Enhancing Non-Dominant Hand Skills Through Inverted Visual Feedback in a Mixed Reality Environment

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概要. Acquiring fine motor skills with the non-dominant hand in a short period is advantageous but often difficult. In this research, we explored the effects of inverted visual feedback using a traditional mirror-based method and a new mixed reality-based approach. Through studies with different visual information requirements, we gained valuable insights into the influence of visual information and cognitive load. The positive results of mixed reality on skill acquisition indicate numerous potential applications.

1 Introduction

Acquiring non-dominant hand (NDH) skills is challenging, especially when the dominant hand (DH) is injured or for tasks requiring bilateral coordination. Traditional methods, including professional training with specialized equipment, are effective but typically require extended time, limiting their utility for rapid skill acquisition [6, 7].

Recent advances in Virtual Reality (VR) and Mixed Reality (XR) show potential for NDH training by replacing physical objects with virtual ones, providing greater flexibility and accessibility [1, 4, 5]. However, existing XR methods often lack the immediacy needed for short-term skill development. Visual feedback has been extensively studied for enhancing upper limb performance [3, 8]. While mirror therapy is effective for short-term skill acquisition, its reliance on physical mirrors can be impractical and cognitively demanding due to fixed positioning [9–12].

This study compares XR-based visual feedback with traditional mirror-based methods for NDH skill acquisition, examining whether XR's flexibility offers a distinct advantage and how various tasks impact NDH dexterity.

2 System Design

2.1 System Setup

To examine whether an XR environment can replicate the benefits of a physical mirror for acquiring NDH skills, we developed an XR system featuring a horizontally inverted view. The external webcam provides a real-time video feed that is inverted in Unity and displayed on the head-mounted display (HMD) of the Meta Quest 3. It allows participants to perceive their surroundings in a flipped view, mimicking the visual effect of a physical mirror (Figure 1).

For baseline performance, we used a plane mirror to achieve a similar inverted view while keeping the training hand out of direct sight (Figure 2). Participants adjusted the position of their inverted hand for comfort with the help of the experimenter prior to the training session.

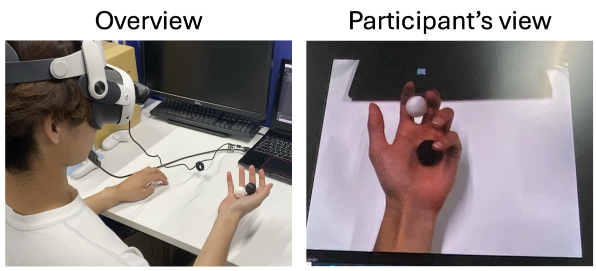

Figure 1. Setup for the XR group.

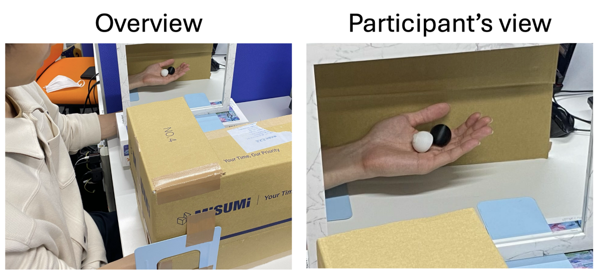

Figure 2. Setup for the mirror group.

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2.2 Task and Procedure

We designed two tasks to assess fine motor skills under varying visual demands. Task 1 involved a ball-rotation task [8], where participants rotated two plastic balls on their palm for one minute. The number of ball rotations was counted to establish a baseline with their left hand. They completed ten one-minute trials with their right hand. Seven participants received XR feedback, while eight had mirror feedback. Finally, participants performed the task again with their left hand to assess performance changes (Figure 3).

Task 2 required participants to transfer 10 beans with chopsticks from a container 20 centimeters away, following the Chopstick Manipulation Test (CMT) [2]. They performed pre- and post-training assessments with their left hand and completed five trials with their right hand, with one-minute rests in between. Six participants received XR feedback, while six received mirror feedback. We measured the completion time of the task to assess the changes in performance (Figure 4).

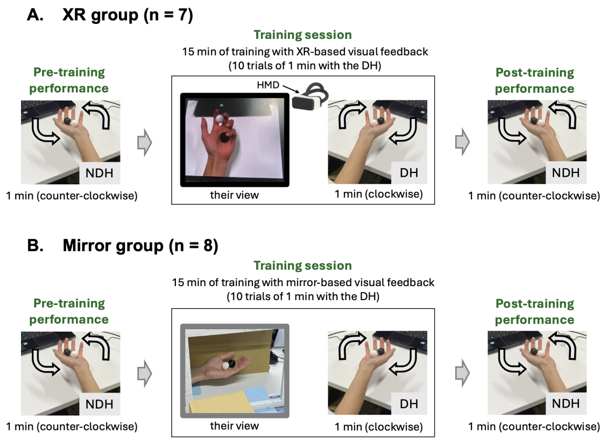

Figure 3. Experimental design for Task 1.

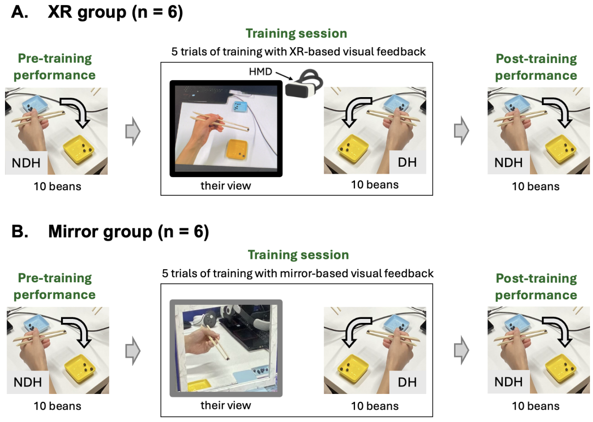

Figure 4. Experimental design for Task 2.

For Task 2, the XR group improved by 13.50 $\pm$ 7.61 seconds ($p = 0.156$), while the mirror group improved by 16.67 $\pm$ 2.74 seconds ($p = 0.031$). The XR group showed greater variation in improvement (Figure 5C).

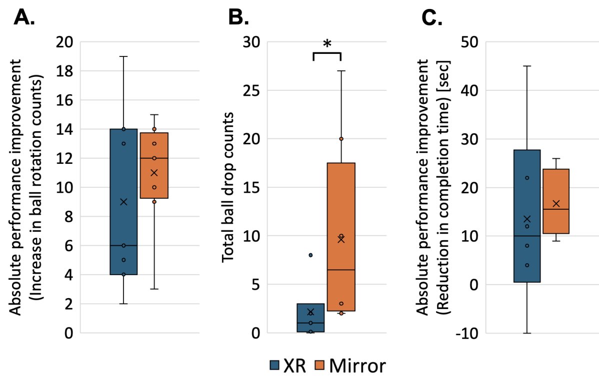

Figure 5. Quantitative results.

3 Results

For Task 1, both groups showed significant improvements in NDH: the XR group improved by 9.00 $\pm$ 2.39 rpm ($p = 0.016$), and the mirror group improved by 11.00 $\pm$ 1.34 rpm ($p = 0.008$). There was no significant difference in the amount of improvement between the groups ($p = 0.602$), but the XR group exhibited greater variability (Figure 5A). Furthermore, the ball drop counts were significantly higher in the mirror group during training (XR: 2.16 $\pm$ 1.05 times; Mirror: 9.63 $\pm$ 3.31 times, $p = 0.022$) (Figure 5B).

4 Conclusion

Both XR-based and mirror-based visual feedback improved untrained hand dexterity, regardless of the task's visual demands. While overall performance gains were similar, the XR group showed more individual variation, likely due to differing levels of system acceptance. The adjustable observation angles in XR allowed for better hand visualization, and the freedom of hand and head positioning contributed to a more comfortable posture. These findings highlight XR's potential in motor skill learning. Future research will address current limitations to develop more versatile XR systems for a broader range of tasks.

参考文献

[1] H. Bostanci, A. Emir, D. Tarakci, and E. Tarakci. Video game-based therapy for the non-dominant hand improves manual skills and grip strength. *Hand Surgery and Rehabilitation*, 39(4):265–269, 2020.

[2] J. Chang, T. Chien, and Y. Lin. Comparison of various patterns of chopstick use and functional performance. *Gaoxiong yi xue ke xue za zhi= The Kaohsiung Journal of Medical Sciences*, 9(7):428–434, 1993.

[3] B. Dexheimer and R. Sainburg. When the non-dominant arm dominates: the effects of visual information and task experience on speed-accuracy advantages. *Experimental brain research*, 239(2):655–665, 2021.

[4] R. M. Eltanamly, H. Elmekawey, M. M. Youssef, and L. M. Hassan. Can virtual reality surgical simulator improve the function of the non-dominant hand in ophthalmic surgeons? *Indian Journal of Ophthalmology*, 70(5):1795–1799, 2022.

[5] J. O. Evans, K. Tsaneva-Atanasova, and G. Buckingham. Using immersive virtual reality to remotely examine performance differences between dominant and non-dominant hands. *Virtual Reality*, 27(3):2211–2226, 2023.

[6] J. Mehrholz, T. Platz, J. Kugler, and M. Pohl. Electromechanical and robot-assisted arm training for improving arm function and activities of daily living after stroke. *Stroke*, 40(5):e392–e393, 2009.

[7] E. Mitchell-Krever and J. M. Lacroix. Evaluation of a comprehensive nondominant hand skills training program. *Canadian Journal of Plastic Surgery*, 6(4):191–195, 1998.

[8] I. Nojima, T. Mima, S. Koganemaru, M. N. Thabit, H. Fukuyama, and T. Kawamata. Human motor plasticity induced by mirror visual feedback. *Journal of Neuroscience*, 32(4):1293–1300, 2012.

[9] C. Park and H. Son. Immediate effects of fine-motor training on coordination and dexterity of the non-dominant hand in healthy adults: A randomized controlled trial. *Behavioral Sciences*, 12(11):446, 2022.

[10] V. S. Ramachandran, D. Rogers-Ramachandran, and S. Cobb. Touching the phantom limb. *Nature*, 377(6549):489–490, 1995.

[11] V. Rjosk, E. Kaminski, M. Hoff, B. Sehm, C. J. Steele, A. Villringer, and P. Ragert. Mirror visual feedback-induced performance improvement and the influence of hand dominance. *Frontiers in Human Neuroscience*, 9:702, 2016.

[12] G. Yavuzer, R. Selles, N. Sezer, S. Sütbeyaz, J. B. Bussmann, F. Köseoğlu, M. B. Atay, and H. J. Stam. Mirror therapy improves hand function in subacute stroke: a randomized controlled trial. *Archives of physical medicine and rehabilitation*, 89(3):393–398, 2008.

未来ビジョン

本研究は，利き手にかかわらずスキル習得が可能な未来を切り拓くことを目指している．多くのアクティビティやタスクは視覚情報と触覚情報の両方を必要とするが，触覚フィードバックには高いハードウェアコストと実装の難しさが伴う．そのため，我々は視覚フィードバックに焦点を当て，スキル習得をより効果的かつアクセスしやすいものにしたいと考えている．現時点では Meta Quest などのヘッドマウントディスプレイは依然として高価であるが，物理的制約の解消やオーバーレイ技術には多くのポテンシャルがある．

今回はシンプルな実装にとどまるが，将来的にはハンドトラッキングを用いたり，利き手をコーチとして活用することで，さらに効率的な学習方法を技術的なアプローチで追求していきたい．また，非利き手でのタスク遂行，たとえば箸を使ったり文字を書いたりすることは，病気のリハビリや脳科学の文脈だけでなく，効率性を追求する現代人の日常生活においてもマルチタスクの観点から価値があると考えている．

どちらの手でも複雑なタスクに容易に適応できれば，生産性が向上し，身体的制約の克服にも繋がる．この研究を通じて，技術が人間の新たな能力を引き出し，社会をより豊かにすることを期待している．また，ローコストかつ親しみやすい形で，この技術の可能性をより多くの人々に届けたいと考えている．