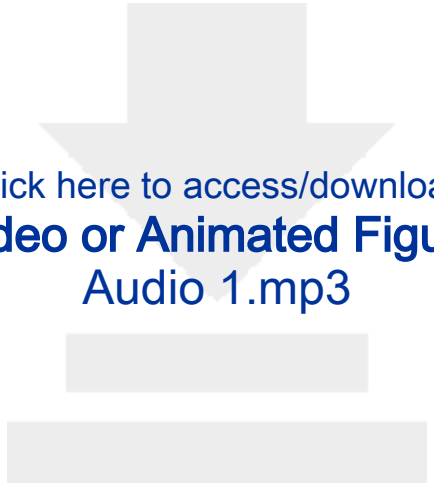
Bouba **Kiki**
Blind Blindfolded Sighted

Trial 11

Bouba **Kiki**
Blind Blindfolded Sighted

Trial 12

Bouba **Kiki**
Blind Blindfolded Sighted

Audio 1



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Audio 1.mp3

Audio 2

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Table 1

Participant group	**Instant bouba/kiki-effect**	**Long term bouba/kiki-effect**		
	Pre-test	*Repeated measure 1*	*Repeated measure 2*	*Repeated measure 3/post-test*
Blind	50.0%	75.0%	91.7%	75.0%
Blindfold	75.0%	58.3%	58.3%	50.0%
Vision	83.3%	75.0%	91.7%	100.0%

Table 2 Click here to access/download;Table;Table 2.xlsx

Participant group	Instant recognition of bouba/kiki shape	Long term recognition of bouba and kiki shapes	
	Congruous shape and audio	*Congruous shape and audio*	*Incongruous shape and audio*
Blind	91.7%	91.7%	83.3%
Blindfold	75.0%	75.0%	66.7%
Vision	100.0%	100%	50.0%

Table 3

Participant group	Instant mental image of bouba/kiki	Long term mental images of bouba and kiki
Blind	72.7%	91.7%
Blindfold	88.9%	66.7%
Vision	80.0%	100.0%

Table of Materials

Click here to access/download;Table of Materials;Table of Materials.xlsx

Name	Company	Catalog	
Bouba/kiki filled			
Bouba/kiki outlined			
Bouba/kiki sound (sine wave)			
Bouba/kiki word (human voice)			
Carton plate/foam board for covering bouba/kiki (white)	Ryman		230461860
Copy paper [white (80 g/m2)]	Ryman		250030000
Foam board for bouba/kiki picture cards [white (5 mm thick)]	Ryman		230461860
MP3-player (smartphone with the VLC app for iOS installed)	Carphone Warehouse		
Plastic embossing film	RNIB Shop	ZM04	
Rollerball pen [black (1.0 mm tip)]	Ryman		827134001
Rubber mat	RNIB Shop	LC177	
Saddleback style	RNIB Shop	B511	
Swell paper	Zychem Ltd	Zytex2 paper	

comments
30 mm horizontal, 23 mm m vertical, , and 0.5 m embossed height
30 mm horizontal, 23 mm m vertical, , and 0.5 m embossed height

297 mm horizontal x 210 0 mm vertical

210 mm horizontal x 148 mm vertical

50 mm horizontal x 50 mm vertical

210 mm horizontal x 148 mm vertical

230 mm horizontal x 150 mm vertical

50 mm horizontal x 50 mm vertical

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Date:	05.18.2019

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Dear Editorial Reviewers
Thank you for reviewing our paper. Please find our changes listed below.

1. The editor has formatted the manuscript to match the journal's style. Please retain the same.
- We have done all revisions in the version formatted by the editor (attached to your email).

2. Please address specific comments marked in the manuscript.
- Please note the new title: 'Investigating the effect of visual imagery and learning shape-audio regularities on bouba and kiki'
- Please note Introduction, third paragraph, first line: 'Accepted' (although in JoVE's Instructions_ for_Authors, B Grammar, second bullet point it says that 'Avoid the use of personal pronouns (e.g., I, you, your, we, our) or colloquial phrases.'
- Please note Design, first comment: Highlights removed.
- Please note Design, second comment: This is found in Introduction, last paragraph, in 1.2.1, and in 6.1.10. Please, do also note that 'experiment' is changed to 'design'.
- Please note Design, fourth comment: This is described in Procedure, the second NOTE: 'Repeat 6.1.4–6.1.12 for all eight trials.' Design describes the design, not what goes on in each trial (which is described in Procedure).
- Please note Design, fifth comment: This is described in Procedure, the first NOTE: 'NOTE: Repeat 6.2.3–6.2.9 for all eight trials.'
- Please note Participants, first comment: 'Rejected', because this would be a description of the study and not the protocol.
- Please note Participants, second paragraph: Number of participants in each group is added in Introduction, last paragraph, third sentence: 'Three groups of individuals participated: blind (N = 12), blindfold (N = 12), and vision (N = 12)[17].'
- Please note Materials, first comment: 'Accepted'.
- Please note Materials, second comment: It should be one file with the spoken bouba word, and one with the bouba sound. Is that not what you hear when you play them? We have had some issues with different equipment (e.g., we can play them from an iPhone but from not a PC).
- Please note Conditions, first comment: We merged together Design and Conditions as suggested. Please do also note that some of the steps in the previous Conditions have been merged together in Design and Conditions, and that parts of the previous Conditions has been moved to Procedure. We 'rejected' the suggested swapping around of sections: It seems logic to keep the order as follows: Design and Conditions, Participants, Materials, and Procedure and scoring. Please note that the highlights are removed.
- Please note Conditions, second comment: 'Accepted'. Previous 2.3 is now a NOTE
- Please note Conditions, third comment: This is found in Introduction, last paragraph, in 1.2.1, and in 6.1.10. Please, do also note that 'experiment' is changed to 'design'.
- Please note Conditions, fourth comment: 'Accepted', and included in the existing NOTE: 'Make sure that in total there are four bouba and four kiki trials; four filled and four outlined tactile/visual shape trials; four auditory sound and four auditory word trials. Total number of trials: 8.'
- Please note Conditions, fourth and fifth comment: 'Accepted', and included in the existing NOTE: 'Make sure that in total there are four tactile/visual bouba and four tactile/visual kiki trials; four filled and four outlined tactile/visual trials; four

congruous and four incongruous (shape + sound) trials. (The auditory bouba/kiki word is not included in this experiment.) Total number of trials: 8.'

- Please note Set-up, first comment: 'Accepted'.
- Please note Set-up, second comment: 'Accepted'.
- Please note Procedure, first comment: New sentence (in new 4.1.1: 'Conduct the three experiments in a room that is neutral in color and quiet, and with all participants individually.'
- Please note Conduct Experiment 3, first comment: Checked. Thank you!
- Please note Representative Results, first comment: 'Accepted". The recruited number of participants per experimental group is included in the first paragraph under each sub-heading. Please do also note the new last paragraph [about how the experiments helped (…)]: '**The effect of visual imagery and learning**. The presented protocol succeeded in investigating the role of visual imagery in the bouba/kiki-effect, whether training in noticing the bouba/kiki shape-audio regularities affects the bouba/kiki-effect and the recognition of individual bouba and kiki shapes, and finally what mental images these regularities produce. Indeed, by including one group of participants with no visual experience (i.e. the blind-group) and two groups with visual experience (i.e. the blindfold and vision-group) was it possible to test the effect of visual imagery, and by including one group of participants with no visual experience and extensive tactile experience (i.e. the blind-group) and one group with extensive visual experience and no tactile experience (i.e. the blindfold-group) was it possible to test the effect of the training in noticing tactile-auditory regularities. The results clearly suggest that the blindfold-group drew upon visual imagery to solve new problems, but not long term (Experiment 1–3); that training in noticing bouba/kiki shape-audio regularities affected the bouba/kiki-effect (Experiment 1) and the recognition of individual bouba and kiki shapes (Experiment 2), but differently in each experimental group (Experiment 1-2), and that all experimental groups created mental images of the most characteristic shape feature of bouba (curve) and kiki [(angle) Experiment 3. Cf. **Table 1; Table 2; Table 3**][17]. Moreover, by including repeated within-group measures of instant and long term effect (Experiment 1-3) was it possible to test when the effect of visual imagery and learning shape audio-regularities actually occurred, and by including three different tasks (i.e. the bouba/kiki-effect in Experiment 1, recognising individual tactile/visual bouba/kiki shapes together with congruous and incongruous bouba/kiki audio in Experiment 2, and drawing mental images of bouba/kiki audio in Experiment 3) to test how robust these effects were. The results clearly suggest that the effect of visual imagery was not robust long term within each task when using haptic touch [cf. the blindfold-group (Experiment 1-3)], whereas the effect of learning shape-audio regularities was, but not always across tasks [cf. the blind-group (Experiment 1-3). Cf. **Table 1; Table 2; Table 3**.)][17].'
- Please note Representative Results, second comment about the Tables: 'Accepted' and about citations: 'Accepted' (The last editorial review asked us to remove all citations in this section.)
- Please note Figure legends: Thank you! We've added the title for each one of the new tables. There should be no need to describe the data any further.
- Please note Discussion, first comment: The Discussion has been revised. Please note that JoVE's Instructions_ for_Authors, Discussion says '3-6 paragraphs'. The current Discussion includes 5 paragraphs, to improve readability.

- Critical steps: Please note second paragraph, new third last sentence: 'Whether testing accuracy, exploration time or both, this protocol has one critical step: In Experiment 2 it is crucial to present the audio exactly as soon as the participant starts exploring the tactile/visual shape, that is, to ensure the presentation of multimodal (congruous or incongruous) information.
- Modifications: Please note the fourth paragraph.
- Limitation of method: Modifications have been suggested based on the limitations. Please note the fourth paragraph.
- Significance of the method: Please note the new fifth paragraph: 'The presented protocol is unique in that it keeps under control both the visual imagery and the sensory information during training and testing. It is flexible: Large and small samples as well as particular individuals can be tested against themselves (cf. the within-group testing) and/or other groups of individuals (cf. the between-group testing). It is possible to test both accuracy and exploration time, to change the number of trials and repeated measures in each experiment and the time between them, and also to change or even collapse the order of trials and/or experiments.'
- Future applications or directions of the method: Please note the second and the third paragraph.

- Please note Funders, first comment: Thank you! This has been changed to 'This work was funded by the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie Actions (grant agreement number 657440) and the Norwegian Association of the Blind and Partially Sighted.'
- Please note References, first comment: Thank you! Checked and corrected.

3.. We need discrete experimental steps for filming purpose.
4. Please adjust the highlight to 2.75 pages including headings and spacings. This is our hard cut limit.
- Please see our revised highlights.

5. Please convert all tables to .xlssx file as we cannot have any other formats. Table of Materials is converted to the required format for your convenience. Please check.
- Thank you! Please note the new Table 1, Table 2, and Table 3. Please do also not that the Table of Materials is checked and corrected.

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- Please note that we have not re-used and figures, tables or audio.

7. Please convert Figure 3 to three tables in the .xlsx file instead.
- Please note the new Table 1, Table 2, and Table 3.

8. There are still some texts in the manuscript which matches with the previously published literature. In this regard, Please reword lines 30-31, 41-44, 54-55, 75, 81-82,106-108, 110, 130-131, 133-134, 136-138, 310,312, 326-327, 339-340, 365-366, 404-405, 456-458, 469-471, 477-479 and most of the representative result rection (you can present the previously

published result but the wording in this section should be original).

- Please note that line(s):
  - 30-31 have been deleted.
  - 41-44 have been moved and revised: 'The experiments were conducted in fixed order with all participants and with no break between them.' Please do also note that a new last sentence has been added in the abstract (line 49-50): 'The protocol is unique in that it keeps under control both the visual imagery and the sensory information during training and testing.'
  - 54-55 have been changed to: '95% of the world's population show an auditory-visual bouba/kiki-effect, associating the visually rounded shape with the spoken word bouba and the visually angular shape with the spoken word kiki, and they do this even when they have not had any experience with either the shape or the word.'
  - 75 has been changed to: '(…) the participants who were blind and partially sighted was caused by a lack of visual imagery: The fully sighted participants had (…)'
  - 81-82 has been changed to: '(…) announcing the bouba/kiki word – rounded lip movements when announcing 'bouba' and angular lip movements when announcing 'kiki'[1,18] –, showing a tactile-visual-auditory (…)'
  - 106-108 have been moved and rephrased: 'The experiments were conducted in fixed order with all participants and with no break between them, that is, to keep under control the participants' amount and type of experience with bouba and kiki.'
  - 110 has been changed to: 'Overall, this study suggested that the effect of visual imagery is robust across tasks, but not long term within each task, whereas that the effect of learning shape-audio regularities is robust long term within each task, but not across tasks[17].'
  - 130-131 have been changed to: 'Conduct the pre-test (Trial 1), that is, test the instant bouba/kiki-effect.'
  - 133-134 have been changed to: 'Conduct the first repeated within-group measure (Trial 4), that is, test the effect of repeated tactile/visual shape (either filled or outlined) and varied audio (word and non-word sound).'
  - 136-138 have been changed to: 'Conduct the second within-group measure (Trial 5), that is, test the effect of new tactile/visual shape (either outlined or filled) and varied audio (word and non-word sound).' and 'Conduct the third within-group measure and post-test (Trial 8), that is, test the effect of the bouba/kiki shape-audio regularities – varied tactile/visual shape (filled and outlined) and varied audio (word and non-word sound).'
  - 310 has been changed to: '(…) on the right, and in both Experiment 1 and Experiment 2 to always present them in the same orientation (cf. **Figure 1**), that is, to enhance the participants' ability to form (…).'
  - 312 has been changed to: '(…) interference from their position and/or orientation on the rubber mat. Make sure not to inform the participants about this fixed presentation of position and orientation.'
  - 326-327 has been changed to: 'Invite the participants who will be exploring and drawing the tactile shapes (i.e. the blind and blindfold-group) to explore the rubber mat (by touch), for example, for size and texture, without any of the picture cards or copy paper/plastic embossing film placed on top.'
  - 339-340 has been changed to: 'In the blind and blindfold-group, ask the participant

to make a fist with both hands. Next, ask the participant to place their fists on top of the presented picture cards (and guide them if needed). Place the left hand on top of the participant's fists.

- 365-366 has been changed to: 'Explain that one tactile/visual picture card will be presented on the rubber mat and that some audio will appear from the MP3-player.'
- 404-405 has been changed to: In the blind and blindfold-group, invite the participant to try out the different drawing equipment, and then to decide for themselves which ones they prefer: Copy paper or plastic embossing film and rollerball pen or saddleback style.'
- 456-458 has been changed to a quote: Ask the scorers to answer two multiple-choice questions per picture in the questionnaire: 'Is the pictured shape "bouba" or "kiki"? and "Is the pictured shape drawn by someone who is blind (since birth), blindfolded, or fully sighted?"[17, p. 207].
- 469-471: Do these lines turn up because they resembles 4.6.15.1? The text is: 'Not correspond' when (I) ≥75% of the scorers agreed on which tactile/visual shape (bouba or kiki) was pictured, and (II) this shape did not correspond to the presented audio (bouba or kiki) in this trial.' In the Acta Psychologica-paper it says "(…) 'not correspond' when (I) ≥9 scorers agreed on which tactile/visual shape (bouba or kiki) the participant in question had drawn, and (II) this shape did not correspond to the presented audio (bouba or kiki) in this trial; and, (…)".
- 477-479 has been changed to: 'Across trials, count a participant as 'correspond' when ≥75% of their drawn mental images, that is, tactile/visual shapes, correspond to the presented bouba/kiki audio.'
- most of the representative result section: Revised, except for the presentation of the qualitative and quantitative results.

9. Once done please proofread the manuscript for any spelling or grammar issues. Please use American English throughout.

- The paper has been proofread (by Oxbridge Proofreading Service) and American English applied.

10. Our UK ALA has been recently revised. Please sign the revised ALA and upload it with the next revision. Thank You.

- Please find our signed UK ALA uploaded.

4. Procedure and scoring

4.1 Set up the test session:

4.1.1 Conduct the three experiments in a room that is neutral in color and quiet, and with all participants individually. Ask the participants in the blindfold-group to put on their blindfold, before setting up the test materials, and make sure they keep their blindfold on throughout (and between) all three experiments.

4.2 Set up the tactile/visual test materials:

4.2.1 Place the rubber mat directly in front of the participant. Then, place (Experiment 1) the two tactile/visual bouba and kiki shapes (Experiment 2), the one tactile/visual bouba or kiki shape and (Experiment 3), the copy paper/plastic embossing film on top of the rubber mat. In Experiment 1, make sure to always present bouba on the left and kiki on the right; and in both Experiment 1 and Experiment 2, to always present them in the same orientation (cf. **Figure 1**): To enhance the participants' ability to form mental images of the bouba and kiki shapes without interference from their position and/or orientation on the rubber mat. Make sure not to inform the participants about this fixed presentation of the tactile/visual bouba and kiki shapes. In the vision-group, always set up the test material behind a carton plate/foam board, to prevent these participants from taking a sneak peek at what is in store.

4.3 Set up the auditory test materials:

4.3.1 Place the MP3 player directly in front of the participant (on the other side of the rubber mat), and with the loudspeaker closest to the participant.

4.4 Conduct Experiment 1, Experiment 2, and Experiment 3:

4.4.1 Invite the participants who will be exploring and drawing the tactile shapes (i.e. the blind and blindfold-group) to explore the rubber mat (by touch): For example, for size and texture, without any of the picture cards and/or copy paper or plastic embossing film placed on top.

4.5 Conduct Experiment 1:

4.5.1 Explain that two picture cards will be presented on the rubber mat, each one picturing a tactile/visual shape. Then, explain that some audio will appear from the MP3 player and that this audio will correspond to one of the tactile/visual shapes.

4.5.2 Place the two picture cards on the rubber mat (cf. **Figure 1**).

4.5.3 In the blind and blindfold-group, ask the participant to make a fist with both hands. Next, ask the participant to place their fists on top of the presented picture cards (and guide them if needed). Place the left hand on top of the participant's fists.

4.5.4 Ask the participant to explore the two tactile/visual shapes, the blind and blindfold-group by touch and the vision-group by vision. Ask them to say 'yes' when they have finished their exploring.

4.5.5 Remove the left hand from the participant's fists (in the blind and blindfold-group) / the carton plate or foam board (in the vision-group).

4.5.6 As soon as the participant says 'yes,' cover the picture cards.

4.5.7 Play the audio.

4.5.8 Ask the participant to signal which tactile/visual shape they associate with the audio, for example, by saying 'left/right,' 'curvy/angular' or 'flower/star'. Do not respond to the participant's answer.

4.6 Conduct Experiment 2:

4.6.1 Explain that one tactile/visual picture card will be presented on the rubber mat and that some audio will appear from the MP3 player.

4.6.2 Explain that the audio will appear one time per picture card, as soon as the participant starts exploring the tactile/visual shape.

4.6.3 Place the picture card on the rubber mat.

4.6.4 In the blind and blindfold-group, ask the participant to make a fist with both hands. Next, ask the participant to place their fists on top of the presented picture card (and guide them if needed). Place the left hand on top of the participant's fists.

4.6.5 Ask the participant to explore the tactile/visual shape, the blind and blindfold-group by touch and the vision-group by vision, and to listen to the audio. Then, ask them to name the tactile/visual shape and the audio as either 'bouba' or 'kiki': One name only[23-25], when they have finished their exploring.

4.6.6 Remove the left hand from the participant's fists (in the blind and blindfold-group) / the carton plate or foam board (in the vision-group) and play the audio.

4.6.7 As soon as the participant names the tactile/visual shape and the audio, cover the picture card.

4.7 Conduct Experiment 3:

4.7.1 Explain that some copy paper/plastic embossing film will be placed on top of the rubber mat, instead of the picture card(s), and that the participant will be asked to draw on it.

4.7.2 In the blind and blindfold-group, invite the participant to try out the different drawing equipment, then to decide for themselves which ones they prefer: Copy paper or plastic embossing film and rollerball pen or saddleback style.

4.7.3 Explain that some audio will appear from the MP3 player and that the participant will be asked to draw the shape they associate with this audio: One shape per segment of audio.

4.7.4 Place the copy paper/plastic embossing film on the rubber mat.

4.7.5 In all three experimental groups (blind; blindfold; vision), ask the participant to make a fist with both hands, holding the rollerball pen/saddleback style. Then, ask the participant to place their fists on top of the copy paper/plastic embossing film (and guide them if needed). Place the left hand on top of the participant's fists.

4.7.6 Ask the participant to draw the shape that they associate with the presented audio. In the blind and blindfold-group, ask the participant to draw a tactile shape; and in the vision-group, a visual shape. Ask the participant to say 'yes' when they have finished their drawing.

4.7.7 Remove the left hand from the participant's fists.

4.7.8 Play the audio.

4.7.9 When the participant has said 'yes,' remove their drawing from the rubber mat and label it with the correct trial number in the bottom right corner. Do not respond to/comment on the participant's answer/drawn shape.

NOTE: Experiment 3 is scored by a group of scorers after all drawing data have been collected.

4.7.13 Ask the scorers to answer two multiple-choice questions per picture in the questionnaire: (1) 'Is the pictured shape "bouba" or "kiki;"' and (2) 'Is the pictured shape drawn by someone who is blind (since birth), blindfolded, or fully sighted?'[17, p. 207]