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POSTER

"Social Leading": Exploring Imposed Behavioral Synchrony in Virtual Reality

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"Social Leading": Exploring Imposed Behavioral Synchrony in Virtual Reality

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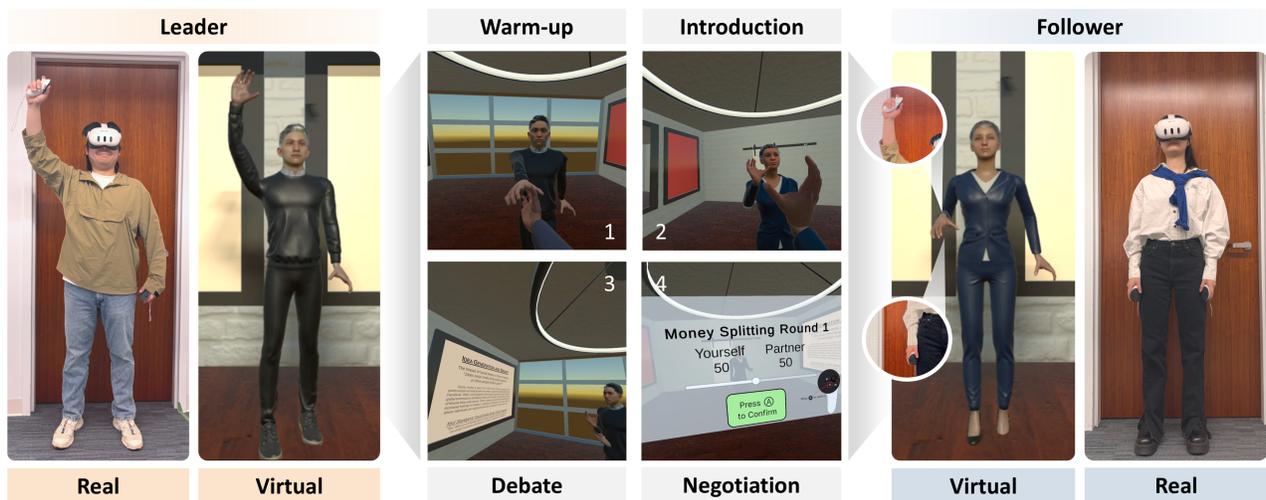


Figure 1: Exploration of "Social Leading" Effect. Two non-co-located participants interact with each other via the Social Leading VR System. The left orange part and the right blue part represent how the "leader" and the "follower" would be like in the physical real world and the immersive virtual world; The middle grey part shows how they would be interacting with each other following a specific pipeline.

Abstract

Immersive social virtual reality allows people to interact socially through avatars with rich behaviors similar to interactions in the physical world. Normally, people's avatars represent their own movements. However, nonverbal behavior can be transformed by modifying the source of avatar movements. We explore the effects of a novel behavioral transformation in dyads interacting in virtual reality - a "Social Leading" effect. In this scenario, the movements of a randomly assigned "leader" influence the movements of their

partner's avatar, the "follower". In a pilot study, we found that no participants noticed the effect. However, leaders disclosed themselves more during self-introduction, spoke significantly more in a debate, and rated their interaction partners as more submissive.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; *Collaborative interaction*; *Computer supported cooperative work*.

Keywords

Social Interaction; Virtual Reality; Behavior transform; Social VR; Avatar Embodiment; Social Leading System

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1 Introduction and Related Work

Social interaction through VR [15, 53] is becoming more and more common nowadays, in part because of its ability to support rich, embodied interactions. How nonverbal behavior is tracked, rendered and transformed by immersive systems is a key area of investigation in social virtual reality. In particular, nonverbal synchrony, whether between two or more human-controlled avatars [31], or between avatars and agents, has been much explored for its effects on liking, affiliation, and trust, among other topics. However, to date, most work has focused on either naturally emerging synchrony between two humans [43], or simulated synchrony, in which an agent is entrained to follow human behavior [3]. Inspired by this work, as well as work on the “avatar-follower effect” [16], and social influence of avatar embodiment, we explore a novel concept of “Social Leading” in which people’s avatar movements are led, modulated or partially controlled by those of their conversational partners.

Previously, research in human-agent interaction has studied people’s perspectives on a virtual agent’s mimicry of the human participant’s behavior [2], including how imposing synchrony on the agent’s behavior would affect group rapport [18, 45] and team dynamics [2, 3]. However, to our knowledge, no work has yet examined the “inverse” situation, i.e., if a person’s own avatar’s movements are controlled to imperceptibly mimic another’s behavior. Though there have been studies injecting human-human mimicry [41], in this case, participants do not perceive their *own* avatar’s movements as modified. This type of transformed social interaction [1] could affect interpersonal dynamics, as a key aspect of the social leading effect is that it occurs in a social context where people not only experience movement modulation, but also are able to see their social partner’s movement acting as a trigger, which may produce further motor and cognitive influence.

Motor contagion is a mostly involuntary phenomenon in which observing another person’s actions triggers similar motor patterns in the observer’s brain [5, 8]. It reflects the human tendency to resonate and mimic naturally with others and can also be observed in virtual environments. Some studies have found that users may subconsciously adjust their movements to other’s avatars even when movements are incongruent, showing that avatar behavior can directly influence user actions and create interactive dynamics in VR [6, 50]. In addition, nonverbal behavior both signals social status and is in itself subtly socially influential [19], including indicating status and dominance.

In the self-avatar follower effect, researchers have found that modifying the motor behavior of a user’s *own* avatar may go unnoticed while still affecting the user’s physical movement. This was shown in an experiment where avatars’ hands were modulated to drift up to 30 degrees outward either gradually or instantaneously, leading participants to follow their avatar’s movements [16]. Similarly, when participants’ avatars were programmed to perform circular movements, participants moved their hand in ellipses when trying to draw straight lines [9], and participants unconsciously decelerated to match their avatars’ slowed movements [40].

Extending from the self-avatar follower effect, other research on avatar embodiment in VR focuses on how avatar embodiment affects user experience in a social scenario [37]. For example, the Proteus Effect tells that our digital self-representation changes our behavior in the virtual environment, as experimental studies show that participants embodying more attractive avatars were more approached confederates more closely and participants assigned taller avatars behaved more confidently in a negotiation task [51]. Participants also exhibited less engagement in a musical drumming task when embodying a self-avatar with business suit compared with embodying in a casual avatar [24].

To our knowledge, no study in social VR has yet examined a “social leading” scenario in which a human participant experiences their behavior being entrained to another’s. As a first step to explore the patterns of communication and interaction when non-verbal behavior synchrony is imposed, we created a scenario in immersive virtual reality with two roles. The participant in the “leader” role has full motor control over their avatar. Their voluntary movements also influence those of their partner, the “follower”. To understand how this might affect task performance, team dynamics, perceptions of self and partner, and emotional state and sense of presence and embodiment, we developed the following hypotheses:

- **H1a:** Leaders are more likely to introduce themselves first
- **H1b:** Leaders will disclose more information about themselves in self-introduction
- **H2a:** Leaders will spend more time talking in debate
- **H2b:** Leaders will speak more words in debate
- **H2c:** Leaders will contribute more ideas than in debate
- **H3a:** Followers’ opinions will change more than leaders’
- **H3b:** Followers’ understanding of the topic will increase more than leaders’
- **H4a & H4b:** Leaders will propose more unfair splits in the first and second rounds
- **H4c:** Followers are more likely to accept an unfair split
- **H5a:** Leaders will perceive themselves as more dominant and less submissive
- **H5b:** Leaders will perceive their partners as less dominant and more submissive
- **H6a:** Leaders will report reduced rivalry to their partners
- **H6b:** Leaders will report greater entitativity
- **H6c:** Leaders will report greater social closeness
- **H7a:** Leaders will report a higher Positive Affect Score
- **H7b:** Leaders will report a lower Negative Affect Score
- **H8a:** Leaders will report higher spatial presence/embodiment
- **H8b:** Leaders will report higher social presence

2 Methods

We built the first iteration of the Social Leading system for dyads using the Unity game engine [46], and implementing the Normcore SDK [33] for networking. We explored social leading in two ways: by modulating *proxemics*, and *gestures*.

Proxemics Modulation Proxemics plays a crucial role in communication and relationship building, reflecting cultural norms and relational dynamics which may influence interactions [29, 30] both face-to-face and in virtual reality [11, 25, 32]. However, few studies have actively modulated inter-personal proximity [48].

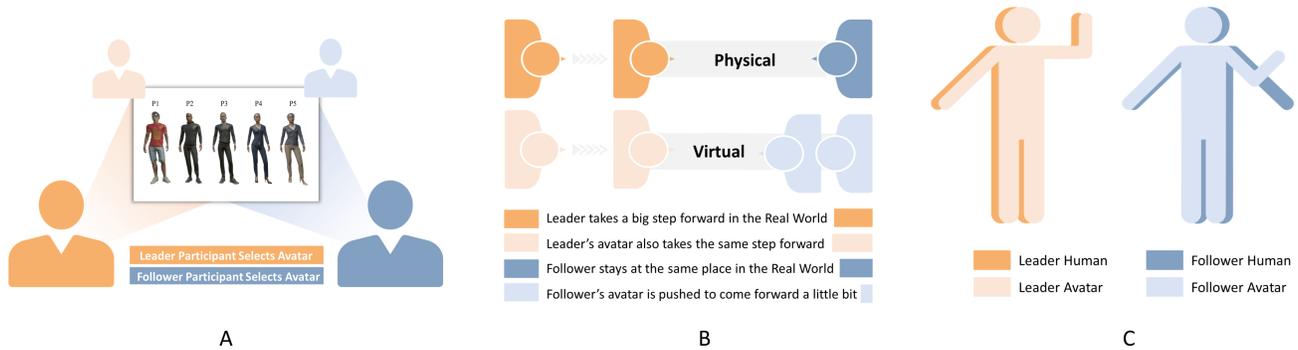


Figure 2: Illustration of the Social Leading System. (A) Participants select their preferred avatars to embody at the beginning of the study. They would be randomly assigned the role of either "leader" (orange) or "follower" (blue) which they would not be told during the study. (B) Proxemics Modulation: follower avatar's positioning in the virtual world would be affected by how the leader moves. (C) Gesture Modulation: follower avatar's upper-limbs movement in the virtual world would be affected by the leader's upper limbs movement.

In the social leading scenario, the "leader's" movement in the X Z coordinate system will modulate the "follower's" position. For example, if the leader approaches the follower, the follower's avatar position will be transformed to also move slightly closer to the leader (See Figure 2-B). If the leader moves backwards, the follower's avatar will also move backward. The mapping between the leader's root movement in the virtual and physical worlds is maintained. But, the follower's avatar position will be affected by both their own and the leader's movements; weighted by a modulation as follows:

$$LVR\ Movement = LPR\ Movement$$

$$FVR\ Movement = FPR\ Movement - LPR\ Movement \times Ratio$$

Here, LVR, LPR, FVR, and FPR Movement stand for Leader Virtual Root Movement, Leader Physical Root Movement, Follower Virtual Root Movement, and Follower Physical Root Movement, respectively. All of them are measured in the same absolute coordinate system. If the modulation Ratio = 0, then the follower will not be affected by how the leader moves. If the Ratio = 1, besides their own movement, the follower's movement will also incorporate leader's full movement. To keep the effect below the threshold of detection, we selected a Ratio of 0.3. We applied this transformation only in the 2D plane (i.e. in the X- and Z- axes) excluding vertical Y-axis movements like jumping or squatting.

Gesture Modulation Proxemics modulation affects absolute movement; i.e., participants' positions in reference to the virtual environment. For our second target, *local* arm movements, i.e., participants' gestures, which convey non-verbal information [42] and are important in both VR and physical world interaction [7, 14, 26, 28, 43], have been modulated. Similar to the proximity modulation, the leader's hands movement slightly leads the follower's avatar's hands, but the follower's hand movements do not effect the leader's avatar (See Figure 2-C).

We calculate the leader and follower's hand positions with respect to their head position. We then integrate these relative positions to generate new relative positions for the follower avatar's hands. Thus, both of the follower-avatar's hands will be slightly led by the leader's corresponding hand movements in the X, Y and

Z axes. For example, if the leader raises their right hand (moving in the Y axis), the follower's right hand will also rise slightly. If the leader reaches out their left hand in the Z axis, the follower's left hand would extend forward slightly as well, regardless of their movements in the physical world. We express this remapping as follows:

$$LVH\ Position = LPH\ Position$$

$$FVH\ Position = FPH\ Position \times (1 - Ratio) + LPH\ Position \times Ratio$$

Here, LVH, LPH, FVH, and FPH Position stand for Leader Virtual Hand Position, Leader Physical Hand Position, Follower Virtual Hand Position, and Follower Physical Hand Position, respectively. All of them are relative positions with respect to their avatars own heads (roots). Here again, we confirm a modulation Ratio = 0.3 so that the follower's avatar hand movements are primarily driven by their physical movements but are also influenced by the leader's hands positioning. Notably, since "hand" is the final segment of the upper limb connected to all segments through inverse kinematics. Thus, modulating the hand's movement actually manipulates the entire arm.

2.1 Participants and Procedure

We recruited 42 participants over the age of 18 (19 male, 23 female) through the university SONA system or flyer advertisement. Their ages ranged from 18 to 29 years old, with an average of 19.57 years old (SD = 1.78). All participants are currently enrolled undergraduate or graduate students. 36 out of 42 participants were compensated with 2 SONA course credits, and six were compensated with \$15 United States dollars. 32 out of 42 participants had previous experience with virtual reality. All procedures were approved by the Institutional Review Board (IRB), and all participants consented to participate in the study and have their movement and virtual interaction data recorded.

Upon arriving at the lab, participants were guided to different rooms to minimize interaction outside of the experiment. After completing informed consent, each participant was randomly assigned to the follower or leader role. Participants selected one of

Table 1: Hypotheses and Measures for Qualtrics Data

Hypotheses	Measures
H5a: Leaders will perceive themselves as more dominant and less submissive	Personality Score [21, 22, 27]
H5b: Leaders will perceive their partners as less dominant and more submissive	Personality Score [21, 22, 27]
H6a: Leaders will report reduced rivalry to their partners	Teammate-Rivalry Relationship
H6b: Leaders will report greater entitativity	Entitativity Scale [47, 52]
H6c: Leaders will report greater social closeness	Interpersonal Attraction [12, 35]
H7a: Leaders will report a higher Positive Affect Score	PANAS-Positive [49]
H7b: Leaders will report a lower Negative Affect Score	PANAS-Negative [49]
H8a: Leaders will report higher spatial presence and embodiment	Presence and Embodiment [17, 20]
H8b: Leaders will report higher social presence	Social Presence Scale [4, 34]

five pre-rigged Mixamo avatars (See Figure 2-A). All avatars' viewing heights (i.e. the distance between their eyes and the ground) were set to 1.60 m to eliminate any influence of height differences.

Warm-up Activities A voice recording instructed participants to 1. wave and say hi to their partner 2. approach to shake hands with their partner, and 3. to high-five with their partner. Next, participants were told to turn to the mirror side and perform a series of movements designed to enhance their sense of embodiment, including tilting and nodding their heads and raising their hands. After this, participants were given 15 seconds to relax and move around freely. Generally speaking, by instructing our participants dyads to initiate both individual and joint actions, we created opportunities for participants to experience either leading or being led by others, which might unconsciously change the interaction dynamics.

Task 1: Self-Introduction Next, participants were instructed to introduce themselves to their partners, for which we used two prompts. We initiated the task and told that either of them could start introducing first. After both of them stopped, we made another prompt to encourage them to say a little bit more. This task allowed us to test *H1a: Introduction Start* and *H1b: Introduction Information*.

Task 2: Debate Next, participants were asked to debate using the prompt, "does social media bring people closer together or drive them further apart?" After viewing the prompt, participants were assigned to either the affirmative or negative side. They were given 60 s to think of arguments and supporting evidence, after which they debated with their partner under standard time management. This addressed *H2a: Percentage of Time Used*, *H2b: Percentage of Words Used* and *H2c: Proposed Ideas and Points*. To address *H3a: Opinion Change Extent* and *H3b: Knowledge Gain Extent*. They reported their opinion change and knowledge increase in-headset using a 7-point Likert-scale.

Task 3: Money-Splitting Similar to [51], participants were told they would propose splits for a hypothetical pool of \$100 between the two of them. In Round 1, each participant designated a split privately, and were shown a 50/50 split from their partner. After accepting or rejecting this split, they could see their partner's "decision" which was always presented as "accepted" as long as it did not exceed \$80 in favor of the participant. The procedure was the same for Round 2, except they were shown a 65/35 split in favor of their partners for them to either accept or reject. The money-splitting negotiation task was intended to test the following hypothesis: *H4a: Proposed Split 1*, *H4b: Proposed Split 2* and *H4c: Acceptance of Unfair Split*.

After their experience in VR, participants completed a survey in Qualtrics. These Qualtrics measures provided the data to test the hypotheses in Table 1.

2.2 Measures

Here, we report all measures collected with their accompanying hypotheses. Since we collected data both in and out of VR, we categorize our measures into behavioral data from VR and self-report data from survey.

In order to measure and analyze participants' behavioral data, we recorded and transcribed audio and video of participants' VR experience as well as the responses to in-headset questions. Specifically, corresponding to the hypotheses, the data for *Introduction Start (H1a)*, *Percentage of Time Used (H2a)*, and *Percentage of Words Spoken (H2b)* were derived from the transcript. Measurement for *Introduction Information (H1b)* and *Proposed Ideas and Points (H2c)* were calculated by coding the number of pieces of information that each participant gave during the corresponding tasks based on the transcript. Participants' responses to *Opinion Change Extent (H3a)*, *Knowledge Gain Extent (H3b)*, *Proposed Split 1 (H4a)*, *Proposed Split 2 (H4b)*, and *Acceptance of Unfair Split (H4c)*, were directly stored in the headset and were retrieved after the VR experiment session ended.

Qualtrics measures are briefly reported in Table 1 together with the corresponding hypotheses (from *H5a* to *H8b*). We cite the existing measures that informed our questionnaire in Table 1. In addition to our questions about perceived dominance, emotional state, rapport, and presence we asked participants to report their simulator sickness and provided two open-ended questions, asking whether participants had any other comments on the study and asking them to guess the study purpose.

3 Results

All analyses were conducted in R [36]. We eliminated conversational behavioral data of one dyad whose transcript was incomplete and self-report data of three dyads who saw an incomplete version of the Qualtrics survey. Except for percentage data which we used the one-sample t-test to see if it is significantly higher or lower than 50%, we used linear mixed-effects models with dyad ID as a random effect for our significance test. The complete results are shown in Table 2 and Table 3, with statistical significance indicated by asterisks (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Table 2: In-VR Behavior Results

Aspect	Item	Follower Mean(SD)	Leader Mean(SD)	Significance p-value
Self-Disclosure	H1a - Introduction Start	0.550 (0.510)	0.450 (0.510)	0.539
	H1b - Introduction Information	5.050 (1.572)	6.000 (2.317)	0.004 **
Debate Metrics	H2a - Percentage of Time Used	0.438 (0.088)	0.562 (0.088)	0.003 **
	H2b - Percentage of Words Spoken	0.456 (0.095)	0.544 (0.095)	0.026 *
	H2c - Proposed Ideas and Points	2.550 (0.826)	3.550 (0.999)	< 0.001 ***
Reflection on Debate	H3a - Opinion Change Extent	3.143 (1.352)	3.857 (1.424)	0.103
	H3b - Knowledge Gain Extent	3.333 (1.528)	3.524 (1.778)	0.693
Money-splitting	H4a - Proposed Split 1	48.143 (19.402)	51.381 (3.612)	0.457
	H4b - Proposed Split 2	46.190 (15.565)	47.667 (10.929)	0.724
	H4c - Acceptance of Unfair Split	0.476 (0.512)	0.476 (0.512)	1.000

Table 3: Self-report Survey Results

Aspect	Item	Follower Mean(SD)	Leader Mean(SD)	Significance p-value
Dominance	H5a - Self-perceived Dominance	3.298 (0.555)	3.302 (0.687)	0.985
	H5b - Perception of Partner's Dominance	3.536 (0.525)	3.091 (0.619)	0.026 *
Team Dynamics and Group Rapport	H6a - Relationship	5.722 (1.406)	5.722 (1.179)	1.000
	H6b - Entitativity	3.435 (0.833)	3.435 (0.779)	1.000
	H6c - Interpersonal Attraction	5.708 (0.960)	5.542 (0.993)	0.518
Emotion	H7a - Positive Affect Score	2.939 (0.684)	3.000 (0.653)	0.786
	H7b - Negative Affect Score	1.550 (0.510)	1.361 (0.347)	0.203
Presence and Embodiment	H8a - Spatial Presence and Embodiment	4.082 (0.642)	4.231 (0.443)	0.423
	H8b - Social Presence	5.102 (1.110)	4.963 (0.733)	0.630

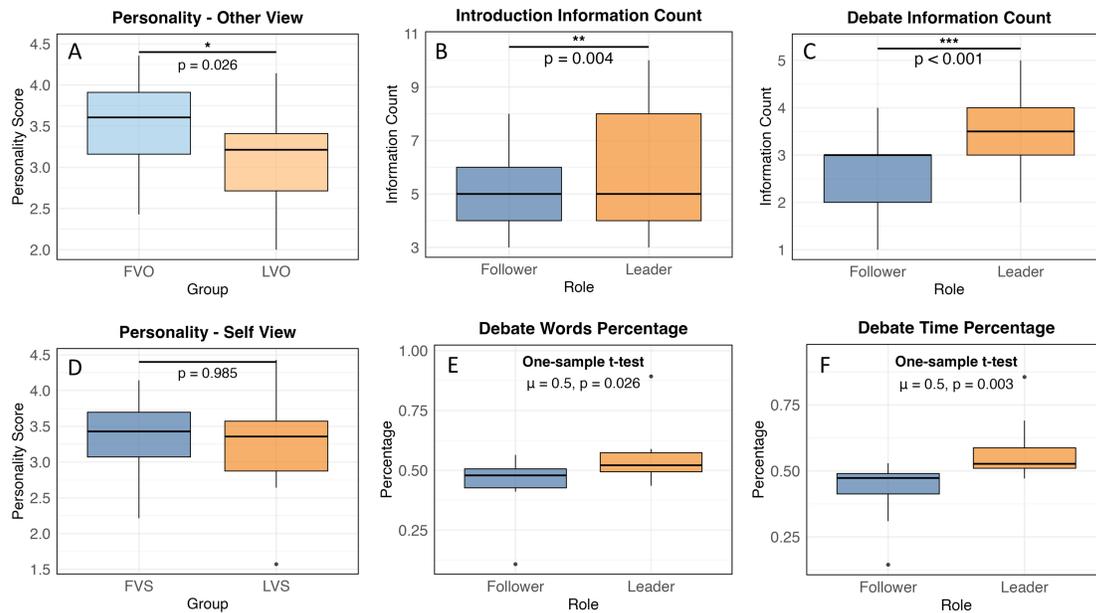


Figure 3: Selected Results between Followers and Leaders in the Social Leading System. (A) Personality Score between FVO (Followers View Others) and LVO (Leaders View Other) (H5b). (B) Pieces of information disclosed between followers and leaders in the self-introduction task (H1b). (C) Number of ideas and points proposed between followers and leaders in the idea generation and debate task (H2c). (D) Personality Score between FVS (Followers View Self) and LVS (Leaders View Self) (H5a). (E)-(F) Percentage of total words spoken (H2a) and total time used (H2b) between followers and leaders in the idea generation and debate task .

In-VR Behavior data could be categorized into four aspects, namely Self-disclosure in Introduction, Debate Metrics, Reflection on Debate, and Money-splitting. Noticeably, followers and leaders did show significant difference in some of the items. In terms of number of information pieces provided in the self-introduction, leaders' contributions ($M = 6, SD = 2.317$) significantly outweighed followers ($M = 5.050, SD = 1.572$), with $F_{(1,19)} = 10.408, p = 0.004$. As for the time used and words spoken during the debate, on average leaders dominated, occupying 56.2% of total time and 54.4% of total words, both significantly higher than 50% as the one-sample t-tests indicated (time: $t = 3.1311, df = 19, p = 0.003$; words: $t = 2.066, df = 19, p = 0.026$). Leaders ($M = 3.550, SD = 0.999$) also proposed significantly more ideas and points than followers ($M = 2.550, SD = 0.826$) did in the debate ($F_{(1,19)} = 31.667, p < 0.001$).

Self-report survey data could also be categorized into four aspects, namely Dominance, Team Dynamics and Group Rapport, Emotion, and Presence and Embodiment. Among them, Dominance was measured by the personality score, with higher score indicating more dominant and lower score indicating more submissive. Here, though both leaders and followers perceived themselves with relatively the same level of dominance, they showed a significant difference in how they perceived their partners' personalities. Specifically, leaders viewed their partners ($M = 3.091, SD = 0.619$) as more submissive (i.e. less dominant) than followers viewed their partners ($M = 3.536, SD = 0.525$) ($p = 0.026$). Seemingly, this was achieved without breaking the embodiment illusion as there were no significant difference in terms of presence and embodiment between the two roles.

Figure 3 shows some of the notable results in box plots.

4 Discussion, Limitations and Future Work

In a small pilot study, we explored the effects of a novel behavioral transformation in dyads interacting in virtual reality - a "Social Leading" effect in which the movements of a "leader" both animate their own avatar and influence the avatar movements of their "follower" partner. In responses to our open-ended questions, neither leader nor follower participants noticed the effect. However, leaders disclosed more information about themselves during self-introduction, spoke significantly more in a debate, and viewed their interaction partners as more submissive.

One potential confound for our results is that followers were significantly more likely to report simulator sickness (three of our 21 followers reported more than "slight" sickness while no leaders did). However, excluding these participants did not change the direction or significance of our key results. Future work should measure behavioral indicators of cybersickness more granularly and include a control group of teams whose nonverbal behavior is not modulated to provide another basis of comparison.

Although we detected some differences in behavior and self-reported perception between the two participant roles, we should ask if these can indeed be attributed to the movement modulation that we imposed, since participants might not move much during the interaction and thus might not be sufficiently exposed to the manipulation. To better alleviate this issue, we requested our participants to perform a series of predefined solo and interactive movements in front of a mirror during warm-up. We also prompted them to

communicate nonverbally during the idea generation and debate task. Among all these tasks, several designated actions (like high fives, raising hands, and applauding) were interspersed as well to mark the beginning and end of different stages. This can increase the potential influence of the self- and other- avatars' non-verbal behavior. However, future studies should examine the relationship between participant movements, for example, nonverbal synchrony, and compare that with effects on behavior and perception.

Another potential confound that deserves additional study is the role of gender. In our study, participants selected from a group of avatars with different presumed genders. However, avatar gender could also influence social dynamics [10, 23, 38].

Assuming these results replicate, an essential question is whether a social leading paradigm could provide an unfair advantage to "leaders"; decreasing trust and increasing the risks of manipulation, as has been proposed for other examples of transformed social interaction [1]. Our project does not compare the task performance or self-perceptions of "socially-led" dyads to dyads whose behavior was NOT modulated. Thus, we do not know what explains the differences between leaders and followers. Leaders' or followers' perceptions and performance may have been boosted or decremented over what they would have been in an unmodulated condition. Further research is needed to determine whether social leading modulations actually disadvantage the "follower" in collaborative social situations, or whether the team as a whole does better than a team who is not experiencing modulation.

While the possibility and risks of manipulation should be taken seriously, there are a number of pro-social outcomes that could arise from deploying modulated behavior in this way. For example, people exercising together could be cued to move in concert by having their movements slightly entrained at a low modulation ratio. Shy people could be prompted to engage in conversations, or practice public speaking more confidently. Social leading could even be an additional way to address the issue of movement initiation in Parkinson's patients, as previous work in XR has done [13, 39, 44], or encourage movement in immersive physical therapy applications. Future work should include examining the effects when participants are informed that their behaviors will be transformed in this way, including their willingness to undergo this transformation.

5 Conclusion

Here, we present the "Social Leading" Effect, an initial exploration of a novel phenomenon with roots in classic virtual reality concepts such as transformed social interaction and the avatar-follower effect. Our analysis suggests that people who embody avatars that "lead" or "are led" by their conversational partners' nonverbal behaviors unconsciously exhibit differences in their behaviors and perceptions. While requiring further study, this concept holds potential for interventions in the health domain. Future work should also investigate the risk of undue persuasion resulting from this type of transformed social interaction in collaboration and other contexts in social virtual reality.

Acknowledgments

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