



# Embodiment in Virtual Environments

## Analyzing the Effects of Latency and Avatar Representation

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*29-31 October, Yamanashi, Japan*

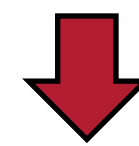
- High quality, expressive avatars important for VR
  - Increase immersion, presence, embodiment



[Yu 2021]

Def. quality:  
visual and control fidelity,  
closeness to appearance

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- Increase system latency through processing
  - Negative on embodiment, cybersickness, user exp.



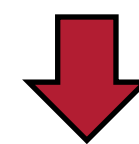
[Yu 2021]



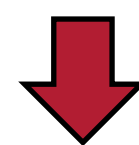
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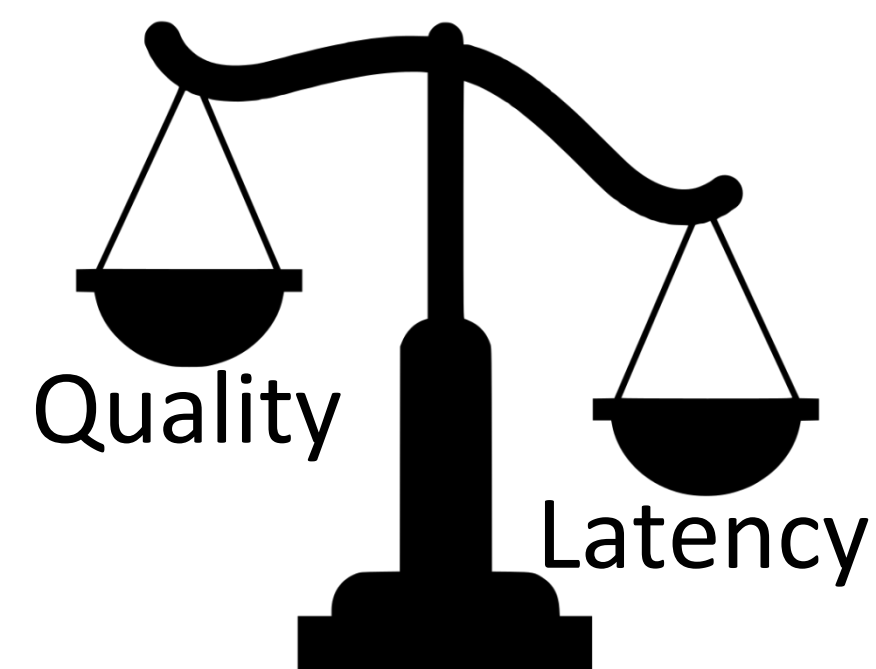
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- Dilemma:



[Yu 2021]



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- Does avatar quality affect latency perception?
- Any statistical interaction effects?
- What is a good trade-off?





# Related Work

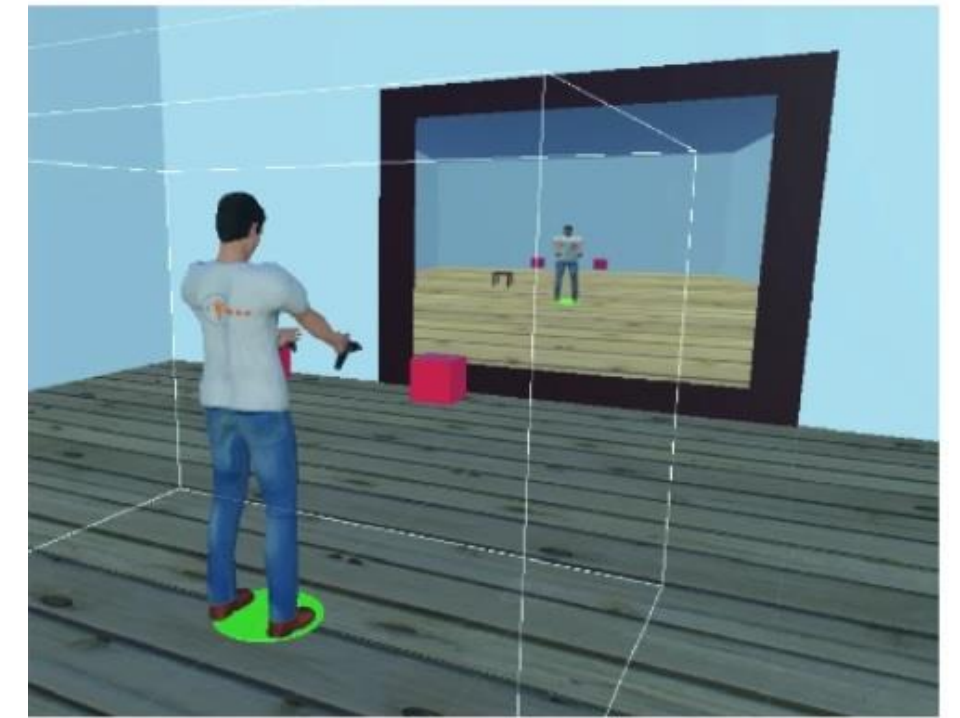
- Avatar quality/personalization incr. embodiment, presence

[Waltemate 2018]

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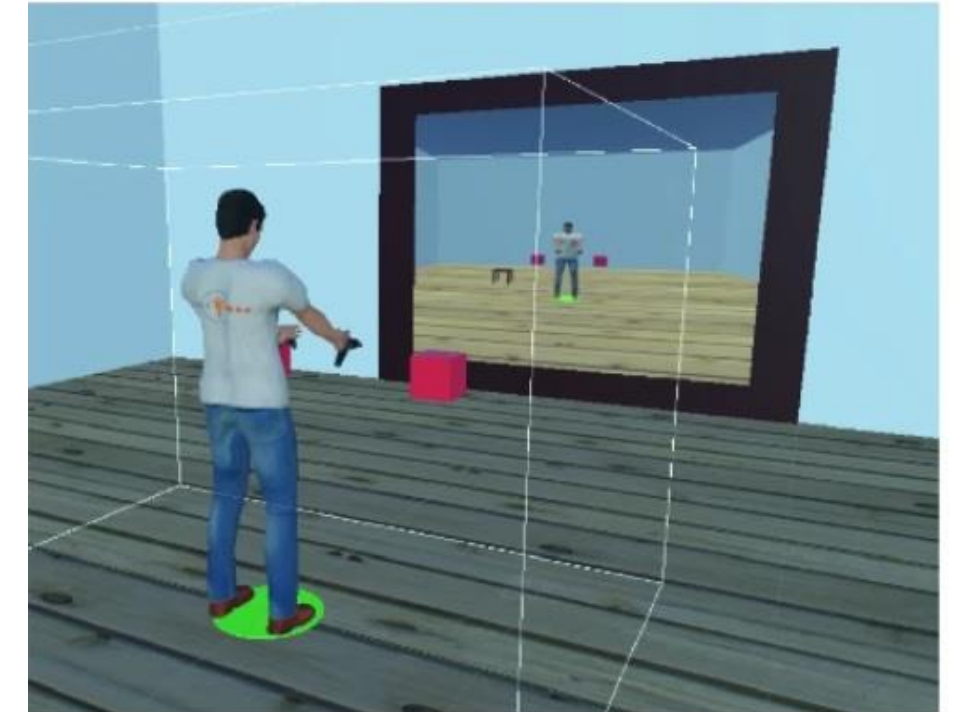
[Waltemate 2018]

- Latency decreases embodiment, presence,  
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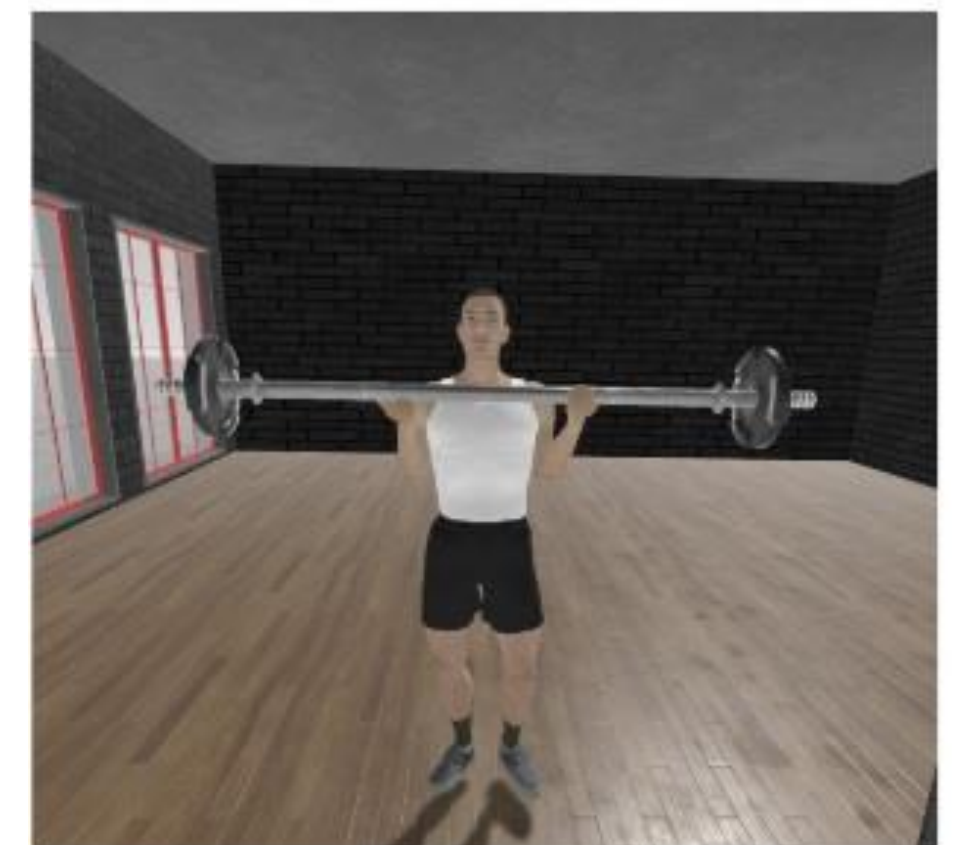


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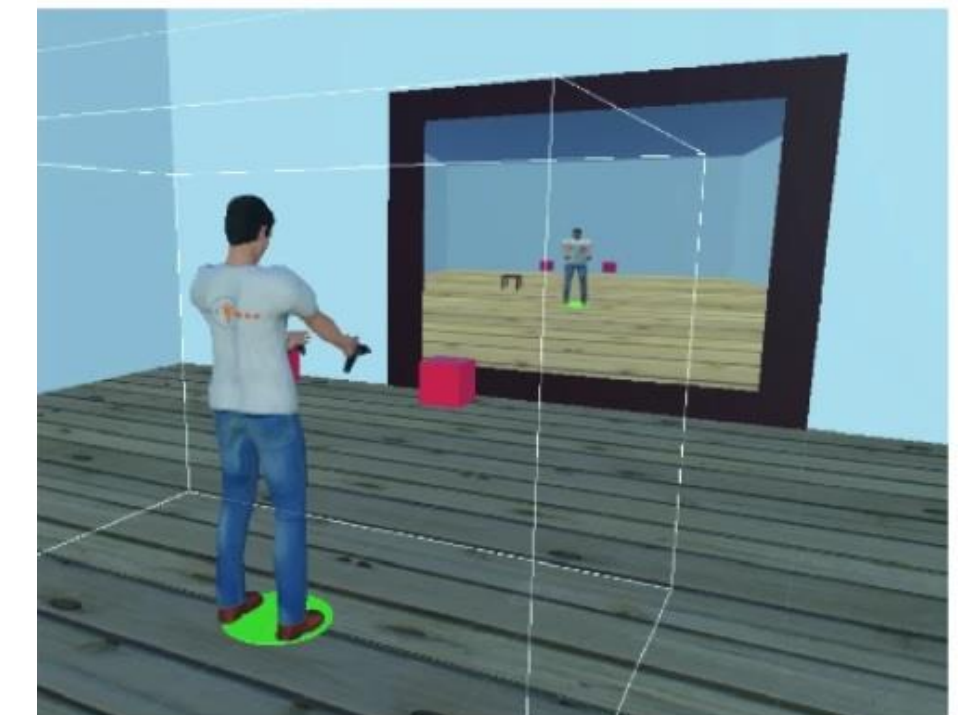


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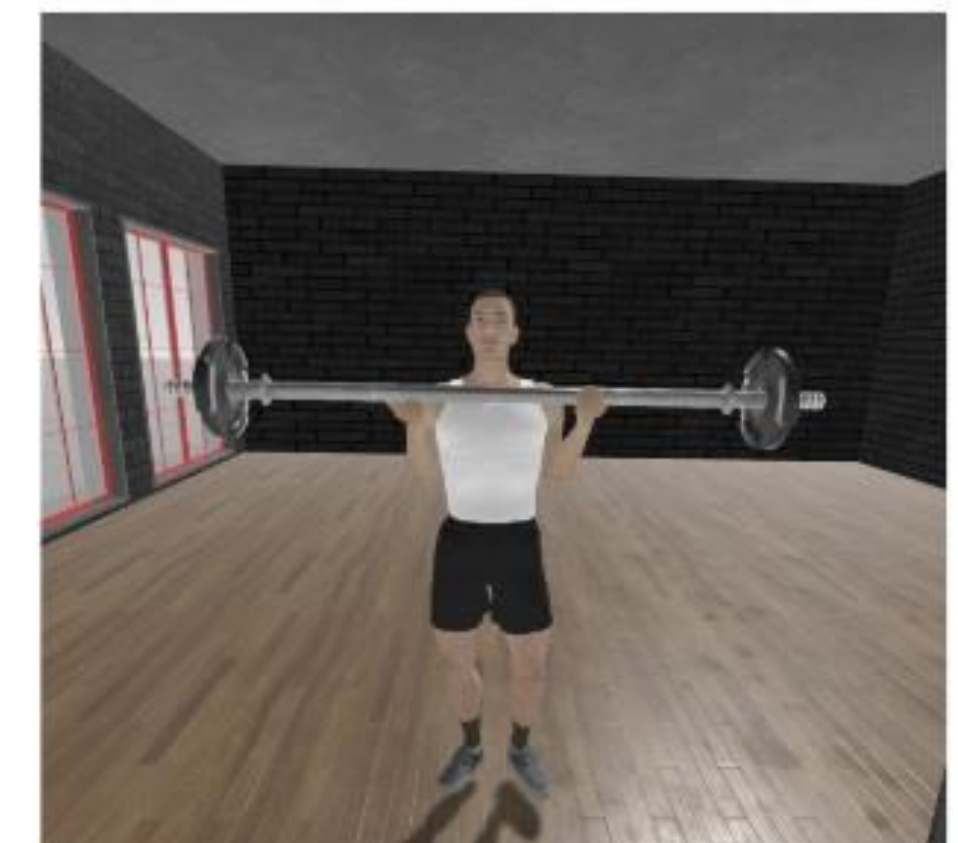


[Halbhuber 2023]

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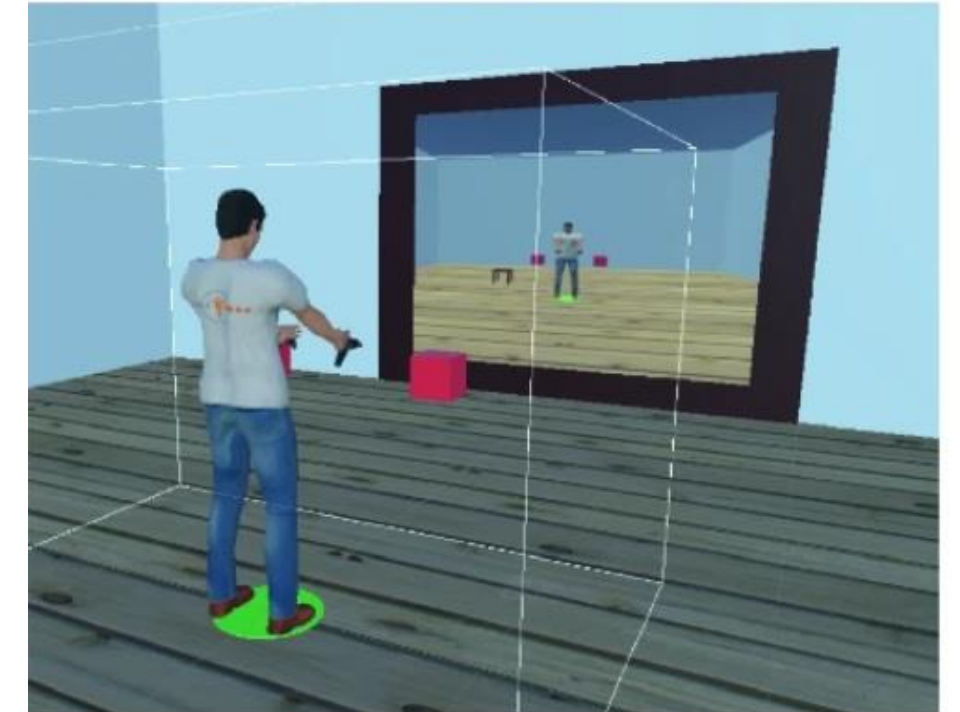


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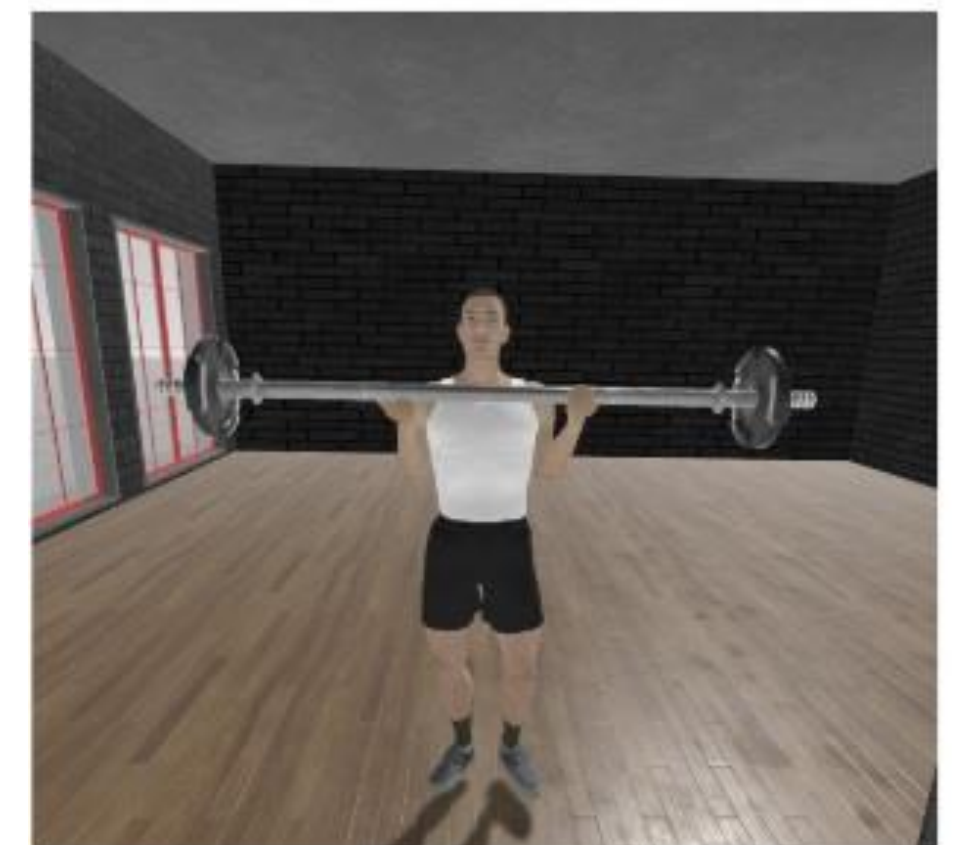


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➔ No answer to research questions



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# Our Contributions

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- Provide valuable insights and recommendations

# Study Design

- Within-subject

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- Participants: 33 (85 % men, 15 % women)

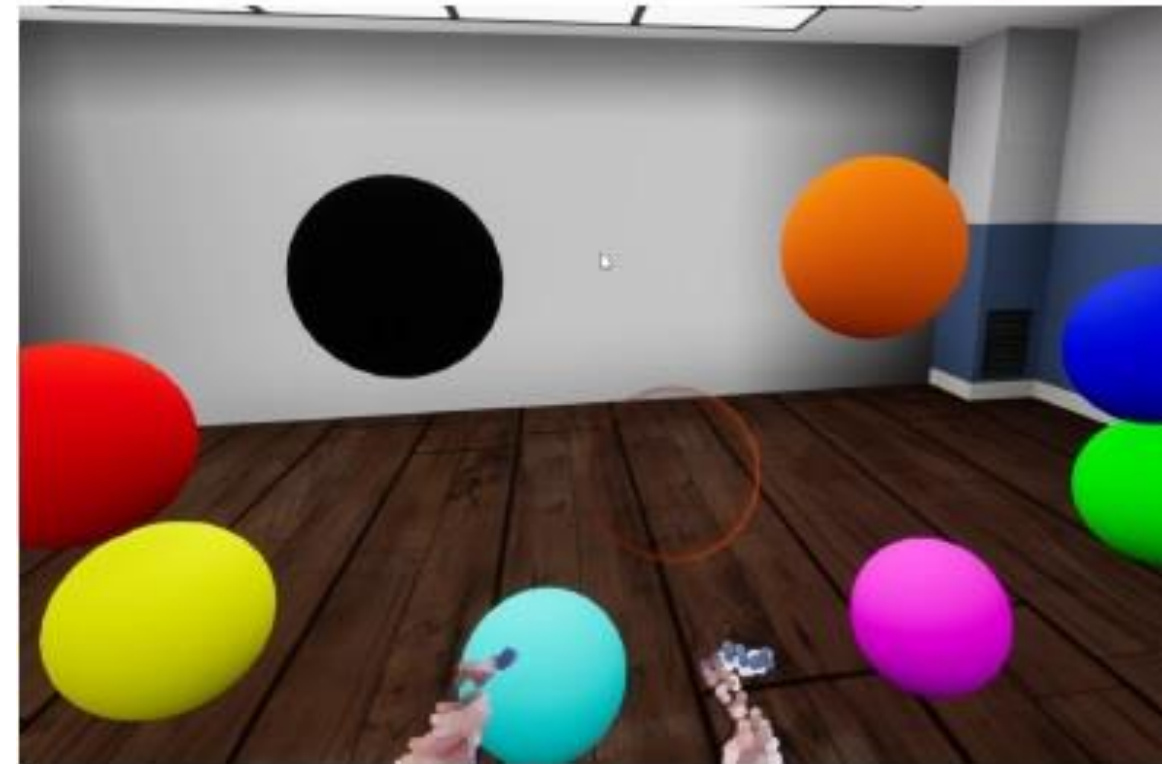
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- Within-subject
- Participants: 33 (85 % men, 15 % women)
- Conditions: 6 = 2 (low/high-quality Avatar) x 3 (150/225/300ms Latency)



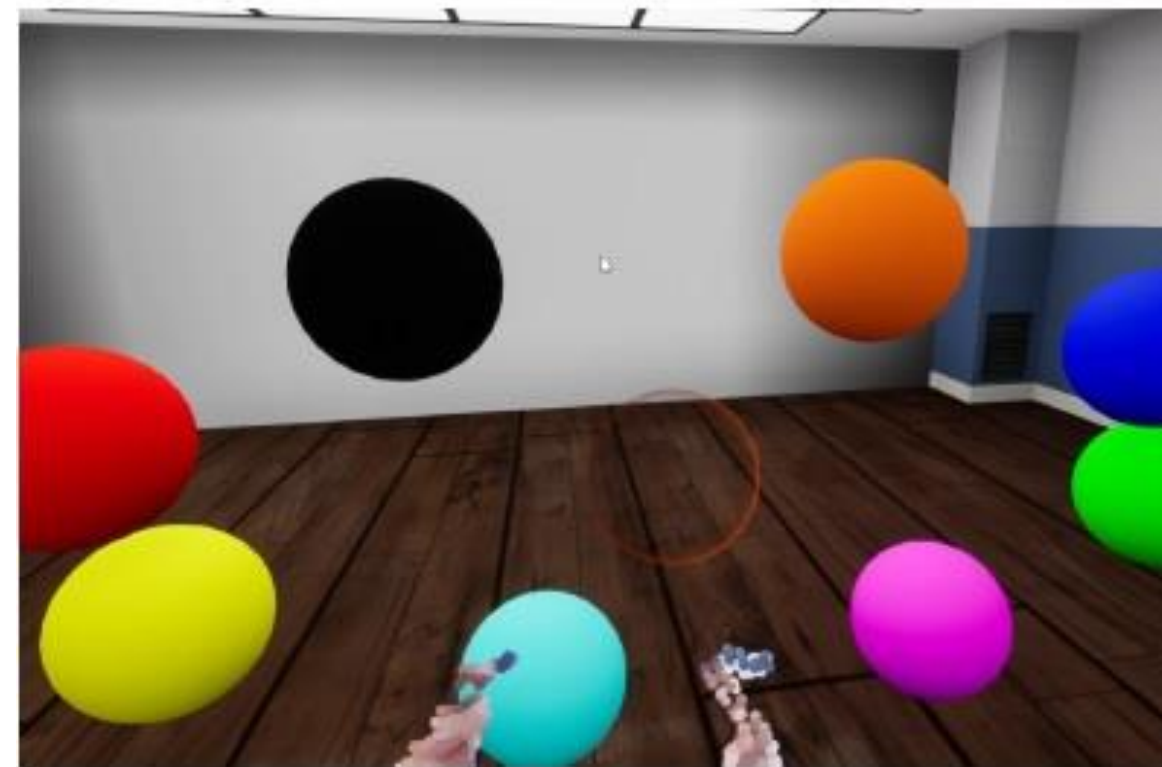
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- Tasks:

## Grabbing & Placing spheres

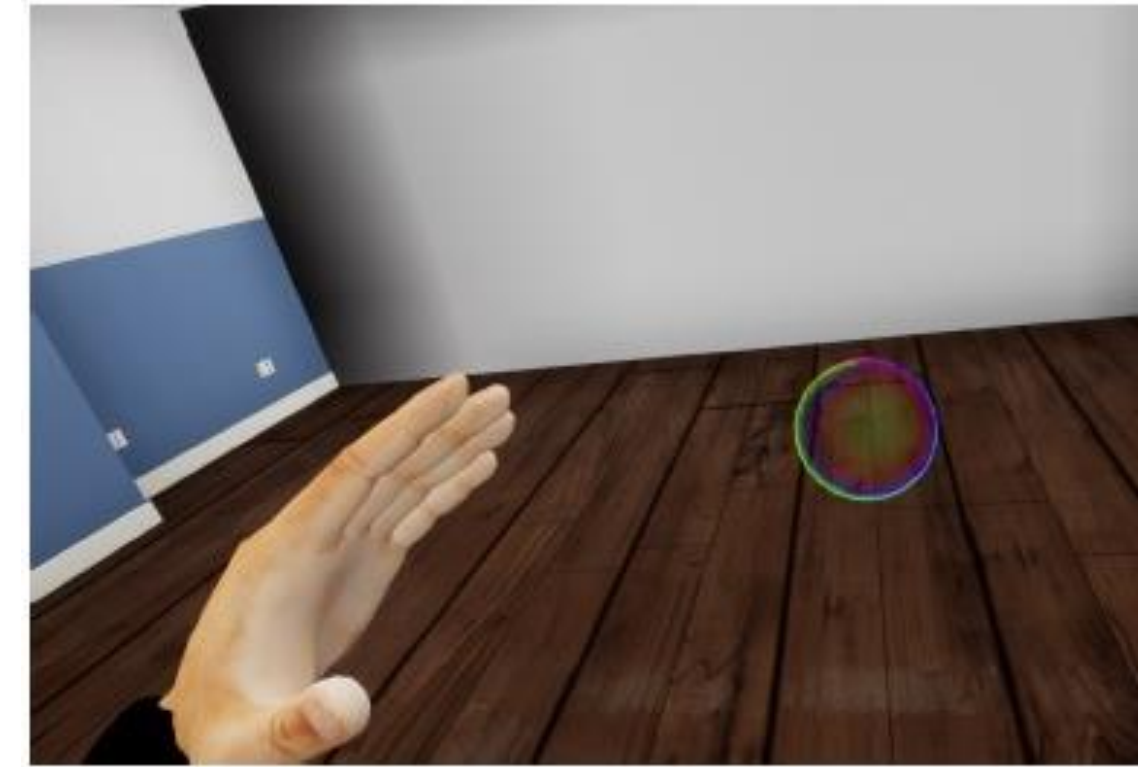


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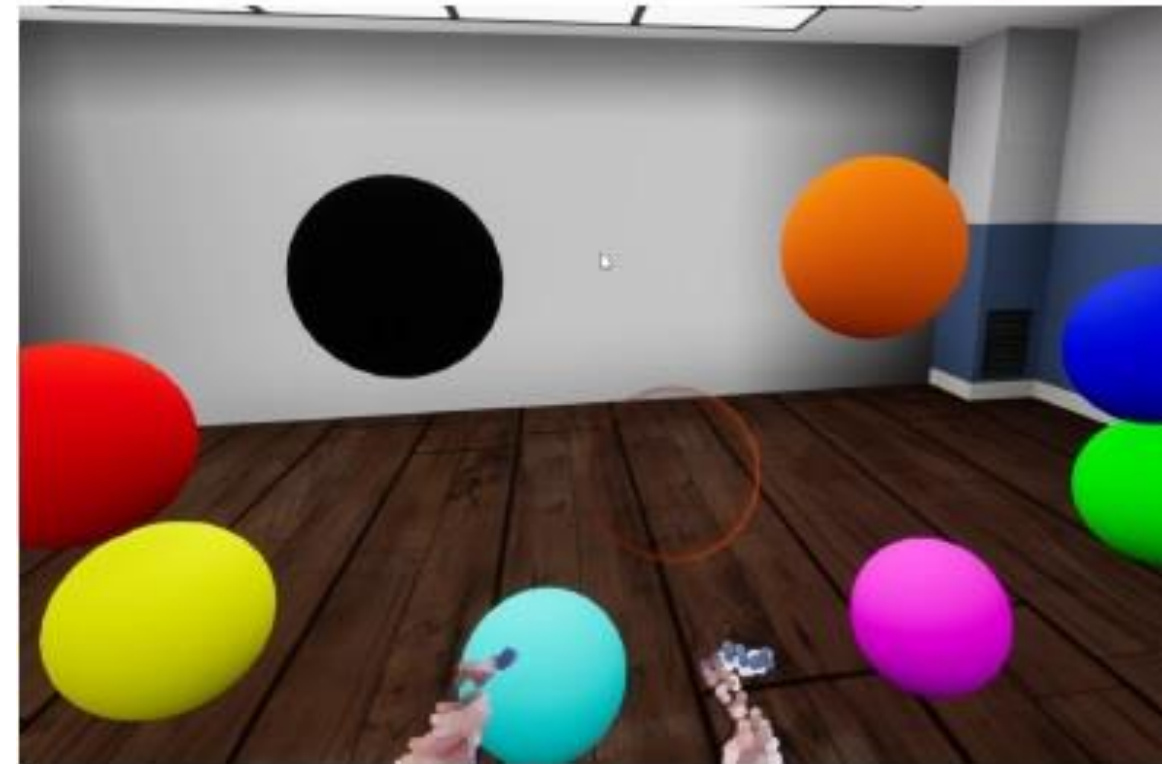
Popping Bubbles



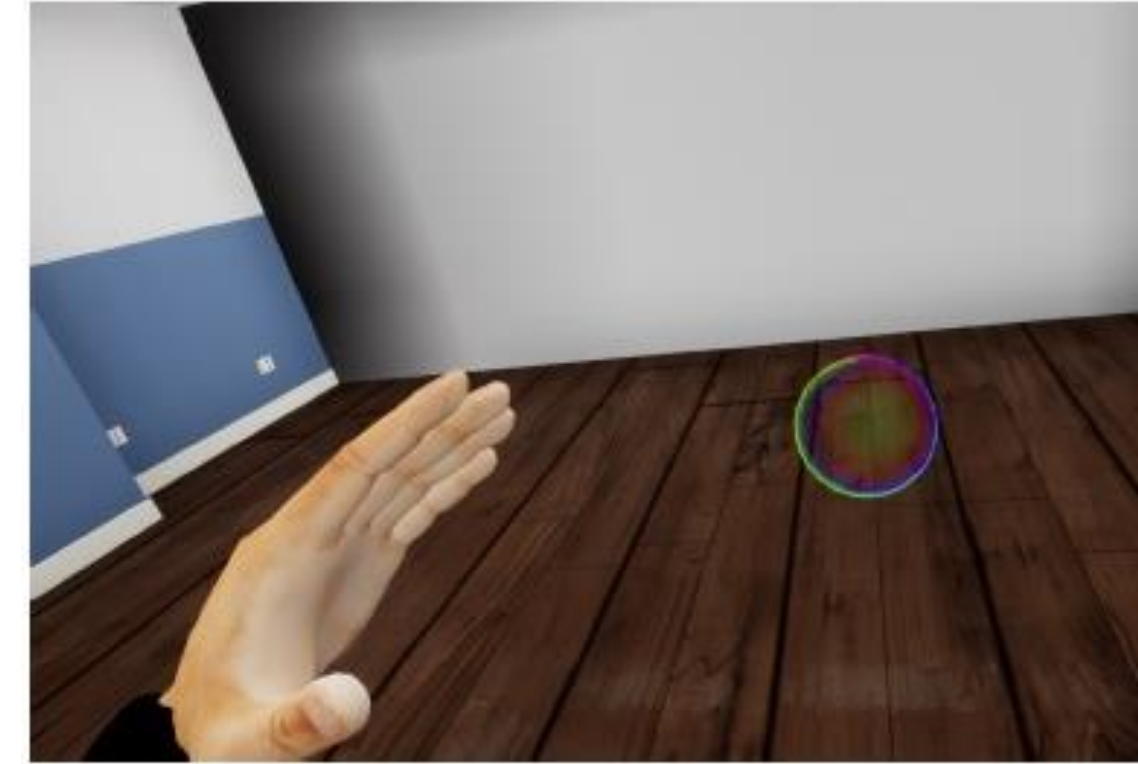


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## Imitating Movements



# Avatars and Study Setup

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- High-quality avatar:  
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# Avatars and Study Setup

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- High-quality avatar:  
live-tracked point cloud  
(Azure Kinect; 640x576@30 Hz)
- Lower-quality avatar:  
non-personalized, pre-modeled mesh  
+ inverse-kinematics (5-point-tracking)



- Embodiment
  - Body ownership
  - Agency
  - Self-location

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- Task efficiency

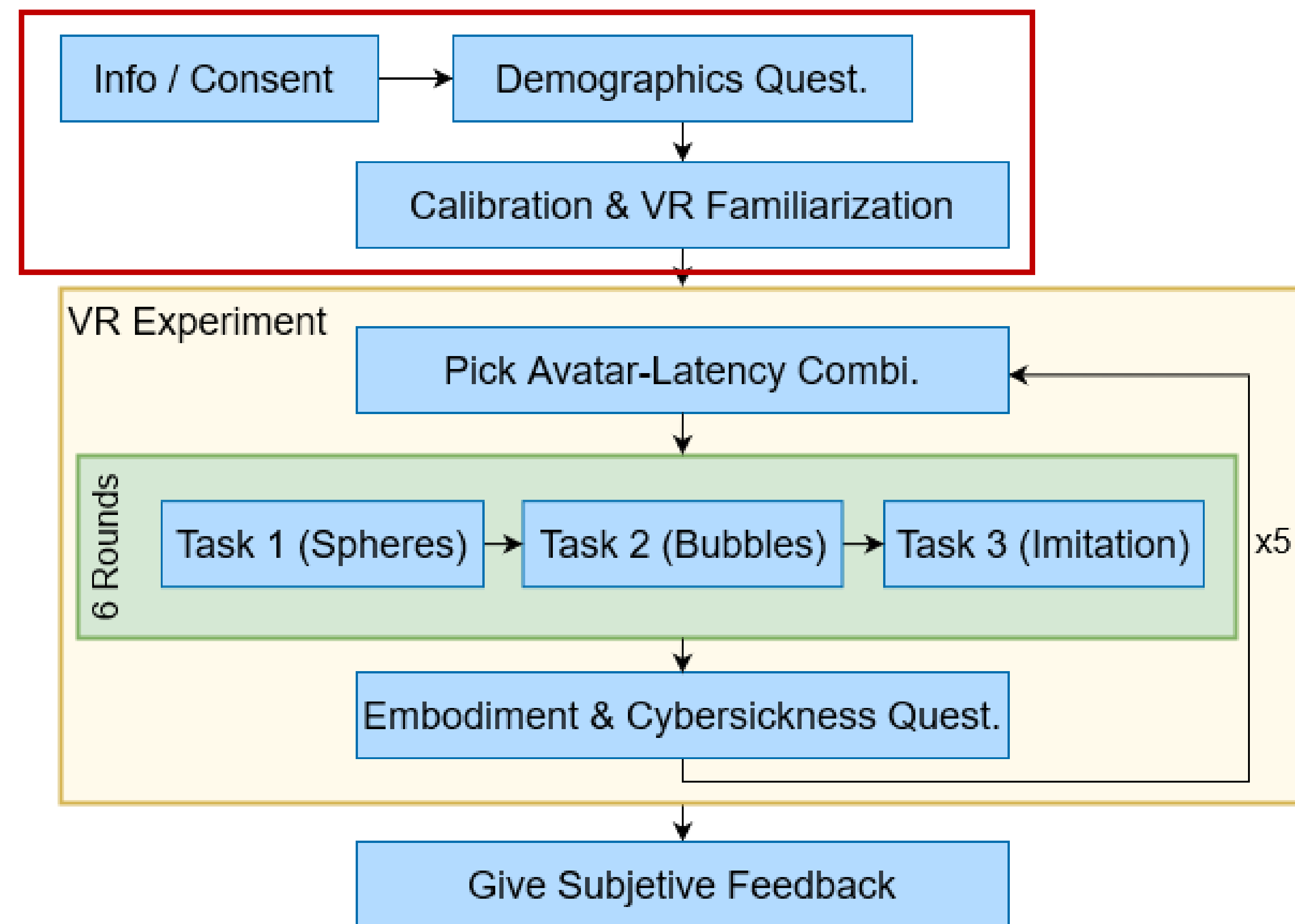
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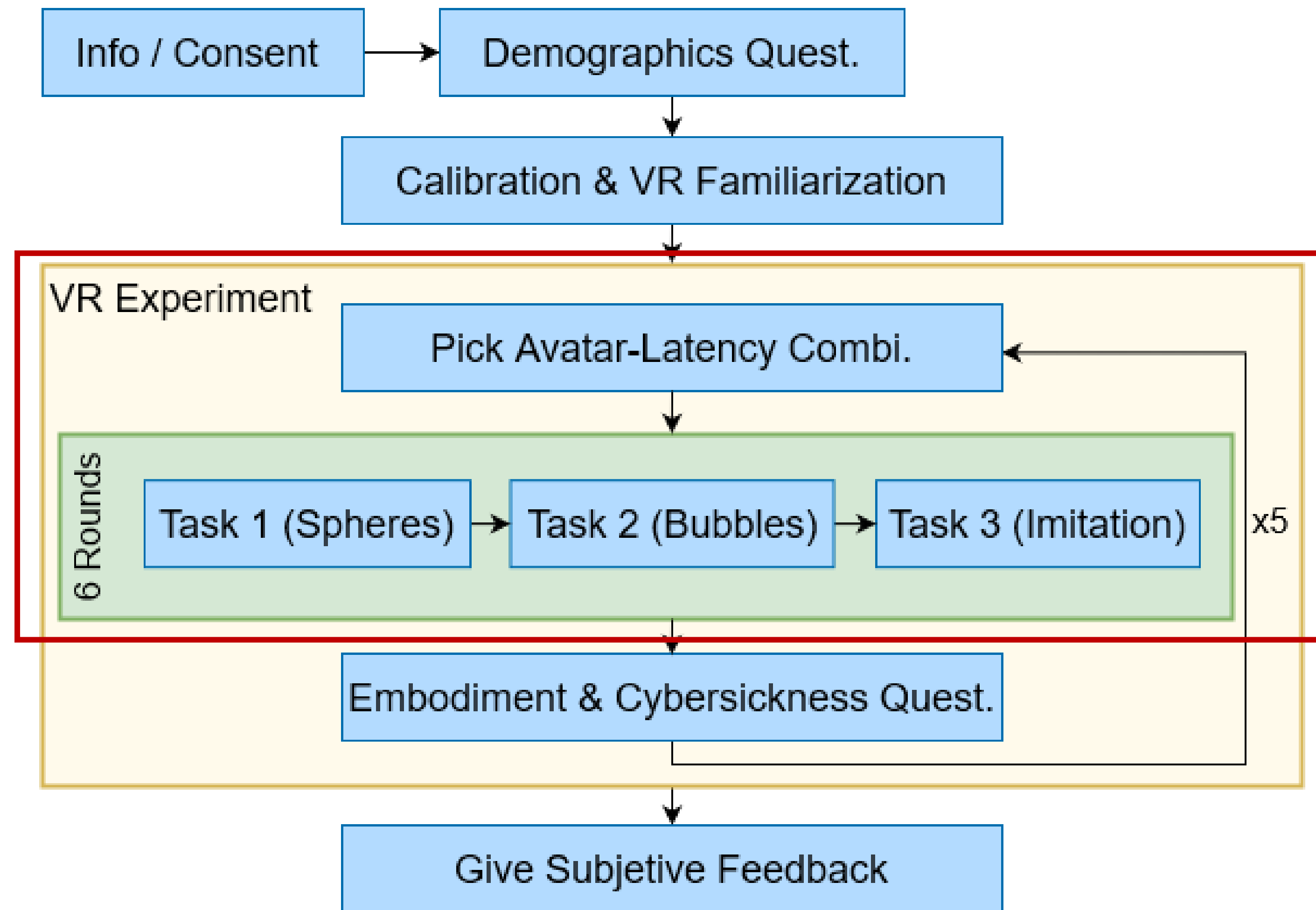
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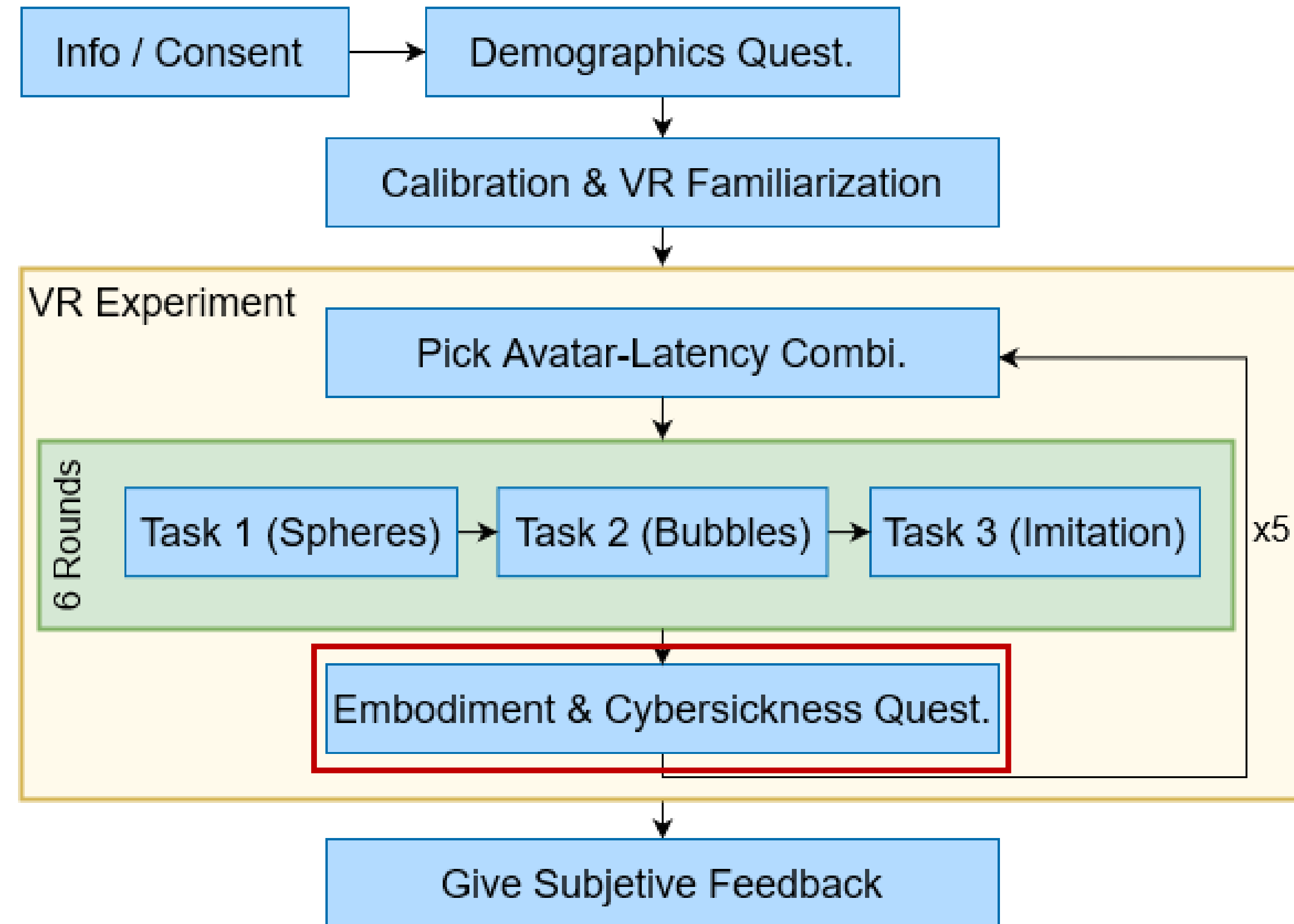


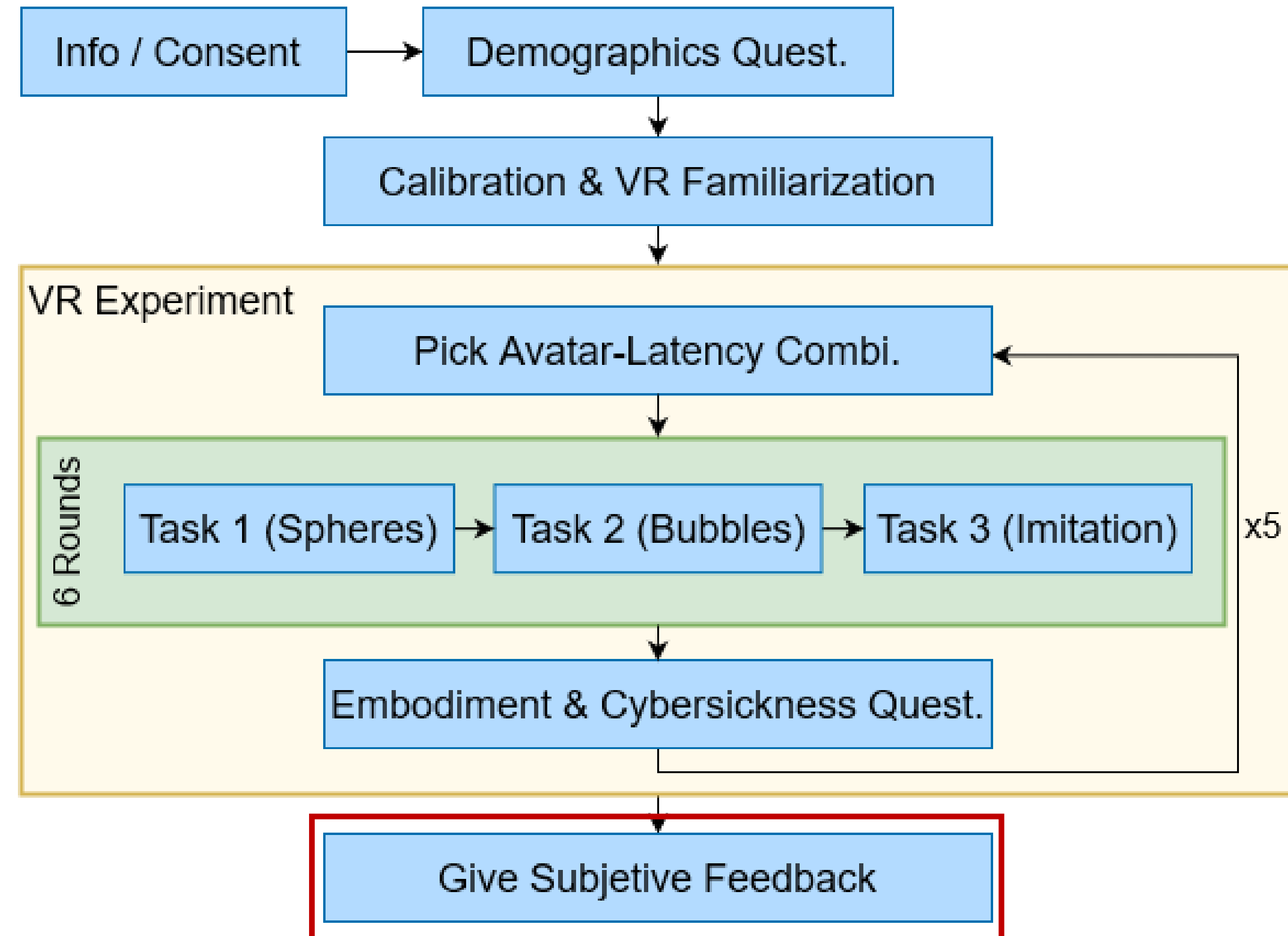
Questionnaires +  
time/performance tracking





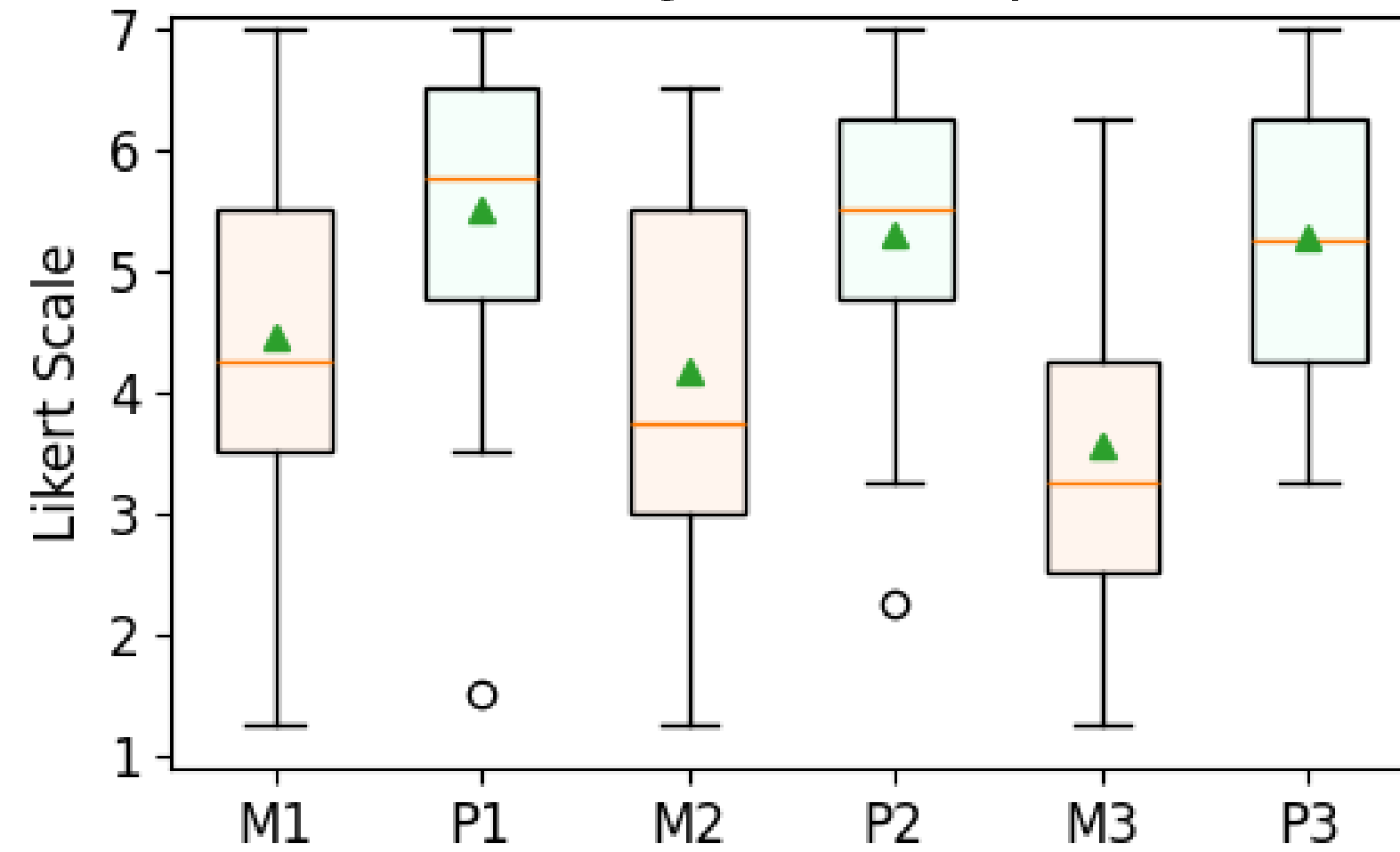




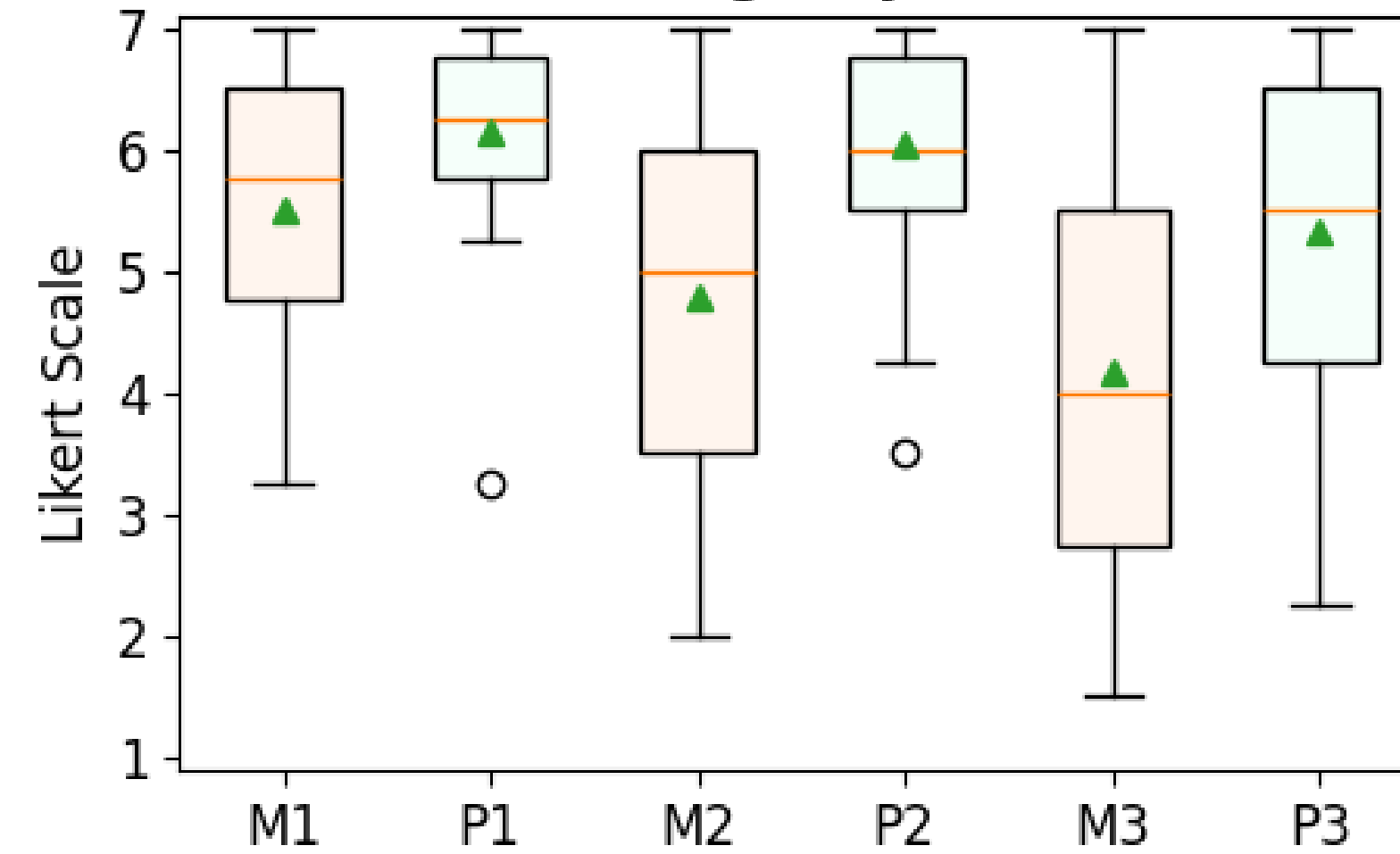


- ART-ANOVA (non-parametric, 2 indep. variables, repeated measure)
- Pairwise Wilcoxon signed-rank test (Bonferroni-corrected)

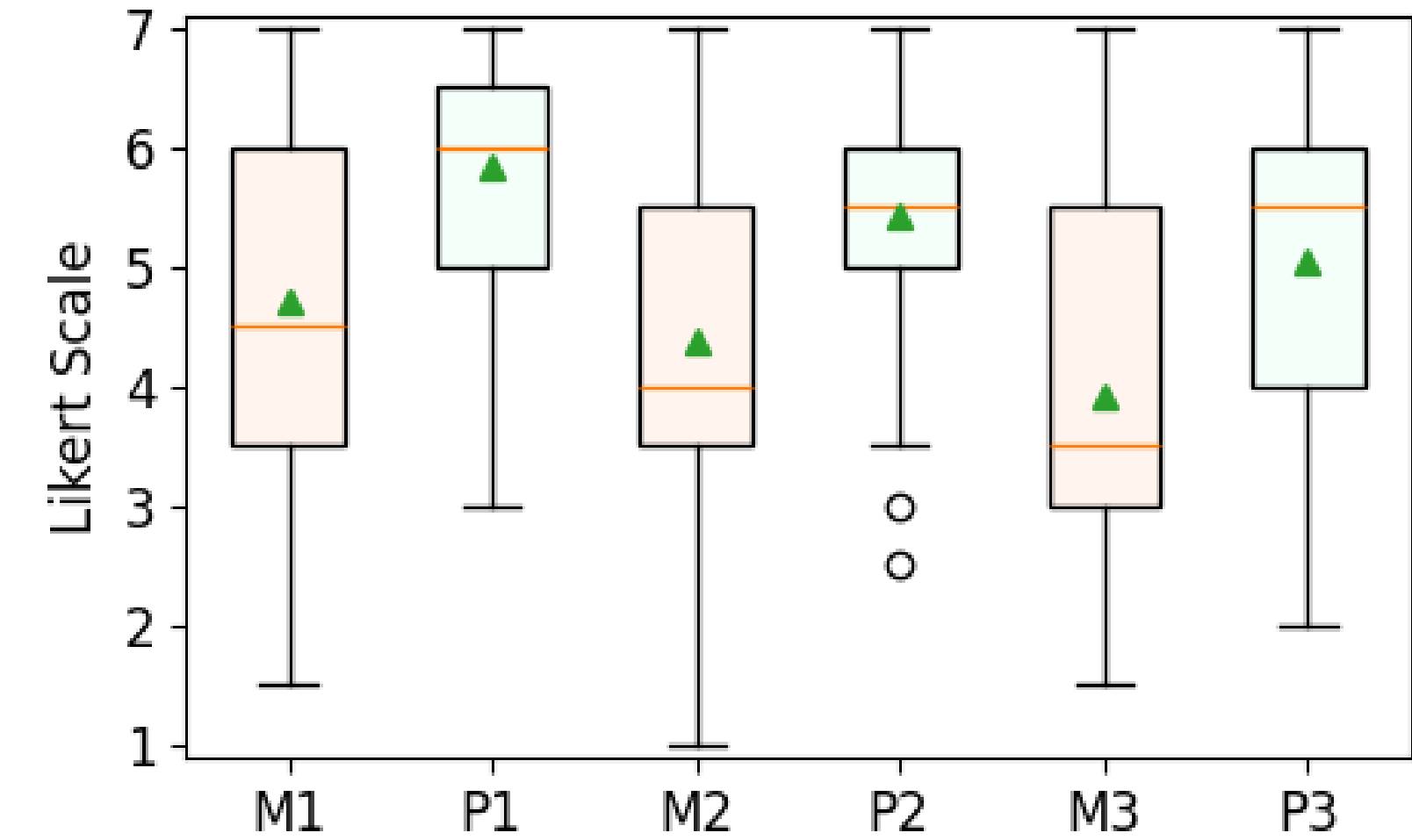
### Body Ownership



### Agency



### Self Location



### Body Ownership

M2	.999				
M3	.005	.053			
P1	.008	.001	.001		
P2	.086	.011	.001	.999	
P3	.159	.001	.001	.999	.999
M1					
M2					
M3					
P1					
P2					

### Agency

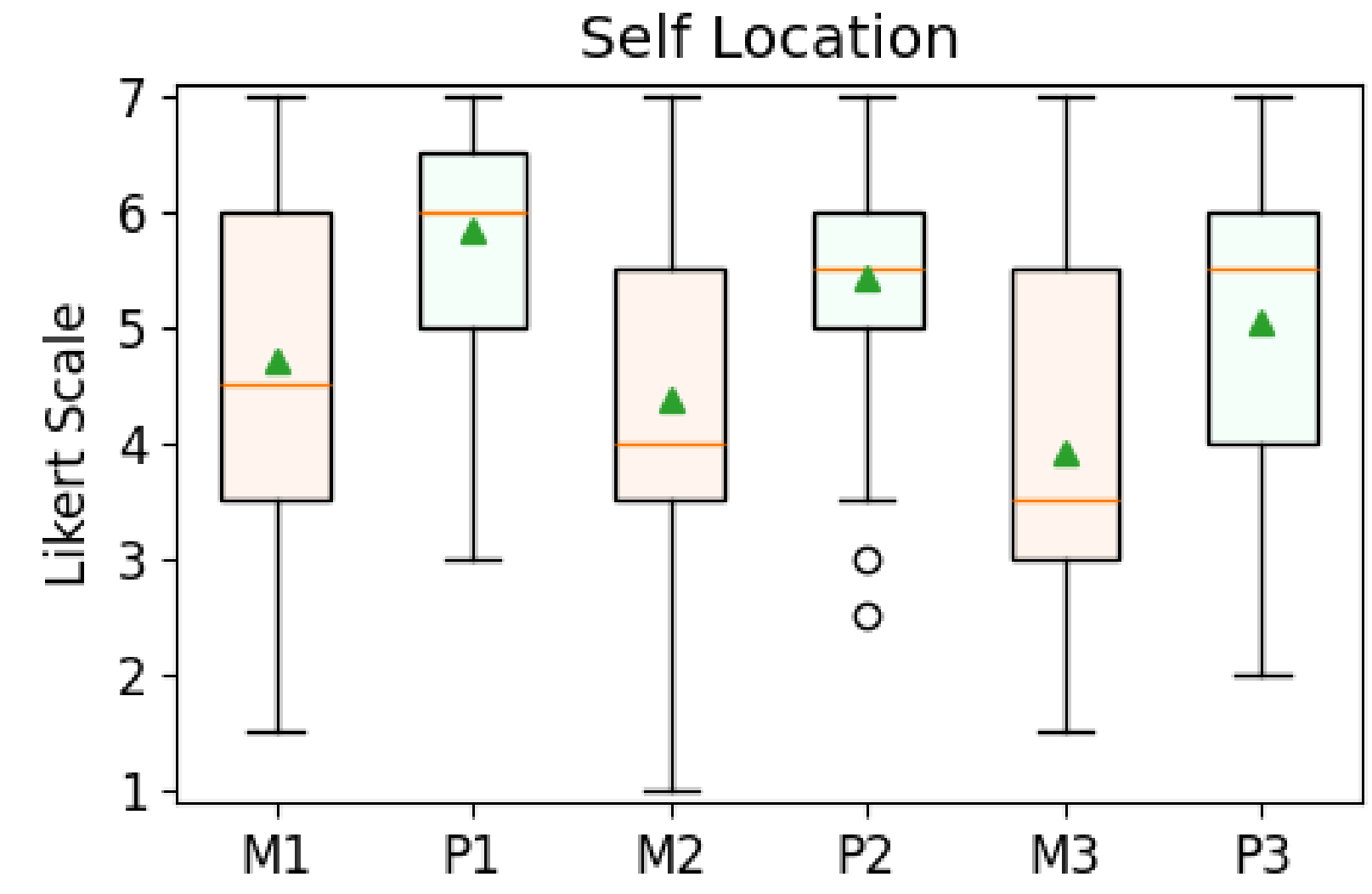
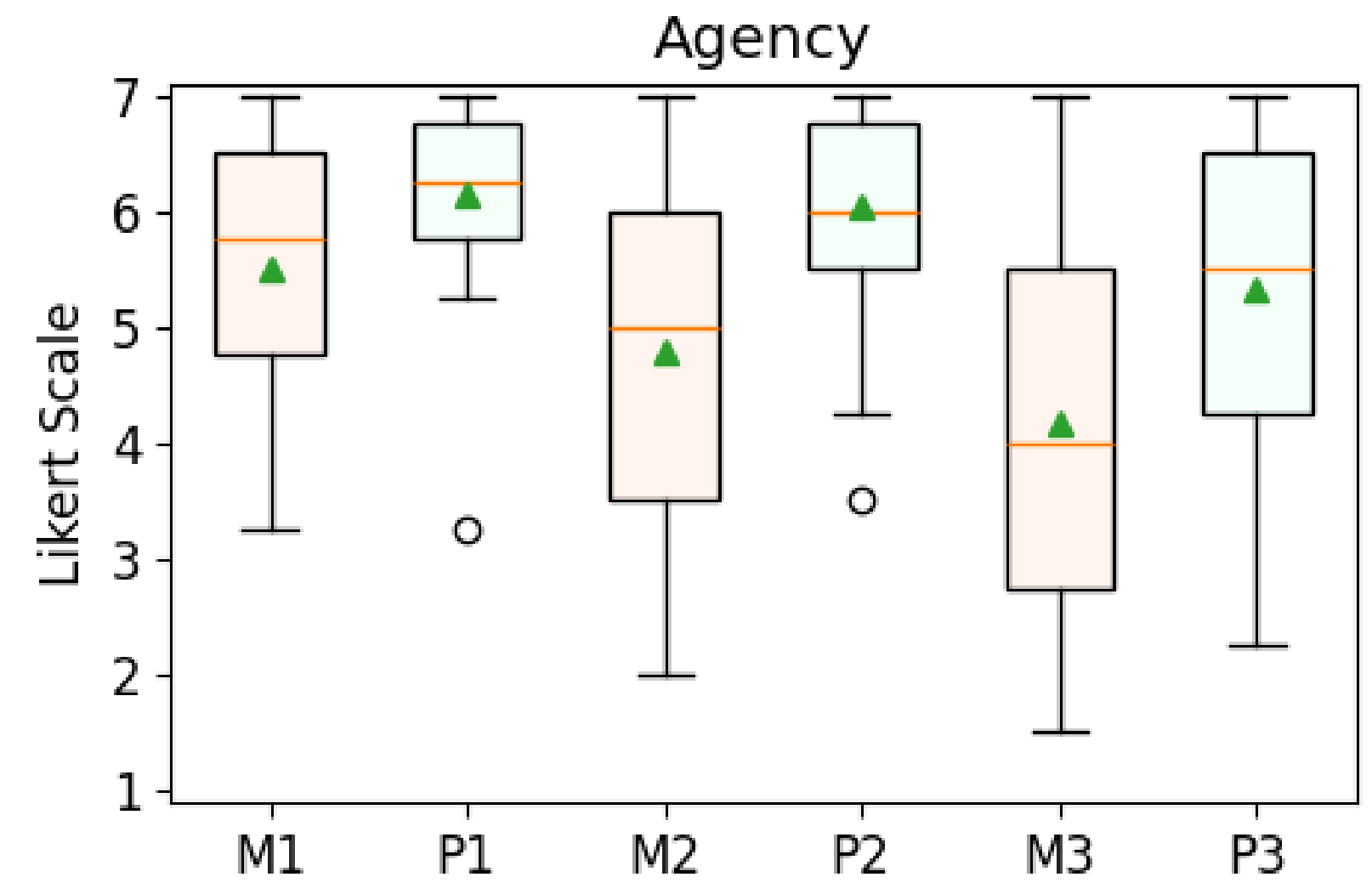
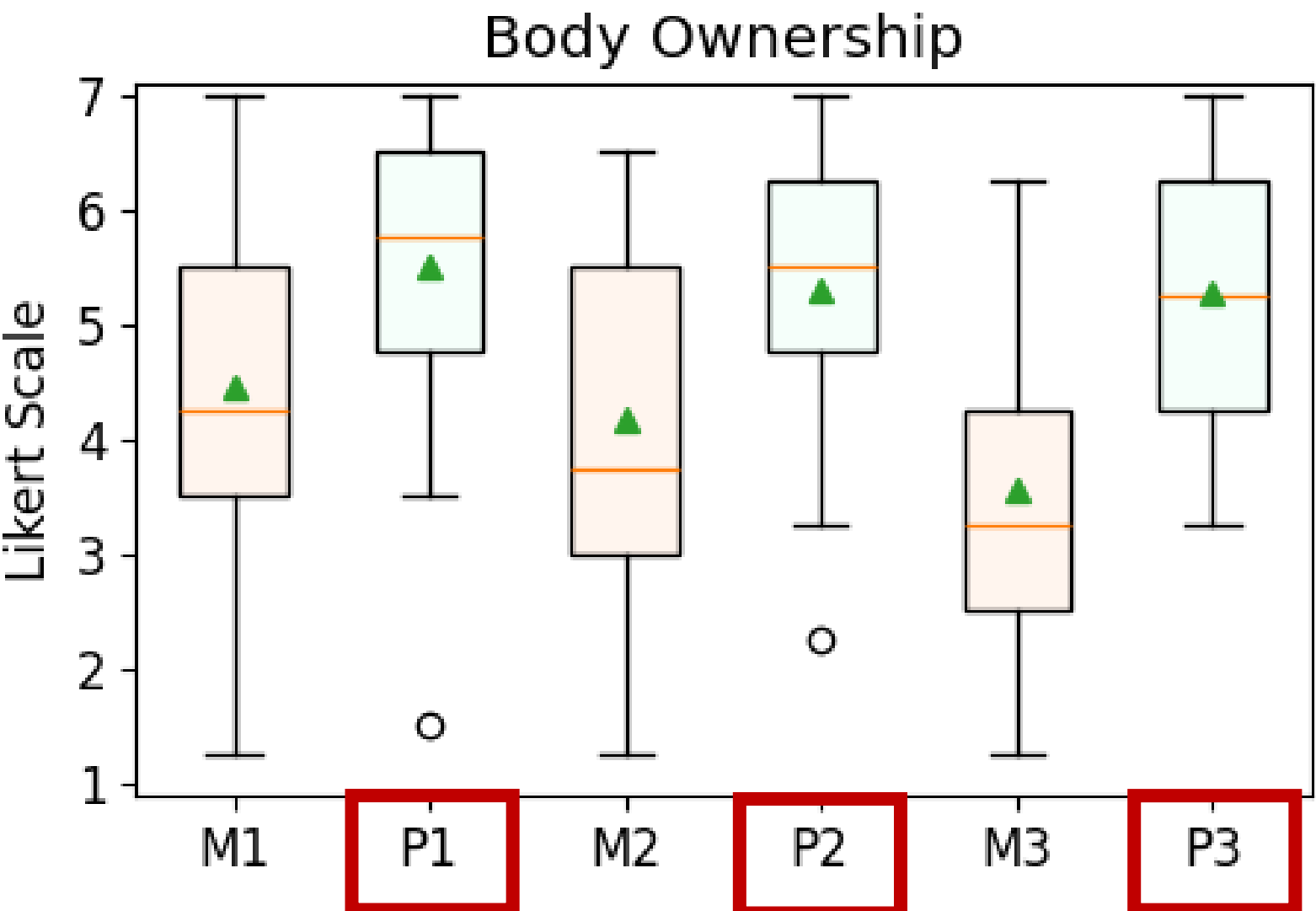
M2	.070				
M3	.001	.905			
P1	.032	.001	.001		
P2	.273	.004	.001	.999	
P3	.999	.089	.001	.011	.057
M1					
M2					
M3					
P1					
P2					

### Self Location

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M3	.009	.349			
P1	.003	.001	.001		
P2	.031	.005	.001	.906	
P3	.999	.044	.001	.007	.760
M1					
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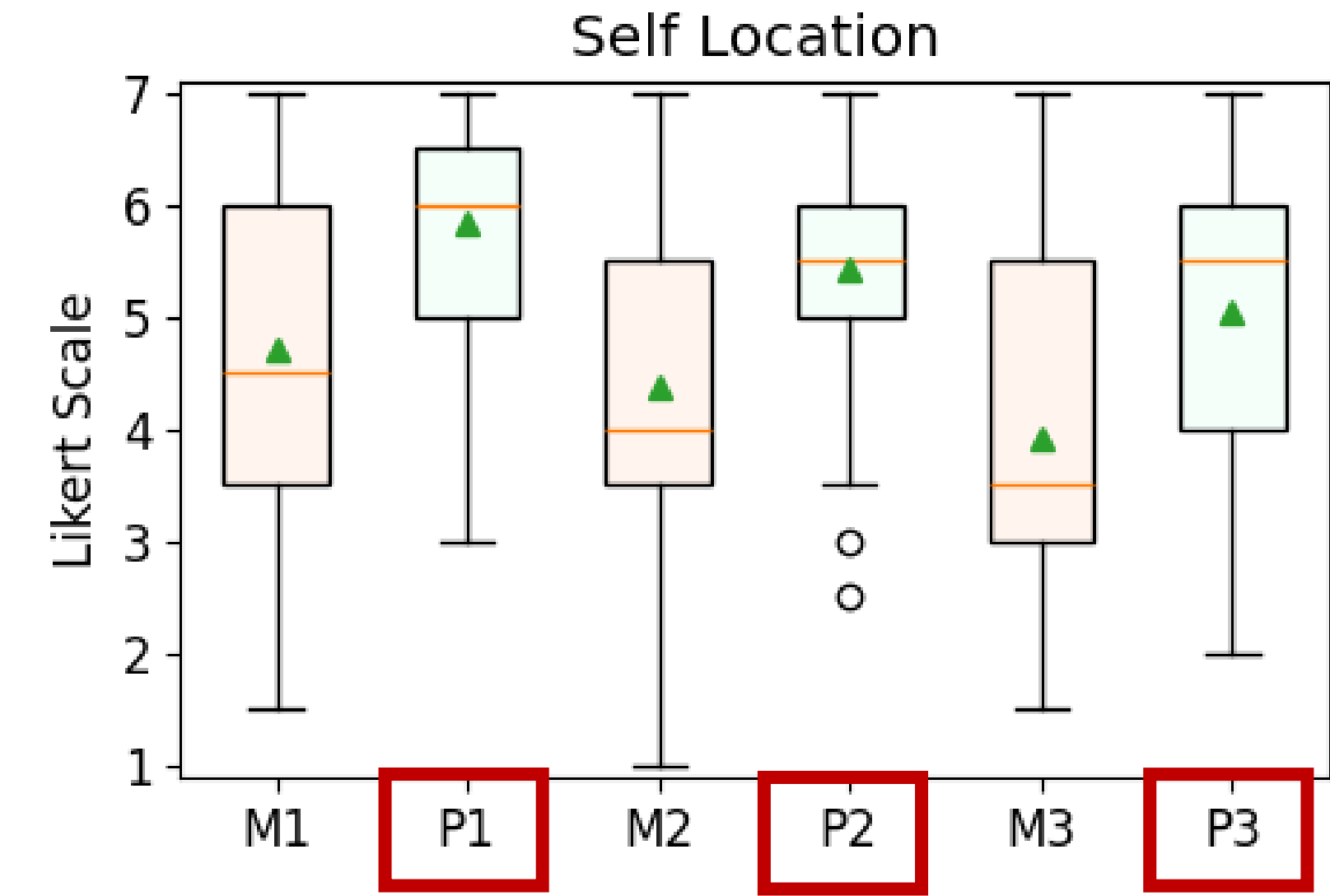
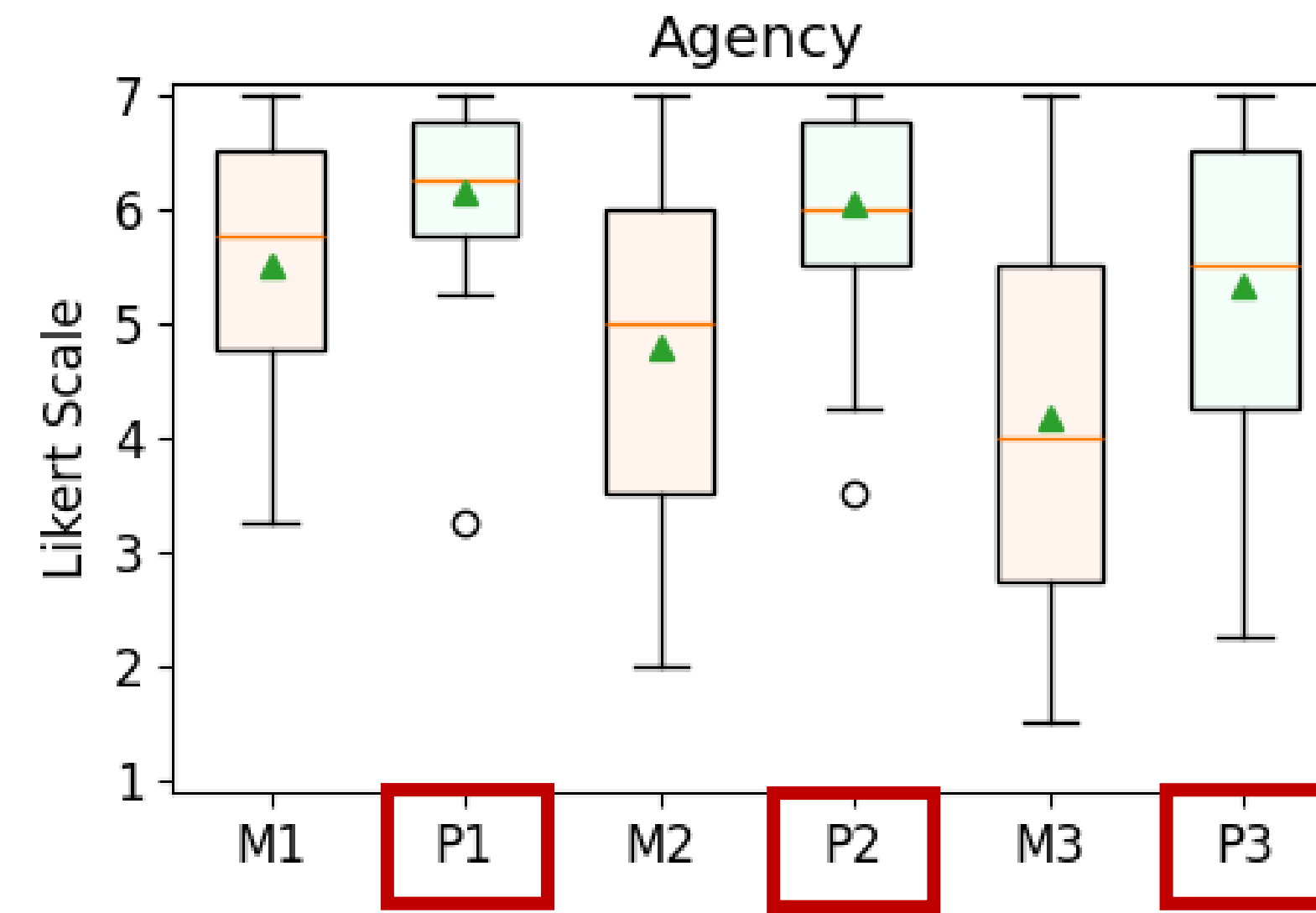
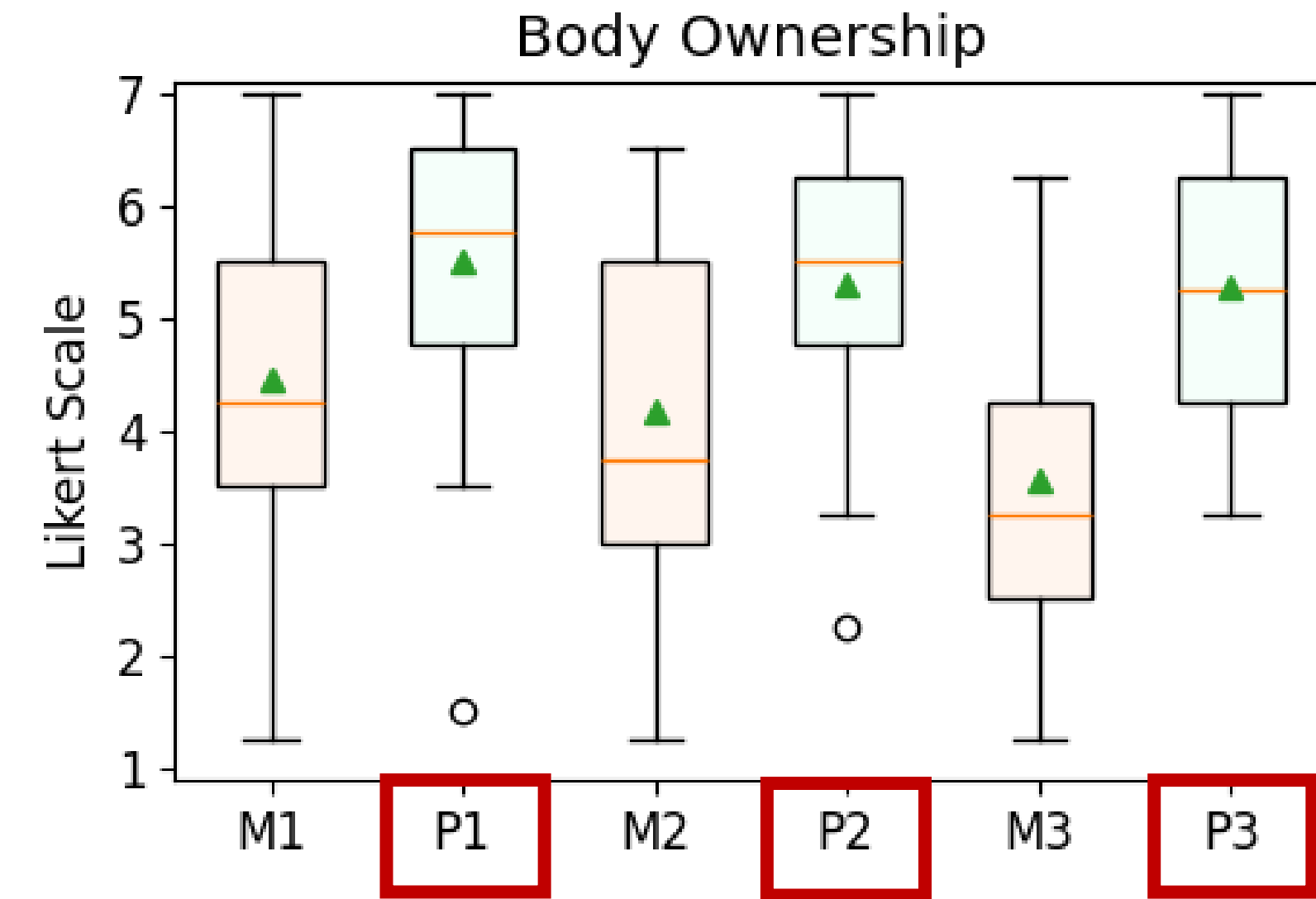
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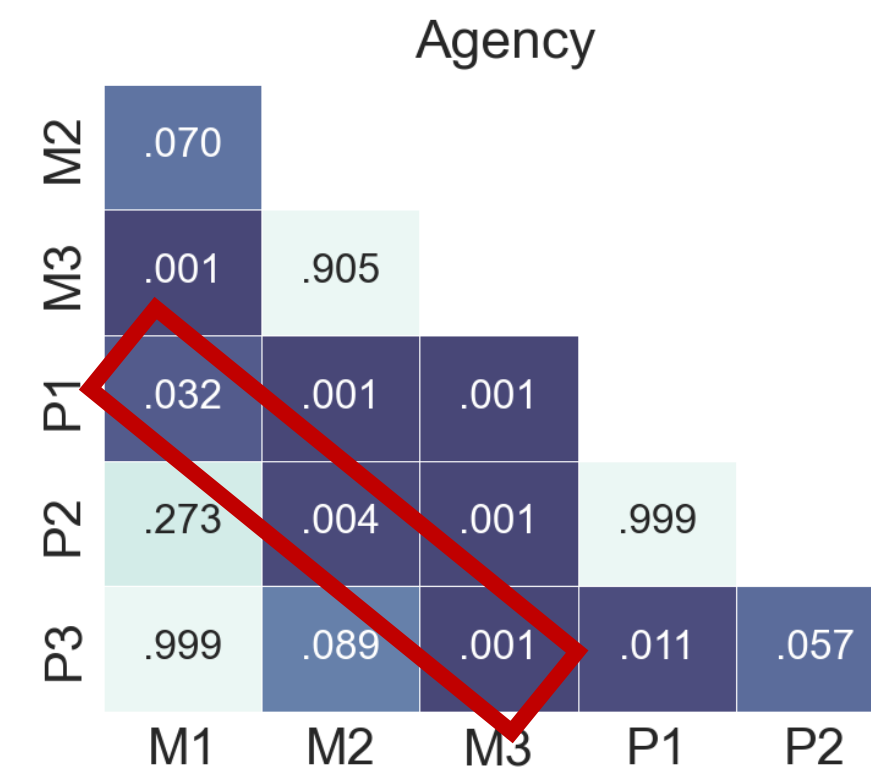
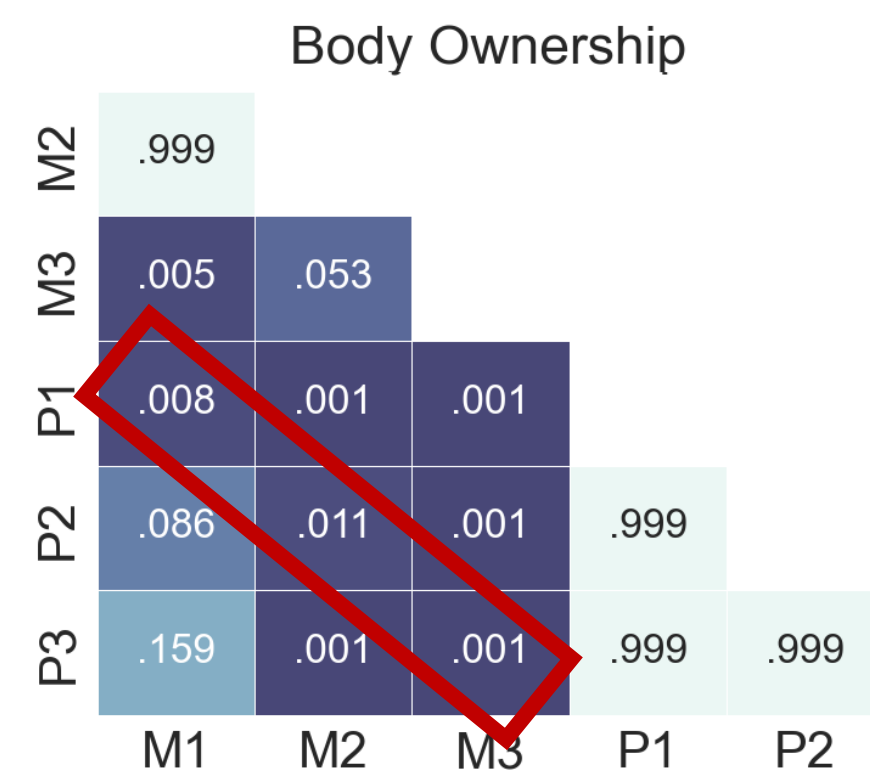
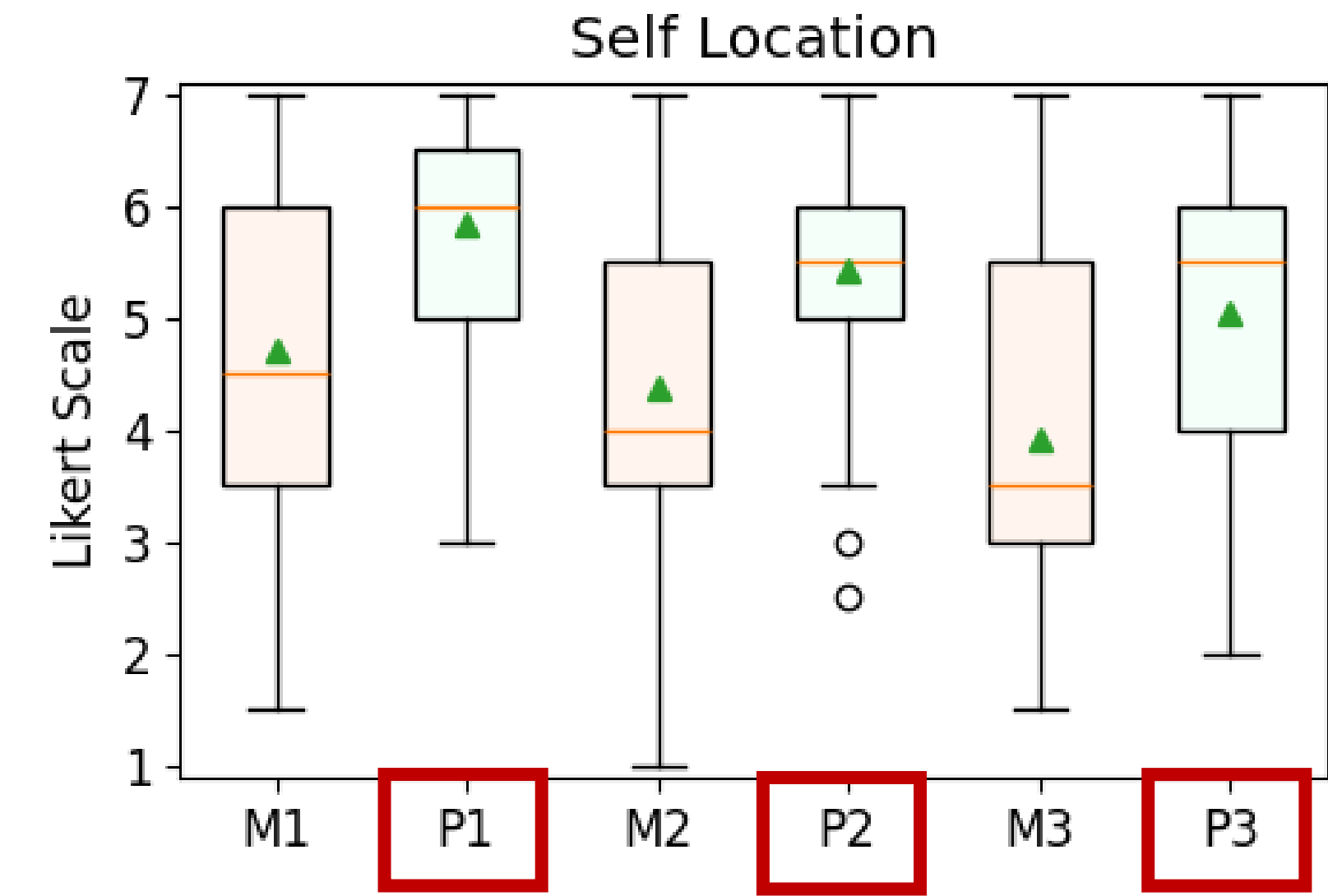
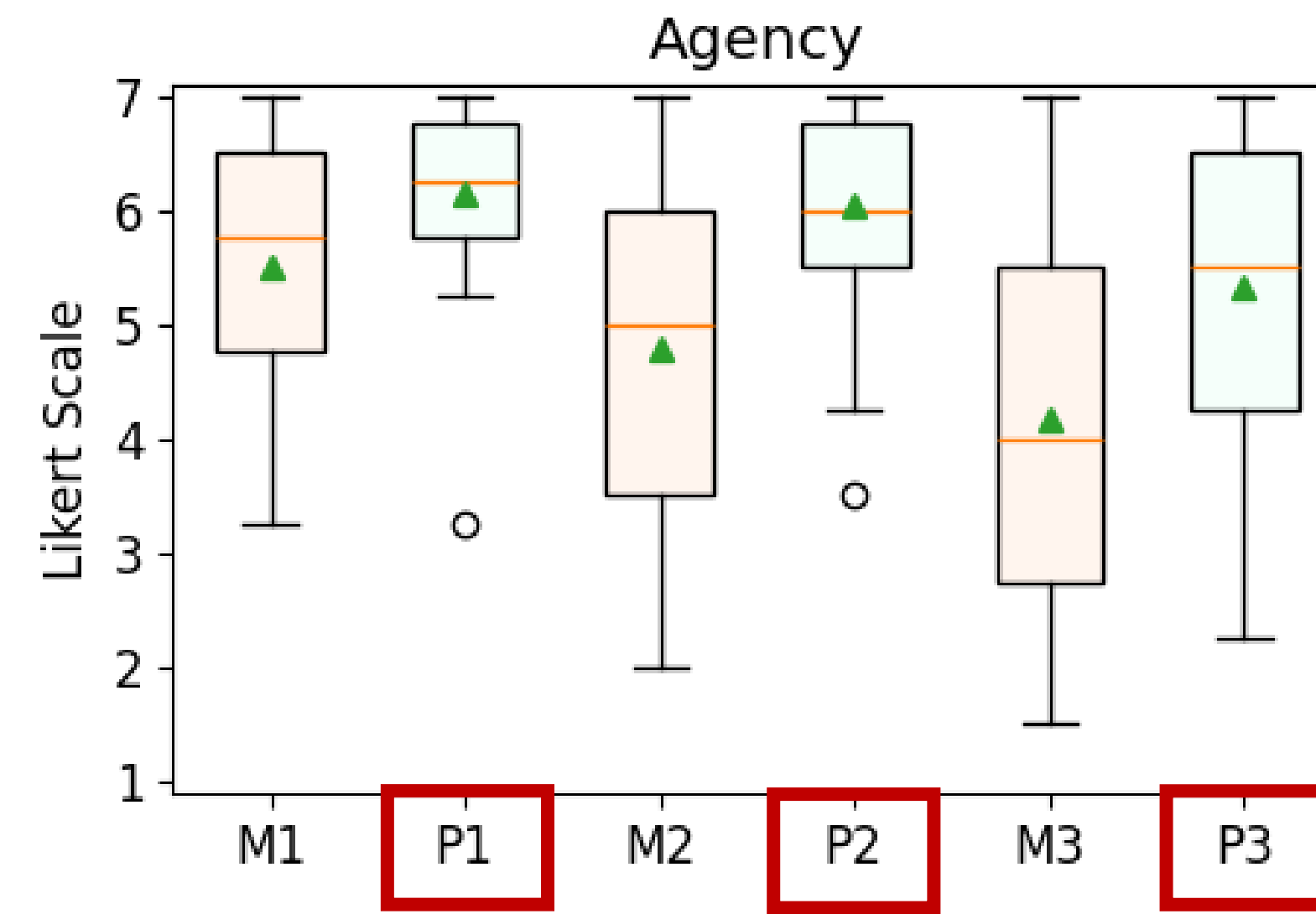
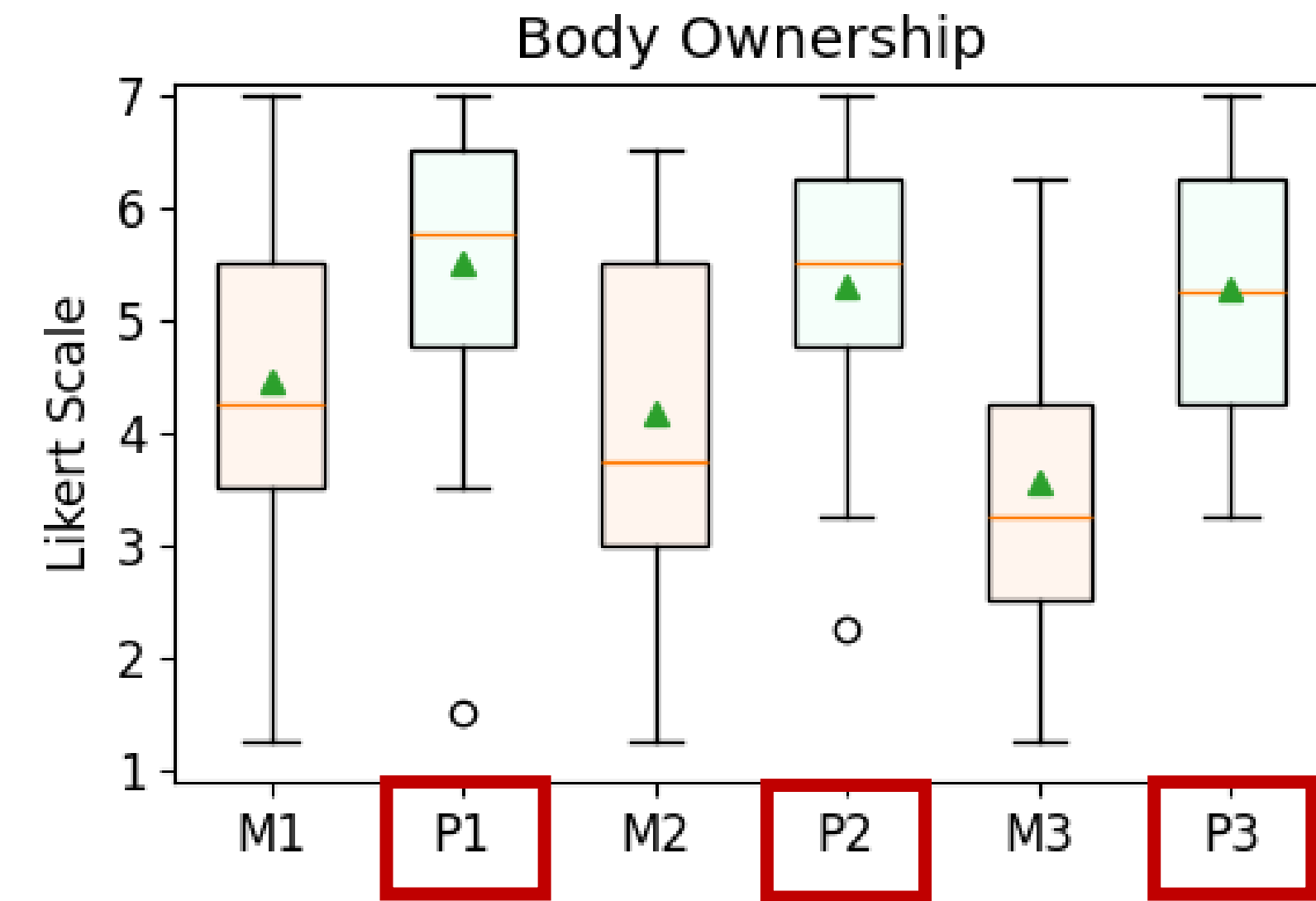
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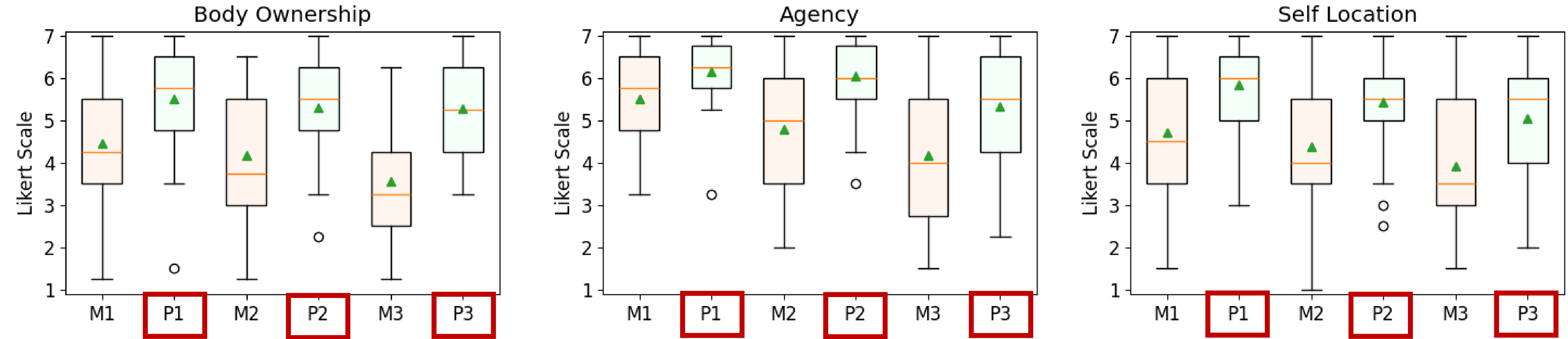
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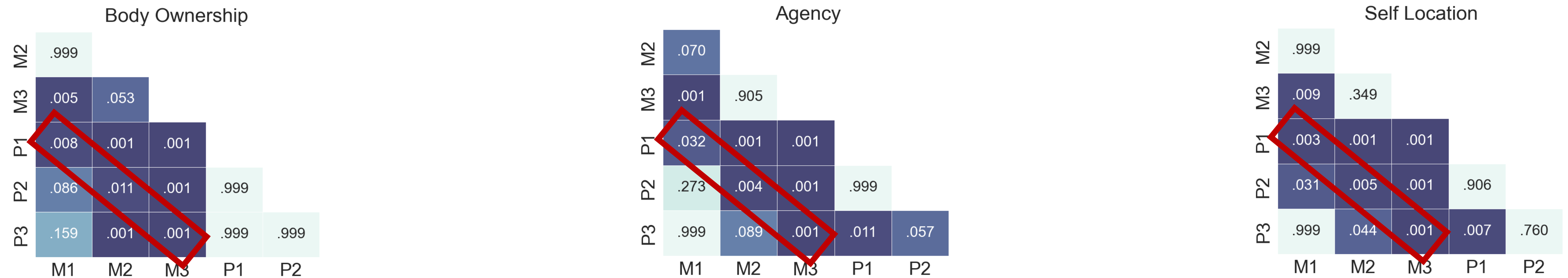
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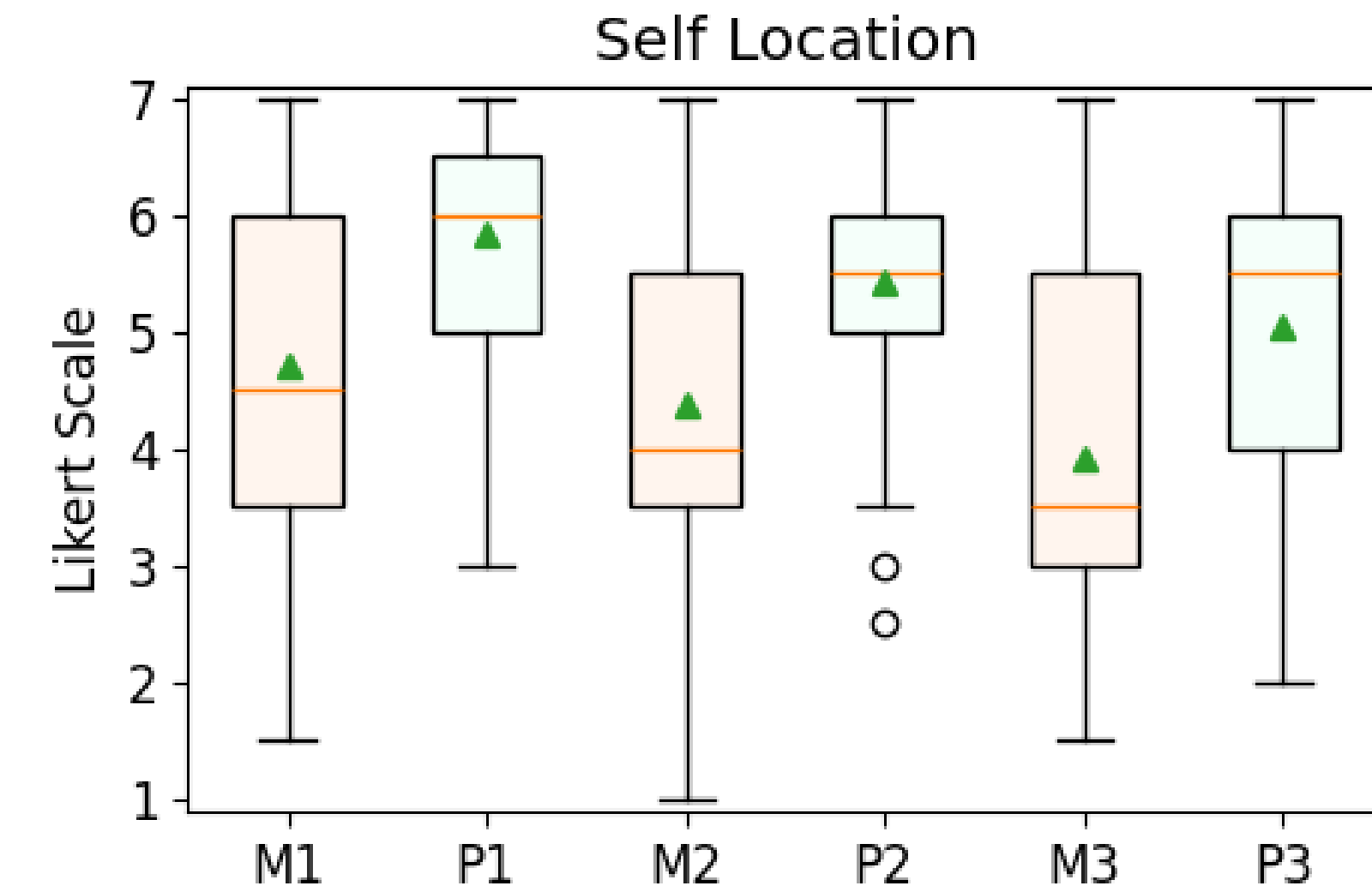
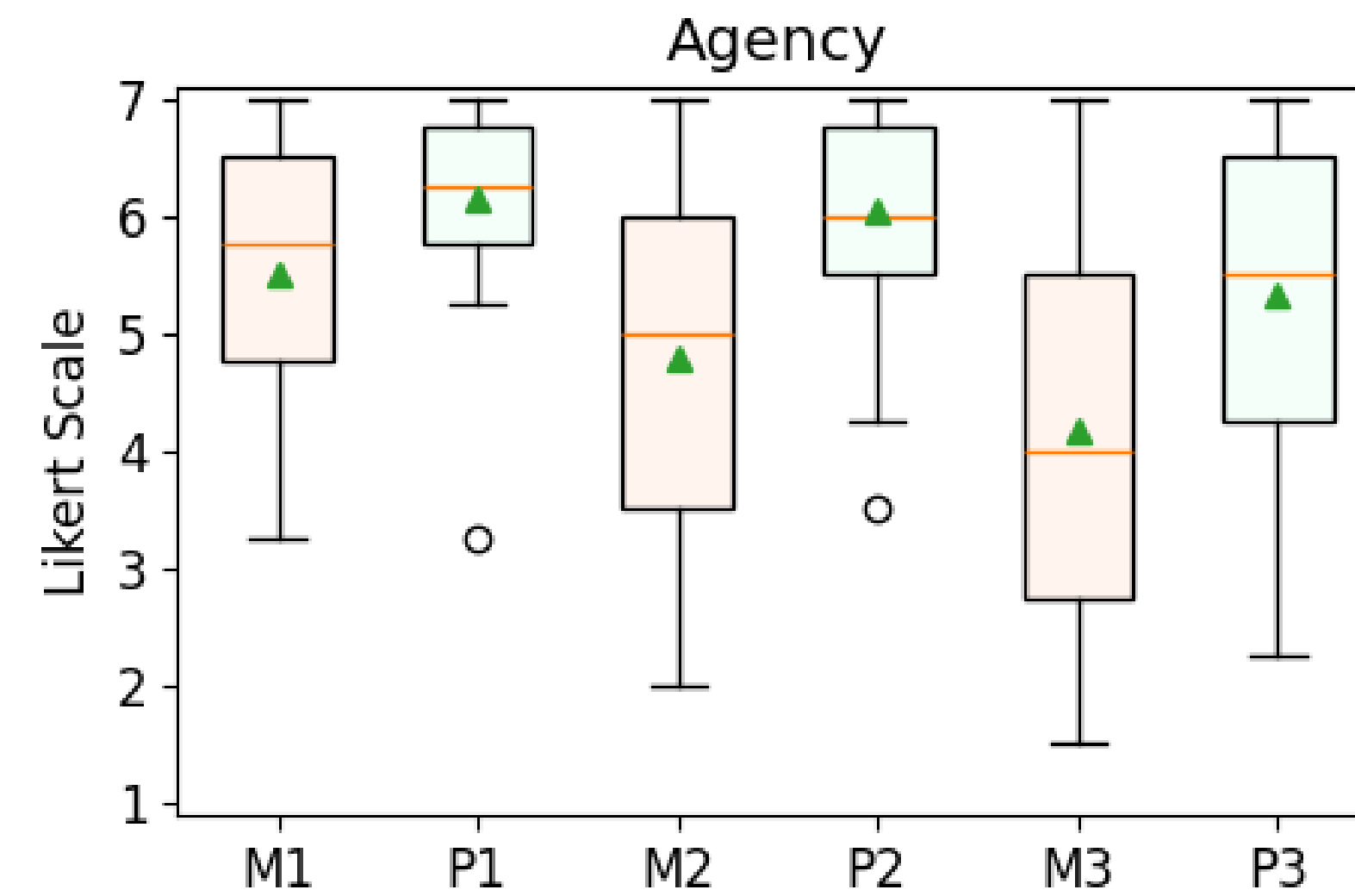
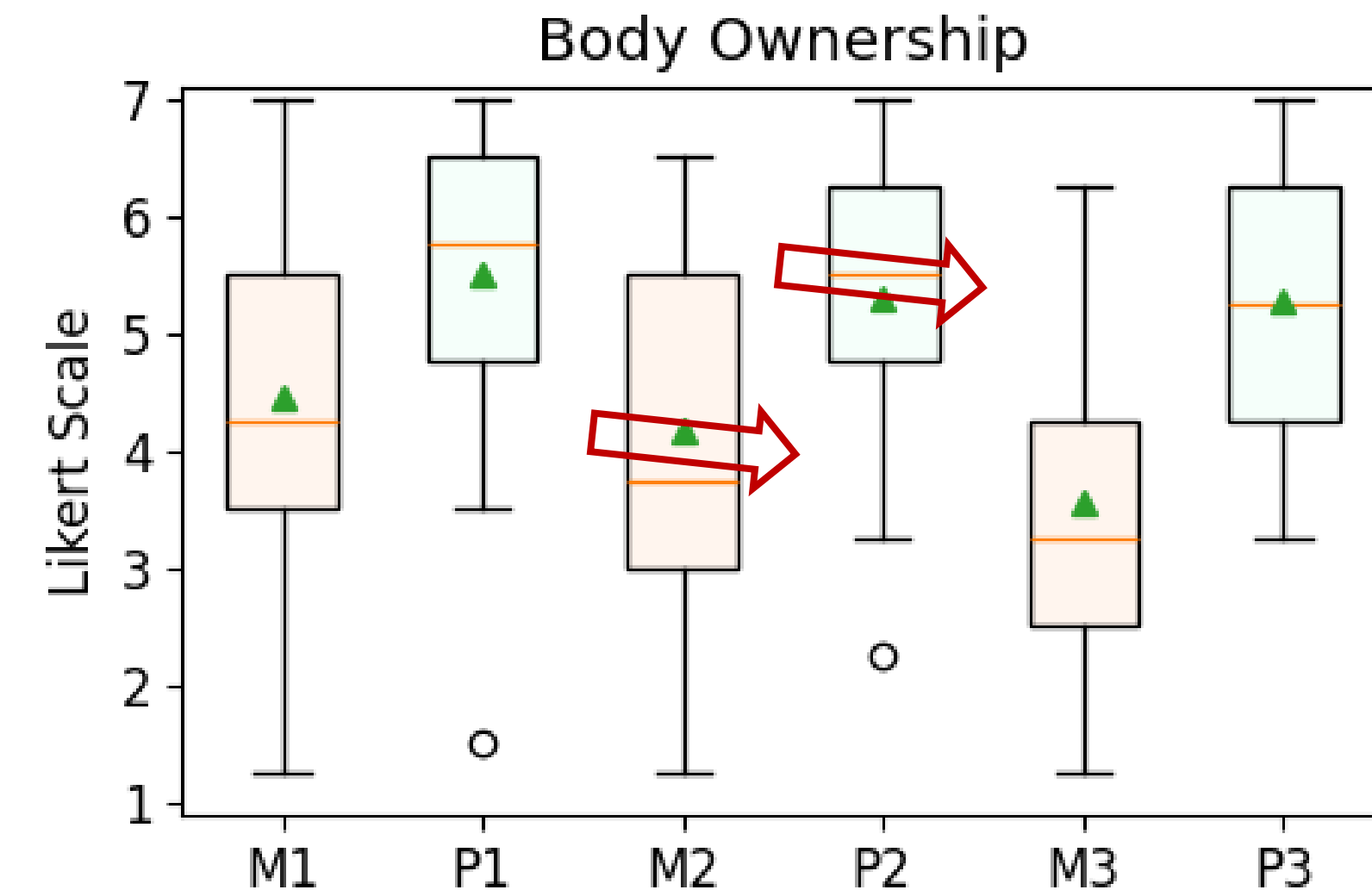
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HQ avatar always better (sign.)



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M: -20% P: -4%

HQ avatar always better (sign.)

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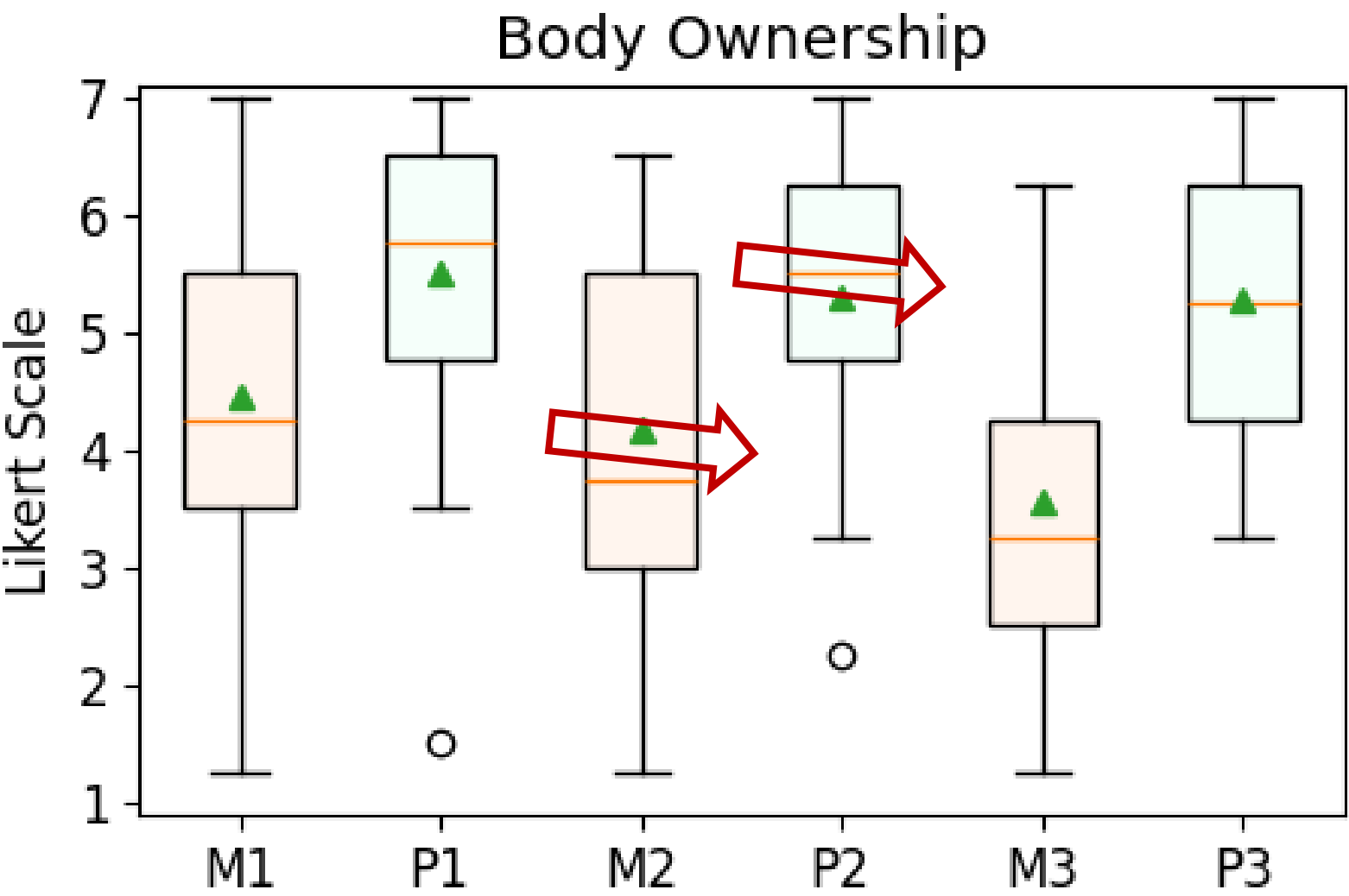
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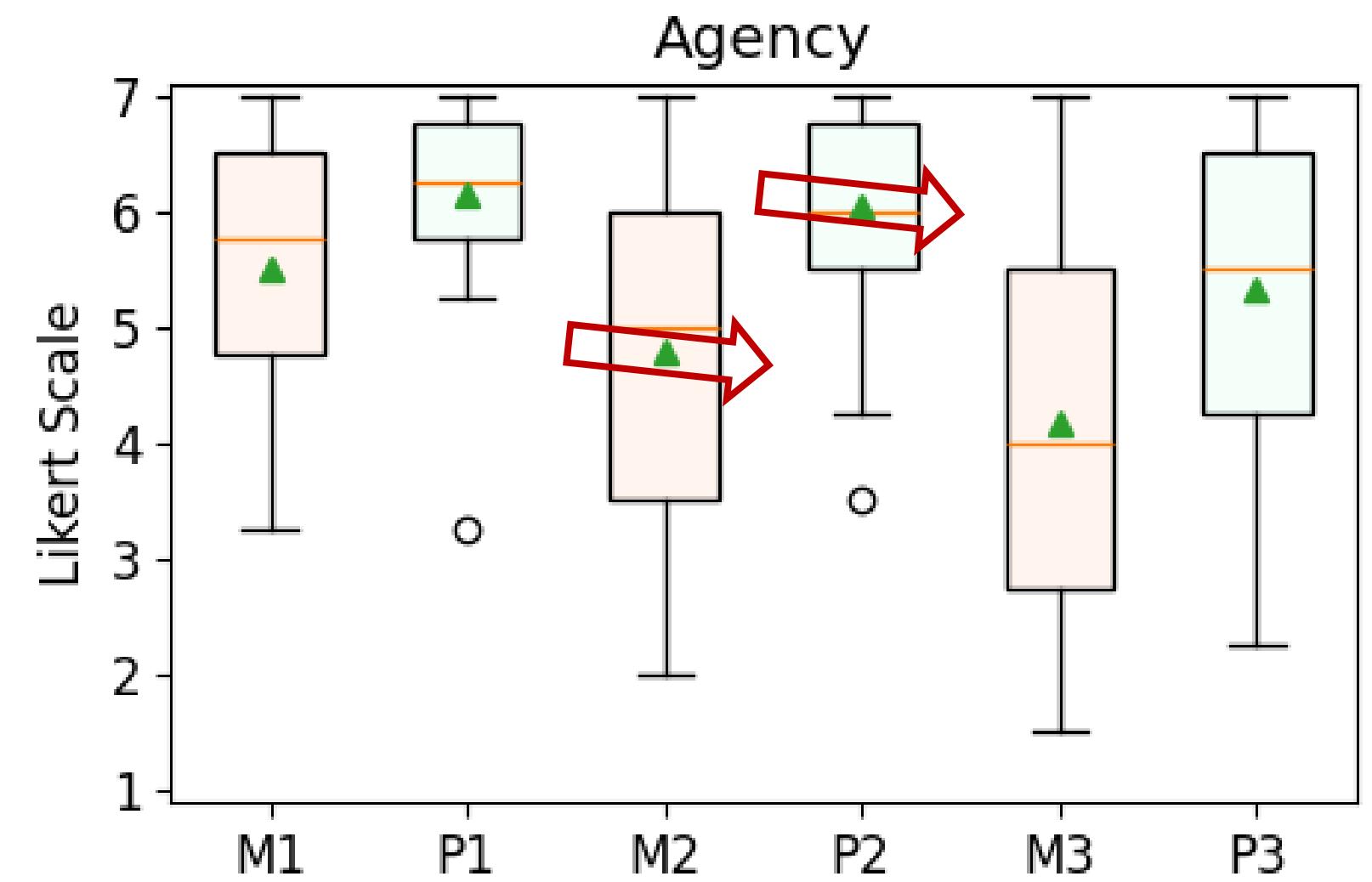
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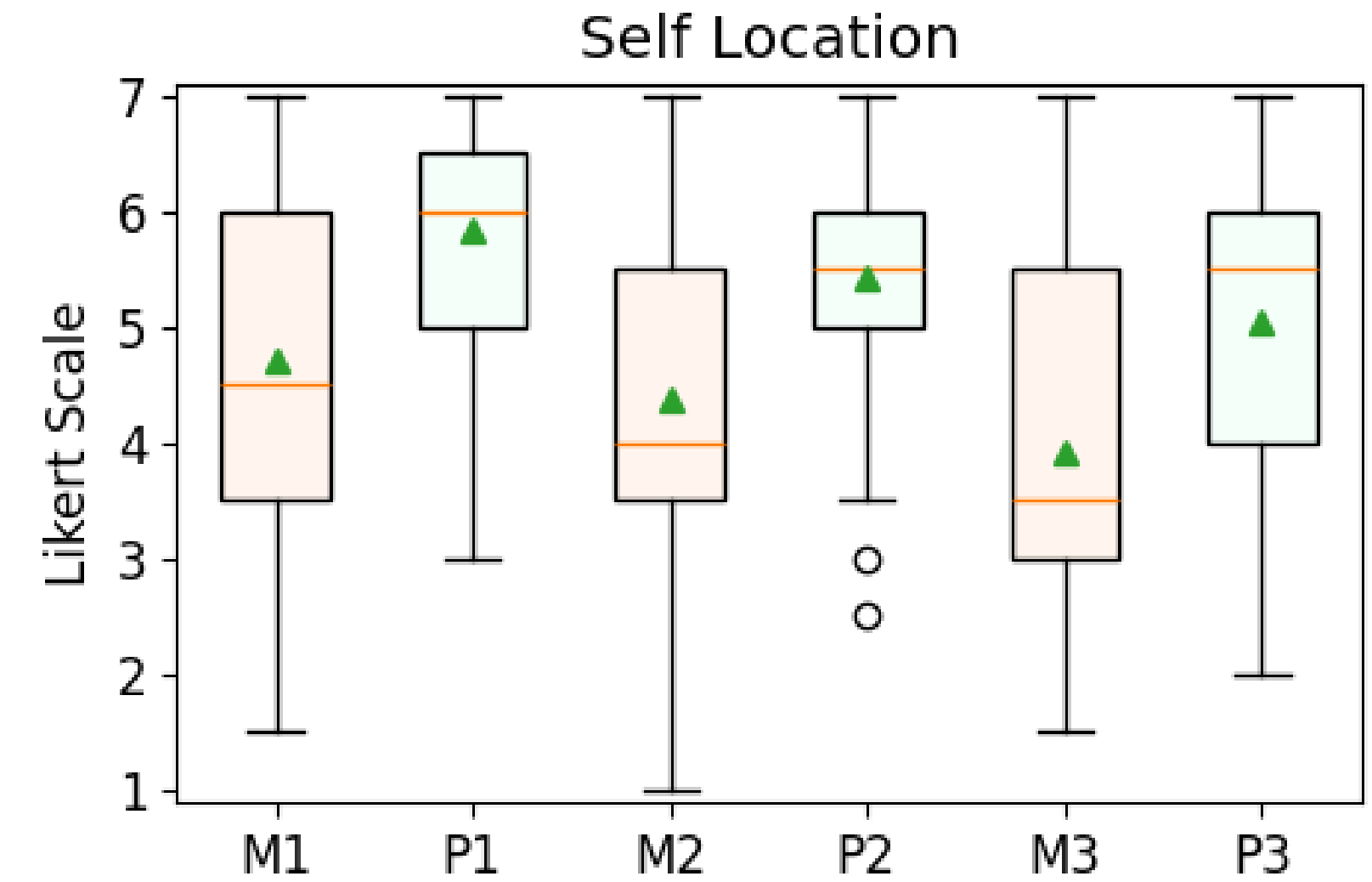
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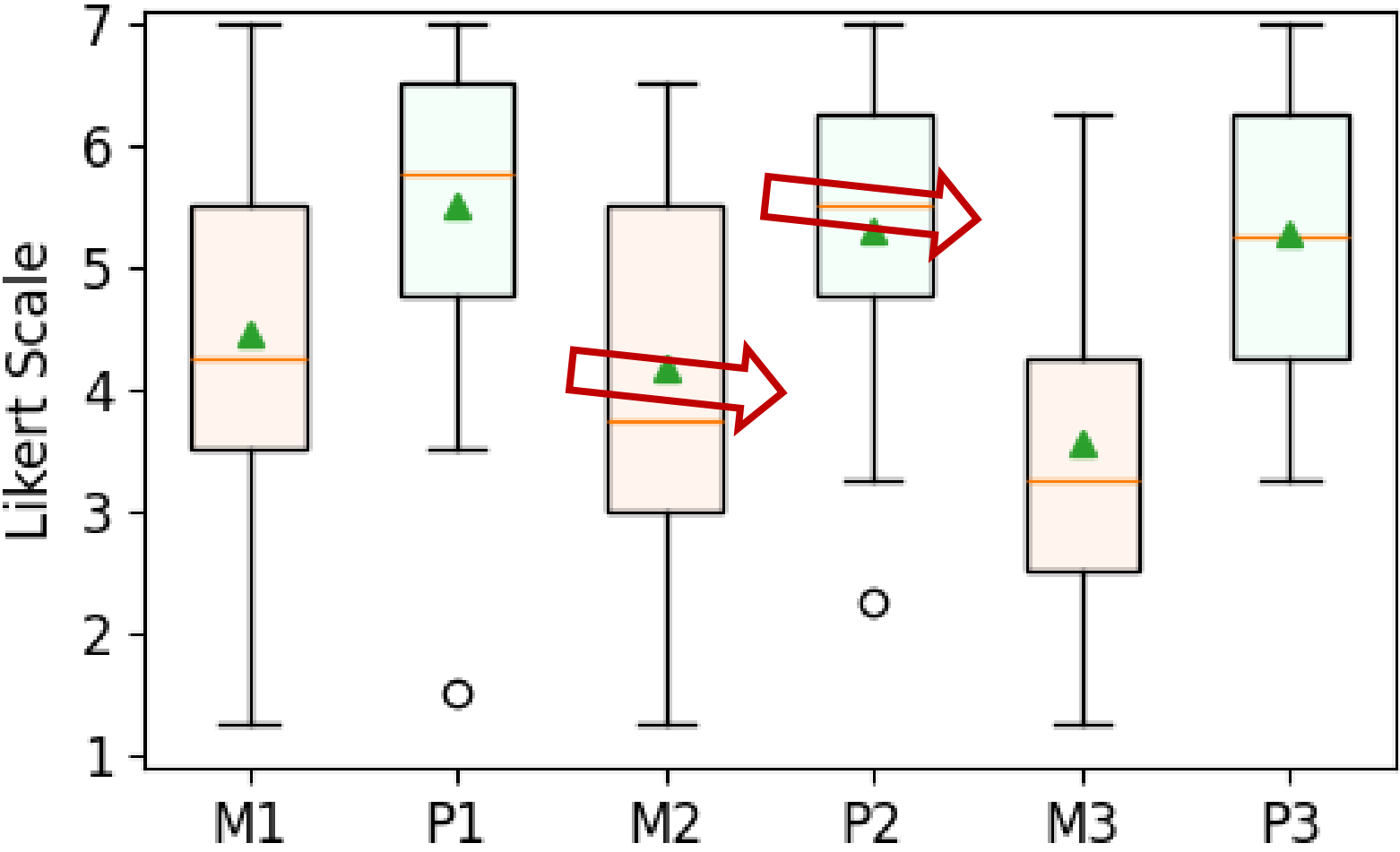
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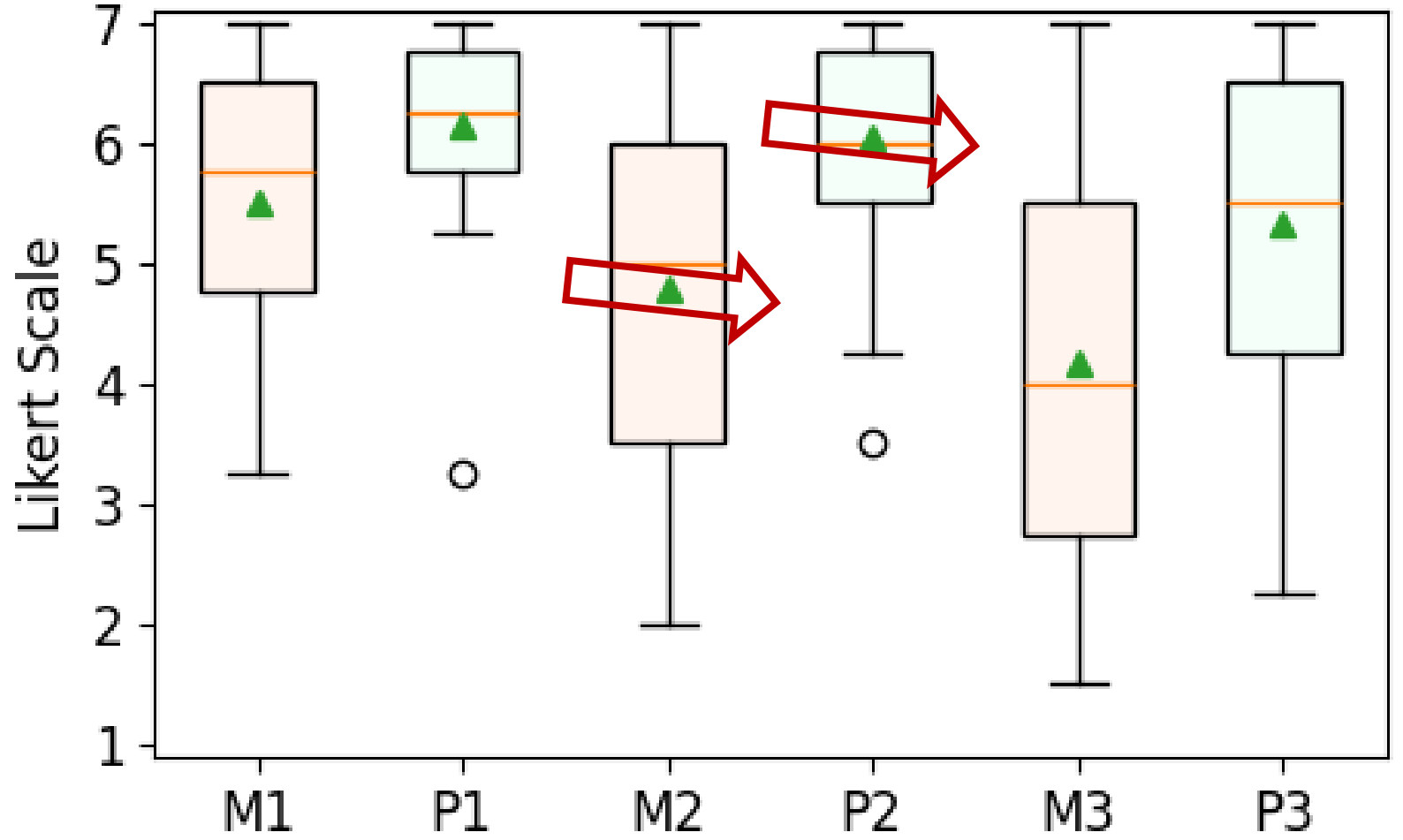
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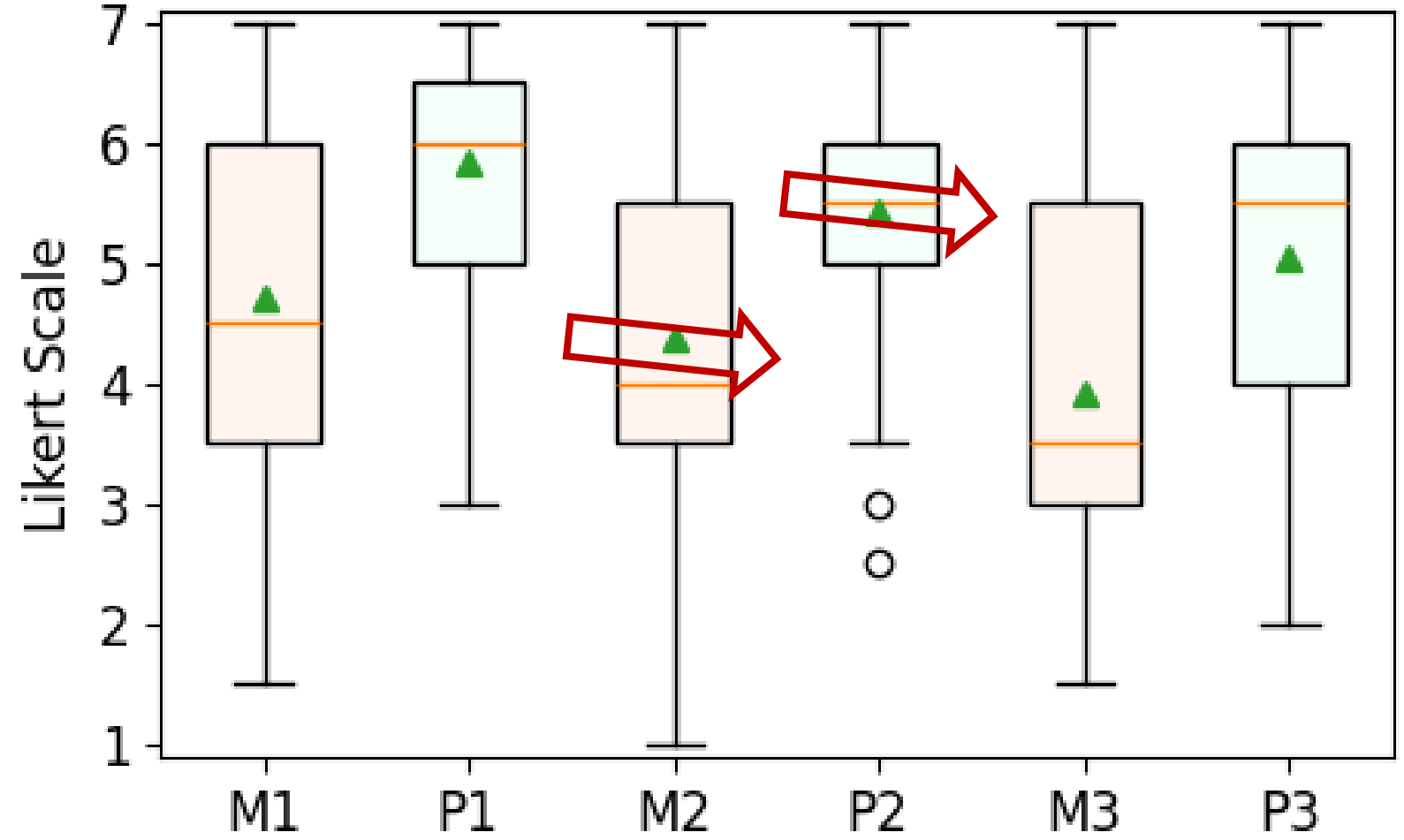
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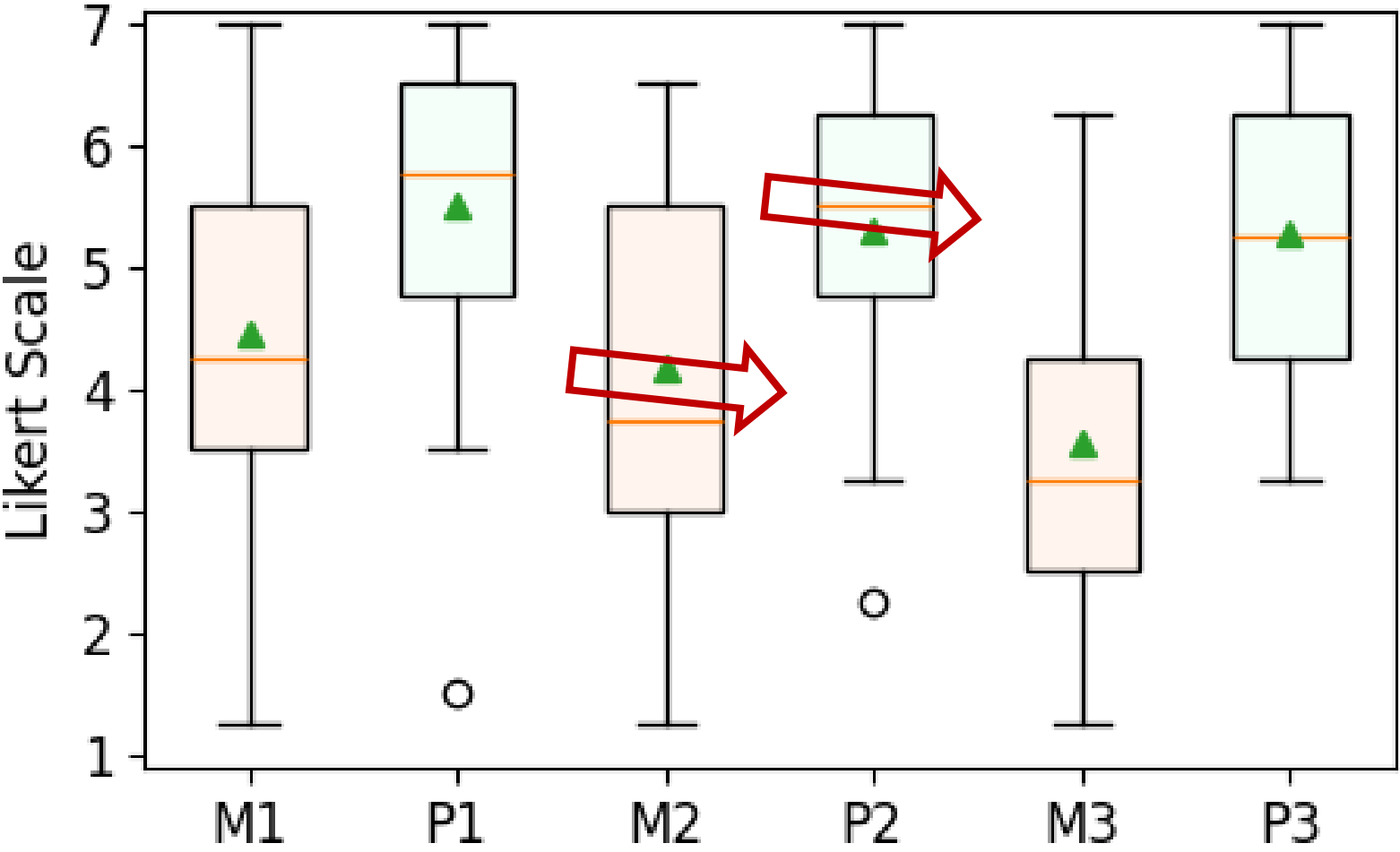
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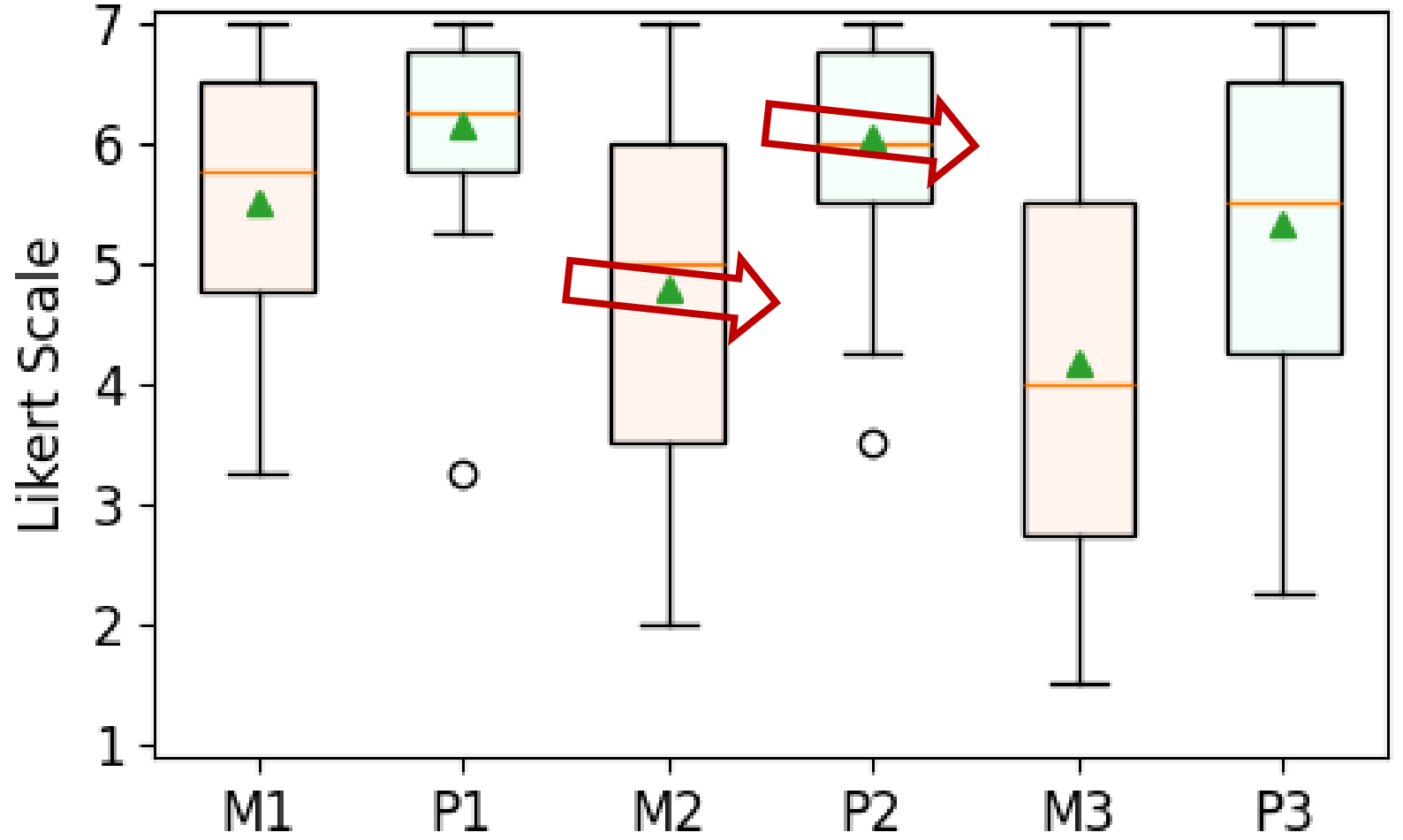
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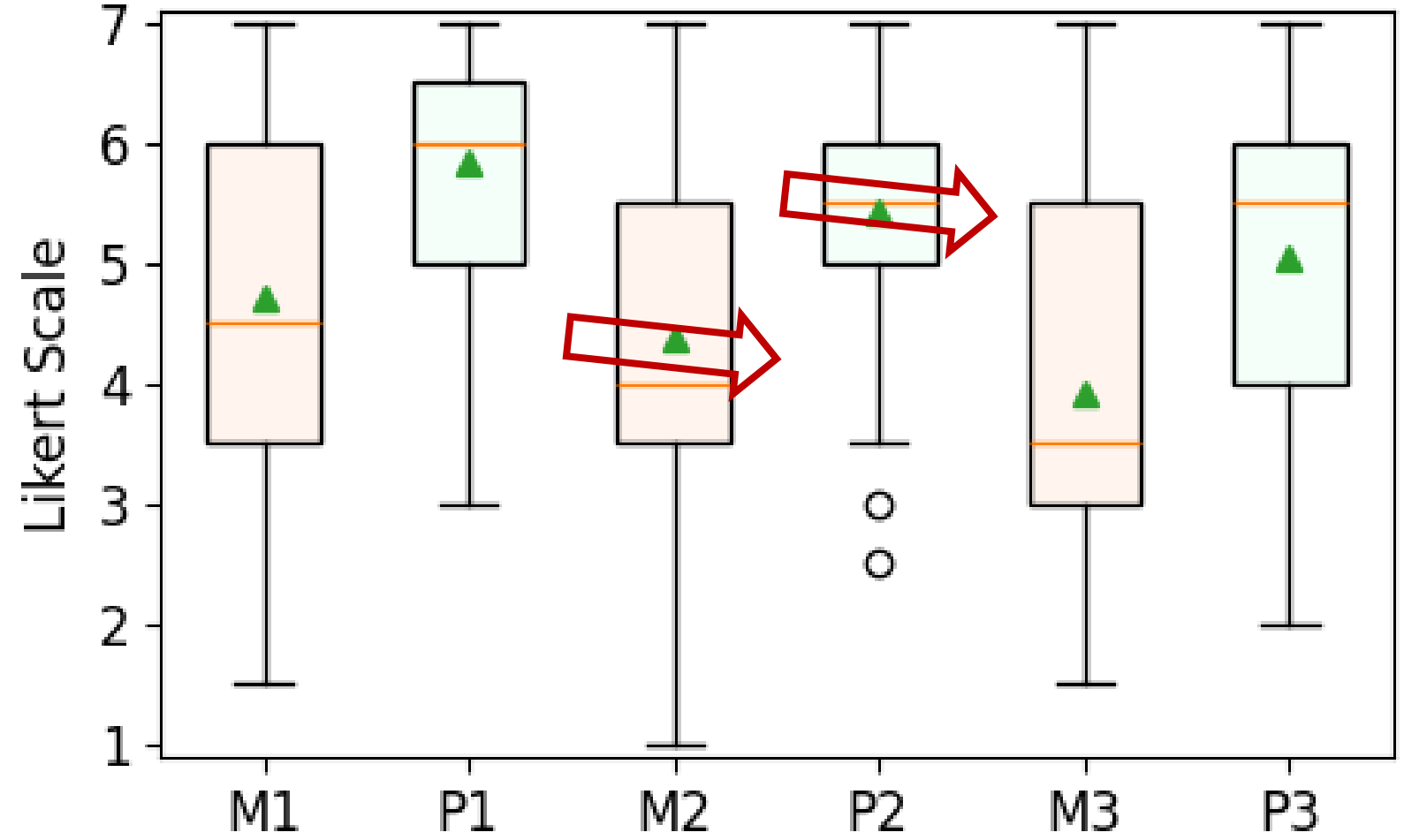
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HQ avatar's loss smaller

Body Ownership

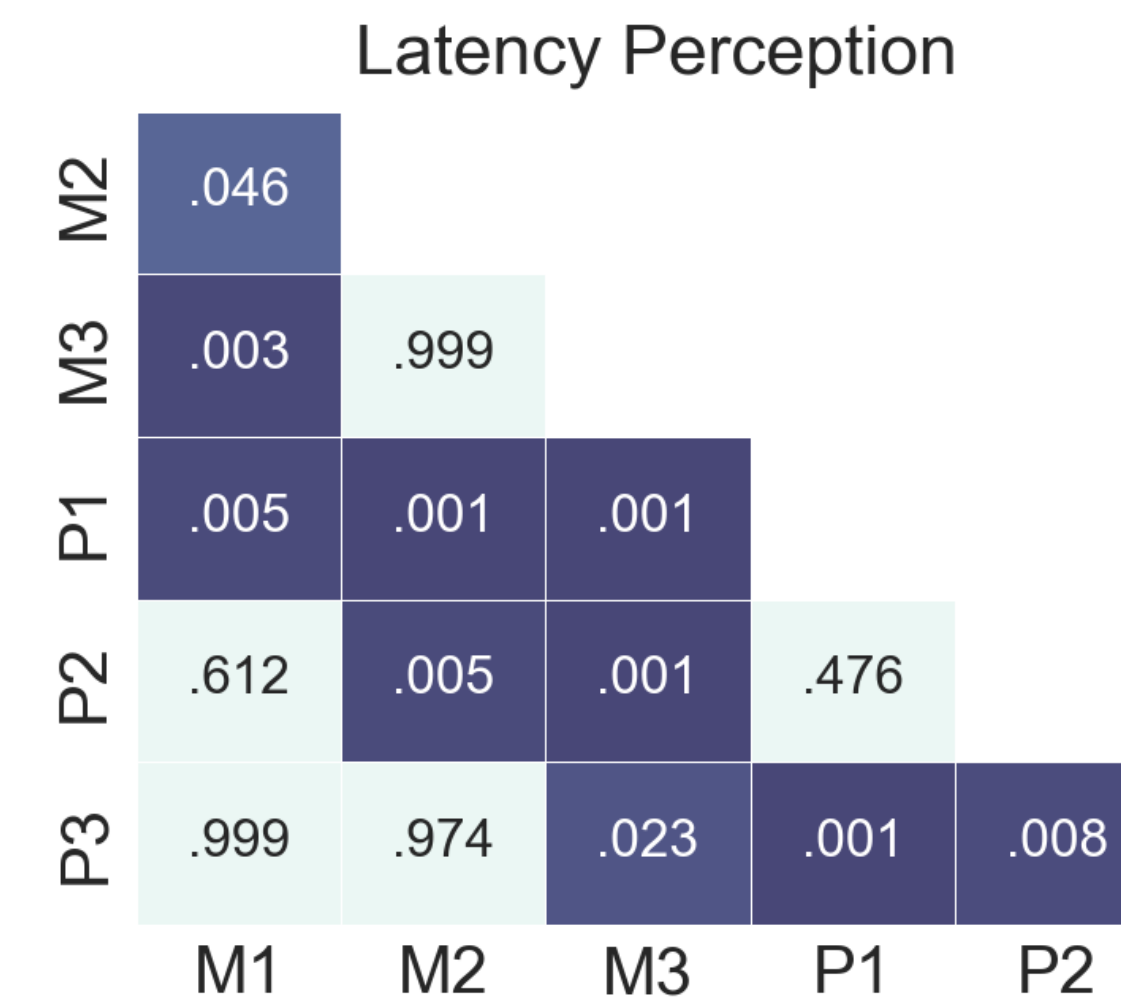
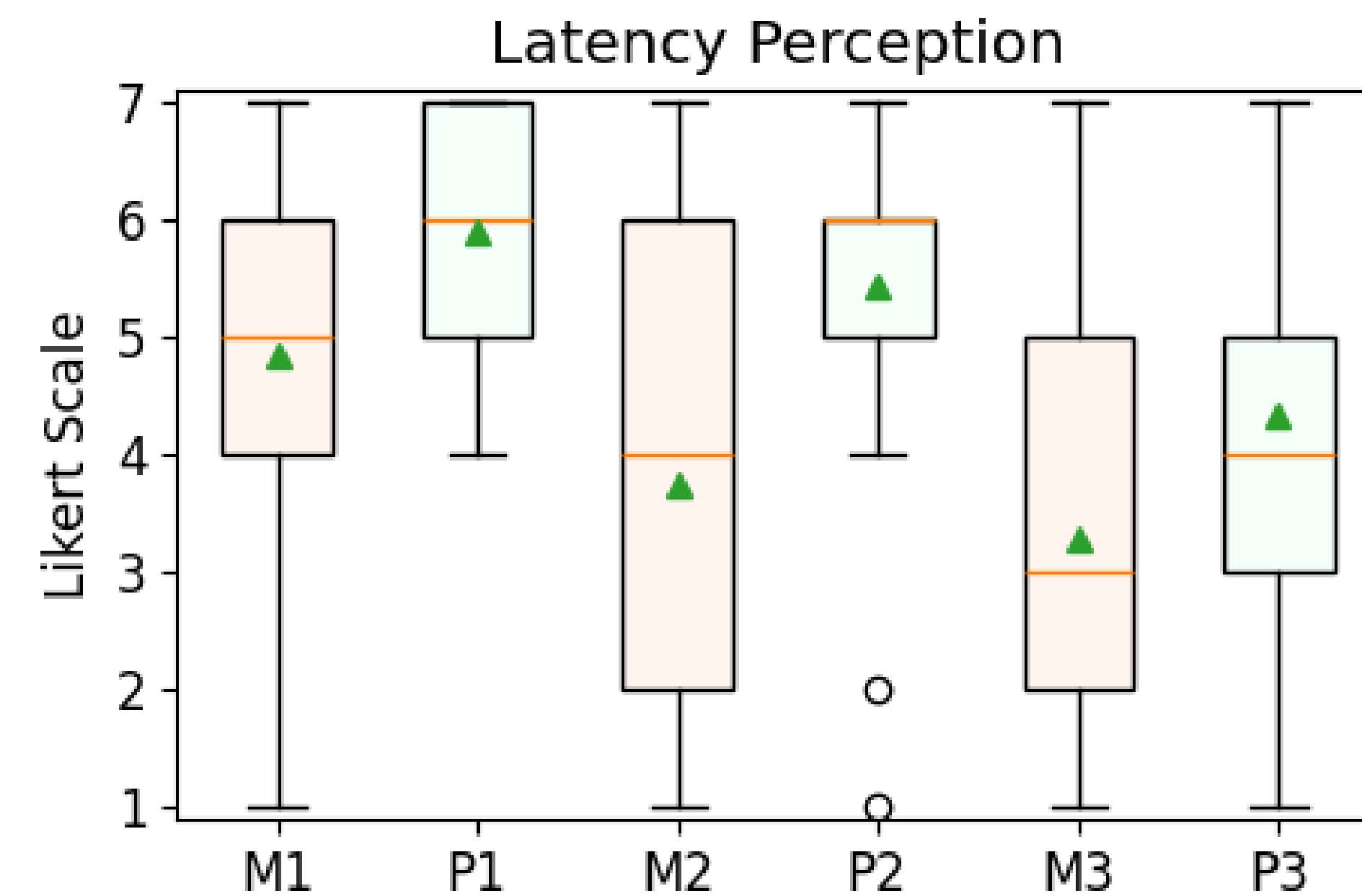
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	M1	M2	M3	P1	P2

Agency

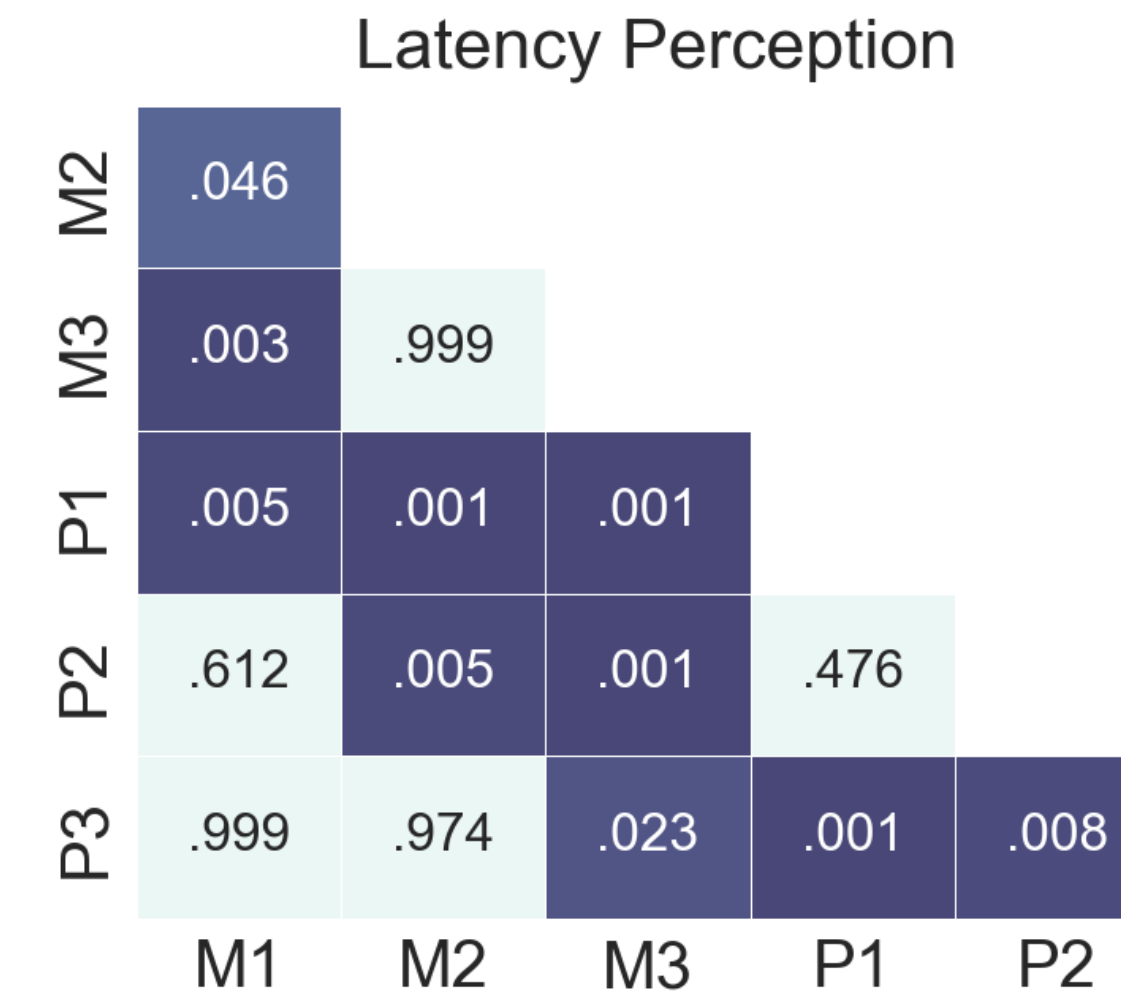
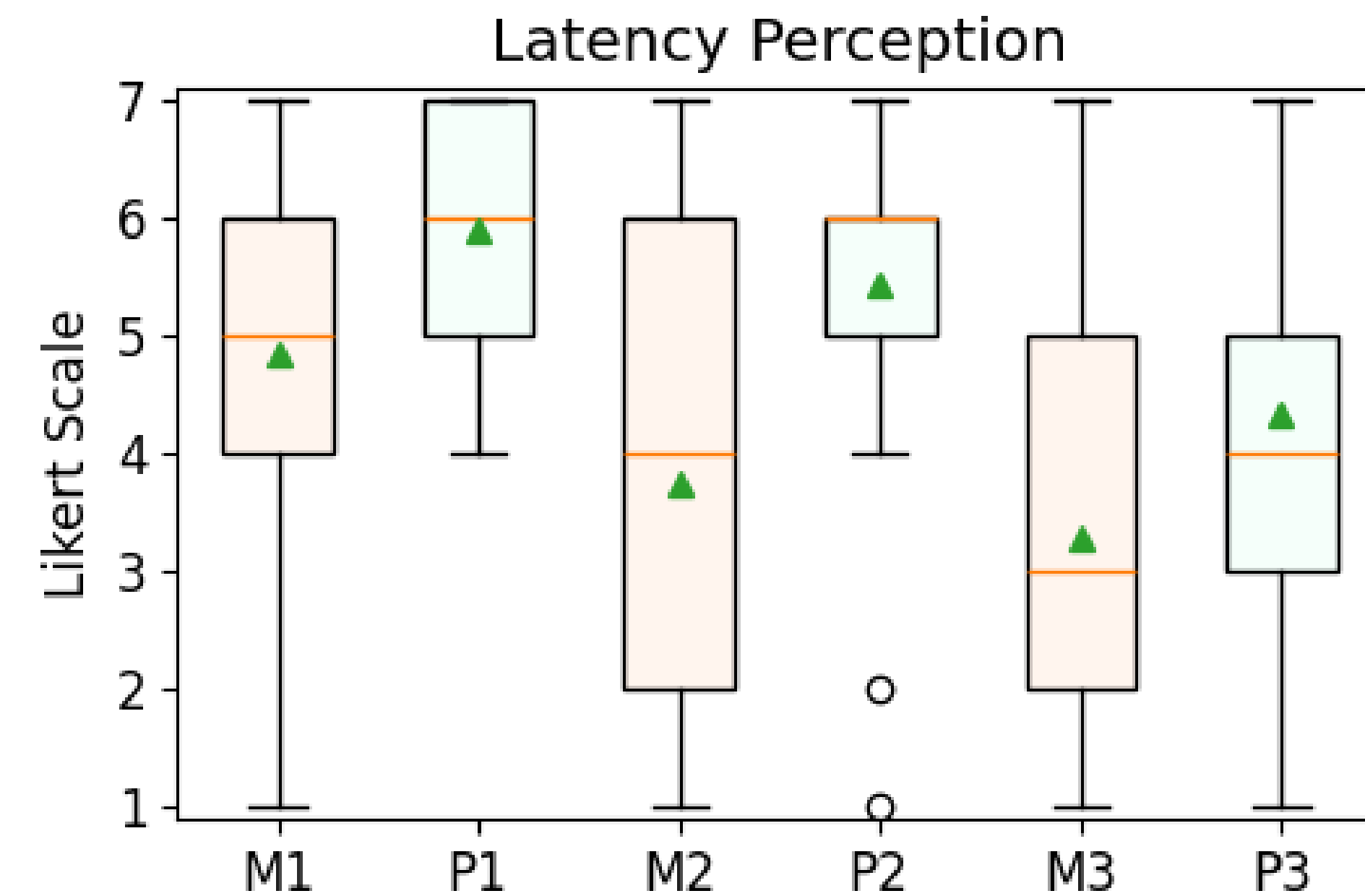
M2	.070				
M3	.001	.905			
P1	.032	.001	.001		
P2	.273	.004	.001	.999	
P3	.999	.089	.001	.011	.057
	M1	M2	M3	P1	P2

Self Location

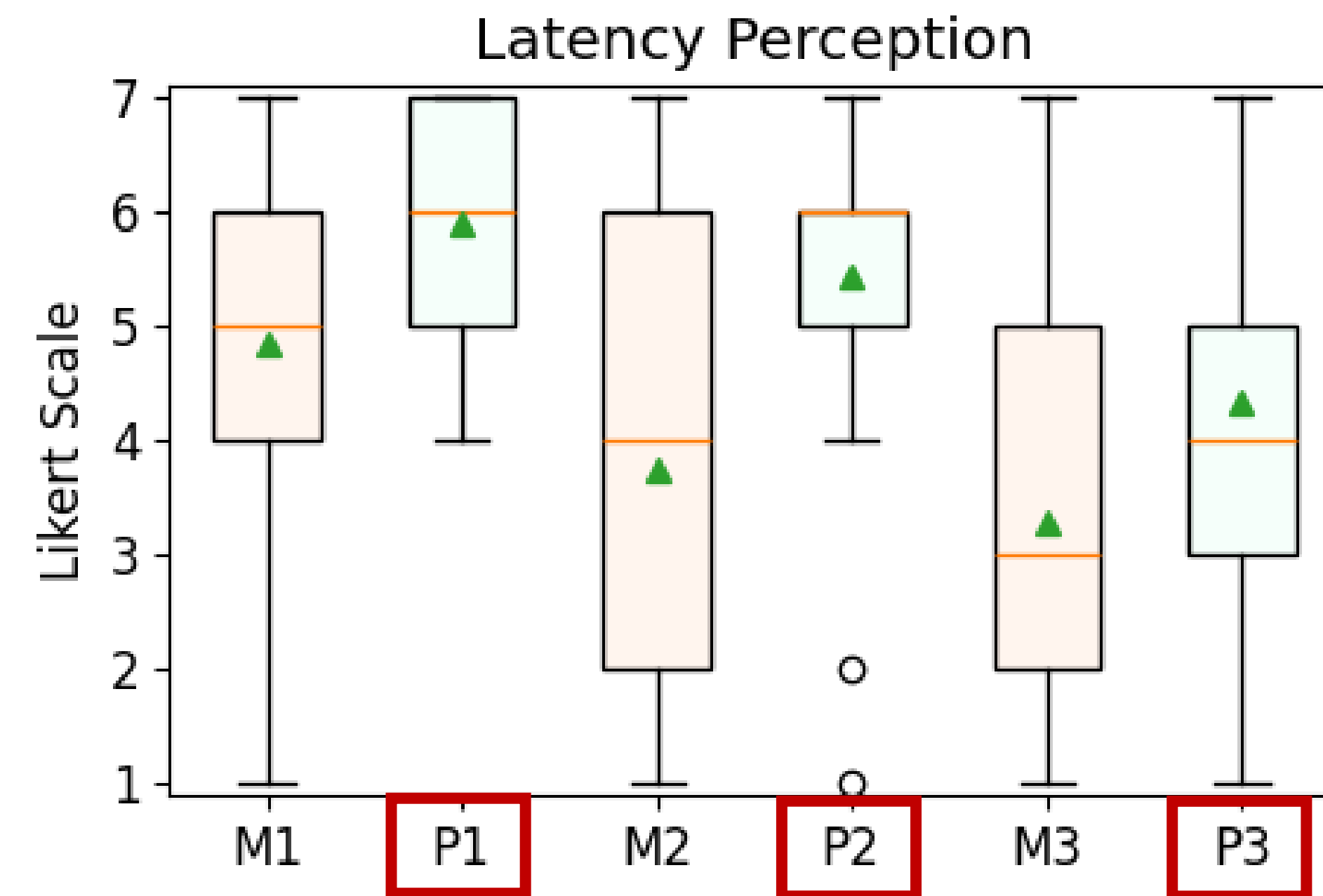
M2	.999				
M3	.009	.349			
P1	.003	.001	.001		
P2	.031	.005	.001	.906	
P3	.999	.044	.001	.007	.760
	M1	M2	M3	P1	P2



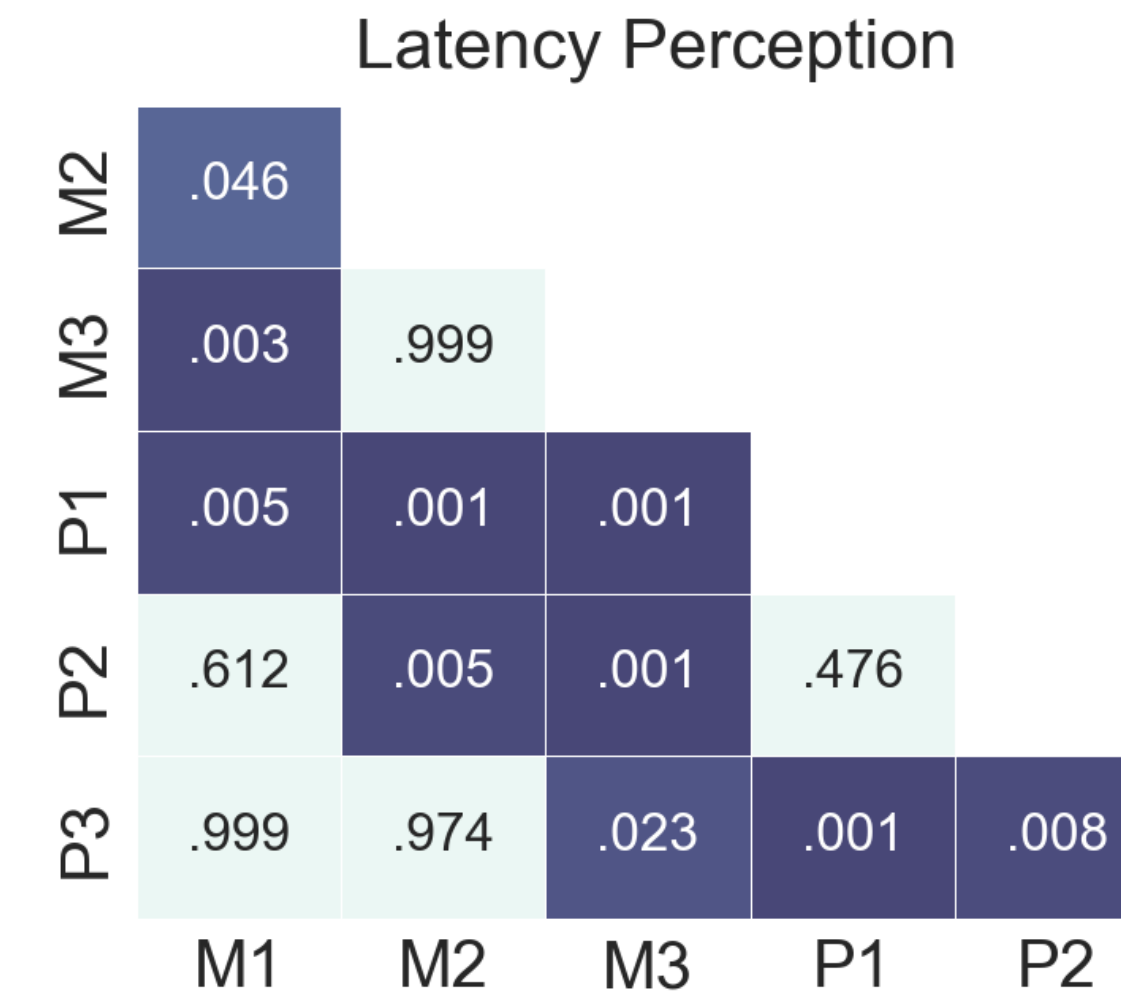
“The movements of the virtual body were synchronized with my own movements”



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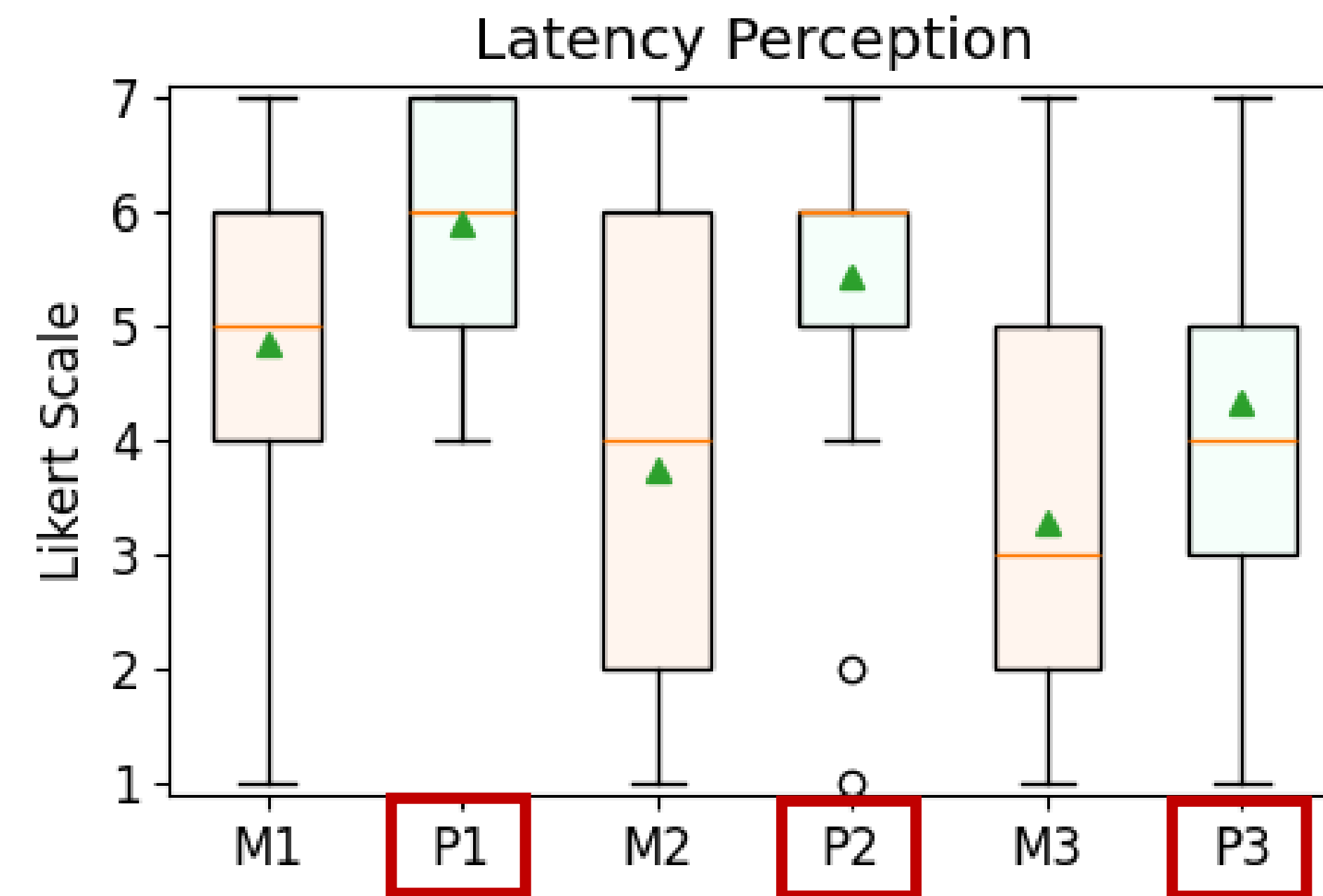


HQ avatar always better (in-sync.)

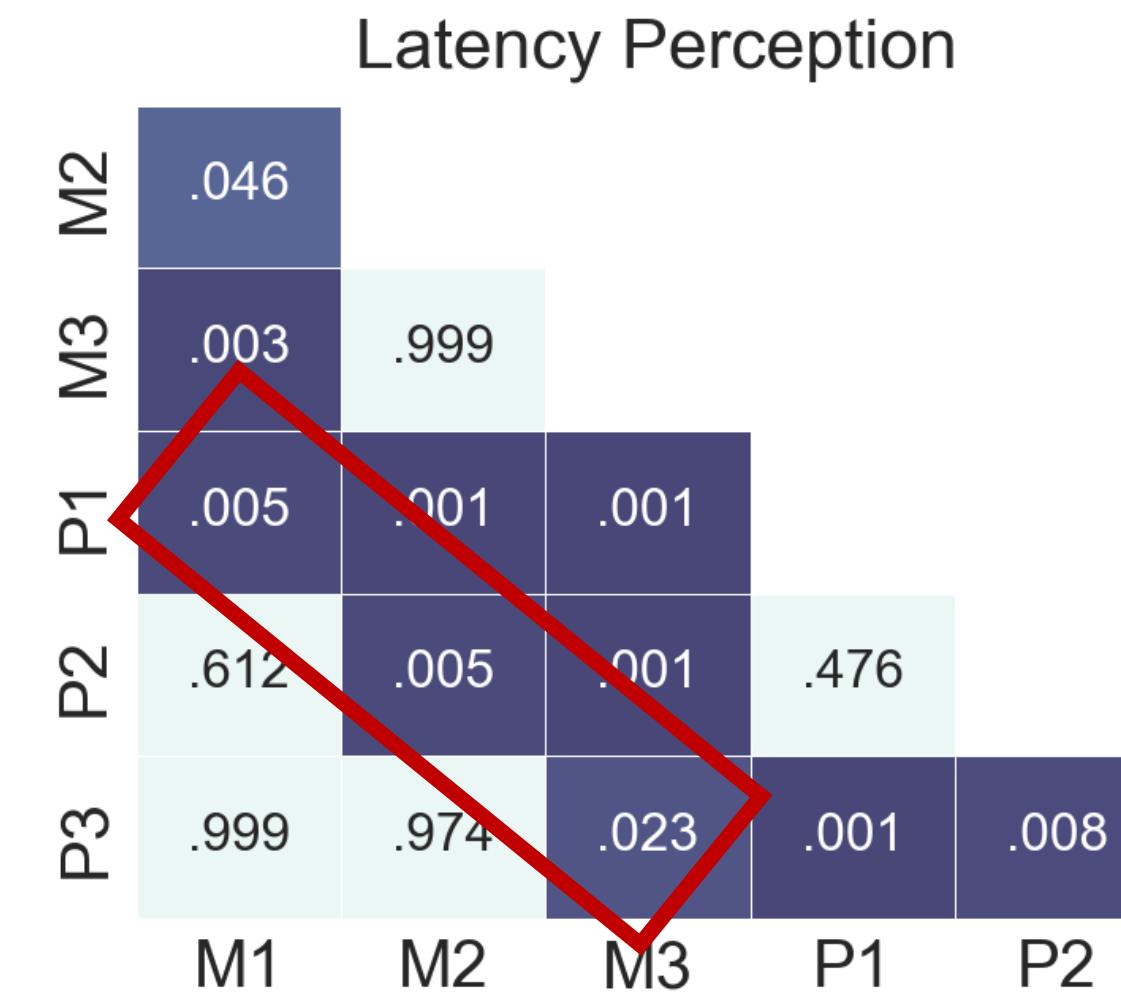




“The movements of the virtual body were synchronized with my own movements”

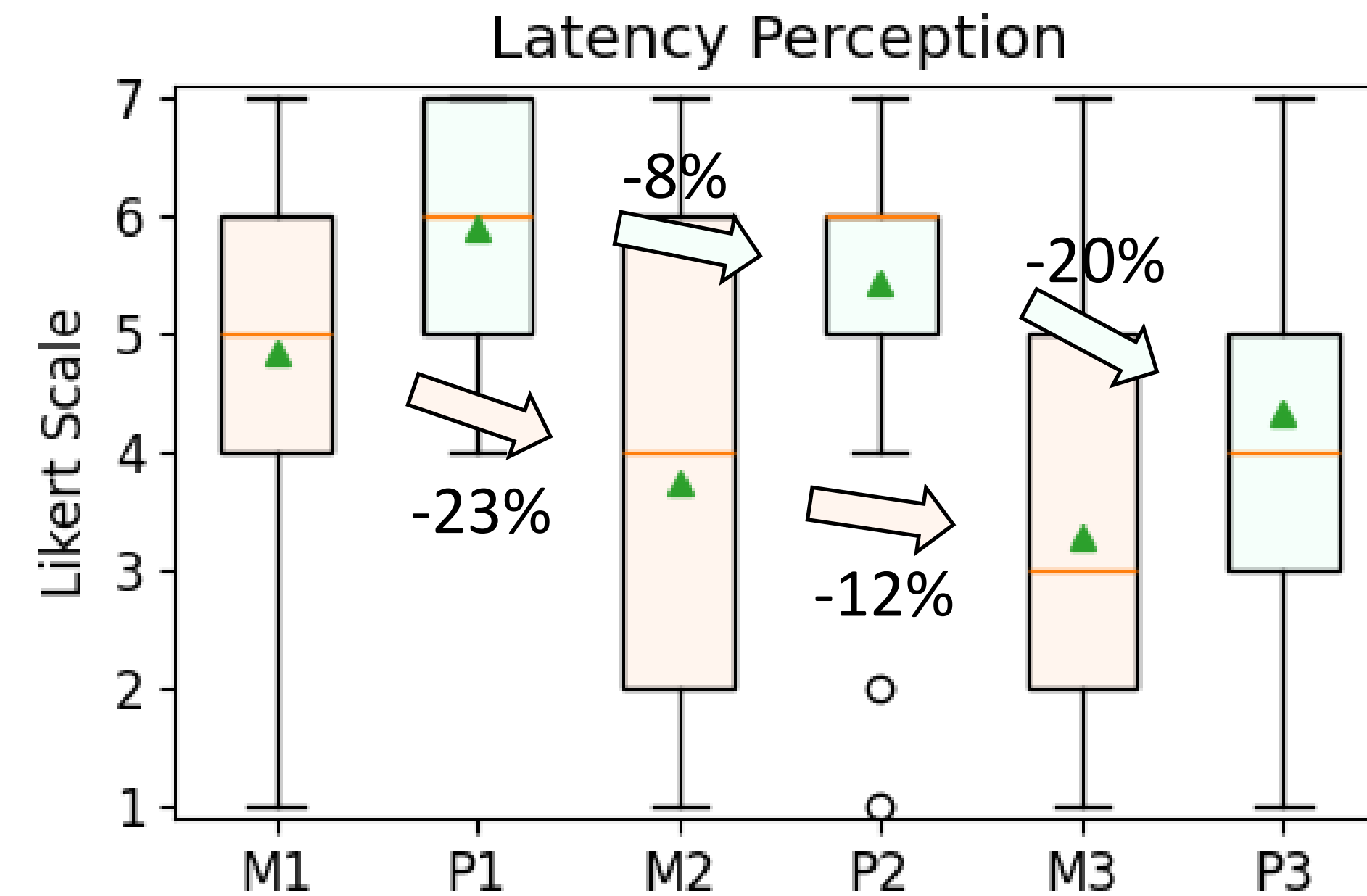


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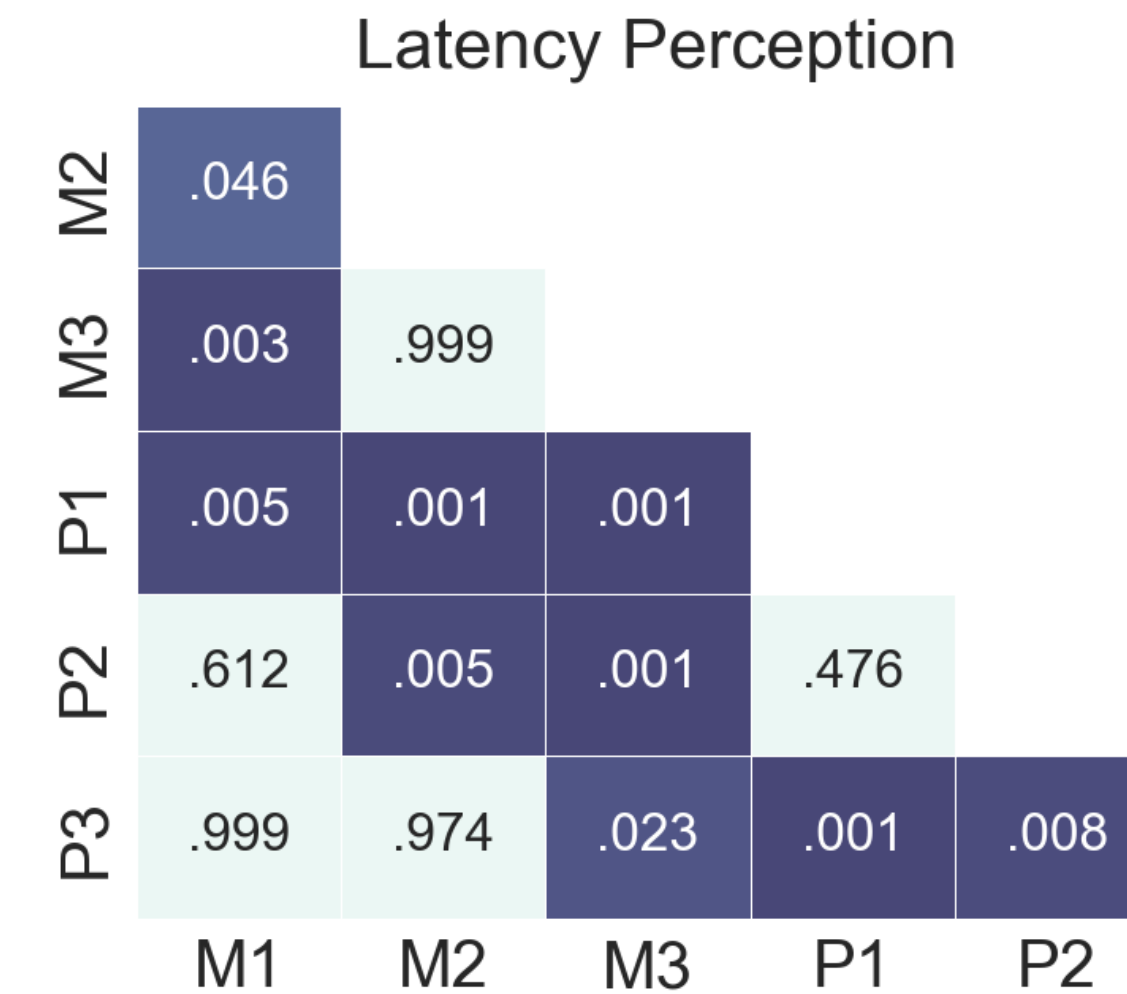


Significant differences

“The movements of the virtual body were synchronized with my own movements”

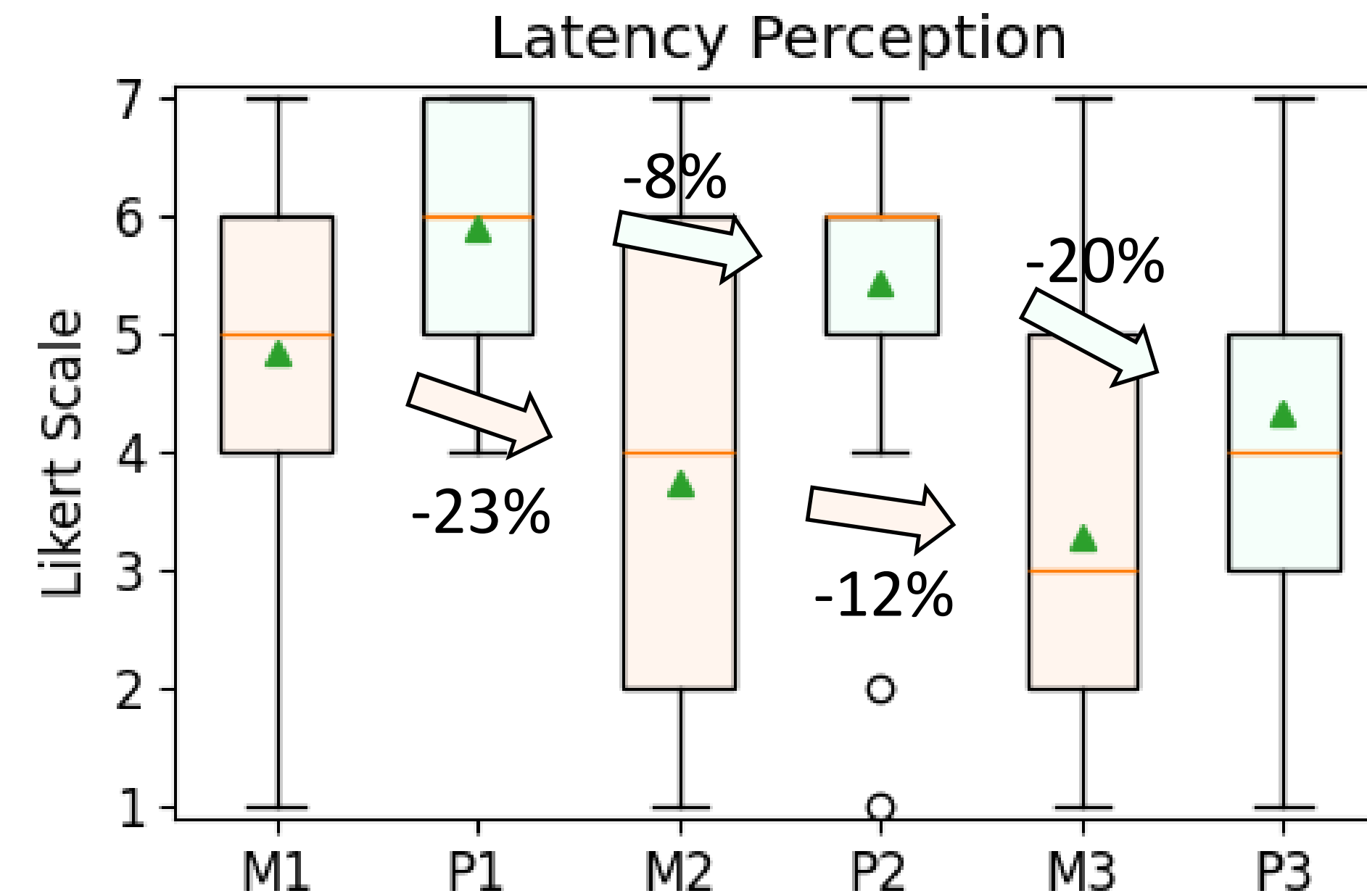


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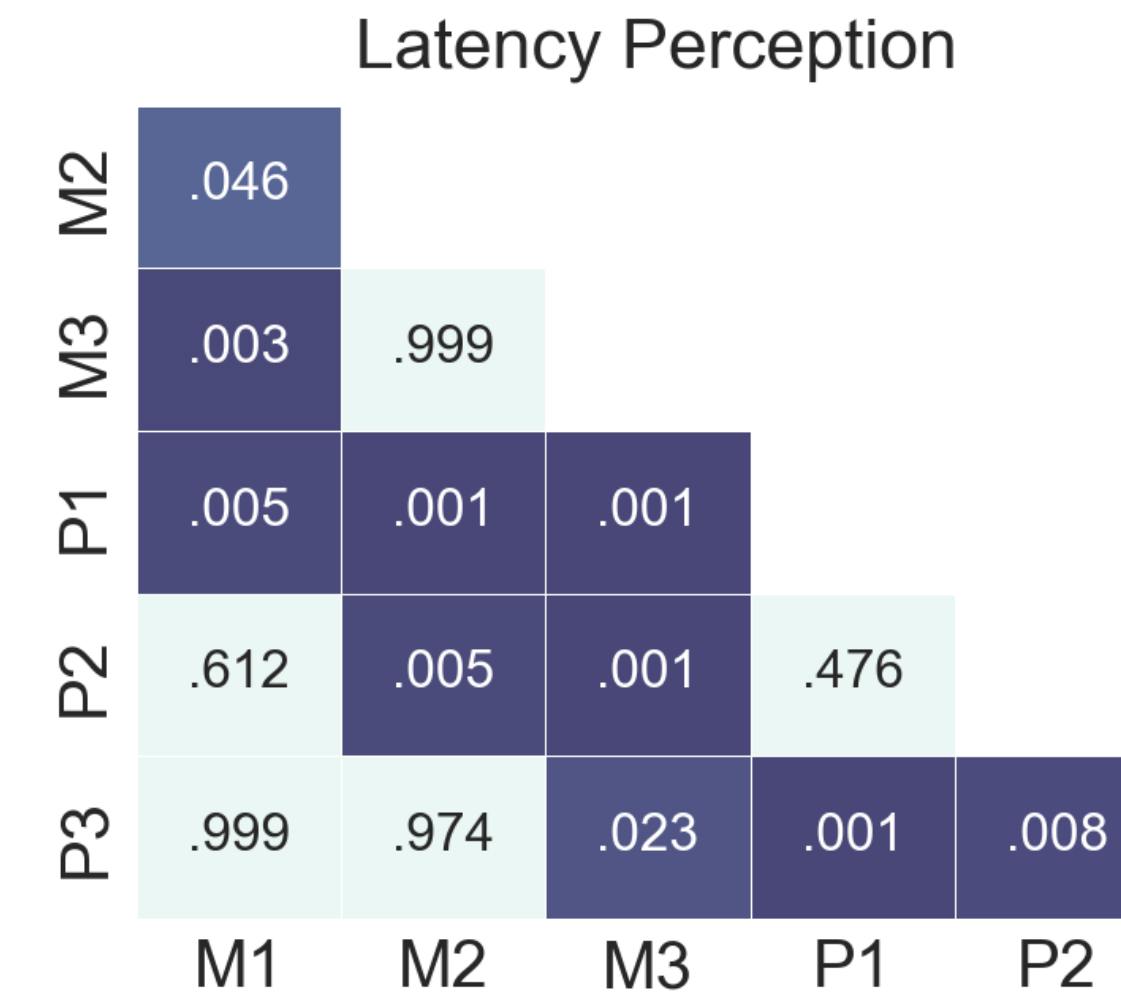
Significant differences

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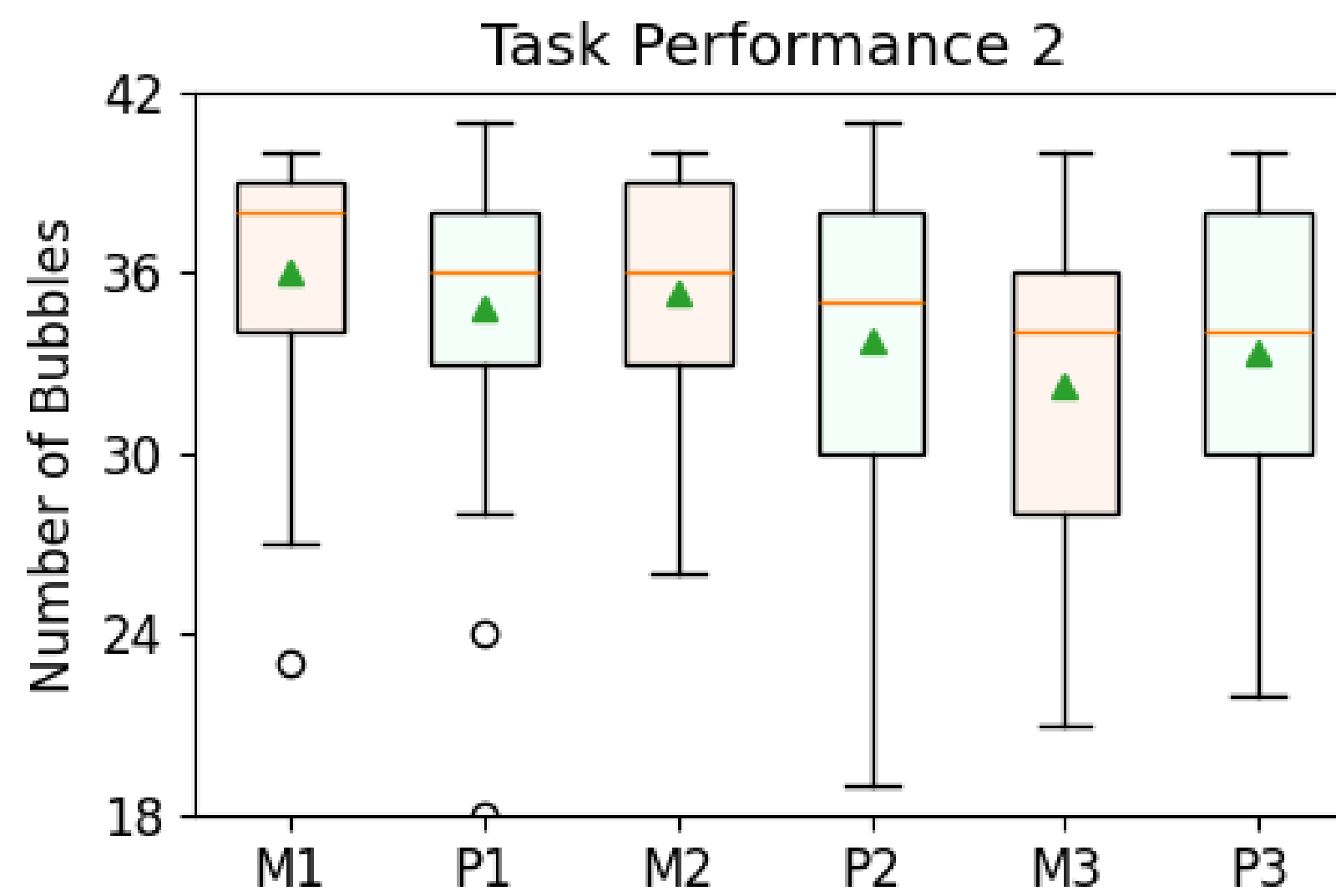


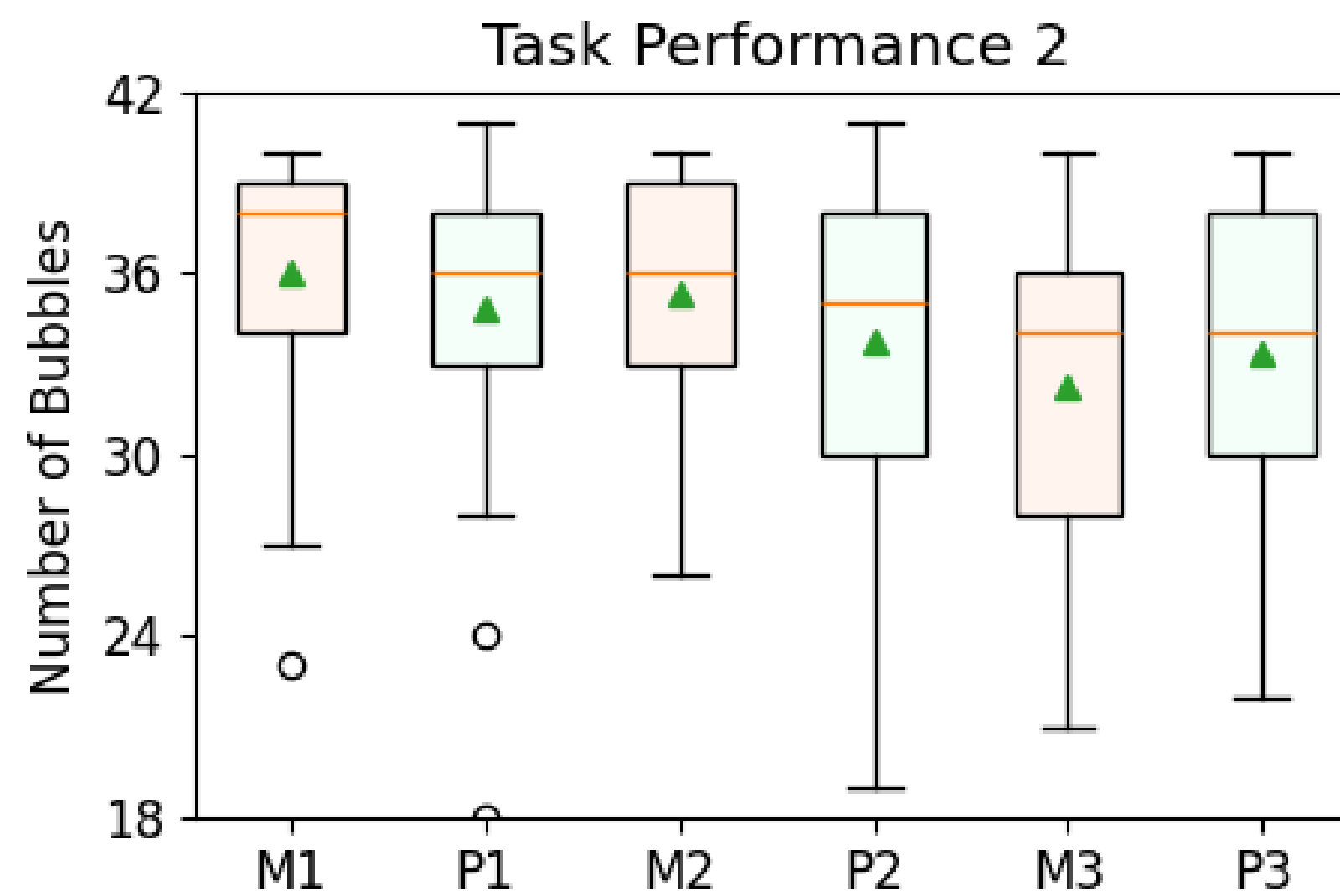
HQ avatar always better (in-sync.)

HQ avatar's loss smaller & later

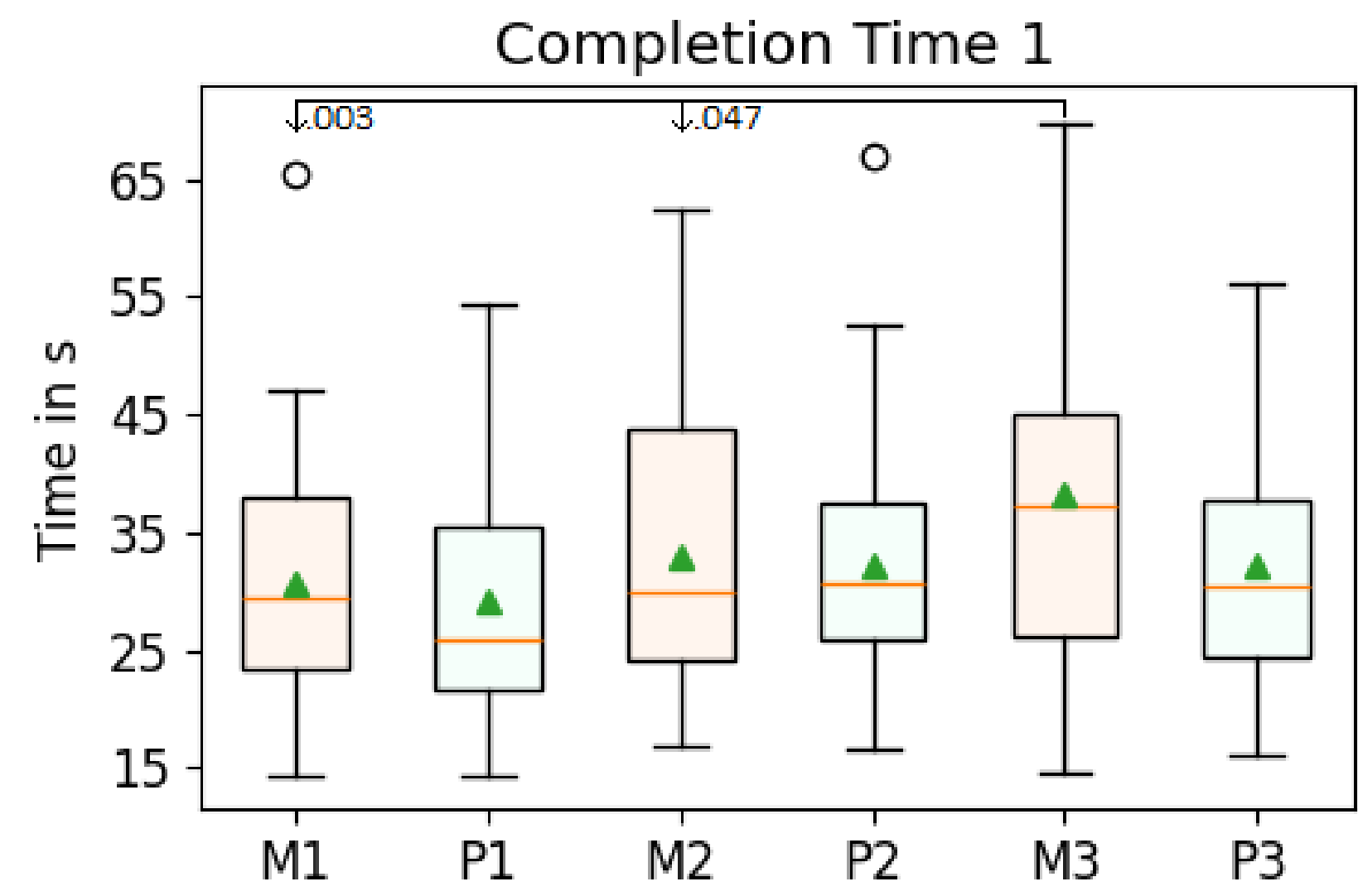
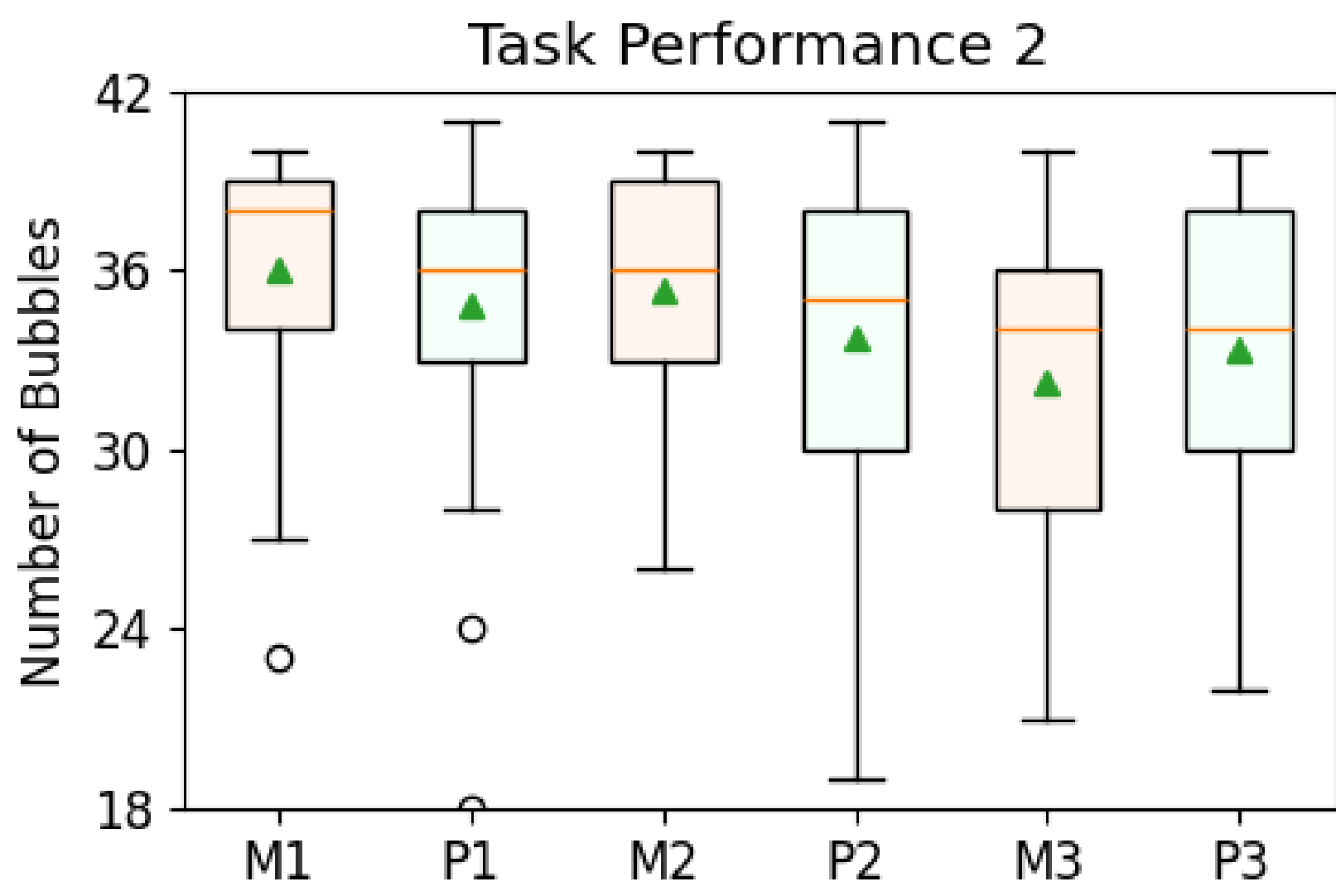


Significant differences



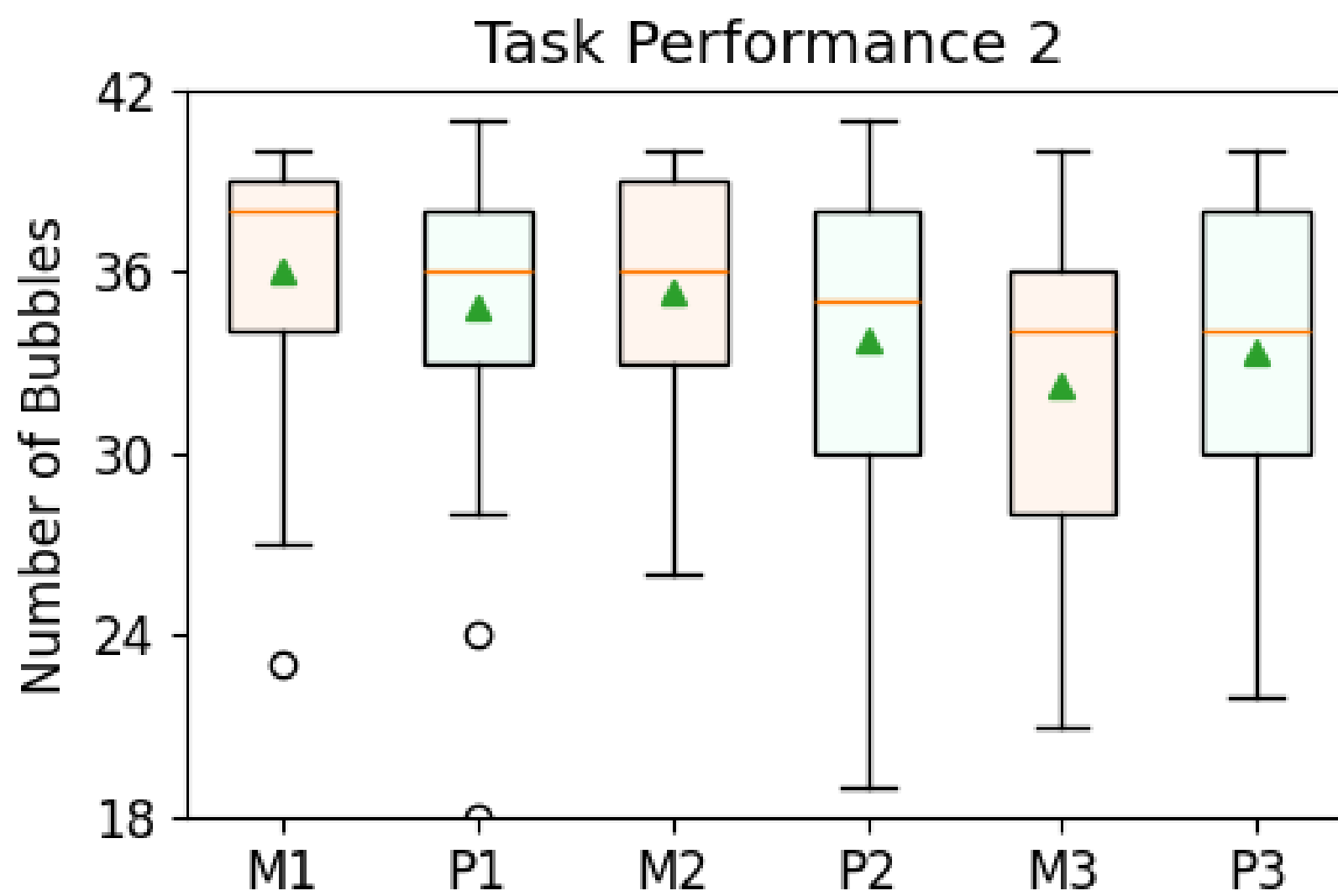


No significant differences

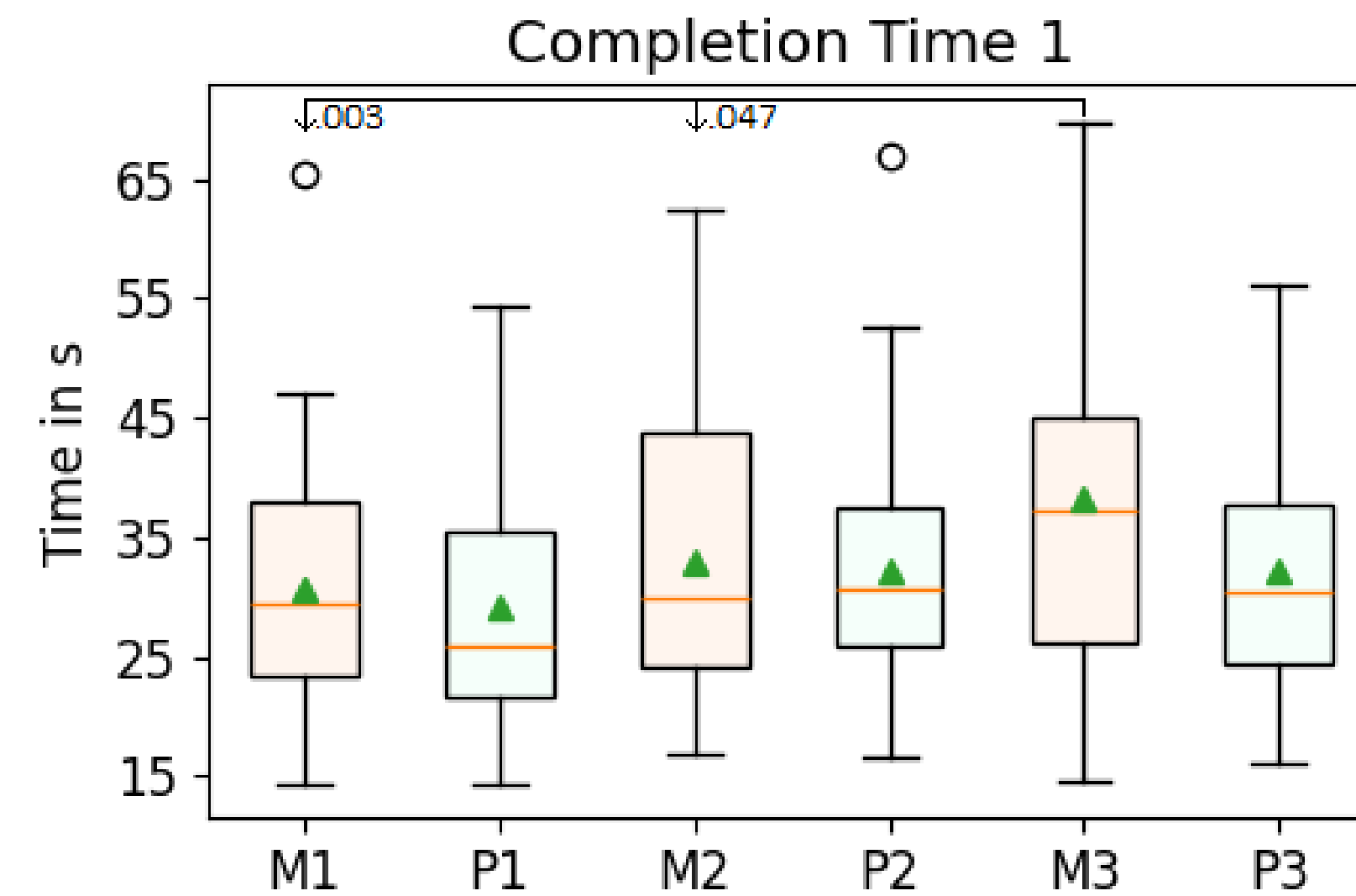


No significant differences

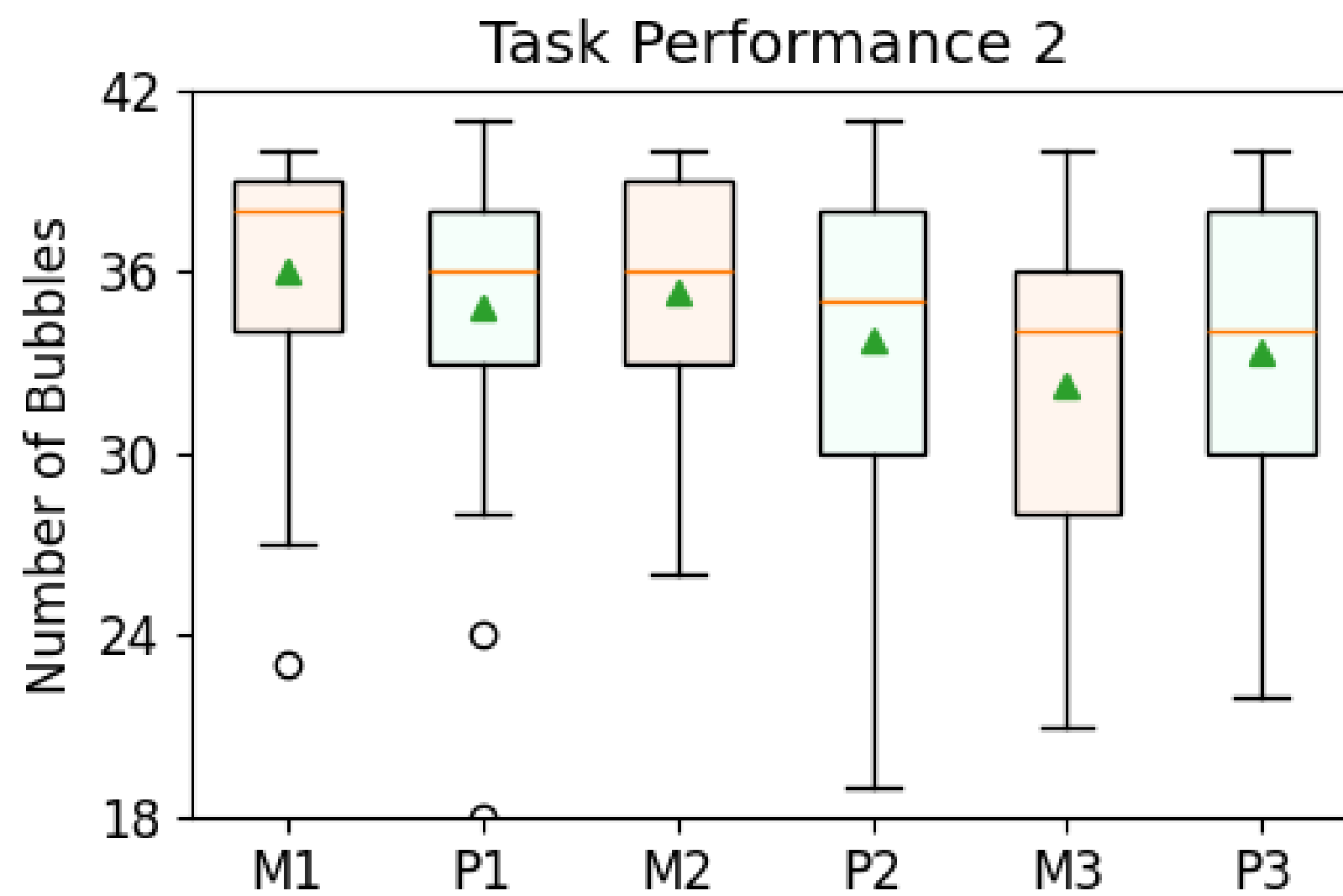




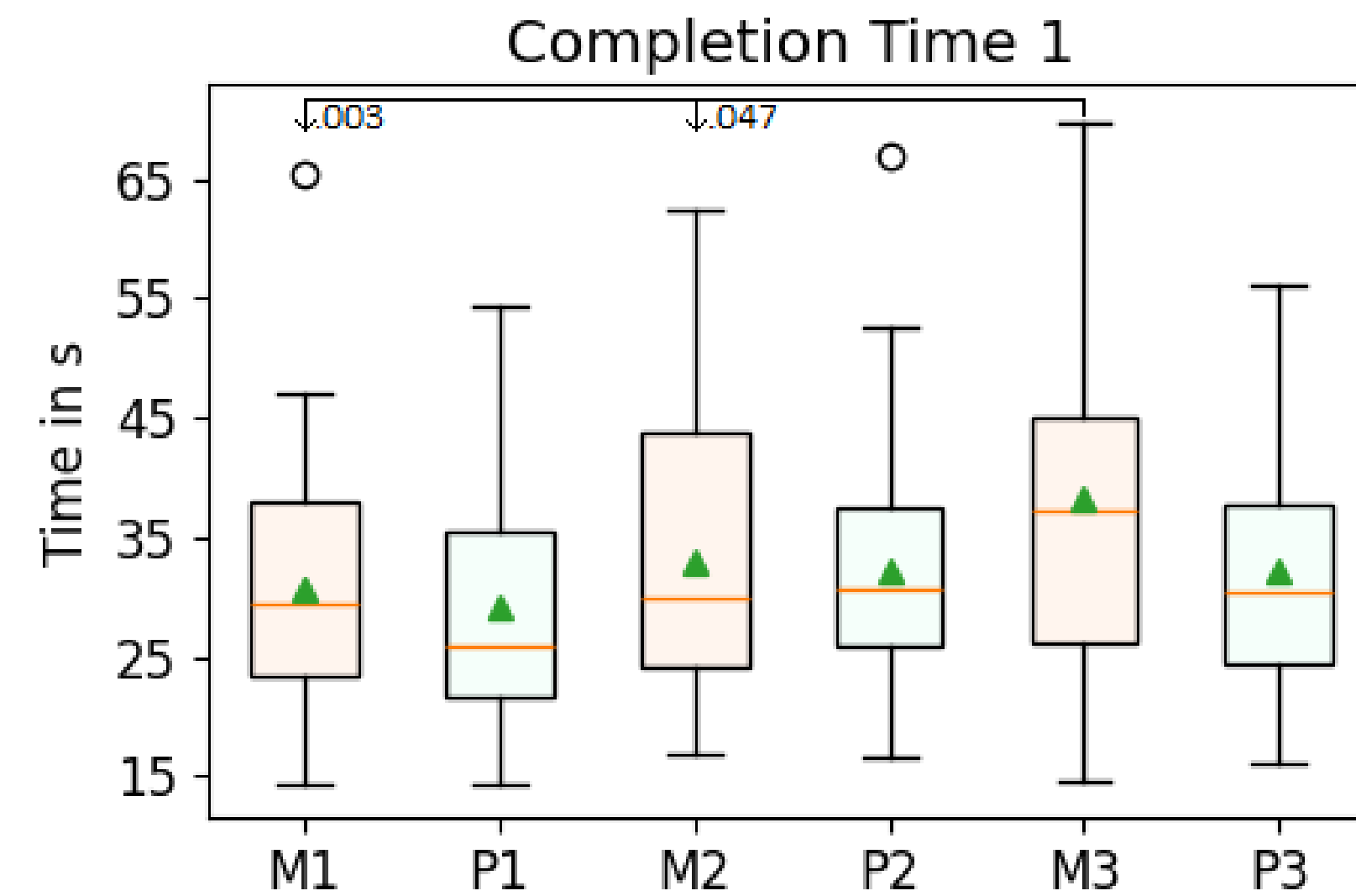
No significant differences



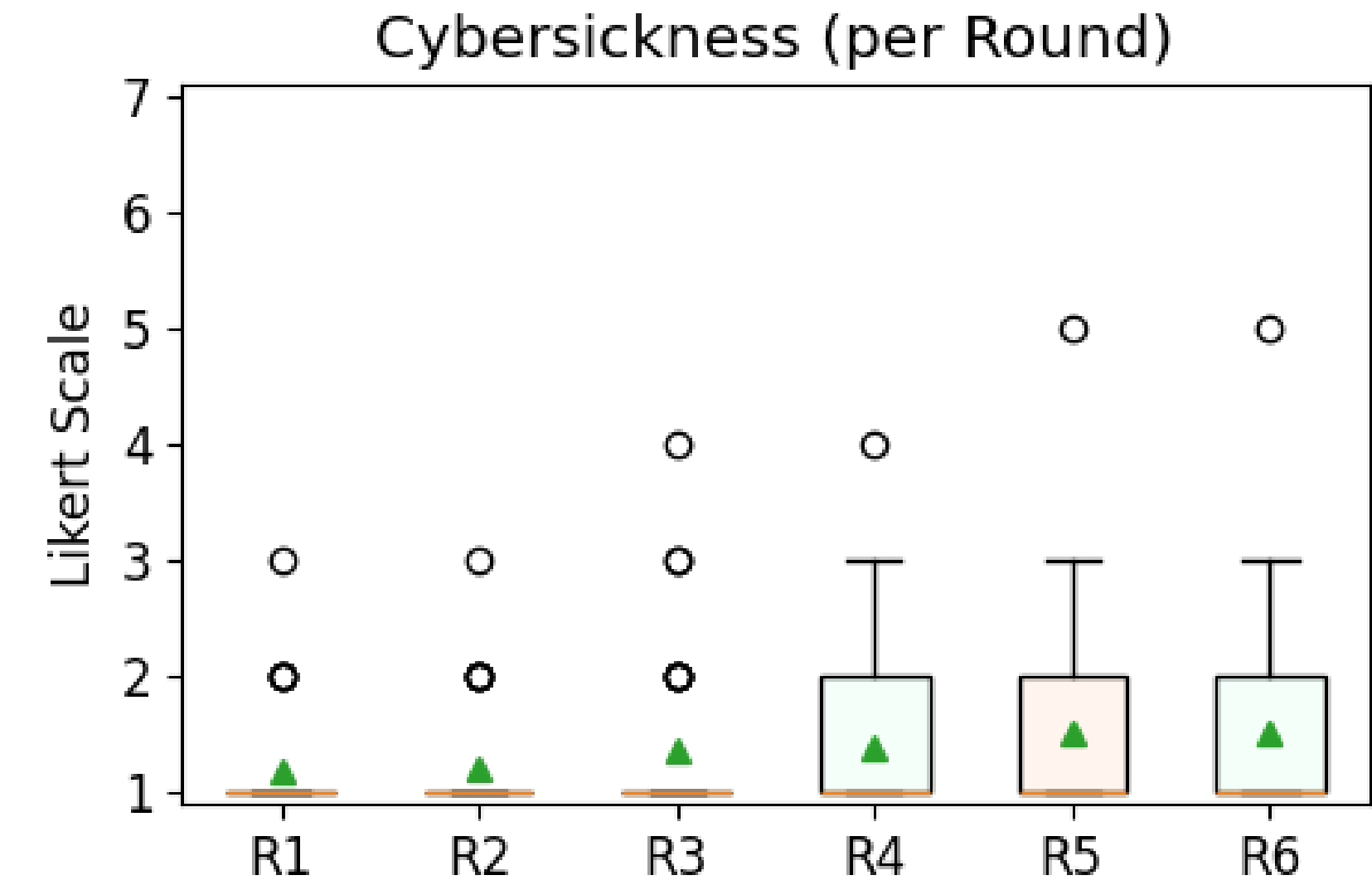
Nearly no significant differences



No significant differences

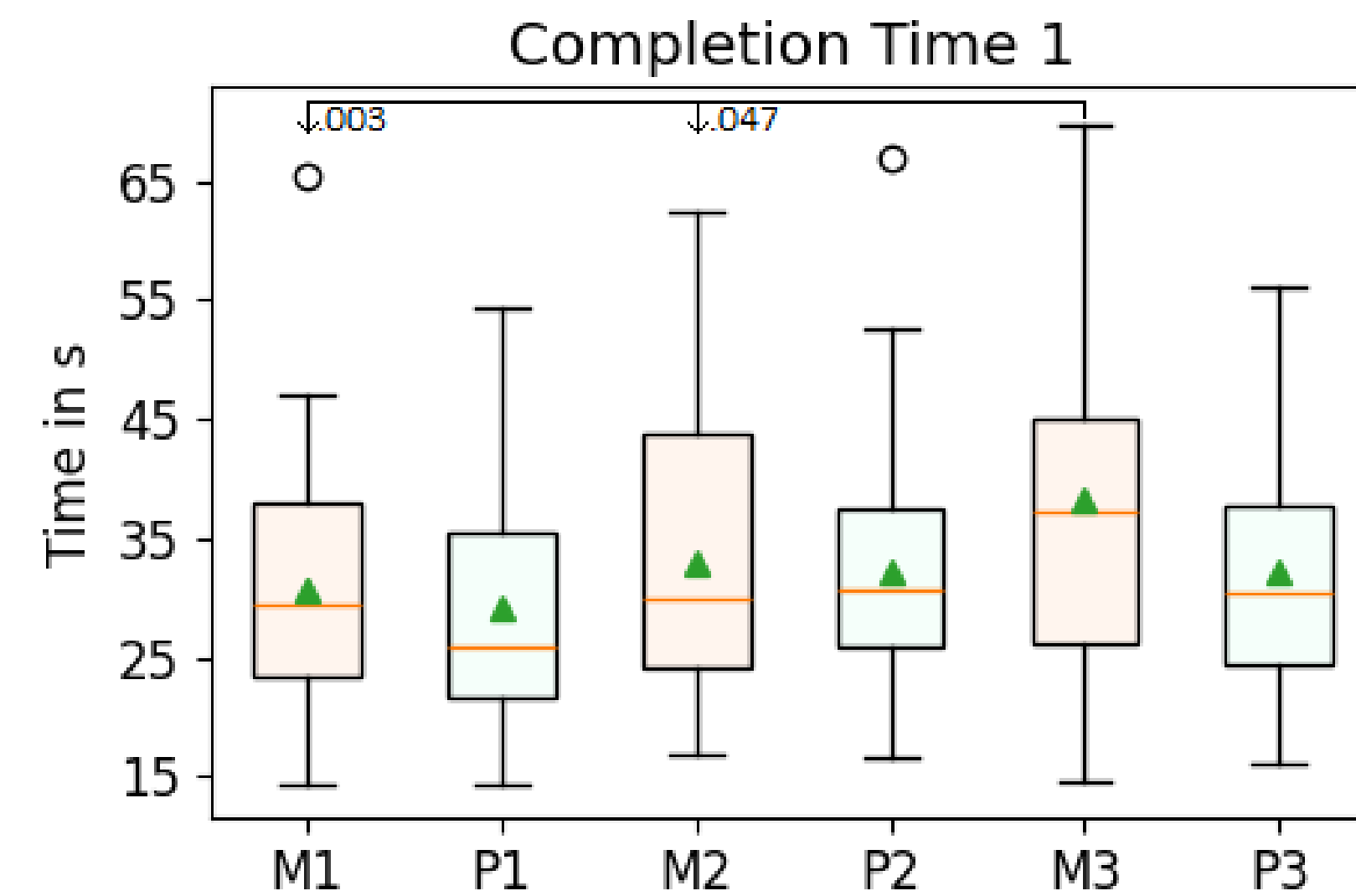


Nearly no significant differences

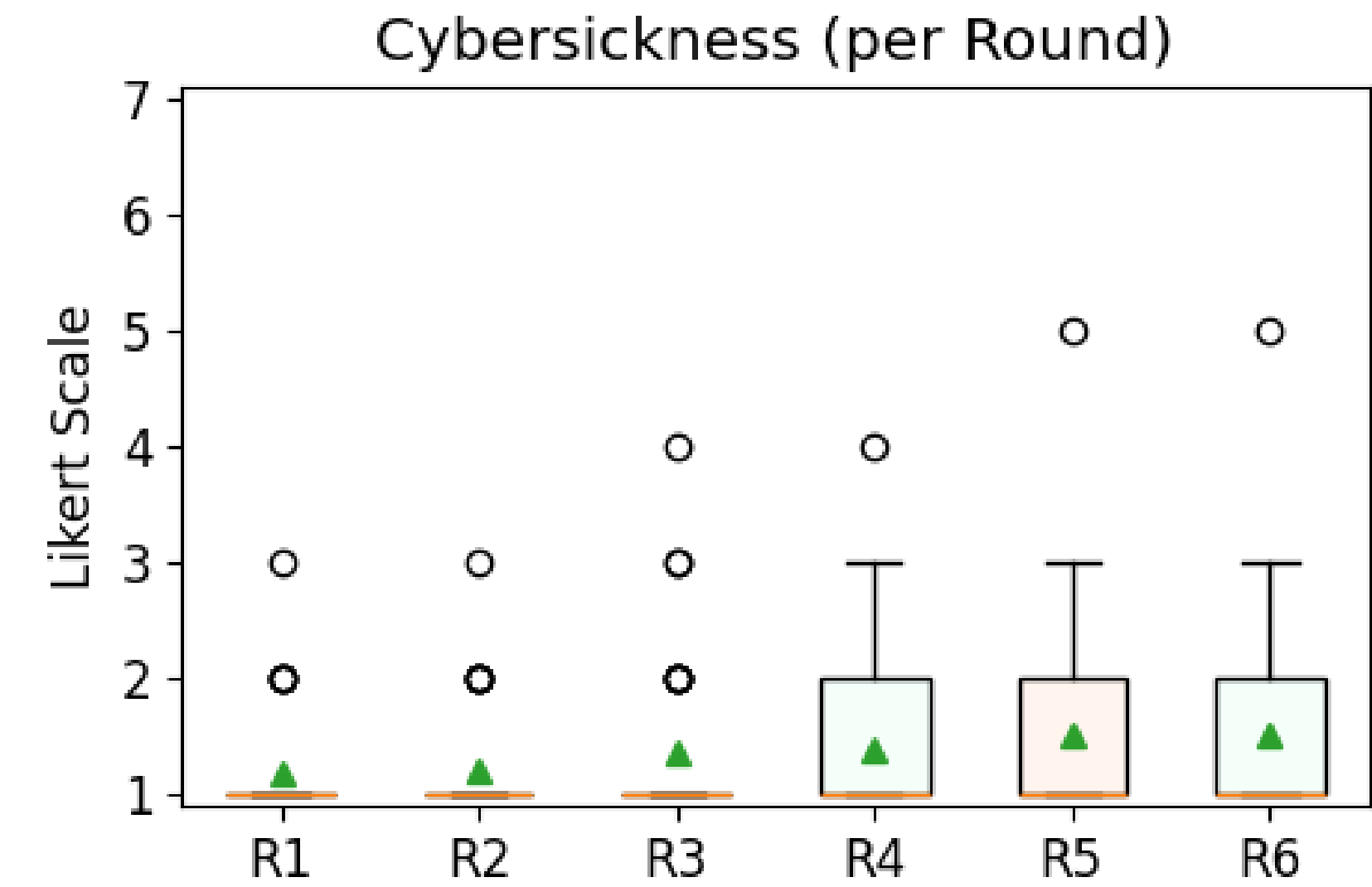




No significant differences



Nearly no significant differences



No significant increase

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  - Embodiment, task efficiency, cybersickness

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- No stat. interactions between avatar/latency
- Valuable insights: Prioritize higher-quality avatars

- Investigate greater latency range

# Future Work

- Investigate greater latency range
- Investigate multiple point cloud/mesh avatars with varying fidelity

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- Investigate greater latency range
- Investigate multiple point cloud/mesh avatars with varying fidelity
- Expand on multi-user scenarios (social and co-presence)





Thank you for your attention!  
Questions?



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Embodiment in Virtual Environments  
Analyzing the Effects of Latency  
and Avatar Representation