Social MatchUP: Collaborative Games in Wearable Virtual Reality for Persons with Neurodevelopmental Disorders

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Abstract. Our research explores game play in Wearable Collaborative Virtual Environments (WCVEs) to provide new forms of treatment for persons with Neurodevelopmental Disorders (NDD) that complement traditional methods of intervention. We investigate this issue using the *Social MatchUP (SMUP)* application as a case study. SMUP provides a set of games in WCVEs that have been co-designed with NDD experts and aim at improving communication skills. In SMUP, multiple users wearing a Virtual Reality visor play together to accomplish collaborative tasks that take place in shared virtual environments and require talking to each other to be completed. The paper presents an exploratory empirical study devoted to evaluate the potential of SMUP games for persons with NDD to improve their speech-based conversational capability. We organized participants (24 persons with NDD) in 2 groups, one playing a game in SMUP and one playing a similar game in the real world, and assessed likability, usability, and a number of conversational performance metrics. Our results indicate that the game experience in SMUP was usable and enjoyable, and boosted higher conversational skills with respect to its counterpart in the physical setting.

Keywords: Collaborative immersive virtual environment · Wearable virtual reality · Serious game · Neurodevelopmental disorders · Communication skill

1 Introduction

Our research explores the potential of serious games in collaborative virtual environments for a specific target group: persons with Neurodevelopmental Disorders (NDD). NDD is an umbrella term for a group of disorders (including, among others, Autism Spectrum Disorders, Intellectual Disability, and Communication Disorders) that are associated primarily with the functioning of the neurological system and brain [1]. According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5 [1]), individuals with NDD typically display co-occurring developmental impairments that very frequently affect social and communication skills, such as the inability to initiate and sustain reciprocal interaction and to apply language and speech to engage in conversations with others effectively. Traditional interventions typically involve one-to-one, clinician-directed

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interactions or group sessions that use different approaches to promote the development of linguistic skills, e.g., storytelling, "social stories", role-play, or collaborative board games [2], which stimulate active engagement and social interaction, create situations that motivate the conversation, and support their generalization to real-life contexts.

More innovative, but still exploratory, approaches use game-based interactive technologies to complement traditional interventions. In this arena, play activities in Collaborative Virtual Environments (CVEs) [23] are thought to be particularly promising and to provide a context for investigating new therapeutic practices. By allowing multiple users to play together within a shared virtual space, CVEs offers a stimulating and engaging environments that seem to promote alternative ways of social learning among individuals with NDD [5, 28].

Most existing studies focus on CVE-based play for improving collaboration capability of this target group. Relatively few studies look at these game experiences as means to practice and enhance communication skills [4, 7, 8]. Our research addresses this latter aspect, focusing on *speech-based conversational* skills. In addition, we consider a subclass of CVE technology, namely, CVEs on *wearable* head mounted displays, hereinafter referred to as *Wearable Collaborative Virtual Environments*, or *WCVEs*.

We explore the potential of WCVE-based games for persons with NDD using a case study - *Social MatchUP* (*SMUP* for short). SMUP is a set of multiplayer serious games that take place in various wearable virtual environments and have been co-designed by a mixed team of therapists and engineers with the specific aim of creating opportunities of spontaneous communication during WCVE collaborative play.

To evaluate the effectiveness of SMUP, we performed an exploratory empirical study that involved *24 persons with NDD* and was devoted to answer the following main research question: "*Does SMUP games enhance conversational skills in individuals with NDD more than analogous games in real-life?*"

Our results indicate that the game experience in SMUP was usable and enjoyable, and boosted higher conversational skills with respect to its counterpart in the physical setting, highlighting that properly designed play activities in WCVE could be adopted for NDD interventions in the communication area.

The rest of the paper is organized as follows: in Sect. 2 we discuss the related work concerning CVEs and WCVEs technologies in research, clinical practice and special education for individuals with NDD. After describing SMUP (Sect. 3), Sects. 4 and 5 present the research methodology of the empirical study and its main results. Sections 6 and 7 discuss the contribution of our research and outline future research directions.

2 State of the Art

Since more than two decades researchers have been investigating how Collaborative Virtual Environments (CVEs) and Wearable Virtual Reality (WVR) can provide means to develop new forms of treatment for various impaired populations, particularly persons with Neurodevelopmental Disorder (NDD) [10–13].

CVEs provide shared virtual spaces for multiple individuals to interact with one another and/or with virtual items, and have witnessed a growing interest for supporting social skills in individuals with NDD, particularly autism [22]. CVEs are especially suitable for simulating collaboration tasks and group work among patients in a safe and controlled environment; they provide opportunities for situational learning where behaviors and responses can be practiced and built upon in a context that provides minimal modification across similar scenes, stimulating generalization and mitigating the cognitive rigidity that often characterizes this target group [18, 25, 26]. CVEs seem to provide an efficient and beneficial means of fostering communication skills particularly among populations with language and emotion impairments [24], reducing the potential stress of face-to-face conversations, prompting communicative production and dialogues better than regular interventions [8, 27, 28], and engaging individuals for longer periods of time [29]. Some studies provide preliminary evidence that students and adults with autism respond socially to virtual characters supporting conversations and nonverbal cues in the CVE better than to humans, suggesting that these shared digital environments could offer useful platforms for intervention in the social and communication area.

In the past, the technological weaknesses of first-generation virtual reality headsets (e.g., poor viewing angles, high latency, and weight) and their high cost prevented the adoption of Wearable Virtual Reality (WVR) in educational or therapeutic interventions. Today's HMD displays are much more comfortable and often commercially available at an affordable cost, and a number of studies show that they are well accepted by persons with NDD. Experiences in WVR typically provide realistic or imaginary settings for practicing practical and social skills [14–18]. Thanks to their high degree of immersiveness, interactivity, and immediate feedback, they are thought to be useful to reduce behavioral problems, improve autonomy, and mitigate phobias. Regarding communication skills, WIVR technologies have been successfully used to encourage children in hospitals to interact with other children who have common conditions or disorders [19, 20]. Play experiences in WIVR seem to stimulate the hospitalized child to explore different scenarios and adopt different identities, which helps them to divert the attention from their health condition, also providing a safe environment in which they feels more comfortable to communicate with peers [21].

Despite the fact that both CVE and WVR technologies proved to have several advantages for individuals with communication deficits, there is a noted lack of CVEs applications that are expressly tailored for wearable devices and are targeted to people with NDD and their communication needs and impairments. These are the two main characteristics of Social MatchUP (SMUP), the game kit presented in this paper. The general game logic of SMUP is simple and mimics existing real-life games. Still, the play experience in SMUP has been explicitly designed to stimulate speech-based conversational skills: Play tasks require a mutual exchange of information between the participants to be completed and involve speech communication among players as a prerequisite for proceeding in the game, which is expected to improve conversational skills. The current version of SMUP extends the one presented in a previous paper [9] (where no evaluation activity was reported) and comprises a larger number of games (four), as discussed in the next session.

3 Smup

3.1 General Features

SMUP is a set of collaborative virtual reality games that are used on smart phones inserted in Google Cardboards. Google Cardboard is composed of two biconvex lenses mounted on a plastic or cardboard structure available in different colors and shapes. The smart phone set inside the visor displays the visual contents, splitting them into two near-identical bi-dimensional images. The illusion of 3D depth and immersion is created by the stereoscopic effect generated by the viewer lenses and the human visual system. The lenses map the up-close display to a wide field of view while also providing a more comfortable distant point of focus. The human brain combines the two images and gives the perception of a single planar representation. Interaction is based on gazing, i.e., looking at virtual objects or areas in the virtual world or changing gaze direction generates (possibly multimedia) effects. Gaze orientation and gaze focus are extrapolated from head position and movements detected by the sensors embedded in the smart phone. This technology has been chosen for two main reasons: low-cost and simplicity of the interaction mode. Smart phones are widely available and Google cardboard costs a few euros. The native interaction mode of this technology involves head movements and gaze control only, which is simpler to learn compared to interaction based external controllers, and more accessible to people with motor impairments or limited motor control.

In each SMUP game, two players share the virtual environment populated with virtual objects, and see each other as avatars. To activate an object, the user must look at it in such a way that the small visual "pointer" in the middle of the screen overlaps with it; After few seconds, the object changes color and can be "grasped" and "moved".

3.2 Games

The current version of SMUP includes four games: Matching Up the Pairs, Fixing, Collaborative Puzzle, and Sorting (Fig. 1). The games were designed in collaboration with NDD therapists from a local care center who collaborated with us in previous Virtual Reality projects, and are inspired to some concepts at the basis of well-known psychometric tests used in clinical practice (the Wechsler Adult Intelligence Scale-IV or WAIS) [33]. "Matching up the Pairs" was designed on the basis of the Symbol Search subtest of WAIS, "Fixing" on the Figure completion subtest, and "Puzzle" on the Visual Puzzle subtest. "Sorting" is the "sort by colors" version of the Sorting task. Play rules are defined keeping in mind an intrinsic characteristic of WCVEs, i.e., the users' *co-presence in the virtual environment,* as well as some additional requirements:

- Users play in pairs (collaboration within a larger group would be too complex) and perform a goal-driven tasks that can completed only by mutually sharing information, initially hold by one of the two players only; each user must therefore speak with his/her companion in order to proceed.
- The objects in the virtual reality space are familiar to the players, i.e., represent common objects that use in regular play (e.g., balls) or in therapy (e.g., picture cards), so that users do not need to understand what these objects are and can focus on what to do with them.

- There is no predefined, temporally rigid turn-taking: each user has the freedom to try a task as many times she or he desires and has all needed time to execute it and to negotiate turns with the companion;
- Games can be personalized (at different degrees) by both the patient and the caregiver, in order to make the experience more engaging and more appropriate to the players' characteristics. For examples, users can choose their own avatars and caregiver can set the complexity level (depending on the game, e.g., number of objects and their shape).
- With respect to the intellectual and motor skills required to play, games are "easy yet challenging": tasks involve actions similar to those that users would perform with physical objects in the real work, but have features (e.g., configurable constraints) that introduce complexity and challenges.

"Matching up the Pairs" Game

The game goal is to discover pairs of identical images (one image per player) and remove them from the scene. Each player has a set of images around him or her and cannot see the other player's set. The number of images is configurable and is the same for each player. Each image is surrounded by a colored aura (red for one player and blue for the other). Players have to look simultaneously at the same image for 5 s to make it disappear (which also generate a cheerful "pop" sound). In order to look at the same image, the players need to communicate with each other and describe the image they are looking at. The game ends when there are no more images in the scene.

"Fixing" Game

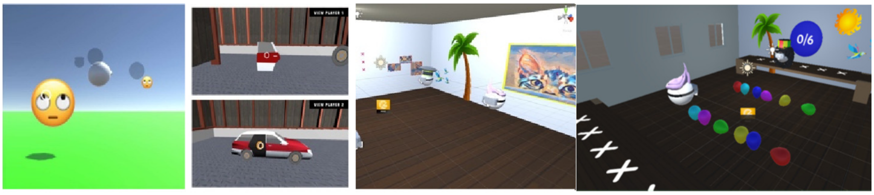
Players cooperate to "fix" some broken parts in a complex object. To do so, one player has to look at the broken object (e.g., a bike without a wheel), while the other one has to select at the corresponding "fixing" element (e.g., the bike wheel). Communication is needed in order to identify the missing element in the broken object.

"Collaborative Puzzle" Game

Players cooperate to complete a puzzle. One user sees the complete picture, while the other places the puzzle pieces on a grid that has configurable dimensions (sized min 3×3, max 10×10). The player selecting a piece must tell the characteristics of the piece to the other player. Th player looking at the puzzle must describe to the companion where to place the piece in the grid.

"Sorting" Game

Each player is in front of a table giving their back to the other player, and can grasp and move a set of balloons that have different colors and are initially located on the ground. The set of balloons is the same - for number of items, size and color of balloons - for each player. The goal of the game is to place all balloons on each table so that the sequence is the same on both tables. The players cannot see change view perspective, i.e., they cannot turn and see the other player's table. To complete the task, they must mutually describe the position of each balloon and negotiate the movements to perform.



(a) (b) (c) (d)

Fig. 1. The four games in SMUP: (a) Matching up the pairs; (b) Fixing; (c) Collaborative Puzzle; (d) Sorting

4 Exploratory Study

4.1 Research Method

We performed an empirical study to explore whether SMUP can enhance conversational skills in individuals with NDD. The research was designed as a controlled study where we compared the improvement of conversational skills in two groups of participants with NDD, respectively playing the Sorting Game in SMUP ("*VR group"; n = 12*) and a similar game in the physical context ("*Physical group"; n = 12*). Moreover. We also evaluated the likability and usability of the SMUP game, using a questionnaire submitted to all participants in the VR group.

4.2 Research Variables

To evaluate *conversation skills*, we adopted specific metrics for linguistic production that are theoretically grounded on Sack's conversational analysis method [34], and considered the following *measures of linguistic performance*:

1. *Length of the conversation*, in which we distinguished two sub-variables:

   a. Time where both players did not speak during the game (*silences*)
   b. Time where at least one player did speak during the game (*speaking time*)

2. *Total number of words* produced during the game
3. *Total number and types of utterances produced*, distinguishing a number of sub-variables:

   a. Total number of *single lexical words* produced (e.g. "yellow")
   b. Total number of *interrogative clauses* (e.g., "Where did you put the balloon?")
   c. Total number of *declarative clauses* (e.g., "I put the yellow balloon on the first spot on the left")

4. *Total number of turn takings* (calculated as the number of times a participant start speaking after the other participant has finished his/her turn of conversation).

The quantitative data to measure to the above variables were extracted by a researcher in linguistics analyzing the video recording of each session. The results were later compared inter-group (VR group vs Physical group) to investigate the potential communication benefits of game-based activities in virtual reality with respect to analogous plat in physical sessions.

Concerning *Likability* and *Usability* of the SMUP game, we used a survey method. Participants in the VR group were asked to complete two questionnaires (reported in Annex): one comprising a set of questions investigating how much they enjoyed the SMUP game, and one focusing on the ease of use of the different actions required by the game. Each questionnaire (see Appendix) consisted in a set of 10 questions, each one associated to a 7 points scale [35] (7 being the highest value, 1 the lowest one). In both surveys some questions asked about positive attitudes towards the application (e.g., “Was the game fun”?) while others investigated negative attitudes towards the application (e.g., “Was the game boring?”).

4.3 Participants

Twenty-four adults with NDD (10 females) aged 20–50 years old (mean = 29;3, SD = 7.7) were recruited from two local non-profit associations. The diagnosis of NDD was based on diagnostic assessment by a psychiatrist and confirmed by the DSM-5 criteria. Among the diagnosis of NDD we acknowledged individuals with Autism Spectrum Disorder, with Intellectual Disability, with motor disorders, with other “not otherwise specified” neurodevelopmental disorders. All the participants were monolingual Italian-speaking. They were randomly assigned to one the experimental conditions (SMUP game and physical game). In each group we randomly created 6 pairs of players. Groups’ characteristics are reported in Table 1, showing that there is no significant difference between the two groups on age (U (23) = 64.5, p = .685).

Table 1. Characteristics of the two groups of participants

Group	Mean Age (y;m) and range	Gender
VR	29;1 (22;0–25;5)	F (n = 6) M (n = 6)
Physical	29;4 (20;9–50;9)	F (n = 4) M (n = 8)

4.4 Apparatus and Materials

The Game

We selected the *Sorting Game* to achieve the highest level of similarity in the two experimental conditions, in terms of objects, environment set-up, and play rules.

Both the virtual and the real environments for game play have the following characteristics: The space was a simple room with no furniture except two big tables in front of which the players are located; The room was symmetric (squared), in order to give players the same exact points of reference in the space (Fig. 2); Each table was marked with white crosses at equally distant positions to identify where objects could be placed; All users had six balloons to manage (a size that therapists suggested to be the appropriate level of complexity for the profile of participants); The two players had to maintain the front view of their table, giving their back to the other player. In the virtual version, the application prevented "by design" each player to turn and see the other player. In the physical version, users were instructed to maintain the front positing and were reminded to follow the rule by their caregivers.

In the virtual version, the player could: grab a balloon by staring at it for a few seconds; drag it with the gaze by moving the head in a given direction, and release it on one of the available positions by stopping there for few seconds. Visual and audio feedbacks were produced when a balloon was successfully grabbed and placed on any free position. A victory sound effect (people clapping) was produced when both players positioned the balloons in the same mutual order.

In physical play, the user grasped the blown-up balloons with their hands and moved them to the different positions (a sticky strip was used to keep the balloon in place), receiving a "bravo!" greeting from the caregiver (otherwise silent, and clapping only at the game completion) (Fig. 3).

Fig. 2. A session of the Sorting Game in SMUP

Fig. 3. Preparing the room for the physical Sorting Game

4.5 Procedure

The study was performed within the therapeutic centers' ordinary schedule, to ensure that the research would not impact the normal flow of participants' activities. All individuals signed a consent form authorization to perform the study following the research protocol. The study received the approval from the Ethical Committee of our University.

Each pair of players was involved in one session and played the game in the assigned modality (either VR or Physical) until they completed the game. Both in the VR and the physical condition, the game was explained to each user before the session. The members of the VR group were trained on Wearable VR before the study, using a "tutorial" application designed for users to learn the gaze-based interaction mechanism. At least one caregiver was present in each session to maintain a high level of focus and a schedule that was appropriate for all participants. Each session was video-recorded. All participants in the VR group filled the two questionnaires (on Likeability and Usability – see Appendix) at the end of the session.

5 Results

5.1 Linguistic Performance

Due to the non-normal distribution of the data (which was confirmed by the Shapiro–Wilk test), our analyses were conducted using non-parametric tests, with ANOVA by ranks (Kruskal–Wallis test) in order to reveal group effects, the Mann–Whitney test for inter-group comparisons, and the Wilcoxon test for intra-group comparisons, associated with Spearman's rank correlations. Results were considered significant at $p < .05$.

Session duration ranged between 3:15 min to 13:40 min. Our findings indicate that the VR group took more time to complete the task than the Physical group, with an average time of 08:24 min of VR sessions against 06:34 min in Physical sessions (Fig. 4). As mentioned in Sect. 5.2, in the analysis of play time we distinguished between the periods during which the participants communicated with each other (*Speaking Time*) and the periods when participants did not communicate (*Silences*).

Speaking Times were similar in the VR group (5:48 min) and the Physical group (5:21 min), while Silences were longer in the VR group (2:36 min) than in the Physical group (1:13 min). Nonetheless, Mann–Whitney inter-group comparisons showed that differences between the two groups were not significant on average time spent playing the game (U (23) = 98, p = .259), on speaking time (U (23) = 22, p = .588) and on silences (U (23) = 26, p = .225).

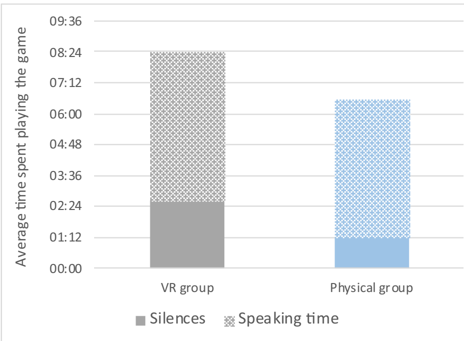


Fig. 4. Average time (silences and speaking time) spent playing the game by each group.

Concerning the *verbalization* produced by the players (Fig. 5), the results show that the average number of exchanged words in the virtual reality play context (*average produced words* = 82.4) was *significantly higher* than the one obtained by players in physical sessions (average produced words = 51) (U (23) = 104.5, p = .047) indicating that the players in the VR group were more engaged in mutual communication than the players in the Physical group, and had a bigger linguistic production.

It is worth considering these findings also in light of the absence of correlation ($r_s = .297$, $p = .158$) between the number of words produced and the amount of time spent by each player communicating with their companion during the game. Figure 6 shows that individuals with NDD who played the Sorting game in VR were more prone to communicate with each other than individuals who played in the physical environment, *even when the "speaking time" was the same in the two conditions.*

Concerning the *number of turn takings*, the value of this variable was significantly higher in the VR group than in the Physical sessions ($U\ (23) = 111$, $p = .024$).

Taken together, these findings suggest that for individuals with NDD, game activities in wearable VR environments might be more effective to stimulate conversational skills that physical play in a real environment.

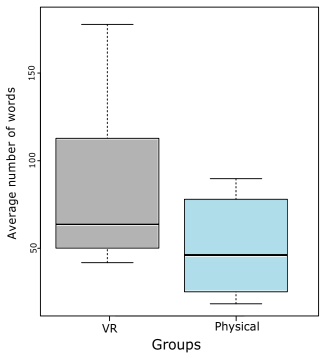


Fig. 5. Mean rate of words produced by the VR group and the Physical group on the Sorting task

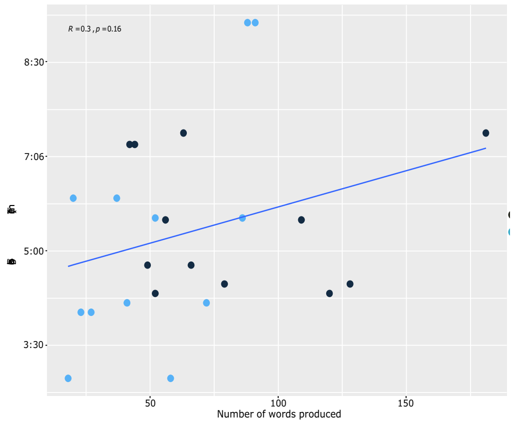


Fig. 6. Comparison between number of words produced and speaking time in minutes for each individual in the VR group and in the Physical group

Regarding the *type of utterances* emerged during the conversation, 75% of the production of the VR group were *declarative clauses*, 12% were *interrogative clauses* and 13% single lexical words. The production of utterances types for the Physical group was distributed as follows: 93% of declarative clauses, 6% of interrogative clauses and 1% of single lexical words. A tendency to significance emerged between the two groups on declarative clauses ($U\ (23) = 102.5$, $p = .081$) and single lexical words ($U\ (23) = 105$, $p = .056$), while no difference emerged on interrogative clauses ($U\ (23) = 93.5$, $p = .195$).

5.2 Likeability and Usability

The results of likeability that emerge from the survey (see Appendix– Table 2) showed a general positive attitude toward the VR game: the overall likeability on items investigating positive attitude towards the application was around 89% of positive responses, with five people who exclusively assigned scores in the range between 6 and 7 points of the Likert scale. Results on the three control items (3, 5, 8) of the questionnaire, investigating whether the participants perceived the game as boring or annoying, showed a general disagreement. In particular, the results confirmed a good degree of engagement of the game task (Fig. 7), with a nearly unanimous high vote on the questions relative to how fun and engaging was to play the game (Items 1, 4, 6, 10). In addition, results showed a general curiosity and attraction toward games in Virtual Reality, with a mean of 6.4 points to question 9: “would you like to play other game with the headset?”. Results emerging from the usability questionnaire (see Appendix– Table 3) were also positive, with a majority of the population who gave an overall score equal or greater than 5 points on the Likert scale, which indicates the effective ease of use of the SMUP game (Fig. 8). Further confirmation was given by the answers to items 5 and 10, which excluded possible negative effects of VR. Comments given by participants with motor disorders pinpointed two critical points in the experience that may affect usability for this population: the difficulty in reaching some objects with the gaze and some uncomfortable feeling in wearing the VR headset.

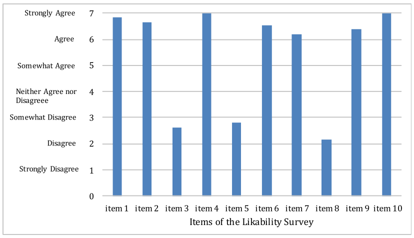


Fig. 7. Questionnaire results: Likeability

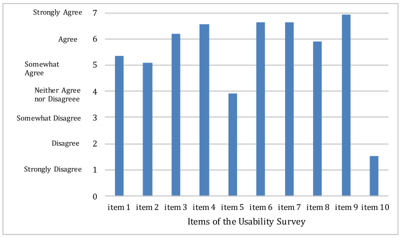


Fig. 8. Questionnaire results: Usability

6 Discussion

The findings of the study seem to suggest that when compared on the same game (Sorting Game) played in wearable virtual reality and in the real world, individuals with NDD were more prone to communicate with each other in the former environment. This evidence emerged from the significantly higher number of words and turn-takings produced by the VR group with respect to the Physical group. Crucially, the amount of speaking time in the two groups was very similar, indicating that playing the task in virtual environments did not lead to a longer amount of time spent conversating, but to a richer conversation between players (in terms of number of words produced).

Quantitative analysis on the types of utterances produced showed no significant result. Nonetheless, some considerations can be made from a qualitative point of view. Declarative clauses (e.g., “I put the yellow balloon on the first spot on the left”) were the most frequently produced utterances in both modalities, indicating that players usually communicate with each other with the aim of describing the exact position of the objects on the tables. Interrogative clauses, particularly “Wh-questions” (e.g., “Where did you put the balloon?”, “Which color is the balloon?”) were more frequent in the VR group than in the Physical group. This may be due to the fact that wearing headsets and being immersed in a shared virtual space never seen before was an unprecedent situation for the participants. This may have led in turn to a higher number of questions to the other player in order to confirm the position or the color of the balloon in the virtual space.

In this vein, we can interpret also the higher mean rate of lexical words (e.g. "yellow") produced in the virtual environment: these single words were usually used as answers to questions. The higher percentage of interrogative clauses in the VR condition w.r.t. the physical condition (the value is doubled in VR) is an interesting finding also from a social interaction perspective. Interrogative clauses are those utterances that – more than declarative clauses – trigger linguistic production between two interlocutors and characterize the "relational" dimension of the conversation and its "dialogic" nature; indeed, dialogue etymologically means "speech through", i.e., an "exchange of speech acts" between two actors).

In general, the results of our research are consistent with previous studies showing the potentiality of wearable VR and CVEs in enhancing communication and social skills in individuals with communication deficits [29–32, 3, 6]. SMUP allowed players to perform the game task in a more controlled and ecological modality, which in turn seemed to prompt and enhance linguistic production and dialogues more than physical play. Even the fact that the time spent playing the game was longer (even tough not significant) in VR than in real-life session could indicate that the use of SMUP engaged individuals for longer periods of time. A deeper morphosyntactic, semantic and pragmatic analyses of the production of persons with NDD during play in the two experimental conditions (planned, but not yet performed) may provide further insights on the differences in linguistic performance level between VR and physical settings.

In summary, our findings indicate that wearable CVEs could be introduced in therapeutic activities, alongside traditional methods, with the specific aim to support communication reinforcement in individuals with NDD.

Still, our empirical study is explorative and has a number of limitations; its results are preliminary, and should be interpreted as early indications. Analogous exploratory studies should be run with the entire game kit of SMUP as well with other games in wearable CVRs to test the validity of the results. Moreover, the size of the groups of participants was comparable to most studies in the field of interactive technology for NDD persons, but is still too small to enable us generalize the benefits of VR game play to the entire population with a similar profile. A higher number of participants would be needed to lead to more statistically significant results. Finally, even if the study procedure and the data analysis protocol were well defined before performing the study, we had to face, as it is common in most empirical studies, some technical issues during the interaction in the VR mode (e.g., network connection issues) that may have biased our results.

7 Conclusions and Future Work

In a society where social and communication disorders are amongst the most frequent co-occurring conditions worldwide [36], it is important to investigate the use of innovative technologies, such as wearable collaborative immersive virtual environments, for individuals with conversational impairments. Our research explores the potential of Wearable Collaborative Virtual Environments (WCVEs) to enhance conversational skills in individuals with NDD (who very often have social and communication impairments). In this paper, we have addressed this issue using a case study: SMUP - a set of WCVE games designed specifically for this target group. Specifically, we have explored whether SMUP can be a suitable and engaging medium with respect to traditional interventions that exploit play activities in physical settings, in order to improve linguistic production capability.

In order to answer to this question, we ran an exploratory study involving two groups of individuals with NDD who played a Sorting Game in SMUP and in a physical setting respectively. We applied domain-specific measures of the linguistic production during conversation (speaking times, silences, turn takings, number of words and utterances) in order to see whether players who completed the activity in the VR were more prone to communicate than players who completed the game in physical settings. Finally, we assessed likability and usability of the SMUP game using two structured surveys submitted to the participants who played in SMUP.

To the best of our knowledge, our research is unique in the current state of the art for a number of reasons. None of the studies in the current literature: i) have verified the effectiveness – for persons with NDD - of playing in wearable collaborative virtual environment by comparing its benefits against the ones of playing the same game in real life; ii) have analyzed the conversational outcome of the activity played in the two situations (WCVE and physical setting) using theoretically grounded linguistic metrics; (2) have involved individuals with forms of NDD other than Autism Spectrum Disorder.

Our study indicates that SMUP is a suitable medium for enhancing conversational skills of people with NDD. This evidence emerged both from results on linguistic production (significantly higher in the VR experience) and from positive findings on the two surveys on likability and usability.

More generally, our study sheds a light on the potential of game play in wearable collaborative virtual environments to provide new forms of interventions for individuals with communication impairments, offerings a means that is engaging and affordable (in term of costs and duration) and might even be more effective than play in traditional physical settings.

There are several items in our future research agenda. We will run a similar experimental study using the other three games of SMUP. We will explore the use of SMUP with other populations, particularly people with specific language disorders (e.g., pragmatic language impairment or stuttering) and persons with NDD from other countries and continents (notably Asia), in order to investigate whether the presence of specific disorders or cultural differences would impact on the linguistic production findings associated to SMUP. Finally, we are working on technological aspects in order to simplify the work of therapists and researchers. We are integrating in SMUP some new features to support automatic data gathering and (at some degree) automatic assessment of linguistic metrics based on the analysis of speech-to-text transcriptions.

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Appendix

Table 2. Survey on Likeability

Items	Questions[a]
Item 1	How much did you like the game?
Item 2	Is the game good?
Item 3	Is the avatar annoying?
Item 4	Is the game fun?
Item 5	Is it bad to play with the avatar?
Item 6	Did you have fun playing the activity?
Item 7	Is the environment nice?
Item 8	Was the game boring?
Item 9	Would you like to play other game with the headset?
Item 10	Was the game engaging?

[a]Each question must be answered on a 7 points scale

Table 3. Survey on Usability

Items	Questions[a]
Item 1	How easy was the game for you?
Item 2	How comfortable was to wear the headset?
Item 3	Is it easy to play?
Item 4	Is it fun to look for the balloons?
Item 5	Is it annoying to keep the headset on?
Item 6	Could you clearly see what was shown by the headset?
Item 7	Was it clear what you had to do?
Item 8	Was it simple to understand where the avatar was
Item 9	Was it simple to find the objects indicated?
Item 10	Was the game too tiring?

[a]Each question must be answered on a 7 points Scale

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