Emotions and Telerebabilitation: Pilot Clinical Trials for Virtual Telerebabilitation Application Using Haptic Device and Its Impact on Post Stroke Patients' Mood and Motivation

Shih-Ching Yeh[1], Margaret McLaughlin[2], Yujung Nam[2], Scott Sanders[2], Chienyen Chang[2], Bonnie Kennedy[2], Sheryl Flynn[2], Belinda Lange[2], Lei Li[3], Shu-ya Chen[2], Maureen Whitford[2], Carolee Winstein[2], Younbo Jung[4], and Albert Rizzo[2]

[1] National Central University, Taiwan
[2] University of Southern California, USA
[3] Microsoft, USA
[4] Nanyang Technology University, Singapore
shihchiy@csie.ncu.edu.tw

Abstract. We describe a pilot clinical trial with a flexible telerehabilitation platform that allows a therapist to remotely monitor the exercise regimen and progress of a patient who previously suffered from a stroke. We developed virtual game environments which were host to a progressive set of training tasks from precise fine motor movements to reaching movements that involve full arm and shoulder activity. Concurrently, the therapist monitored the progress of the patient through a video channel. Assessment of psychosocial variables show that negative feelings (confusion, $t(13)=2.54$, $p<.05$, depression $t(13)=2.58$, $p<.05$, and tension, $t(13)=2$, $p<.1$) were significantly lessened after the game play. Patients' overall satisfaction with the telerehabilitation system was positively correlated with the feeling of co-presence of the therapist, $r(8)=.770$, $p<.005$. Patients felt less efficacious in continuing therapy after participating in the telerehabilitation game compared to their reported perseverance self-efficacy before the game, $t(5)=2.71$, $p<.05$ and showed decreased willingness to persist in therapy regardless of fatigue after the game play, $t(5)=2.67$, $p<.05$. However, when patients' pretest mood scores were taken into account, this trend was reversed. Patients' active mood before the game was positively correlated with their willingness to persist in the therapy after the game, $r(14)=.699$, $p<.005$. Telerehabilitation significantly enhanced stroke patients' psychological states.

Keywords: Virtual reality, stroke rehabilitation, telerehabilitation, haptics.

1 Introduction/Background

For a number of years a large interdisciplinary team of researchers at the University of Southern California has been engaged in a series of studies of virtual environments

R. Shumaker (Ed.): Virtual and Mixed Reality, Part II, HCII 2011, LNCS 6774, pp. 119–128, 2011.

and games for recovery of motor function following a stroke. Our goals have been to create rehabilitation scenarios and exercises that maximize therapeutic movement with cortical reorganization goals in mind; motivate patients to persist in training using gaming features; provide immediate feedback; are easy for therapists to administer and monitor; provide useful data in repeated-measures designs; and result in improved real-world function. Some of our efforts in this regard are reported in [1-4]. We have also turned our attention to extending this work into distributed environments where patient and therapist are not co-located. Well-defined and standardized outcomes used in telerehabilitation studies indicate that progress in addressing motor deficits may be addressed by remotely delivered therapeutic regimens [5] but the emotional and cognitive impact on patients may not be addressed. It is well documented that post-stroke patients suffer wide ranging psychological and cognitive disorders induced by cognitive impairment from damage to one side of their body or other limitations.

Below we report on a pilot trial investigating some factors influencing the satisfaction of therapists and patients with a telerehabilitation system and the impact of telerehabilitation game play on patient mood states and willingness to persist in therapy.

The primary argument for using games or game-like exercises for motor rehabiitation is that they may be sufficiently enjoyable to motivate patients to persist where other less engaging methods result in a substantial loss of interest in continuing training. Design choices made in games and the virtual environments in which they are played may influence enjoyment through encouraging a sense of presence, the feeling of “being there” when the player becomes totally absorbed and awareness of the physical place of game play is lost. In telerehabilitation, the critical element may be the sense of co-presence. A satisfactory experience will require that both parties experience themselves as co-located and mutually aware of, responsive to, and responsible to one another. Based on the foregoing we expect that the telerehabilitation experience will create elevated mood states and that the extent to which patients and therapists experience a sense of co-presence will be associated with satisfaction with the telerehabilitation system and willingness to persist in therapy. Thus

- H1: Mean scores on negative feelings after playing the telerehabilitation games will be lower than the scores before the game play.
- H1a: Patients’ scores on feeling confused will be lower after playing the telerehabilitation games than before the game play
- H1b: Patients’ scores on feeling depressed will be lower after playing the telerehabilitation games than before the game play
- H1c: Patients’ scores on feeling tension will be lower after playing the telerehabilitation games than before the game play
- H2: Patients' overall satisfaction with the telerehabilitation system is positively correlated with the level of presence of therapists during the game play.
- H3: Patients will demonstrate increased willingness to persist in therapy after the game play.
- H3a: Patients will demonstrate increased willingness to adhere to daily therapy regimen after the telerehabilitation game play.

- H3b: Patients will demonstrate increased willingness to persist in therapy regardless of fatigue after the telerehabilitation game play.
- H4: Patient's active mood before the game play is positively correlated with their willingness to persist in the therapy after the game play.

2 Materials and Methods

Approval for the study was obtained from the Institutional Review Board at the University of Southern California. All participants were provided with an information sheet describing the purposes and requirements of the study and written consent was obtained. Participants were recruited for either a patient or a therapist role. Inclusion criteria for the patient role were impairment of motor coordination in a upper extremity following stroke, traumatic brain injury, spinal cord injury, or amputation. Exclusion criteria were sensory, cognitive or linguistic limitations that would be make it difficult for them to respond to a computer interface, follow instructions, or complete questionnaires orally in response to an English-speaking interviewer. The inclusion criterion for the therapist role was that the individual was currently practicing occupational or physical therapy in California.

Patient volunteers were recruited at Precision Rehabilitation, Rancho Los Amigos Rehabilitation Clinic and other rehabilitation clinics in Southern California. Clinic managers and staff therapists were provided with flyers to raise patient awareness of the study and provide potential patient volunteers with the investigators' contact information if they were interested in finding out more about the study. Therapist volunteers were recruited from Precision Rehabilitation, Rancho Los Amigos Rehabilitation Clinic and other rehabilitation clinics in Southern California. Recruitment took place through clinic managers who were provided with flyers and a form letter email describing the study and the investigators' contact information.

2.1 Experimental Protocol

All telerehabilitation sessions were held at the facilities of Precision Rehabilitation in Long Beach, California. This outpatient facility is focused primarily on rehabilitation of individuals with spinal cord injury, traumatic brain injury, stroke and amputation. Therapist/patient pairs were taken into separate rooms. A third room was used for administrative tasks and questionnaire administration .Each of these rooms had a door which remained closed during the questionnaire administration and computer game sessions so that study activities would not be accessible or visible to others at the center who were not directly involved.

Each participant had the study explained to him or her and each was provided with the opportunity to ask questions. Following informed consent, the patient and therapist separately completed a series of questionnaires (see Measures, below). The therapist was provided with an instruction sheet for the technical aspects of the telerehabilitation session and a script to engage the patient in the therapeutic tasks. Both participants were informed that they would communicate with one another over an Internet connection between the rooms. The therapist’s role was to guide the patient through the setup of the systems and then talk him/her through three computer games designed to provide motor rehabilitation exercises for the upper extremity. Following completion of the tasks, the patients and therapists were asked to complete a usability questionnaire answering a series of open-ended and closed-ended questions and a post-test questionnaire about willingness to persist in training. Study personnel able to handle technical issues with the networking components or assist the patient with equipment use were available at all times.

2.2 System Description

The telerehabilitation system was composed of two subsystems: a motor rehabilitation system and a tele-communication system.

Motor Rehabilitation System

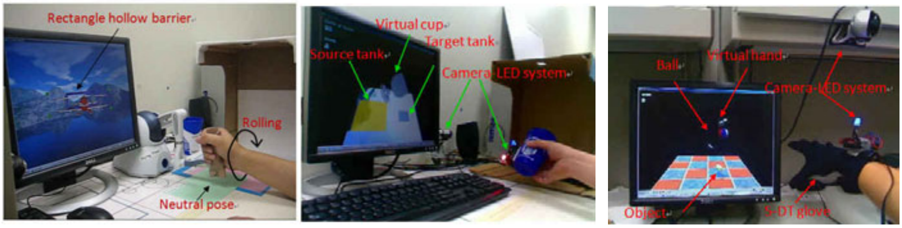
Task 1: Plane Flying. This task was designed for practice in wrist pronation/ supination. In the virtual environment; there was an airplane moving forward with a constant speed and participants had to manipulate the airplane up-down or left-right and roll the airplane via wrist pronation/supination in order to fly through a sequence of hollow rectangular barriers set with different rolling angles. To interact with the virtual environment, the user employed an Omni haptic device. The Omni provided force feedback as an indication to the participants that the airplane had hit the rectangular barrier. To come up with various difficulty levels so that participants were able to repeatedly challenge the limits of their current motor capability, several parameters were chosen and combined in different ways. First, the size of the rectangular barriers (width and height) was a parameter that determined how accurate and stable the movement was required to be to position the airplane appropriately without hitting the edges of the barrier. The smaller the size of the barrier, the greater the accuracy and stability of wrist movement that was required. Second, the “rolling angle” of the barrier was set to direct the offset of wrist rotation from a neutral position. The larger the rolling angle of the barrier, the more rotation of the wrist was required. Third, the “speed” of the moving airplane was a parameter determining how soon in the user’s forward motion the airplane approached the next rectangular barrier. A higher moving speed of the airplane meant that participants had a shorter reaction time to respond. Three difficulty levels were designed with the combination of the parameters above. To measure the performance of participants, a rate of passing through the barriers was defined as the ratio of the number of successful passing trials to the number of total trials.

Task 2: Water Pouring. This task was designed for the practice of wrist pronation/supination. In the virtual environment, participants manipulated a cup via wrist pronation/supination in order to fill it with water from a source water tank and pour the water into a target water tank. The interaction between participants and the virtual environment was achieved by a camera-LED tracking system. To define various difficulty levels so that participants were able to repeatedly challenge the limits of their current motor capability, several parameters were selected. First, the “size” of the source and target water tanks was a parameter to determine how accurate and stable the movement would have to be in order to fill or pour water without loss. The larger the size of the water tank, the less accuracy of movement required to fill or pour water. Second, a threshold with respect to the rolling angle offset from the neutral pose of the wrist was set to determine if the water was able to flow into/out of the cup. Specifically, the rolling angle made by the wrist should exceed the threshold in order to activate the water flow. A higher threshold required a larger rolling angle of the wrist to complete the task. With the combination of parameters mentioned above, three difficulty levels were designed. The total time to complete each task was recorded as a measure to evaluate participants' performance. Performance score was further defined as the summation of the reverse of total time at each level, multiplied by a weighting factor for each difficulty level. A higher score meant a better performance.

Task 3: Ball Dropping. This task was designed for the practice of hand opening. In the virtual environment, participants manipulated a virtual hand with a ball in it. Their task was to reach an object hanging above a grid and drop the ball via hand opening as rapidly as possible. A 5-DT data glove and the camera-LED tracking system were used to sense the hand opening and hand movement respectively. A difficulty level could be determined by the degree of finger extension which defined hand opening and taking into account the initial calibration for each participant. (However, in this pilot study we set the degree of finger extension as a constant). To measure the performance of participants, several measures were defined. First, movement efficiency, defined as the length ratio of the actual moving path over the shortest possible path was used to evaluate the efficiency of participants' moving paths. A smaller value of moving efficiency represented greater moving efficiency. Second, the time (move time) spent in moving the virtual hand from the start position to the top of the target object was recorded. A lower value of move time represented greater mobility. Third, the time (hand open time) spent in opening the hand was recorded as an indication of the dexterity of hand opening. A lower value of hand open time represented better performance.

Tele-communication System. The tele-communication system was designed with the use of peer-to peer network technology as a flexible platform that can deploy applications which require high-speed transmission of delay-sensitive media streams, such as audio, video, and miscellaneous data. Beyond the transmission of media streams, three functionalities were further developed to satisfy various objectives from the perspectives of therapy, usability and human perception. First, SkypeTM was embedded into our framework to enable oral and visual communication (with the use of webcams) between the patient and the therapist; thus, the therapist was able to remotely monitor the exercise regimen and progress of a patient and direct the patient through a complete practice session using interactive VR tasks as in clinics. Second, while the patient focused on interaction with the game environment, a view-synchronization mechanism was made so that the view of the game environment as seen by the patient was transmitted to the therapist's screen. Thus, in addition to watching the live video stream of the patient's behavior through a second camera focused on the patient's arm, the therapist could also see exactly what the patient saw on screen. The system was designed to enhance the sense of presence in the virtual environment and co-presence between the patient and the therapist who were located remotely. Finally, a remote database system was constructed to store various measures of the patient's performance, such as motor data, task completion time, task completion rate, etc., which were transmitted immediately and continuously via DSL.

The therapist was able to retrieve the data of the patient's performance at a later time for further analysis.



(a) (b) (c)

Fig. 1. (a) Plane Flying task. (b) Water Pouring task. (c) Ball Dropping task.

2.3 Measures

Data collected from patients included a demographic and computer use questionnaire; the mood as measured by the POMS-A; experience of "presence" in the telerehabilitation environment, willingness to persist with therapy, and a telerehabilitation usability questionnaire. To therapists we administered a demographic and computer use questionnaire, a presence measure, and a usability questionnaire.

Mood was operationalzed by modifying the Brunel Mood Scale (POMS-A). Composite indices of three mood items, (1) negative, (2) confused and (3) active mood, and one item measuring depression were drawn from the relevant POMS-A items. Evaluation of negative mood was created combining the eleven 5-point scale negative attitude items (Chronbach's alpha = .953). This includes the following individual mood items; feeling downhearted, annoyed, exhausted, bitter, unhappy, anxious, worried, miserable, angry, tired and bad tempered. Confusion was a composite index combining the following four items from the POMS-A; feeling confused, mixed-up, sleepy, and uncertain (Chronbach's alpha=.819). Evaluation of active mood was an index composed of the following four items; feeling lively, energetic, active, and alert (Chronbach's alpha = .952).

Telerehabilation usability for the patient was an composite index of thirty-seven 7-point scale items, including "The telerehab system was easy to use;" "I felt comfortable using this system;" "The instructions helped me complete this task;" "I learned to do the movements quickly with videoconferencing;" and "Overall I am satisfied with the amount of time it took to do the exercises" (Chronbach's alpha = .917). Telerehabilitation usability for the therapist was composed of twenty-six 7-point scale items (Appendix A) including; "I am satisfied with the feedback system;" "The feedback window easily allowed me to see changes in the patient's performance;" "I would recommend the telerehabilitation system to other people;" "Overall, I have the impression that the telerehabilitation system will increase the scope of patient care/treatment;" "Overall, I have the impression that the telerehabilitation system will increase patients' accessibility to clinicians" (Chronbach's alpha = .909).

Willingness to persist in therapy was measured by two 7-point scale items; "I believe I can do therapy every day that it is scheduled;" and "I believe that I can do therapy no matter how tired I may feel."

Presence in the telerehabilitation environment for patients was measured with five 7-point items; "I felt like I was with the therapist;" "There were times I felt like the therapist was with me in the same room;" "I felt like the therapist and I worked well together;" "I felt like the exercises using the telerehabilitation system were the same as working with the therapist face-to-face"; "I felt that there was another person working with me on the exercises" (Chronbach's alpha=.815). Presence for therapists was similarly measured by five 7-point scale items such as the following; "To what extent, if at all, did you have a sense of being with the patient?"; "To what extent were you and the patient in harmony during the course of the exercises?"; and "Overall, rate the degree to which you have a sense that there was another person interacting with you during the exercises" (Chronbach's alpha = .882).

3 Results

Paired-samples t tests were conducted to evaluate whether a patient's negative mood states were lessened after playing the telerehabilitation games. The assessment of psychosocial variables showed that negative feelings were significantly lessened after the game play. The mean score for feeling confused was significantly less after game play (M = 4.50, SD = .76) than the scores before the game play (M = 6.58, SD = 3.07), t (13) = 2.54, p < .05, (*Ns* for all were 14). Participants reported feeling less depressed after game play (M = 5.17, SD = 1.49) than before playing the game as well (M = 6.67, SD = 3.15), t (13) = 2.58, p < .05. The mean score on feeling tension was also significantly lowered after playing the games (M = 6.00, SD = 2.08) than before (M = 7.08, SD = 3.00), t (13) = 2, p < .1. Overall, we found that participants felt less confused, less depressed and more relaxed after playing the games, supporting hypotheses 1(a)(b)(c).

A correlation coefficient was computed between the patients' overall satisfaction with the telerehabilitation system and the therapists' level of co-presence during the game play. The result showed that the correlation of the participant's overall satisfaction and the therapists' feeling of presence was statistically significant, r (8) = .770, p<.05, N=8. Overall, therapists whose patients rated the telerehabilitation system more useful and satisfactory were more likely to feel higher co-presence during the game play and vice versa, supporting H2.

Paired sample t tests compared the pre- and post-test scores of patients' willingness to persist in therapy. The result of the mean comparison between pre- and post-test data did not provide support for the hypotheses on the positive impact of the game play on patients' level of perseverance. Patients reported that they felt significantly less capable of following through daily therapy regimen after the telerehabilitation game play, t(5)=2.71, p<.05, N=6 (M=6.83, SD=.41 in the pre-test, M=6, SD=.63 in the post-test). Similarly, they felt significantly less capable of persevering in the therapy regardless of fatigue after the telerehabilitation game compared to before the game play, t(5)=2.67, p<.05, N=6 (M=6.16, SD=.75 in the pretest, M=5.35, SD=.50 in the post test). The results show that patients felt less efficacious in continuing therapy after participating in the telerehabilitation game compared to their normal level of perseverance.

A correlation analysis supported hypothesis 3. An active mood before the experiment was positively correlated with patients' willingness to persist in the therapy after the game, r (14) =.699, p < .005, N=14. The results suggest that if patients report that they feel active and motivated, they tend to state that they are willing to continue in the therapy after the game play regardless of their experience with the telerehabilitation games.

4 Discussion

This pilot clinical trial examined whether a telerehabilitation platform with a built-in video communication component between a therapist and a post-stroke patient would be effective in improving patients' psychological states and motivation to persist in training. The telerehabilitation system was host to a set of virtual games and a video communication module that ran concurrently with the game platform. The three virtual rehabilitation games contained full arm and shoulder training activities with a focus on pronation and supination and hand opening and closing. The difficulty levels and the progress in gameplay was monitored and manipulated through a live video chat during the exercise. Post-stroke patient volunteers with impairment of motor coordination in the upper body and staff therapists who monitored and guided the patients through virtual game play participated in the pre-post design experiment. The task involved completing three virtual tasks: 1) The plane flying task involved manipulating a virtual airplane to fly through a sequence of rectangular barriers by pronating and supinating the wrist using an Omni haptic device; 2) The water pouring task was designed for improving motor capability by filling a virtual water cup from the source and pouring it into the target tank. A camera-LED tracking device tracked the wrist pronation and supination mapped onto the virtual objects; 3) The ball dropping task involved a hand opening and closing motion. Patients reached a virtual object above a grid and dropped it at the target by opening their hands. A 5-DT data glove with the camera-LED tracking system traced the hand opening and closing motion.

The results showed that the telerehabilitation games for recovery of motor function were effective in producing psychological gains and a sense of co-presence. However, these advantages in changing emotions and mood were closely related to their psychosocial states before the game play. The therapist's feelings and level of co-presence was shown to affect the patient's overall satisfaction with the telerehabilitation system.

Patients' negative mood states were significantly lowered after playing the telerehabilitation virtual games. All three aspects of negative emotions including confusion, depression and tension, assessed by related psychosocial variables, were lessened after completing three virtual telerehabilitation tasks. Our previous work has reported functional advantages of the telerehabilitation platform in improving therapeutic movement with cortical reorganization and regaining motor function of an upper extremity among post-stroke patients. This finding demonstrates that telerehabilitation exercises using video game features such as an immediate reward and encouragement can positively impact the patient's psychological states as well. Mood disorders such as anxiety and depression followed by physical disability and intellectual impairment from stroke are prevalent among post-stroke patients [6]. Neuropsychological studies show that the prevalence of negative emotions after the stroke are often associated with negative impact on motor, cognitive and intellectual recovery such as lack of motivation in participating in therapy, slow progress in recovery, longer stays in the hospital, less engagement with leisurely activities and even lower survival rate [7]. Given a strong association between less positive moods and the negative impact on recovery from stroke, it is important to address how the telerehabilitation system can enhance emotional states and sense of wellbeing of patients.

The study also showed that participants whose therapists felt a higher sense of co-presence during the game play reported higher overall satisfaction with the telerehabilitation game play experience. When therapists felt more immersed in the telerehabilitation experience and fully engaged with the presence of the patients, patients' general sense of acceptance of the remote rehabilitation session and positive evaluation of the overall experience were higher. The quality and experience of participating in the telerehabilitation exercise should be comparable to the clinic-based therapy where physical therapists are physically present with the patient [8]. An experience of spatial co-location, mutual comprehension, and emotional closeness in a virtual environment is crucial in creating a higher sense of co-presence [9]. The telerehabilitation platform with a built-in system design that allows patients and therapists to see and communicate with each other in real-time enhanced the level of engagement and communication between patients and therapists. Therapists could closely evaluate the patient's movement progress, performance updates and emotional states and manipulate the difficulty levels and pace of the game play accordingly. It is important to recreate a comparable sense of co-presence between therapist and patient in a remote telerehabilitation session as in onsite training since it plays a large role in the patient's immediate sense of satisfaction upon completing tasks. Despite the technological advancement and sophisticated telerehabilitation platform, a good relationship between the patient and the therapist and their sense of working together still contributes significantly to the rehabilitation process.

5 Conclusions

We hypothesized that patients would demonstrate increased willingness to persist in therapy after the telerehabilitation game play. However, patients felt significantly less willing to adhere to their daily therapy after the telerehabilitation game play. They also reported decreased willingness to persist in therapy regardless of fatigue after the participation. The telerehabilitation training seemed to have a negative impact on patient's level of perseverance and motivation from the initial analysis. However, the trend was reversed when the patient's baseline mood was considered in the interpretation. When patients felt active and motivated in the pretest, their willingness to persist in therapy was more likely to increase after the game play. Many studies have documented a variety of health consequences resulting from lower health efficacy levels and lack of motivation [10]. However, it has not been widely investigated whether level of stimulation and elated mood in a virtual telerehabilitation setting is related to patient's willingness to persist in therapy afterward. This result confirms the previously mentioned relationship between mood states and their potential impact on the effectiveness of telerehabilitation training. The finding demonstrates that lack of motivation and negative moods could be related to a failure to adapt to the exercise regimen in a virtual telerehabilitation training session.

References

1. Jung, Y., Yeh, S., McLaughlin, M., Rizzo, A., Winstein, C.: Three-dimensional game environments for recovery from stroke. In: Ritterfeld, U., Cody, M., Vorderer, P. (eds.) Serious Games: Mechanisms and Effects, Routledge.Natl ons (2009)
2. McLaughlin, M.L.: Simulating the sense of touch in virtual environments: Applications in the health sciences. In: Messaris, P., Humphreys, L. (eds.) Digital Media: Transformations in Human Communication. Peter Lang Publishers (2005)
3. Yeh, S.-C., Stewart, J., McLaughlin, M., Parsons, T.D., Winstein, C.J., Rizzo, A.A.: Evaluation approach for post-stroke rehabilitation via virtual reality aided motor training. In: Dainoff, M.J. (ed.) HCII 2007 and EHAWC 2007. LNCS, vol. 4566, pp. 378–387. Springer, Heidelberg (2007)
4. Stewart, J.C., Yeh, S., Jung, Y., Yoon, H., Whitford, M., Chen, S., Li, L., McLaughlin, M., Rizzo, A., Winstein, C.: Intervention to enhance skilled arm and hand movements after stroke: A feasibility study using a new virtual reality system. Journal of NeuroEngineering and Rehabilitation 4, 21 (2007), doi:10.1186/1743-0003-4-21
5. Holden, M.K., Dyar, T.A., Dayan-Cimadoro, L.: Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke. Transactions on Neural Systems and Rehabilitation Engineering 15(1), 36–42 (2007)
6. Berg, A., Lonnqvist, J., Palomaki, H., Kaste, M.: Assessment of depression after stroke: a comparison of different screening instruments. Stroke 40(2), 523 (2009)
7. Spencer, K.A., Tompkins, C.A., Schulz, R.: Assessment of depression in patients with brain pathology: the case of stroke. Psychological Bulletin 122, 132–152 (1997)
8. Lewis, J.A., Boian, R., Burdea, G., Deutsch, J.E.: Remote console for virtual telerehabilitation. In: Proc. MMVR 2005, Long Beach, CA, January 2005, pp. 294–300 (2005)
9. Biocca, F., Burgoon, J., Harms, C., Stoner, M.: Criteria and scope conditions for a theory and measure of social presence. Media Interface and Network, E. Lansing (2001)
10. Miller, W.R., Rollnick, S.: Motivational Interviewing: Preparing People for Change, 2nd edn. Guilford Press, New York (2002)