Embodying a Quadrupedal Avatar Through Posture- and Hand-Gesture-Congruent Locomotion

🎤Shuta Tanahashi[*1], Satoshi Hashiguchi[*1], Fumihiko Nakamura[*1], Yuta Kataoka[*1], Fumihisa Shibata[*1], Peter Mohr[*2], Ana Stanescu[*3,*2], Shohei Mori[*4,†], and Asako Kimura[*1,†]

[*1] Ritsumeikan University [*2] Graz University of Technology [*3] Adelaide University
[*4] VISUS, University of Stuttgart [†] Shared last authorship



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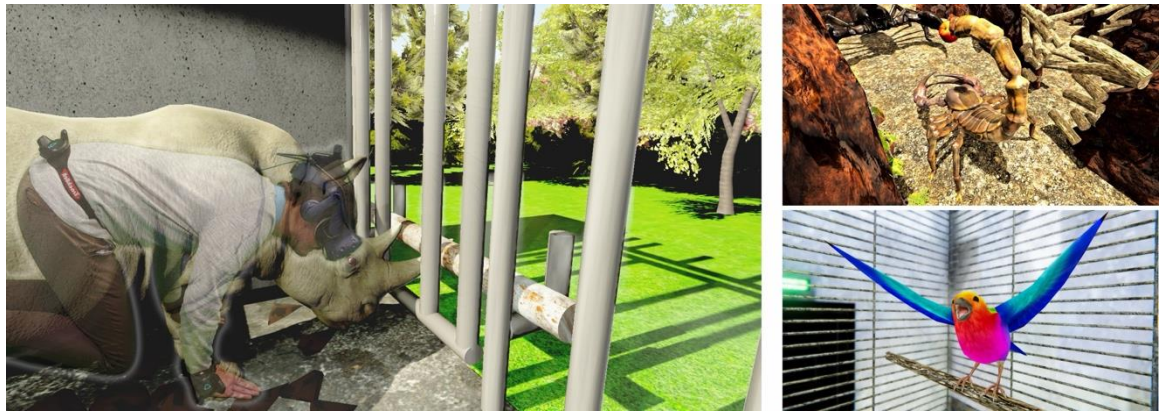
Walking in a Bear's Body



Becoming an Animal in VR

- Embodying animals in VR
  - Boosts connection to nature[*1]
  - Works for non-humanoid bodies[*2]
- But four-legged walking is hard
  - Crawling is exhausting[*3]



How to move a quadruped avatar without crawling?

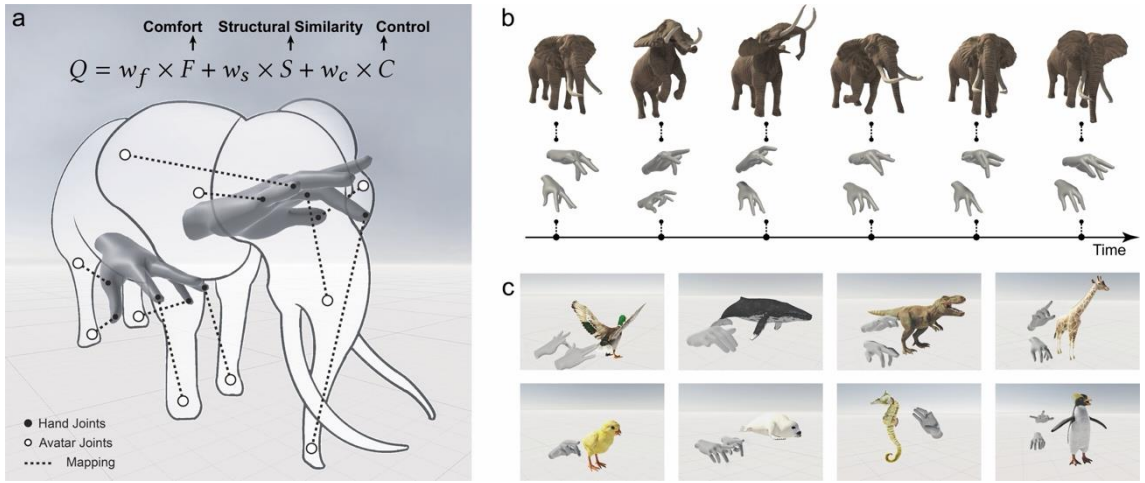
*1 Sun Joo (Grace) Ahn et al. 2016. Experiencing Nature: Embodying Animals in Immersive Virtual Environments Increases Inclusion of Nature in Self and Involvement With Nature. Journal of Computer-Mediated Communication 21, 6, 399–419. doi:10.1111/jcc4.12173

*2 Andrey Krekhov, Sebastian Cmentowski, Katharina Emmerich, and Jens Krüger. 2019. Beyond Human: Animals as an Escape from Stereotype Avatars in Virtual Reality Games. In Proc. CHI PLAY 2019, 439–451. doi:10.1145/3311350.3347172

*3 Andrey Krekhov, Sebastian Cmentowski, and Jens Krüger. 2019. The Illusion of Animal Body Ownership and Its Potential for Virtual Reality Games. In Proc. IEEE CoG 2019, 1–8. doi:10.1109/CIG.2019.8848005

Non-Humanoid Locomotion

- VR locomotion gestures
  - Arm swinging aids orientation[*1]
  - Seated walking-in-place[*2, *3]
- Controlling non-humanoids
  - HandAvatar: hands drive animals[*4]
  - Spiders: usability vs. exertion[*5]



→ Drive animals with the hands, not the full gait

*1 Morgan McCullough et al. 2015. Myo Arm: Swinging to Explore a VE. In Proc. ACM SAP 2015, 107–113. doi:10.1145/2804408.2804416
*2 Liwei Chan et al. 2024. Seated-WIP: Enabling Walking-in-Place Locomotion for Stationary Chairs in Confined Spaces. In Proc. CHI 2024. doi:10.1145/3613904.3642395
*3 Yusuke Kitaura et al. 2025. Not All WIP Are Perceived Equally: Different Speed Expectations in Seated Walk-in-Place Locomotion. In Proc. VRST 2025. doi:10.1145/3756884.3765970
*4 Yu Jiang et al. 2023. HandAvatar: Embodying Non-Humanoid Virtual Avatars through Hands. In Proc. CHI 2023. doi:10.1145/3544548.3581027
*5 Philipp Thayer and Martin Kocur. 2025. Investigating How to Control Virtual Spiders While Embodying Them in Virtual Reality. In Proc. VRST 2025. doi:10.1145/3756884.3765989

Embodiment & Self-Perception

- Sense of embodiment[*1]
  - Ownership (SoBO), agency (SoA)
  - Visuomotor sync → ownership[*2]
- Proteus effect[*3]
  - Users act like their avatar
  - Mainly with high SoBO[*4]



Mostly studied via appearance

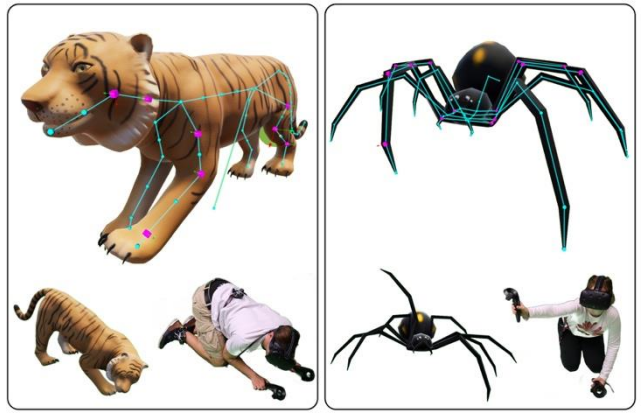
Does movement shape self-perception too?

*1 Martin Guy, Jean-Marie Normand, Camille Jeunet-Kelway, and Guillaume Moreau. 2023. The Sense of Embodiment in Virtual Reality and Its Assessment Methods. Frontiers in Virtual Reality 4. doi:10.3389/frvir.2023.1141683
*2 Aske Mottelson, Andreea Muresan, Kasper Hornbæk, and Guido Makransky. 2023. A Systematic Review and Meta-analysis of the Effectiveness of Body Ownership Illusions in Virtual Reality. ACM TOCHI 30, 5. doi:10.1145/3590767
*3 Nick Yee and Jeremy Bailenson. 2007. The Proteus Effect: The Effect of Transformed Self-Representation on Behavior. Human Communication Research 33, 3, 271–290. doi:10.1111/j.1468-2958.2007.00299.x
*4 David Mal et al. 2023. The Impact of Avatar and Environment Congruence on Plausibility, Embodiment, Presence, and the Proteus Effect in Virtual Reality. IEEE TVCG 29, 5, 2358–2368. doi:10.1109/TVCG.2023.3247089

Two Factors in Prior Work

- Gesture congruence[*1]
  - Human or gorilla avatar × 2 gestures
  - Congruent → identification & UX ↑
- Posture congruence[*2]
  - Full- vs. half-body control
  - Half-body: ownership kept, fatigue ↓

	Arm swinging (human-like)	Arm rolling (gorilla-like)
Human avatar	**Congruent**	Incongruent
Gorilla avatar	Incongruent	**Congruent**



Gap: posture × gesture never crossed in one animal avatar

Do the two factors interact?

*1 Omar Khan, Hyeongil Nam, and Kangsoo Kim. 2025. Impact of Avatar-Locomotion Congruence on User Experience and Identification in Virtual Reality. IEEE TVCG 31, 11, 9878–9888. doi:10.1109/TVCG.2025.3616836
*2 Andrey Krekhov, Sebastian Cmentowski, and Jens Krüger. 2019. The Illusion of Animal Body Ownership and Its Potential for Virtual Reality Games. In Proc. IEEE CoG 2019, 1–8. doi:10.1109/CIG.2019.8848005

RQ and Hypotheses

RQ How do **posture** and **gesture** shape embodiment, skill, workload, and self-perception?

H1  **Rowing** >  **Swinging**

H2  **Quad** >  **Stand**

H3 **Posture × Gesture**interaction

H4  **Quad** &  **Rowing**

Self-perception: feeling you have the avatar's speed, size, weight, and strength (cf. Proteus effect[*1])

*1 Nick Yee and Jeremy Bailenson. 2007. The Proteus Effect: The Effect of Transformed Self-Representation on Behavior. Human Communication Research 33, 3, 271–290. doi:10.1111/j.1468-2958.2007.00299.x

Approach: Bear Avatar

- Hands drive the gait
  - No crawling
- Why a bear?
  - Plantigrade, like humans*1
  - Shoulder–elbow–wrist layout*2
  - Forearm rotates 70–80° *3
- Palm-down hand → forepaw
  - Driven by IK



Same hand-to-forepaw mapping in all conditions

*1 Catherine L. Shine. 2016. Ursidae Locomotion: Right Down to the “Bear Bones”. Ph.D. Dissertation. University of Idaho.
*2 D. Dwight Davis. 1949. The Shoulder Architecture of Bears and Other Carnivores. Fieldiana: Zoology 31, 34, 285–305. doi:10.5962/bhl.title.1291
*3 Hayato Amaike et al. 2021. Mobility of the Forearm Skeleton in the Asiatic Black (Ursus thibetanus), Brown (U. arctos) and Polar (U. maritimus) Bears. Journal of Veterinary Medical Science 83, 8, 1284–1289. doi:10.1292/jvms.21-0198

Two Locomotion Gestures

Rowing (bear-like)



- Reach out and pull back, like pawing
- Stroke: backward > 0.5 m/s

Swinging (human-like)

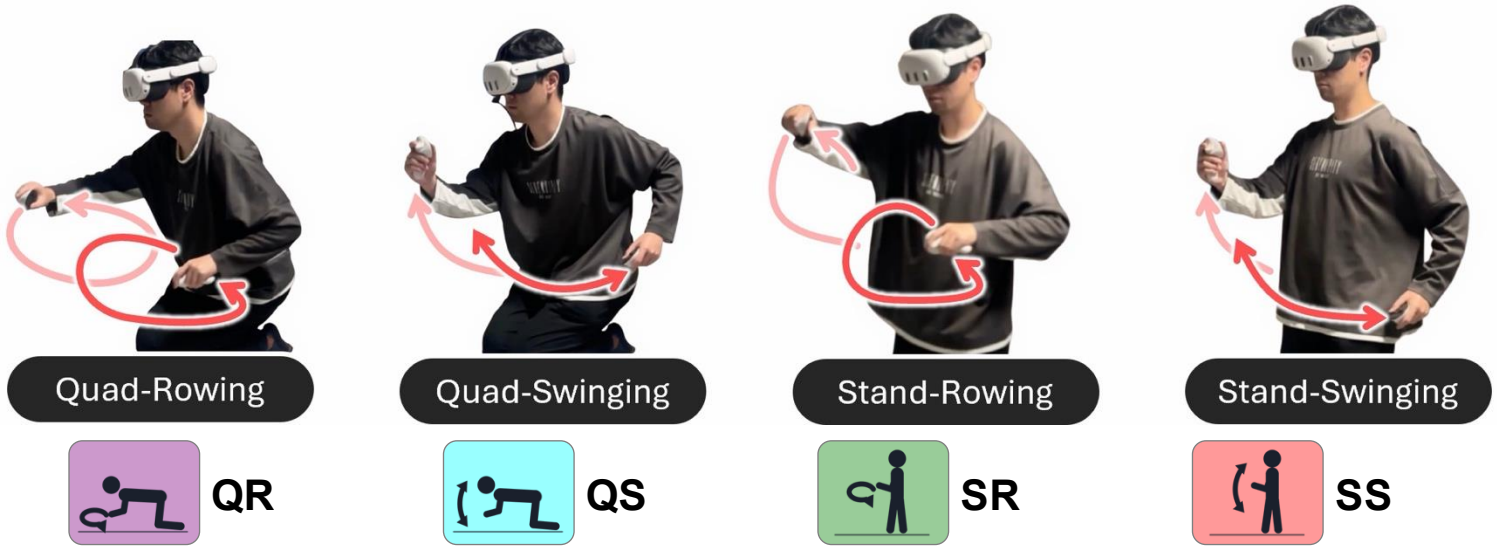


- Swing arms alternately*1
- Elbows at about 90°
- Stroke: vertical > 0.5 m/s

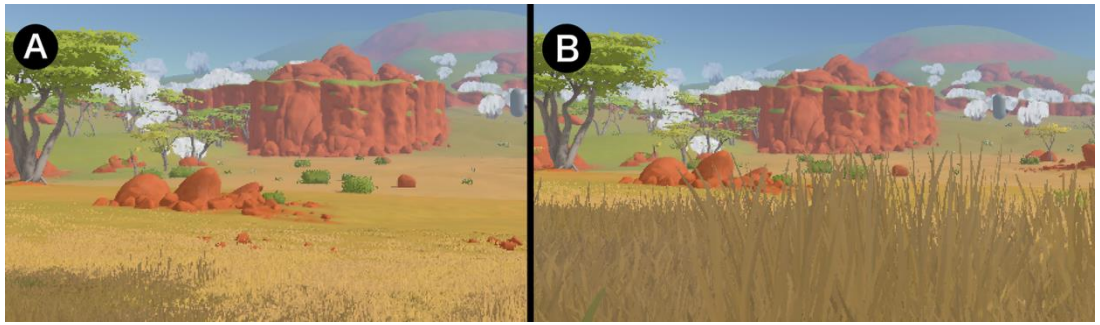
1 stroke = 1.5 m at 1.5 m/s*2 | Steer with the head

*1 Yun Suen Pai and Kai Kunze. 2017. Armswing: Using Arm Swings for Accessible and Immersive Navigation in AR/VR Spaces. In Proc. MUM 2017, 189–198. doi:10.1145/3152832.3152864
*2 Catherine L. Shine et al. 2015. Grizzly Bear (Ursus arctos horribilis) Locomotion: Gaits and Ground Reaction Forces. Journal of Experimental Biology 218, 19, 3102–3109. doi:10.1242/jeb.121806

Study Design: 2 × 2



- Posture × Gesture
  - Within-subjects
  - Quad: kneel, back flat
  - Stand: upright
  - Rowing vs. Swinging



Posture also sets eye height and avatar scale
→ **compared as whole configurations**

Four Conditions in Action



Four Conditions in Action



Four Conditions in Action

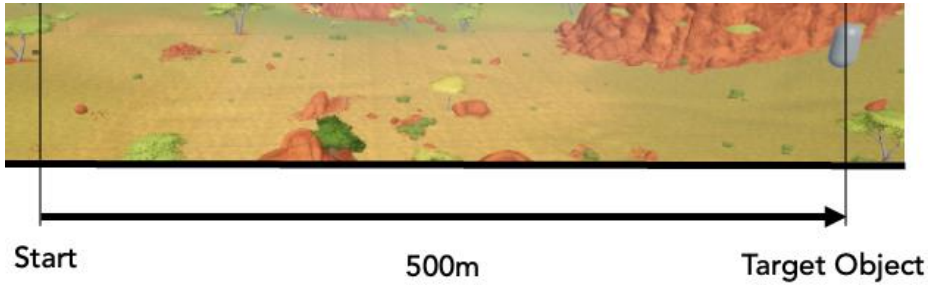


Four Conditions in Action



Procedure and Measures

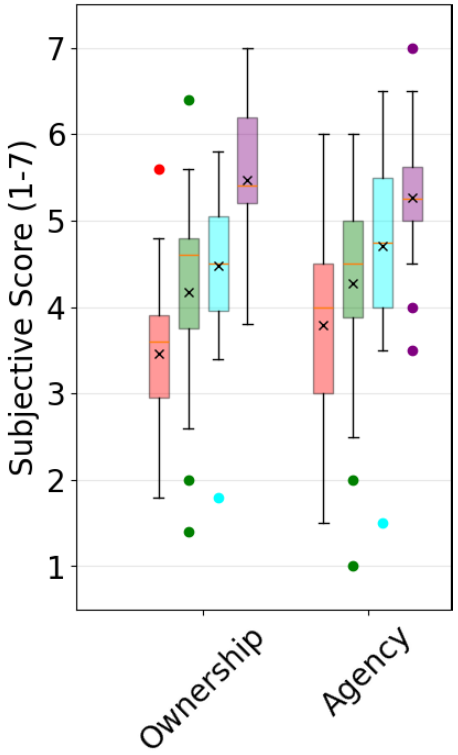
- Procedure
  - N = 24 (age 19–25), Quest 3
  - 2-min trial × 4, Latin square
  - Target 500 m ahead

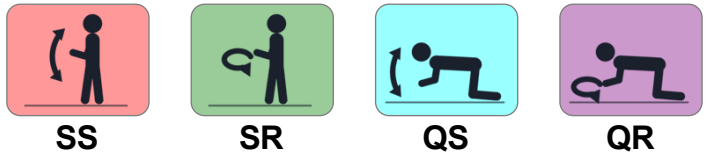


- Measures (per trial)
  - SoBO, SoA: adapted AEQ items*1
  - Enjoyment, skill: IMI items*2
  - Workload: adapted raw TLX*3, *4
  - Self-perception: speed, size, weight, strength
- Analysis: RM-ANOVA, ART ANOVA*5

*1 Tabitha C. Peck and Mar Gonzalez-Franco. 2021. Avatar Embodiment. A Standardized Questionnaire. Frontiers in Virtual Reality 1. doi:10.3389/frvir.2020.575943
*2 Center for Self-Determination Theory. Intrinsic Motivation Inventory (IMI). Official questionnaire and instrument description.
*3 Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In Human Mental Workload, 139–183. doi:10.1016/S0166-4115(08)62386-9
*4 Sandra G. Hart. 2006. NASA-Task Load Index (NASA-TLX); 20 Years Later. Proc. HFES Annual Meeting 50, 9, 904–908. doi:10.1177/154193120605000909
*5 Jacob O. Wobbrock, Leah Findlater, Darren Gergle, and James J. Higgins. 2011. The Aligned Rank Transform for Nonparametric Factorial Analyses Using Only ANOVA Procedures. In Proc. CHI 2011, 143–146. doi:10.1145/1978942.1978963

Results: Embodiment



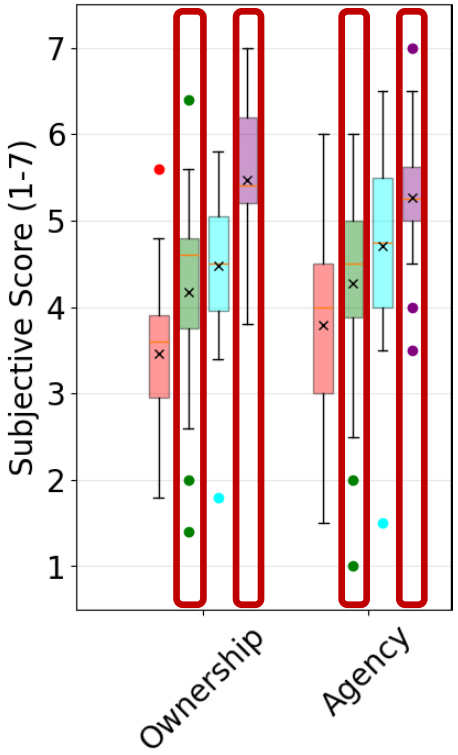


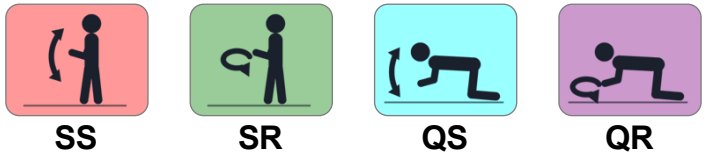
H1  **Rowing** >  **Swinging**

H2  **Quad** >  **Stand**

H3 **Posture × Gesture** interaction

Results: Embodiment



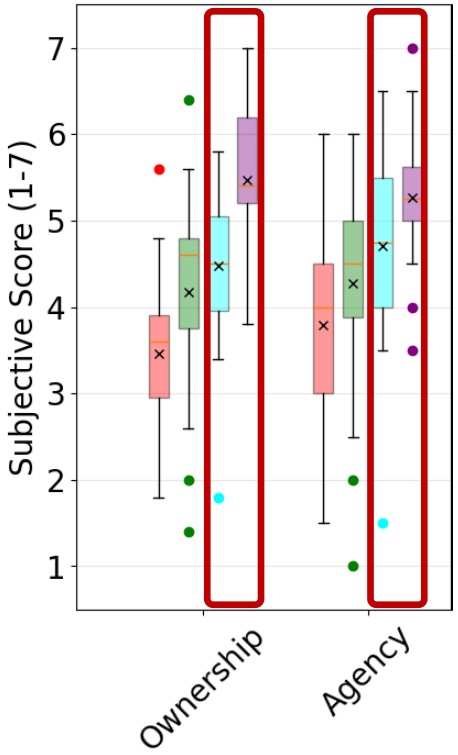


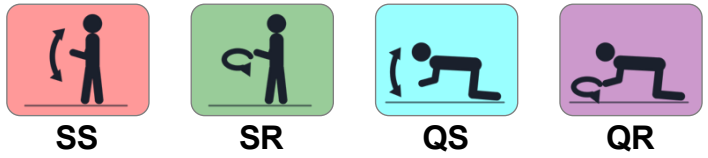
H1  **Rowing** >  **Swinging** — Supported

H2  **Quad** >  **Stand**

H3 **Posture × Gesture** interaction

Results: Embodiment





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Results: Embodiment

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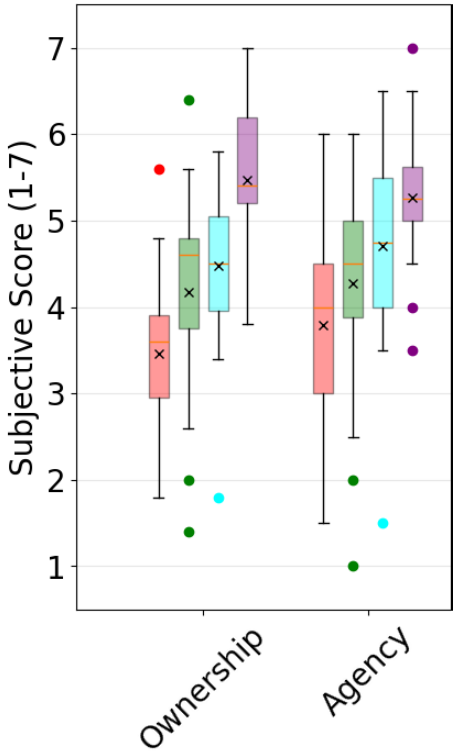
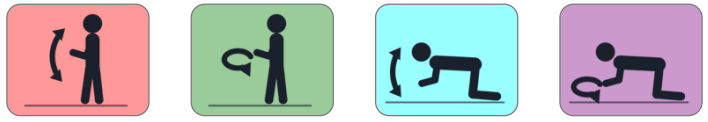




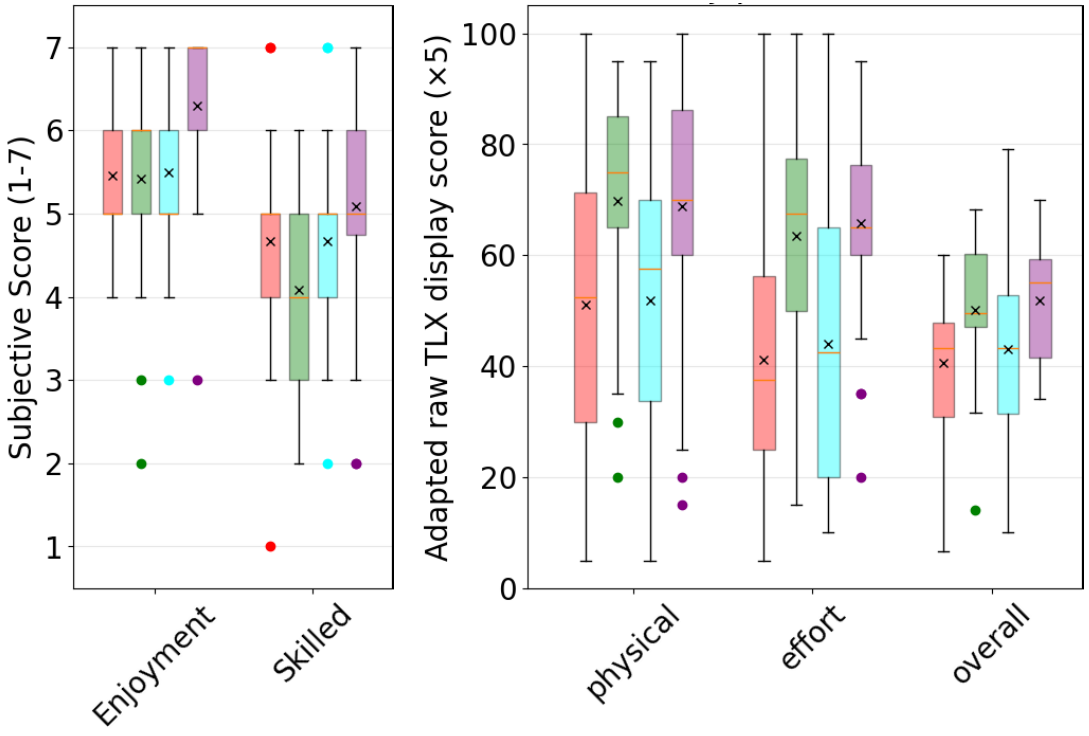
H1  **Rowing >**  **Swinging** — Supported

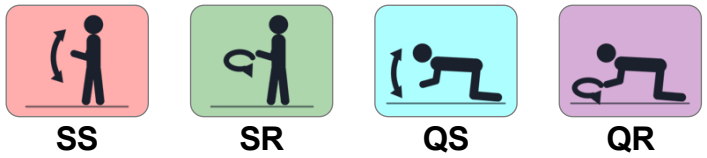
H2  **Quad >**  **Stand** — Supported

H3 **Posture × Gesture** interaction — Not supported

Each factor helps on its own

Results: Skill & Workload





Exploratory: no hypotheses

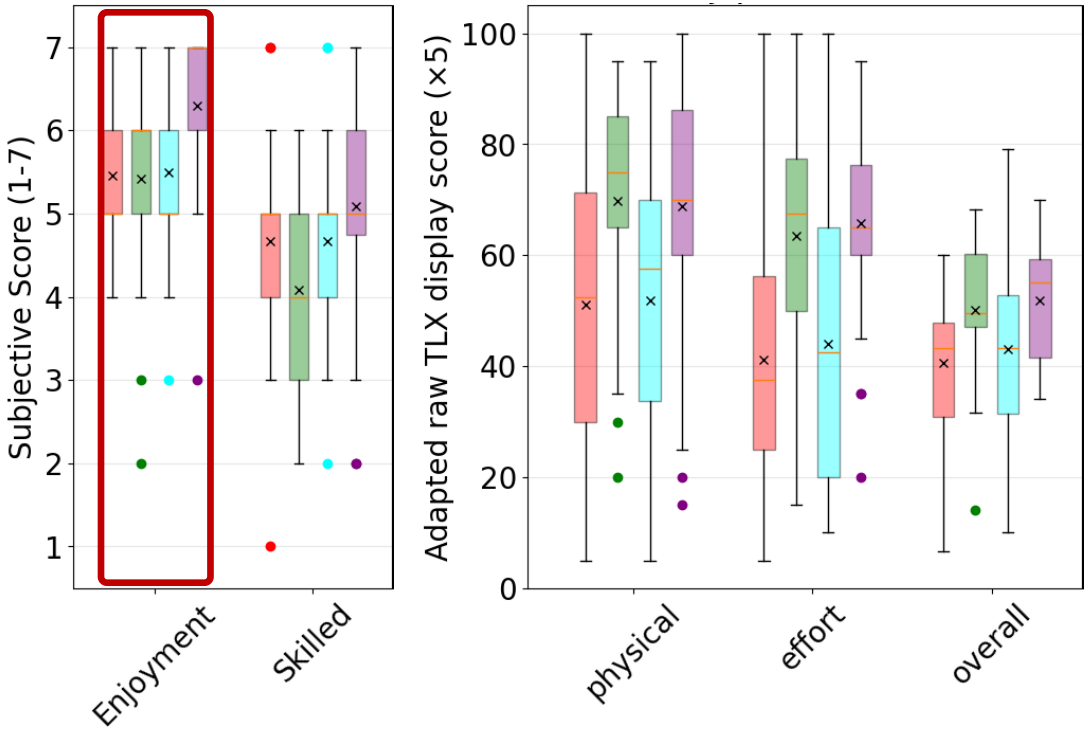
Enjoyment — Quad ↑ Rowing ↑

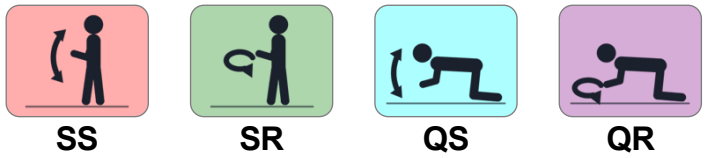
Skill — QR > SR

Workload — Rowing ↑

Rowing: skillful only on all fours, and tiring

Results: Skill & Workload





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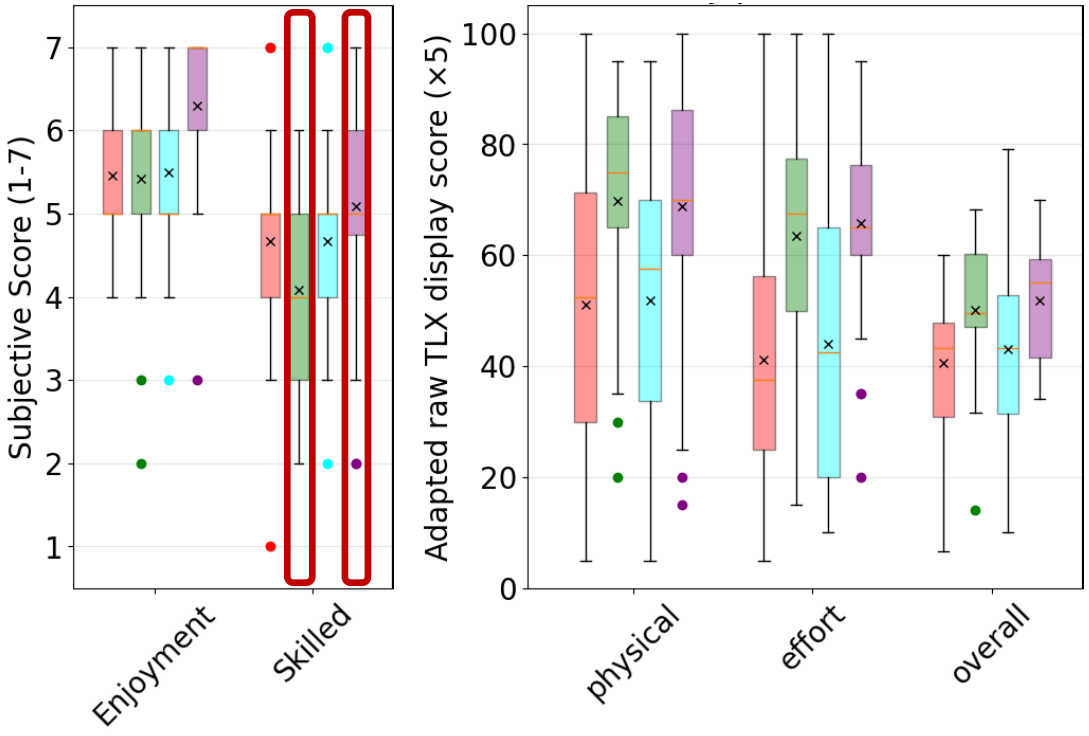
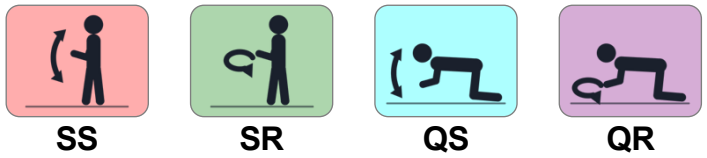
Results: Skill & Workload





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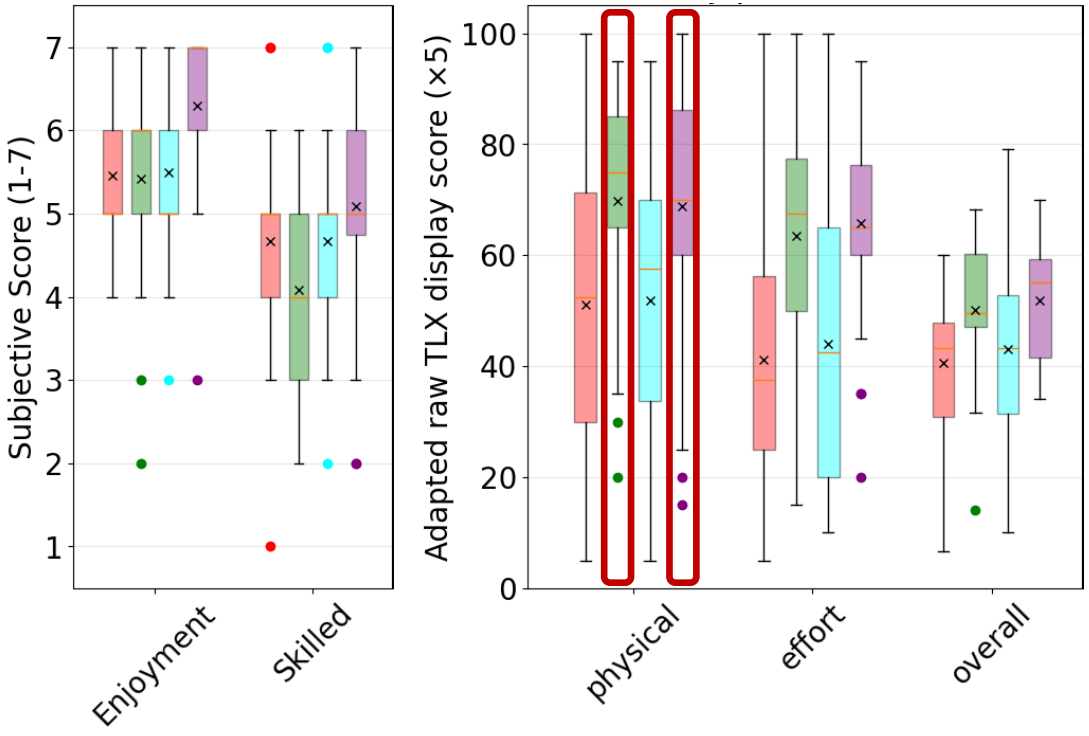
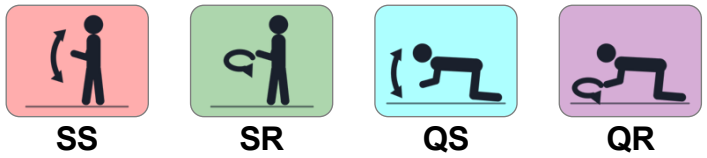
Results: Skill & Workload





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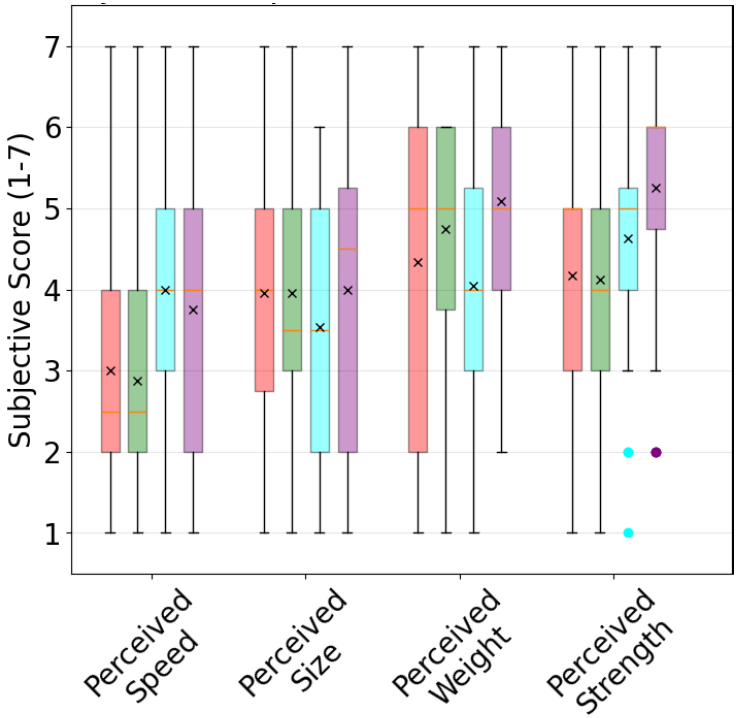
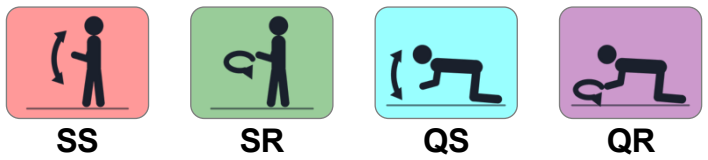
Rowing: skillful only on all fours, and tiring

Results: Self-Perception





H4 Quad & Rowing

Speed	Size	Weight	Strength

Results: Self-Perception

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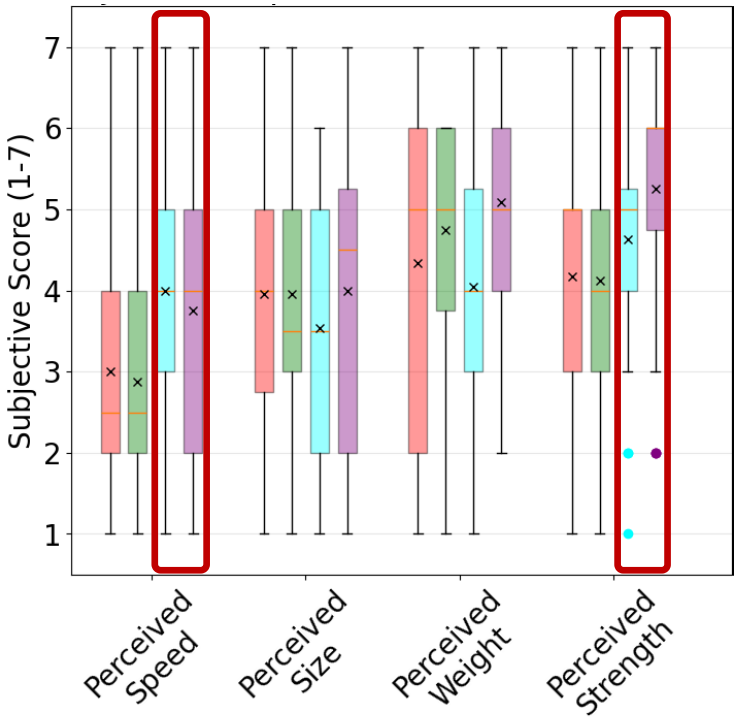
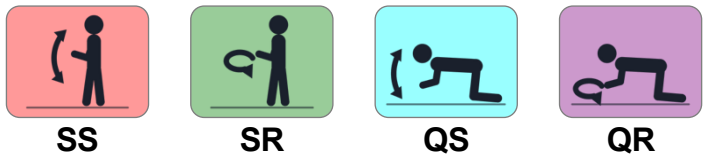
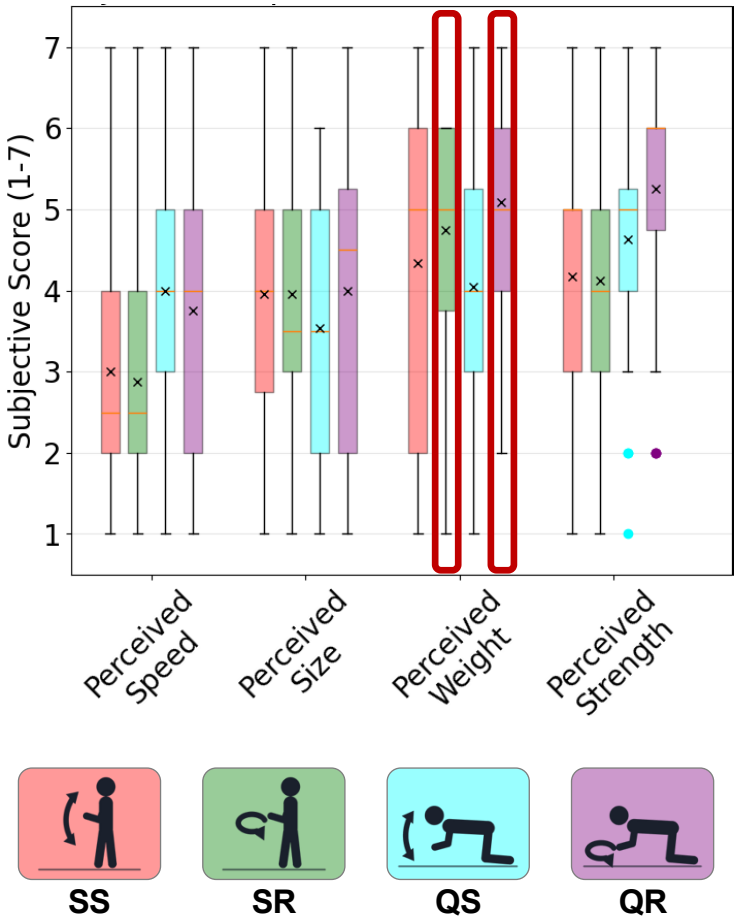




H4 Quad & Rowing

Speed ✓	Size	Weight	Strength ✓
Quad ↑			Quad ↑

Results: Self-Perception



H4 Quad & Rowing

Speed ✓	Size	Weight ✓	Strength ✓
Quad ↑		Rowing ↑	Quad ↑

Results: Self-Perception

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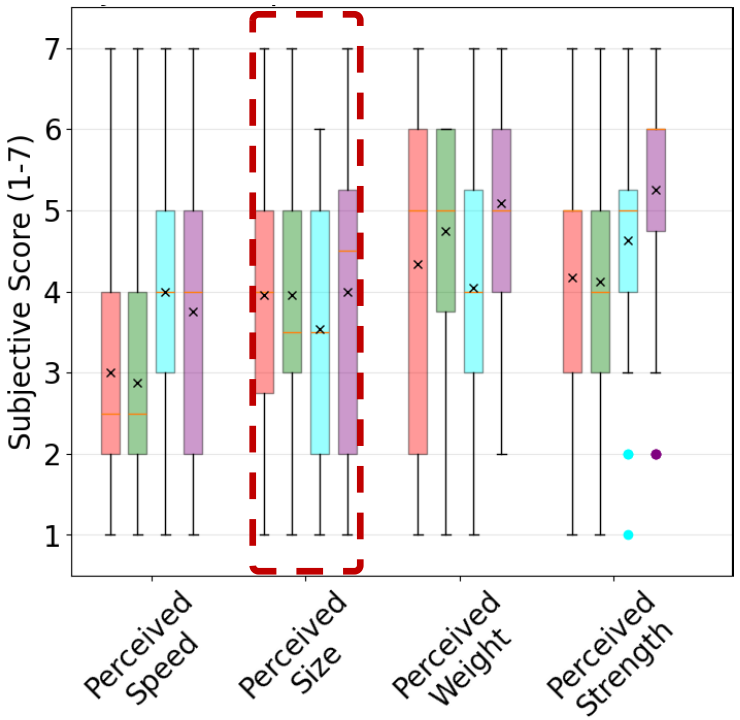
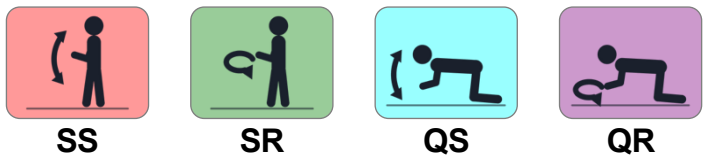




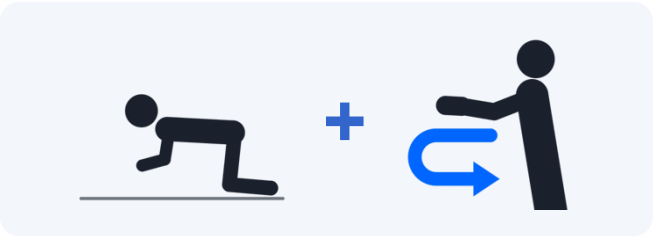
H4 Quad & Rowing — Partially supported

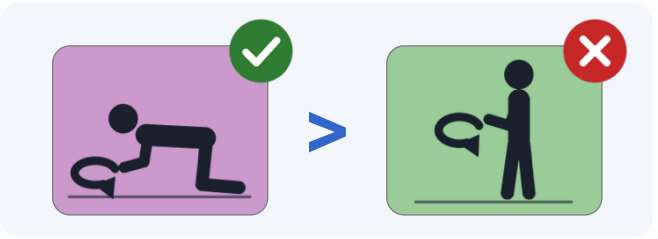
Speed	Size	Weight	Strength
Quad ↑	No effect	Rowing ↑	Quad ↑

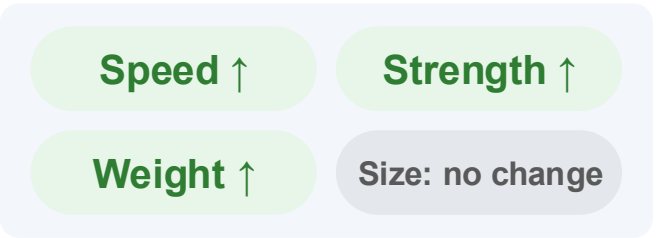
How you move changes how bear-like you feel

Discussion

- Posture and gesture add up
  - No interaction: **each helps alone**
  - May act as **separate cues**[*1]
- Skill needs both
  - Rowing feels skillful **only on all fours**
  - Crawling motion + standing view: **unnatural**
- Movement shapes self-perception
  - Same bear, **different movement**
  - Largest shifts with **highest ownership**[*2]



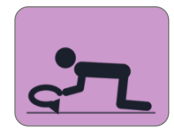
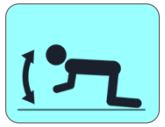




*1 Ernst & Banks, Nature 2002 *2 Mal et al., IEEE TVCG 2023

Design Implications

- Match posture to the avatar
- One factor alone still helps
- Rowing costs effort

	Rowing	Swinging
Quad	 **QR** ✓ **Best embodiment** skillful · more effort	 **QS** **Posture alone helps** less effort
Stand	 **SR** ✗ **Avoid** feels less skillful	 **SS** **Easy, familiar** weakest embodiment

Limitations & Future Work

- Plantigrade animals only
- Posture tied to eye height & size
- Hands never touched the floor
- Short trials, self-report

Next: other foot postures[*1]



Prediction: the gesture effect weakens as front legs become less hand-like

*1 Kimura, Kaibogaku Zasshi 1993

Conclusion

- Posture and gesture both raise embodiment
- Rowing: skillful on all fours, but tiring
- As a bear: faster, stronger, heavier — not bigger



Thank you!



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RITSUMEIKAN

University of Stuttgart Germany

VISUS VISUALISIERUNGSINSTITUT DER UNIVERSITÄT STUTTGART