Investigating the processing of real and prosthetic hands: What can mental rotation tell us?

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Background

Laterality judgement tasks (LJT) rely on the process of mental rotation. When participants judge whether rotated hand images are left or right hands, or whether rotated letters are mirror reversed, we do so by first mentally manipulating the image into an upright position (Conson et al., 2013).

Mental rotation of hands evokes motor imagery (action imagination) and is influenced by the limits of our own available movement (Parsons 1994).

This influence, known as a biomechanical constraint effect (BCE) allows us to use LJTs to detect and measure motor imagery.

The uncanny valley predicts that stimuli which fall short of appearing human are often perceived as eerie (Mori et al., 2012).

While mostly studied in faces, research has shown that the phenomenon can also apply to prosthetic hands (Poliakoff et al., 2013, 2018, Buckingham et al., 2019).

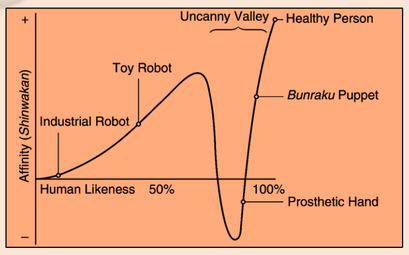

Fig 1. Mori's depiction of the 'uncanny valley'

Implicit measures of 'uncanniness' are important, allowing the detection of subtler manifestations of the phenomenon (Ratajczyk et al., 2019).

Our study aimed to combine these areas: using laterality judgement tasks to study whether hands which appear eerie elicit differences in motor imagery when mentally manipulated.

Design and Method

We conducted two experiments with participants completing two LJTs in each. One LJT contained palm and dorsal images of three hands while the other used standard and mirror reversed images of the letter R; stimuli were presented in randomised order at 0°, 90°, 180°, and 270° orientations.

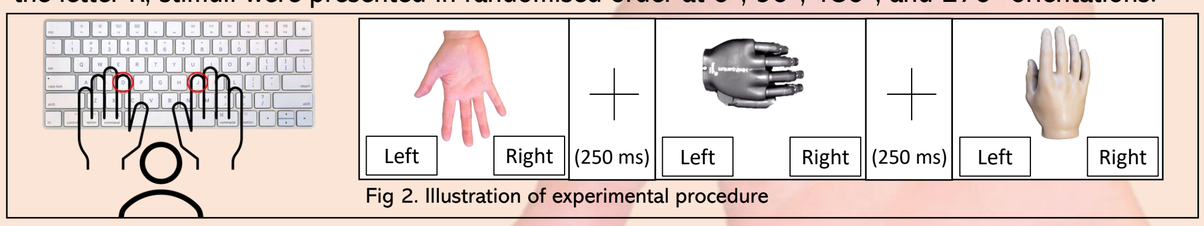

Fig 2. Illustration of experimental procedure

To conclude, participants rated all hand stimuli on scales of eeriness, familiarity, and human likeness (with the addition of 'likeability' in experiment 2).

Reaction times and error rates were recorded and used to calculate biomechanical constraint effects and slope scores (representing mental rotation speed).

Experiment 1

102 student participants recruited in exchange for course credits (23 males), mean age (± SD) = 19.5 (± 1).

Experiment 2

107 adult participants recruited through Prolific (51 males), mean age (± SD) = 24 (± 4.5).

Fig 3. Illustration of hand stimuli across experiments as right hands (mechanical, realistic, real)

Results

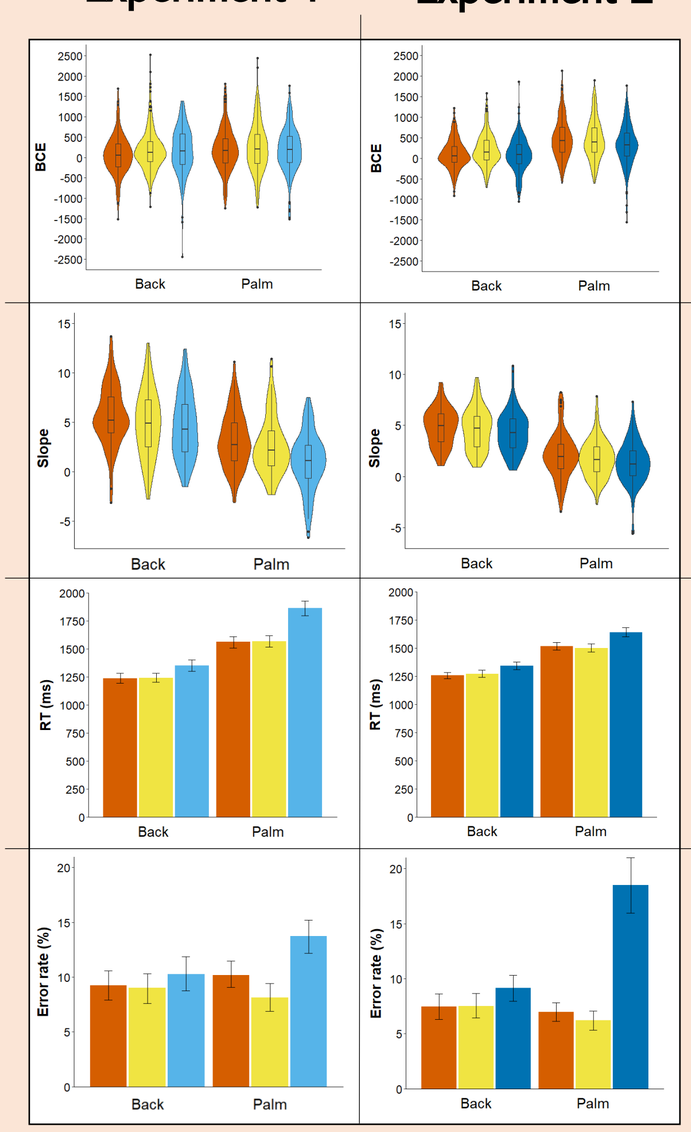

Fig 4. 3x2 repeated measures ANOVAs compared measures between our 3 hand types and back of hand/ palm of hand perspectives

- In our initial experiment, we found palms to produce higher BCE scores but no difference between hands.
- In our follow up, the new mechanical hand produced lower BCE scores, suggesting a reduced reliance on motor imagery, though this was only present for palms.
- In both experiments, real hands produced significantly higher slopes than mechanical, with realistic hands in between.
- Palms produced consistently lower slope scores, indicating a slower speed of mental rotation.
- Mechanical hands were responded to slowest in both experiments while real and realistic hands did not significantly differ.
- Palms were reliably slower than backs of hands for all hand types.
- Mechanical hands produced more errors than real and realistic hands.
- In both experiments this was present most dramatically for palms of hands.

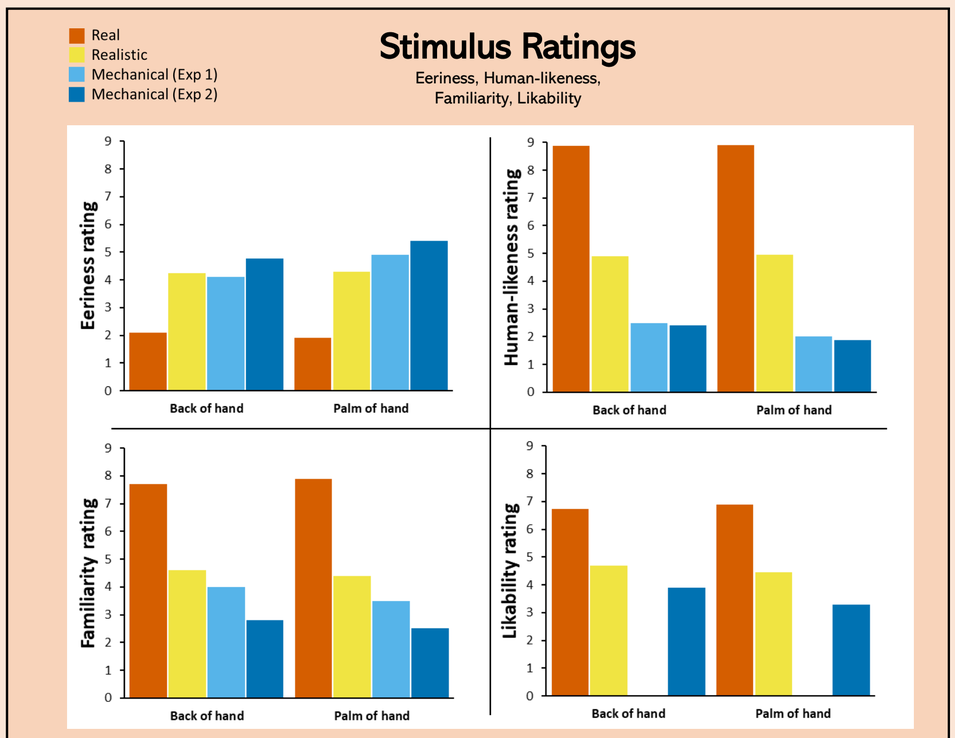

Fig 5. Stimulus ratings averaged across experiments (except for likability, measured only in experiment 2)

- Participants rated both mechanical prosthetics as more eerie and less likable than real hands, with realistic hands commonly rated in-between.
- No reliable correlations were found between stimulus ratings and our four statistical measures.

Discussion

- All three hand types produced a BCE, indicating the use of motor imagery to make the laterality judgment.
- However, differences in reaction time, slope (effect of angular rotation on reaction time), and to some extent BCE were found between the hand types.
- The ratings did not provide evidence for the uncanny valley as both mechanical and realistic artificial hands were rated as eerie. However, across both experiments slope appears to vary between hand types in line with their human-likeness.
- The lower slope for the mechanical hand might be affected by difficulty in identifying hand perspective (palm up, palm down), which can be observed in the error rate. Indeed, one way in which the mechanical hand might be less human-like is that the difference between surfaces was less obvious.

Summary

- Mentally rotating prosthetic hands is constrained biomechanically, suggesting that people use motor imagery to embody even clearly non-human hands
- However, differences in slope and BCE scores suggest possible differences in the processing of less human-like hands which merit further investigation

References

Buckingham, G., Parr, J., Wood, G., Day, S., Chadwell, A., Head, J., ... & Poliakoff, E. (2019). Upper-and lower-limb amputees show reduced levels of eeriness for images of prosthetic hands. *Psychonomic Bulletin & Review*, *26*(4), 1295-1302.
Conson, M., Mazzarella, E., & Trojano, L. (2013). Developmental changes of the biomechanical effect in motor imagery. *Experimental Brain Research*, *226*(3), 441-449.
Mori, M., MacDorman, K. F., & Kageki, N. (2012). The uncanny valley [from the field]. *IEEE Robotics & automation magazine*, *19*(2), 98-100.
Parsons, L. M. (1994). Temporal and kinematic properties of motor behavior reflected in mentally simulated action. *Journal of experimental Psychology: Human perception and Performance*, *20*(4), 709.
Poliakoff, E., Beach, N., Best, R., Howard, T., & Gowen, E. (2013). Can looking at a hand make your skin crawl? Peering into the uncanny valley for hands. *Perception*, *42*(9), 998-1000.
Poliakoff, E., O'Kane, S., Carefoot, O., Kyberd, P., & Gowen, E. (2018). Investigating the uncanny valley for prosthetic hands. *Prosthetics and Orthotics International*, *42*(1), 21-27.
Ratajczyk, D., Jukiewicz, M., & Lupkowski, P. (2019). Evaluation of the uncanny valley hypothesis based on declared emotional response and psychophysiological reaction. *Bio-Algorithms and Med-Systems*, *15*(2).