A framework for low-level joint action in VR

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Social interactions, including joint actions, are a central aspects of human life (Frith, 2007; McCabe et al., 2001; De Jaegher et al., 2010). Joint action can be described as any social interaction whereby two or more people temporally and spatially align their actions (Sebanz et al., 2006). Due to their interactive nature, however, joint action studies are usually conducted under strictly supervised laboratory conditions with simplistic stimuli to obtain maximum control over all variables (Redcay and Schilbach, 2019). As a consequence, traditional paradigms often struggle to achieve an adequate level of ecological validity (Parsons et al., 2017). A potential solution to studying joint action in a more realistic setting without incriminating experimental control is the use of Virtual Reality (VR), in particular head-mounted displays (Giglioli et al., 2017; Marín-Morales et al., 2020). Moreover, aspects of participants' behavior can be measured and controlled in real-time, including subtle factors like non-verbal communication or interpersonal distance. Furthermore, VR technologies enable researchers to conduct experiments that are dangerous or unethical in real life (Skulmowski et al., 2014; Niforatos et al., 2020). Consequently, implementing joint action paradigms in VR could significantly reduce their variability while substantially increasing an experiment's reliability, replicability, and transparency (Pan and Hamilton, 2018).

Given its advantages, it is curious why there is a lack of low-level joint action research conducted in VR and a possible reason might be technical limitations due to multiplayer networking. Joint action studies focus on subtle behavioral factors and often rely on eye-tracking or reaction time measurements. Networking these variables becomes crucial for real-time interaction, and hence, an authentic simulation. However, since the majority of networking solutions are designed for consumer applications such as online gaming, they often lack low-level control of the networking variables and other essential modification options. To solve this need, we propose the new networking framework "LightNet" that is specifically designed for multiplayer experiments in VR. LightNet is a C# library created for - but not limited to - the usage with the game engine Unity and it allows for customizable real-time interaction between participants. LightNet provides complete control over sent and received data, and allows precise assignment of transferred variables, therefore improving data management options, performance, and frame rate of the virtual experiment. Like this, redundant or irrelevant information will not be transferred which makes data propagation more efficient. Further, LightNet is utilizing a reliable but slow TCP (Transmission Control Protocol) channel for transferring sensitive information like the experiment state, and an unreliable but fast UDP (User Datagram Protocol) channel for data that requires a quick response, like precise synchronization of position data between participants. Typical network solutions also emphasize a symmetric design of the contents and roles of agents inside the virtual environment, thereby restricting the design of dyadic experiments which is not the case with

LightNet. Additionally, it benefits from a lightweight architecture which can facilitate the usage for experimenters. In short, due to its customizable structure, LightNet allows individual modifications and customization of data transmission between participants, providing the necessary control that is crucial for low-level joint action experiments. To test its practicality we implemented two networking examples, each based on a well-known joint action study. The first example is based on a shared gaze study during a visual search task (Brennan et al., 2008). Similar to the original design, participants complete an O-in-Q search task but we adjusted the stimuli to trophies on a "Wall of Fame" (Fig. 1b). To implement the networking functionality, we needed to transfer the continuous shared gaze data of both participants while also transmitting the complex stimuli information due to changing, randomized number and rotation of distractors and target. The second experimental design originally examined mechanisms of anticipatory control during joint action (Knoblich and Jordan, 2003). While the task stayed similar to the original study, we adjusted the design so that participants control the beam of a laser cannon (tracker) on a spaceship to stay as close as possible to a moving target (Fig. 1c,d). The challenges of this example centered around networking and controlling the tracker and auditory feedback as they depend on both participants' input. In both networking examples, we explore different levels of modifying the 3D environment to increase immersion, encourage participant engagement, and add storytelling elements to the task. As our focus was to design a general framework, we refrained from recording data after successfully piloting the examples. However, LightNet (github.com/Ben1138/lightnet-unity) and the second networking example (github.com/Westdrive-Workgroup/Dyadic-interactions-2) are freely available for implementation or conduction. Overall, the networking examples demonstrate the usability of our networking solution LightNet and provide a framework for low-level joint action research in VR.

In conclusion, VR could be a promising solution, allowing real-time interaction in a controlled and ecologically valid setting. Applied to joint action, VR potentially increases a study's reproducibility, replicability, and transparency. Since appropriate networking is crucial for multiplayer experiments, we propose the new networking solution LightNet. Further, by implementing two networking examples, we provide a proof of concept for our framework. Thus, the presented networking solution LightNet and the networking examples can make VR more accessible for the scientific landscape of joint action research.

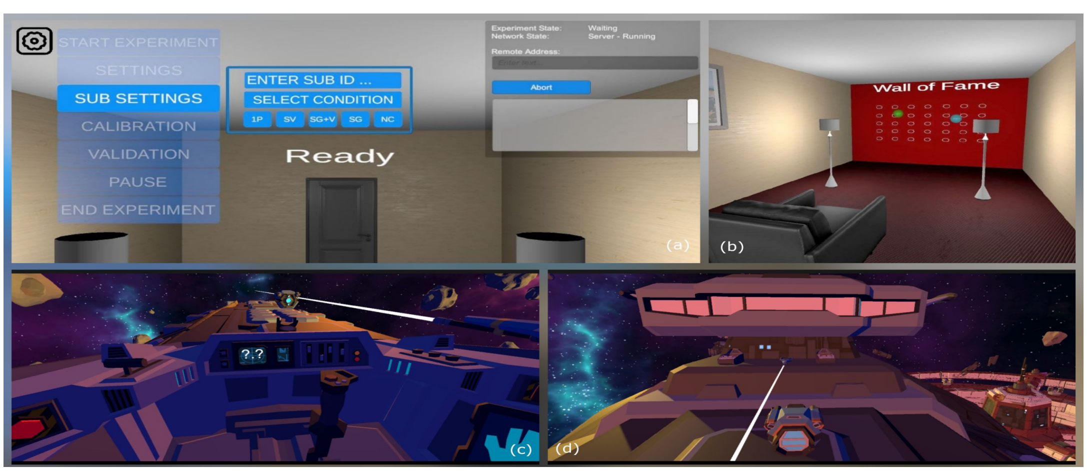

Figure 1. Networking examples. ***Example 1****, (a) main menu (left) and LightNet graphical interface (right), (b) experimental setup with visible gaze spheres.* ***Example 2****, (c) handle to control the laser beam (tracker), and target, (d) dyadic experimental setup.*

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