When acoustic stimuli turn visual circles into ellipses: sounds evoking accelerations modify visuo-motor coupling

Thoret Etienne[1,3,4], Aramaki Mitsuko[1,3,4], Bringoux Lionel[2,3], Kronland-Martinet Richard[1,3,4], Ystad Sølvi[1,3,4]

1. Laboratoire de Mécanique et d'Acoustique, CNRS, UPR7051, Marseille
2. Institut des Sciences du Mouvement, CNRS, UMR7287, Marseille
3. Aix-Marseille Université, Marseille
4. Ecole Centrale Marseille

Background & Goal of the study

Vision is tuned to perceive biological motions kinematics, and induces perceptual-motor illusions

The velocity-curvature covariations, i.e. the 1/3 power law, constrains the visual perception of:
- dynamic shape geometry (Viviani et al., 1989)
- constancy of velocity (Viviani et al., 1992)

Visuo-motor tracking in closed loop is facilitated when visual motion complies with biological rules (Viviani et al., 1987)

Audition also enables the identification of biological motion kinematics thanks to timbre variations

- Friction sounds produced by someone who is drawing reveal the underlying gesture

- An experiment reveals that subjects are able to calibrate kinematics-related synthesized friction sounds to evoke the most natural motion which interestingly corresponds to the 1/3 power law (Thoret et al., 2014)

- Subjects are even able to associate simple geometrical shapes to the friction sounds produced when they are drawn (Thoret et al., 2014)

What happens in a multimodal context?

- **Vision is known to dominate audition when perceiving discrete spatialized motions, but what happens with continuous audio-visual motions?**
- **Can sounds evoking dynamic cues modify visuo-motor coupling?**

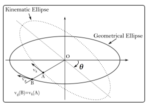
Methods

Task

The subjects were asked **to synchronize their gestures** with *Visual Motions* (exp. 1) or *Audio-visual Motions* (exp. 2) **without seeing their hands** (i.e. in visual open-loop) to help them imagine that they produced the motion themselves. **The characteristics of their motor performances** reveal the motion they perceived.

Mathematical Definition of Motions

Two different ellipses are considered: the **Kinematic** (dotted line) and the **Geometrical** (solid line) ellipse.



The kinematic ellipse is rotated of an angle theta and follows the **Lissajous motion** which complies with the 1/3 power law:

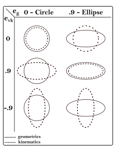
$$\begin{cases} x_g(t) = A_{xg}\sin(\phi(t)) \\ y_g(t) = A_{yg}\cos(\phi(t)) \end{cases}$$

The spotlight velocity at point B ($v_g(B)$) of the geometrical ellipse equals the kinematic one at point A ($v_{vk}(A)$).

Stimuli

Visual Motions (exp. 1 & 2)

Six visual motions were generated from 2 geometrical shapes ($e_g = 0$ or .9) and 3 kinematic ellipses ($e_{vk} = 0$, .9 or -.9)

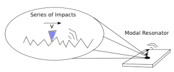


($e_g = 0$, $e_{vk} = 0$) and ($e_g = .9$, $e_{vk} = .9$) comply with biological motions, in the other configurations, mismatching accelerations are perceived.

Auditory Motions (exp. 2)

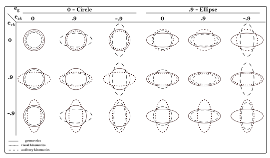
Three auditory motions were considered according to the visual motion orientation. Synthesized friction sounds were generated from the velocity profiles: $e_{ak} = 0$ (Circle) – $e_{ak} = .9$ and -.9 (Horizontal or vertical Ellipses)

A phenomenological friction sound model **which brightness varied with the velocity profile was used**



Audio-visual Motions (exp. 2)

18 audio-visual motions were generated from the combination the 6 visual and the 3 auditory motions



($e_g = 0$, $e_{vk} = 0$, $e_{ak} = 0$) and ($e_g = .9$, $e_{vk} = .9$, $e_{ak} = .9$) comply with biological motions, in the other configurations, mismatching accelerations are perceived.

Subjects

17 subjects (15 men, mean age 28.59, SD = 7.99) took part in the 2 experiments

Apparatus

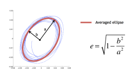
The visual motions were displayed at 60 Hz in a dark room.

The sounds were presented through headphones at 44100 Hz sampling rate.

Motor performances were recorded thanks to a graphic tablet Wacom Intuos5 at 129 Hz.

Data Analysis

The **Eccentricity** is fitted by using the characteristics of the inertial tensor by considering the recorded sampled data as a set of unitary masses.



$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

The **Kinematic Distortion**, characterizing the kinematic asynchrony between the produced movement and the visual trailing motion, enables to determine the accuracy to restitute the motion.

$$KD = \sqrt{\frac{\sum_i \left(|\hat{v}_{ref}|_i - |\hat{v}_{exp}|_i\right)^2}{\sum_i |\hat{v}_{ref}|_i^2}}$$

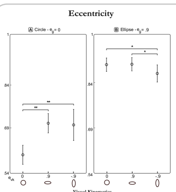
Statistical Analysis

Repeated measures ANOVA are performed for each shape and each descriptor. Newman-Keuls post-hoc tests are performed to further analyse the significant effects.

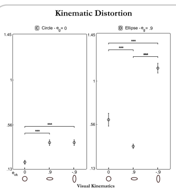
Experiment 1 – Visuo-motor coupling

Results

Unnatural kinematics significantly affected the *Eccentricity* and the *Kinematic Distortion* for the two shapes.



Unnatural kinematics had **flattened circles** ($F(2,32) = 3.40$, $p < .001$) and **rounded ellipses** ($F(2,32) = 3.94$, $p = .02$).



Unnatural kinematics were **harder to follow** for the two shapes ($F(2,32) = 67.42$, $p < .001$ and $F(2,32) = 204.70$, $p < .001$).

These results **confirmed those of Viviani et al. and extended them to the visual open-loop situation**:

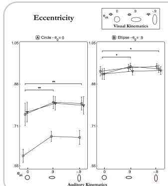
- **the visual perception of shape and the visuo-motor coupling is constrained by the co-variations of the velocity curvature** (i.e. the 1/3 power law)

- these results extended Viviani's results to the visual open-loop situation suggesting that biological motions are processed at an amodal level

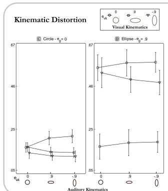
Experiment 2 – Audiovisuo-motor coupling

Results

Sounds evoking motions significantly affected the *Eccentricity* and the *Kinematic Distortion* for the two shapes.



Sounds evoking motions significantly flattened natural circles, and **this effect was further enhanced for unnatural visual kinematics**. The effects were weaker for the ellipses but nevertheless incongruous auditory kinematics **significantly rounded ellipses.**



Sounds evoking motions significantly affected the accuracy of the synchronization with the trailing visual motion for incongruous audio-visual stimuli.

These results showed that **sounds significantly affected visuo-motor coupling** by divulging accelerations which are not perceived in the visual motion. Moreover, **sounds amplified the distortions for unnatural visual kinematics** when auditory accelerations were congruous with visual ones.

These results and previous knowledge suggest that motions, and particularly biological ones, are encoded at an amodal level, whatever the modality: vision[1], kinesthetic[5], or audition[4].

Conclusions & Perspectives

- These two experiments firstly confirmed that the visuo-motor coupling is actually constrained by biological velocity-curvature co-variations.
- Secondly, they highlighted the role of auditory perception in the integration of audio-visual motions in a way never investigated before. The use of continuous sound morphologies pointed out that sounds can strongly affect the weight of visual modality in a multisensory restitution task.
- Theoretical and applicative perspectives can be envisaged, from the investigation of cognitive processes underlying biological motions perception, to the development of new interfaces using an audio-visual feedback for motor rehabilitation for expert gesture learning.

References

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This work was founded by the French National Agency (ANR) under the MetaSon: Sound Metaphors project (ANR-10-CORD-0003)