Exploring Intergroup Dynamics in Multi-User Social Virtual Reality Spaces using AI-driven Analytics ⋆

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Abstract

Social Virtual Reality (SVR) platforms enable embodied, multi-user interaction with rich nonverbal signals (e.g., proxemics, gaze, gesture, and spatial audio), creating new opportunities for mediated intergroup contact and deliberation. Building on intergroup contact principles, we hosted three moderated SVR deliberation sessions focused on the climate crisis with a culturally diverse participant pool. Using mixed methods, we combined pre-/post-session questionnaires on ethnic identity and connectedness, diversity attitudes, sensitivity to inequality, and Big Five personality traits with synchronized headset/controller telemetry logs e.g., proximity, gaze-aligned head motion, hand movements, and speech turn-taking. We found that inclusive facilitation and cooperative task structure supported intergroup engagement and constructive dialogue, while language norms and identity cues had minor effect on participation dynamics. Exploratory links between reported inclusion/identity measures and interaction patterns suggest that computational analysis of participant behavior and movement in the VR space can be linked to participants' perceptions and attitudes about diversity and about their ethnic and social affiliations, and especially to personality traits. Overall, our findings show that SVR can enable scalable intercultural deliberation when design emphasizes equal-status participation, inclusive atmosphere, clear shared goals, and attention to symbolic hierarchies. Across sessions, participants reported high enjoyment and curiosity. The AI-supported results align with qualitative observations by identifying consistent behavioral patterns associated with different engagement 'personas' (e.g., quiet-but-attentive listeners, socially affiliative participants, and high-energy frequent speakers), offering practical insights into intergroup and social interactions in SVR and support facilitator decisions and design choices aimed at supporting intergroup interaction and dialogue.

Keywords

Social Virtual Reality, Intergroup Contact, Deliberation, Embodied Interaction, Telemetry Analytics, Machine Learning

1. Introduction

Deliberative processes increasingly aim to include diverse publics, in part because diversity can enrich the knowledge base and improve decision quality, while also strengthening legitimacy and trust in outcomes [1, 2]. In heterogeneous deliberative groups, diversity can yield cognitive gains and enhanced performance through varied knowledge [3, 4]. In particular, participants from minority, historically underrepresented, or marginalized groups praise the equal opportunity to speak and the experience of being heard attentively [1, 5]. At the same time, these benefits are easily jeopardized by "process losses" such as relationship conflict and cohesion reduction [6, 7, 8]. Inclusion is not guaranteed by mere presence: differences in status, communication styles, and institutional power can shape who participates and how their contributions are valued. Research on group deliberation and diversity

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therefore emphasizes both the benefits of heterogeneous groups and the need for careful design to prevent marginalization or tokenism. Successful public debate therefore depends on overcoming stereotypes and perceived bias, and on ensuring that historically marginalized participants have equal opportunities to speak and be heard.

Intergroup contact Theory (ICT) is a cornerstone approach in social psychology for reducing prejudice and improving intergroup relations [9, 10, 11]. Building on Allport's contact hypothesis [12], contact decreases stereotypes and advances mutual understanding [10, 12, 13, 14]. Beyond prejudice reduction, contact can increase empathy, intergroup trust, and forgiveness [15, 16, 17, 18].

Contact is not uniformly positive. Negative intergroup contact can exacerbate bias and conflict, with detrimental effects that sometimes outweigh the benefits of positive encounters [19, 20, 21, 22, 23]. Intergroup Contact Theory and later refinements therefore highlight facilitating conditions under which contact reduces prejudice, including equal-status interaction, common goals, cooperation, and institutional support [9, 10, 12, 24].

Because geographic, cultural, and social segregation often restrict direct contact opportunities, research has increasingly pursued mediated intergroup contact interventions [25, 26]. Legacy online platforms such as forums, social networks, and older text-based or 2D virtual worlds struggle to replicate key nonverbal mechanisms of communication, relying on limited cues and constrained avatar-mediated signals. Social Virtual Reality (SVR) environments—multi-user 3D virtual spaces typically accessed via Head-Mounted Displays and motion controllers—leverage core VR features to facilitate embodied human-to-human interaction [27, 28, 29, 30, 31]. SVR is characterized by increased levels of spatial and social presence and is designed to support rich, embodied interaction more similar to face-to-face communication than non-immersive platforms.

These affordances can also surface symbolic hierarchies, including linguistic privilege: English-language dominance and norms of fluency and legitimacy can shape who is heard and how meaning is evaluated in SVR voice/text channels [32]. Identity representation is central in SVR because avatars can amplify, obscure, or reconfigure social identity cues. Customization may enable self-expression and comfort, yet visible markers (e.g., skin tone, religious attire) can also activate social categorization and implicit bias [33, 34, 35]. Prior work on dominance and voice allocation in VR and online contexts suggests that conversational control, interruptions, and linguistic privilege may produce symbolic hierarchies even in spaces framed as egalitarian [32, 36]. These dynamics matter for deliberation on contested issues such as climate policy, where participants' lived experience and cultural values shape problem framing and proposed solutions.

2. Study Design and Data

This work addresses three questions: (i) which SVR design/content/context characteristics promote or hinder intergroup interaction and dialogue; (ii) how multicultural groups behave in multi-user SVR deliberations; and (iii) How can AI-driven analysis of behavioral data generated from participant headsets, controllers and the VR platform provide insights into these interactions?

The study comprised three SVR sessions in Mozilla Hubs, designed to host participatory deliberative events focused on the climate crisis, examining intercultural group dynamics, participation, and interaction within a shared immersive environment. The structure intentionally mirrored key 'effective contact' conditions by establishing shared objectives (collective sense-making and solution ideation), equal-status ground rules (respectful turn-taking, explicit encouragement of quieter voices), and moderator support. Sessions were conducted in English as a lingua franca and were moderated to support respectful exchange and balanced participation.

Participants sent a profile picture to the researchers one week before their session; researchers created avatars for participants using ReadyPlayerMe (https://readyplayer.me/). The avatars preserved key identity markers (e.g., skin tone, clothing, religious attire), enabling both self-recognition and social readability.

Each session lasted approximately 45-60 minutes and followed a structured flow: a 10-minute

greeting and orientation (joining the environment, assistance with avatar/display settings, and norms), 5 minutes of formal presentation of the topic of climate crisis, and then a collaborative phase in which participants were instructed to form teams of three to four people to develop easy-to-implement solutions supporting global efforts to reduce global warming. Teams worked for about 15-20 minutes and received notifications a few minutes before time was up.

Teams then reconvened for a sharing and summary segment: the moderator invited each team to briefly present its solution, followed by a debrief and closing.

Participants were recruited from the Quest 2 and Quest 3 Community Facebook pages. In total, 28 participants took part, representing over 15 nationalities across Europe, Asia, Africa, and the Americas.

We used a qualitative, quantitative and computational mixed methods approach. Participants completed pre- and post-session questionnaires. The pre-session questionnaire asked about attitudes toward cultural diversity and their level of connectedness to their ethnic origins, and importance they place into social groups, as well as the Big Five personality traits using the Big Five Inventory (BFI). The post-session questionnaire asked participants to rate how interesting and comfortable the event was, what they thought of the diversity of the session, and how free they and others felt to share ideas; it also gathered open-ended feedback on the overall atmosphere, design, and interaction, as well as reflections on what was learned or challenged during the interaction. Additionally, before the session ended, the moderator conducted a debrief with all participants inside the SVR environment to capture open-ended interpretations of the discussion, perceived group dynamics, and how avatar presentation influenced interaction. The sessions were recorded and we qualitatively analyzed the recording and the sessions live in an observation analysis manner (taking notes and recording various forms of interactions and social dynamics).

To collect the data from the headsets, we used a platform called VR-Dialogue that was built and published by two of the authors of this paper [37], who deployed an instance of open-source, WebVR-based Mozilla Hubs on Amazon Web Services (AWS). The authors [37] used an existing open-source extension delivered by Li et al. [38] and Williamson et al. [39] for a CHI 2020 workshop. The solution published on GitHub [40] allows data collection via client applications of VR users. The component builds upon Hubs architecture to extract basic parameters such as the position and direction of avatar's body and head and voice volume level. The authors [37] modified and extended that client application by including additional data parameters, optimized the performance and coupled it with AI-driven analytics and feedback infrastructure deployed on a separate AWS cloud machine. the VR-Dialogue platform captured time-stamped behavioral traces during sessions. We logged and calculated behavioral telemetry based on the data collected from the headsets and controllers of participants (e.g., head and hand motion summaries, proximity patterns, speaking time and turn-taking). The design intentionally supports triangulation: qualitative observations and participant narratives help interpret behavioral patterns, while telemetry offers a systematic lens on interaction dynamics that are difficult to capture reliably through human observation alone.

3. Telemetric and Survey Dataset

Analysis triangulated qualitative observations and debrief comments with questionnaire responses and descriptive behavioral indicators from the session traces.

Our analytics approach fuses three complementary views of interaction: (i) what participants did in the SVR space (movement and conversational dynamics), (ii) what they reported about attitudes and identity, and (iii) an automatically learned 'motion signature' that summarizes patterns in embodied behavior. We emphasize interpretation over automation: outputs are treated as cues for facilitator reflection and hypothesis generation, and are cross-checked against field notes and participant accounts. The goal is not to label individuals, but to surface interaction styles and social dynamics.

The dataset combined VR movement logs (telemetric data) from three headset sessions with the pre-session questionnaire files and computed delta from all 28 participants. The VR logs contained time-stamped motion and position data for each participant, which were cleaned and turned into

fixed-length time series segments. Questionnaire responses were linked to participants in the VR logs by matching names (and, when possible, parts of their email addresses).

4. Findings

4.1. Qualitative and design-oriented observations

The multicultural composition of the sessions produced high engagement and curiosity. Personalized avatars allowed participants to present identity cues (e.g., skin tone or religious attire), which shaped recognition of social identity. The structured agenda (orientation, shared lecture, cooperative task, and moderated plenary) supported common goals and interdependence—core facilitating conditions for productive intergroup contact in deliberative settings. However, design choices also carried challenges: some participants noted that language (English as lingua franca) may have privileged fluent speakers, while avatar affordances and platform defaults have constrained accurate self-representation for some participants, due to the simplicity of the environment.

Across sessions, participants frequently described the atmosphere as lively and supportive, with humor and curiosity functioning as affiliative mechanisms. Participants often asked each other clarifying questions about local climate impacts, cultural practices, or political constraints, which helped transform potentially abstract climate discussions into situated narratives. Facilitators observed that avatar embodiment made spatial behaviors socially meaningful—for example, participants would step closer when expressing agreement or listening to a speaker in a conversation.

Survey responses and debrief comments suggest that the sessions supported perspective-taking and intercultural learning. Many participants reported that hearing first-person accounts from other regions increased the perceived complexity of climate responsibility and adaptation. Participants also described a heightened sense of social presence—'being with others' rather than merely exchanging messages—which some linked to greater willingness to disclose personal experiences.

4.2. Behavioral telemetry and questionnaire links

Using Q-only VR sessions (27 participants; 1,086 sessions in total), a hybrid late-fusion approach identified distinct, interpretable persona clusters and achieved moderate out-of-sample performance when evaluated with person-level splits (test accuracy ≈ 0.681; balanced accuracy ≈ 0.739; weighted F1 ≈ 0.589). Overall, cluster differences were visible in both (a) self-report profiles (identity and Big Five traits) and (b) movement and interaction dynamics captured through telemetry.

These results suggest that VR behavioral signals contain meaningful information about stable individual differences, although conclusions remain exploratory given the small sample. At an aggregate level, indicators related to movement, body language and interaction dynamics varied alongside self-reported diversity attitudes and personality traits, suggesting that how participants "take space" in SVR can reflect (and potentially shape) preferences, intergroup attitudes and experience of the session. We interpret these associations cautiously and use them to motivate more targeted follow-up studies.

The AI-supported analysis identified systematic links between behavioral patterns and questionnaire measures. In plain terms, certain body-language signatures tended to co-vary with self-reported engagement and inclusion-related measures. These associations are correlational, but they provide converging evidence that embodied attention and conversational participation in SVR are meaningfully connected to how participants experience the interaction.

4.2.1. Telemetry–trait alignment (cross-signal associations)

Across the dataset, several telemetry features showed small-to-moderate correlations with questionnaire measures. For example, higher vertical hand positioning relative to the head (hands_head_dy_mean) (r=0.28) and higher fraction of frames where any interaction is active ("entered_frac") (r=0.27) aligned positively with level of participant's connection, to their ethnic origin. Head turning rate

("head_turn_rate_mean") aligned positively with openness psychological trait (r = 0.24). Higher mean frames per second ("fps_mean") aligned positively with positive attitudes towards diversity (r=0.24) and with neuroticism personality trait (r=0.24). In contrast, the same feature (fps_mean) showed a negative correlation with emotional connection to ethnic group (r = -0.30), larger hand spread (hand_spread_mean) was negatively associated with neuroticism personality trait (r = -0.28) and larger spread between hands and head (hands_head_dist_mean) was negatively associated with connection to ethnic origin (r=-0.28).

4.2.2. Persona-style clusters and interaction styles

Cluster profiles were derived by aggregating predicted persona assignments and comparing normalized questionnaire and telemetry signatures. Below, "higher" and "lower" reflect deviations from the overall mean in the report's standardized cluster summaries.

Cluster 0: Self-report profile: Higher extraversion and conscientiousness (and mildly higher Neuroticism), alongside lower connection to ethnic group and lower support for diversity; younger age profile.

VR behavior profile: Elevated head turning (mean and p95), indicating frequent visual scanning. Slightly higher remote interaction fraction, but comparatively lower high-end locomotion and head movement speed and lower speed variability.

Taken together, this cluster appears attentive and outward-oriented (more head-turning) while moving in a more controlled, less speed-variable way, and engaging in remote interactions with others (not relying on proximity only).

Cluster 1: Self-report profile: Higher neuroticism and slightly higher extraversion, slightly higher support for diversity; lower openness and notably lower conscientiousness; younger age profile.

VR behavior profile: High peak movement speed (p95), slightly higher head speed (p95), and slightly higher sampling rate (fps), while head-turning is notably lower and overall samples are reduced.

This pattern is consistent with more direct, brisk movement through the environment and fewer head-sweeps—i.e., less exploratory visual search—potentially reflecting a task-driven, 'move-first' interaction style.

Cluster 2: Self-report profile: notably higher connection to ethnic identity (both cognitive and emotional indices, including grouped versions), alongside lower extraversion and lower neuroticism; youngest age profile.

VR behavior profile: highest head turning among all clusters (mean and p95) and slightly higher variability in movement speed (speed_std), while typical locomotion (speed and speed median) is lower as well as left-hand speed.

Overall, this suggests a comparatively slower-moving style with pronounced visual exploration—more looking around than moving quickly—consistent with a cautious or reflective engagement pattern.

Cluster 3: Self-report profile: Older age group, higher openness and slightly higher conscientiousness, lower extraversion, and lower ethnic identity connection measures.

VR behavior profile: higher high-end locomotion and head movement and more sampled sessions, while head-turning is lower and remote interaction is reduced.

This cluster therefore appears to navigate actively and consistently, but with fewer head-sweeps and less reliance on remote interaction—more proximity-based, 'go-and-do' movement through the space rather than scanning or interacting from a distance.

Collectively, the clusters suggest that persona differentiation in VR is not driven by a single "activity" axis and highlight that similar VR tasks can be enacted through markedly different combinations of locomotion (speed), visual exploration (head-turn dynamics), and interaction modality (remote vs close), and that these differences co-vary with self-reported traits and identity-related measures in this exploratory sample. Given the limited number of participants, findings should be framed as exploratory evidence that multimodal VR telemetry can support persona discovery and hypothesis generation for larger-scale validation.

5. Implications for SVR intergroup deliberation

Our findings reinforce SVR's potential as a medium for scalable intercultural deliberation: it can host structured, cooperative tasks under moderated conditions while enabling rich multimodal interaction and identity expression. From a design perspective, supporting equal-status interaction and voice equity likely requires attention to group formation tools, turn-taking facilitation, and affordances that reduce linguistic and cultural barriers. From an analytics perspective, motion-only and telemetry-based models can surface patterns related to identity and inclusion profiles, but these inferences should be treated as probabilistic, context-dependent signals rather than deterministic labels.

Designing SVR deliberations for intergroup contact should therefore treat facilitation and platform affordances as coupled. Practical implications include: (a) explicitly pacing turn-taking and building 'slow rounds' to counter language-based dominance; (b) using avatar customization thoughtfully, recognizing that visible identity markers can foster recognition and belonging but may also activate stereotyping; (c) leveraging spatial affordances (circles, small-group breakouts, shared objects) to redistribute attention and promote engagement; and (d) using lightweight analytics as reflective support for facilitators, particularly to notice when participation equity drifts over time. Because telemetry can be interpreted in multiple ways, triangulation with participant accounts remains essential.

6. Limitations, ethics, and interpretive cautions

The dataset is small (three sessions; 28 participants; 27 participants in the Q-only modeling subset), so results should be interpreted as exploratory. Model performance and feature associations may shift with different platform affordances, tasks, group compositions, and hardware measurement characteristics. Moreover, behavioral telemetry in SVR is sensitive: motion, gaze/pose, and voice activity traces can be identifying and inference-rich. Responsible use therefore requires data minimization, clear consent, careful governance over downstream interpretations, and reporting practices that foreground uncertainty and avoid stigmatizing conclusions about individuals or groups.

This work is exploratory and constrained by sample size and platform-specific affordances. Behavioral indicators can be confounded by headset fit, individual gesturing habits, disability-related movement differences, or cultural norms of expressiveness. The analytics are therefore positioned as probabilistic cues rather than diagnostic measures. Ethically, collecting embodied telemetry raises privacy and consent concerns, and interpretation can easily drift into overreach if outputs are treated as objective 'truth'. We address this by limiting identifiable reporting, emphasizing participant-centered interpretation, and framing analytics as a facilitator aid rather than a classification tool.

7. Conclusion

By combining a deliberative SVR intervention with synchronized telemetry, observations, qualitative feedback and survey measures, and by applying an interpretable hybrid ML pipeline, this work demonstrates a practical path for studying intergroup dynamics at high temporal resolution. Identity-adjacent attitudes and inclusion norms exhibited coherent survey structure and showed systematic alignment with embodied patterns in VR, while cluster-level profiles illustrated multiple interaction styles in multicultural group deliberation. Future work can extend these methods with larger samples, richer speech/turn-taking measures, and design experiments that directly test how SVR affordances shape voice equity, comfort, social dynamics and intergroup outcomes.

Overall, the study demonstrates that multi-user SVR can host meaningful intercultural deliberation while making interactional inequalities visible in new ways. By combining mixed-method observation with interpretable AI-supported analytics, we offer a practical approach to diagnosing when contact conditions are being met and when they are eroding. The findings motivate a design agenda for SVR deliberation that centers inclusion: structured facilitation, culturally responsive pacing, and careful, ethical use of behavioral signals to support—not replace—human judgment.

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Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT for Grammar and spelling check, and improving writing style. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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