the game parameters during the session to suit each patient, for example by changing the sensitivity of the accelerometer or the speed and location of the moving butterflies.

Fig. 4. A screenshot from "Catch the butterflies," a game requiring bimanual interaction. Both of the tangibles shown in Fig. 2 are used, and both dominant and non-dominant hand must be coordinated in order to catch the butterflies in the jar.

VI. Conclusions and Future Work:

During the design of our system, we interacted with clinicians and solicited their feedback. Their comments and suggestions were used to ensure our system was both appropriate for use with our target population and easy to use by therapists. More input mechanisms are being investigated which will mirror and enhance exercises currently used in therapy. For example, a common exercise is a squeezing action. This exercise helps improving strength, but it is difficult to motivate patients to perform this action. Interactive games could help achieving this goal.

Our current hardware does not directly measure range of motion, but rather the patient's compensatory activities. Recent research has used wearable technology to estimate clinical scores of functional level of stroke patients [16]. The provision of this detail would be a useful addition to our system, as it would provide a more quantitative measure of a patient's ability and progress over time.

More complex combinations of accelerometer feedback and touchscreen data are also being researched, to allow for better quantification of range of motion such as counting the number of correct bimanual stretches performed. This data would allow therapists to track a patient's progress, and combined with the immersiveness of a virtual environment, would motivate patients to perform better in therapy sessions.

One observation by therapists was that in some cases a certain amount of trunk flexion is unavoidable – for example slow, lateral leaning in patients with hemiplegia. This will be integrated into further revisions of the system. Another common suggestion from therapists was to tilt the display at an angle towards the patient. This would enable three-dimensional reaching tasks to be used with patients, and allow further fine tuning of the system to suit patients' individual needs.

Acknowledgement

The authors would like to thank Ulrike Berzau, Michelle Coldwell, Debra Margolis, Dr. Donna Nimec, and Dr. Brian Snyder for their valuable insights and feedback.

References

[1] P. Rosenbaum, N. Paneth, A. Leviton, M. Goldstein, M. Bax, "A report: the definition and classification of cerebral palsy", *Developmental Medicine & Child Neurology*, 49: 8-14, 2006.

[2] A. Johnson, "Prevalence and characteristics of children with cerebral palsy in Europe," *Developmental Medicine & Child Neurology,* 44: 633-640, 2002.

[3] M. A. Tonkin, "The upper limb in cerebral palsy," C*urrent Orthopaedics*, 9: 149-155, 1995.

[4] D. R. Patel, "Therapeutic Interventions in Cerebral Palsy," Indian Journal of Pediatrics, 72(11): 979-983, 1995.

[5] M. Leitner, M. Tomitsch, T. Költringer, K. Kappel, T. Greshenig, "Designing tangible tabletop interfaces for patients in rehabilitation," in *Conference & Workshop on Assistive Technologies for People with Vision & Hearing Impairments: Assistive Technology for All Ages (CVHI 2007),* M. A. Hersh, Ed. Spain Aug. 2007

[6] N. Mumford, J. Duckworth, R. Eldridge, M. Guglielmetti, P. Thomas, D. Shum, H. Rudolph, G. Williams, P. H. Wilson, "A virtual tabletop workspace form upper-limb rehabilitation in traumatic brain injury (TBI): A multiple case study evaluation," in *Virtual Rehabilitation,* Vancouver, Canada, 175-180, 2008.

[7] N. Mumford, J. Duckworth, P. R. Thomas, D. Shum, G. Williams, P. H. Wilson, "Upper limb virtual rehabilitation for traumatic brain injury: Initial evaluation of the elements system," *Brain Injury,* 24(5): 780-791, 2010.

[8] M. Annett, F. Anderson, D. Goertzen, J. Halton, Q. Ranson, W. F. Bischof, P. Boulanger, "Using a Multi-touch Tabletop for Upper-Extremity Motor Rehabilitation," in *Proc. 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7,* Melbourne, Australia, 261-264, 2009.

[9] J. C. van den Noort, V. A. Scholtes, J. Harlaar, "Evaluation of clinical spasticity assessment in Cerebral palsy using inertial sensors," *Gait & Posture,* 30: 138-143, 2009.

[10] H. G. Hoffman, D. Patterson, G. Carrougher, "Use of Virtual reality for Adjunctive Treatment of Adult Burn Pain During Physical Therapy: A Controlled Study," *The Clinical Journal of Pain,* 16(3): 244-250, 2000.

[11] E. Steele, K. Grimmer, B. Thomas, B. Mulley, I. Fulton, H. Hoffman, "Virtual Reality as a Pediatric Pain Modulation Technique: A Case Study," *CyberPsychology & Behavior,* 6: 633-638, 2003.

[12] D. A. Das, D. A. Grimmer, A. L. Sparnon, S. E. McRae, B. H. Thomas, "The efficacy of playing a virtual reality game in modulating pain for children with acute burn injuries: A randomized controlled trial," *BMC Pediatrics,* 5, 2005

[13] S. L. Kilbreath, J. Crosbie, C. G. Canning, M. J. Lee, "Inter-limb coordination in bimanual reach-to-grasp following stroke," *Disabil Rehabil,* 28: 1435-43, 2006.

[14] G. N. Lewis, E. J. Perrault, "Side of lesion influences bilateral activation in chronic, post-stroke hemiparesis," *Clin Neurophyisiol,* 118: 2050-62, 2007.

[15] L. Sheppard, H. Mudie, E. Froude, "An investigation of bilateral isokinematic training and neurodevelopmental therapy in improving use of the affected hand in children with hemiplegia," *Phys Occup Ther Pediatr,* 27: 5-25, 2007.

[16] S. Patel, R. Hughes, T. Hester, J. Stein, M. Akay, J. G. Dy, P. Bonato, "A novel approach to monitor rehabilitation outcomes in stroke survivors using wearable technology," *Proc IEEE*, 98(3): 1-12, 2010.