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学术论文

Understanding User Performance of Acquiring Targets with Motion-in-depth in Virtual Reality

虚拟现实中深度运动目标获取用户表现建模

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Interactive dynamic content is ubiquitous in modern computing applications such as games, real-time simulations and data visualizations. Dynamic content is particularly prevalent in virtual reality (VR). One of the most fundamental interaction tasks encountered in such scenarios is the acquisition of moving targets. Acquiring moving targets is still very challenging for most users due to the level of sensory-motor coordination required. In VR, the higher degree of freedom of motion makes it more difficult for users to locate and select moving targets.

We concentrates on motion-in-depth, that is, where a target predominantly exhibits approaching or receding movement as opposed to lateral motion across the user's field of view. A better understanding of the factors influencing moving target acquisition in VR, and how these factors affect user performance, can help drive improvements in interaction design (**Fig 1**).

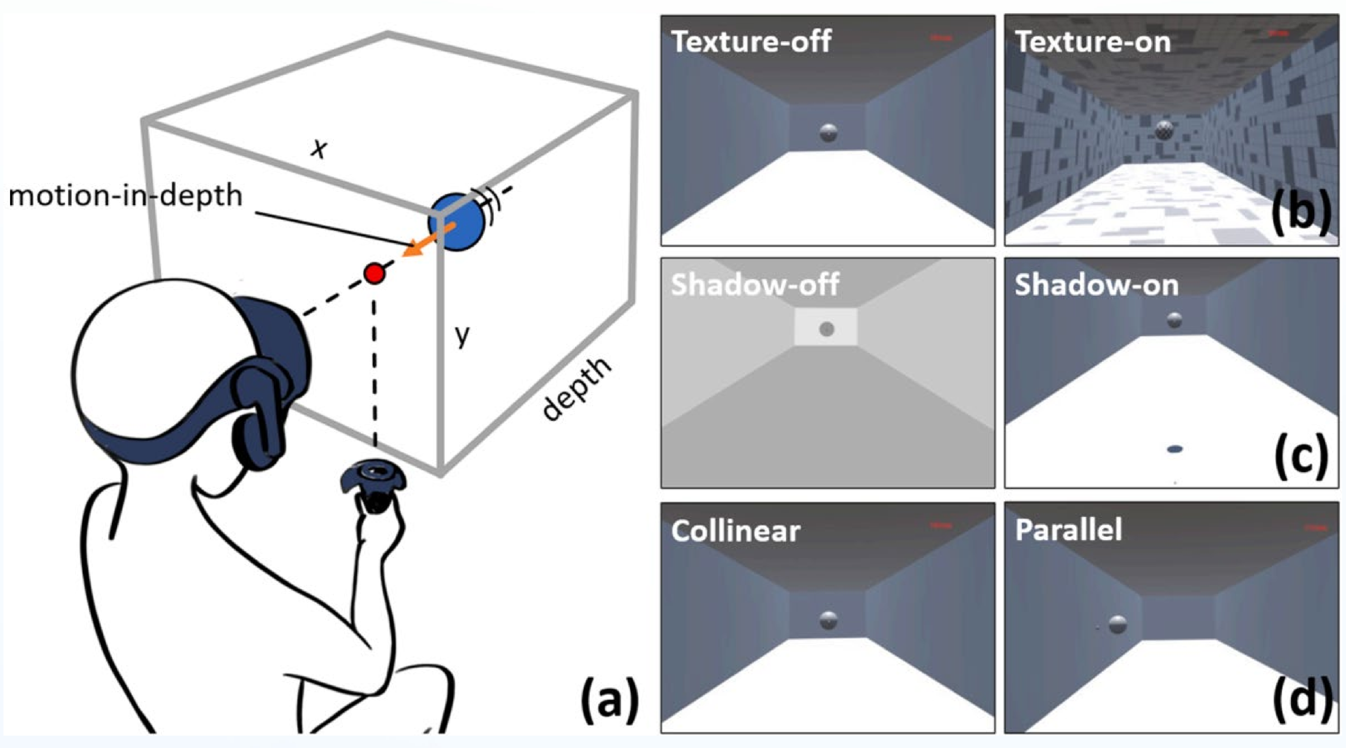

Fig 1. VR configuration for studying moving target acquisition in depth. a) Schematic diagram of acquisition of targets with motion-in-depth; b-d) Conditions of the design factors investigated in this study.

The essential difference between interactions in VR and other lower-dimensional (1D/2D) settings lies in the extra degree of freedom in depth. Previous studies indicate that the perception and behavioral patterns of users in the depth dimension are different from those in other dimensions; this motivates our investigation of user performance in acquiring moving targets specifically in the depth dimension, or what we term 'motion-in-depth' in this paper.

Compared to the extensive studies on static target pointing, there is far less existing work on assisting moving target pointing in VR. Recent works in moving target acquisition offer good explanations and models for user pointing behaviors in moving targets. However, the results from these studies cannot be directly transferred and generalized to target motion in the depth dimension.

We conducted two user studies. The first study investigates the influence of speed, moving direction, texture, shadow and alignment on perception accuracy of objects with motion-in-depth (**Fig 2**).

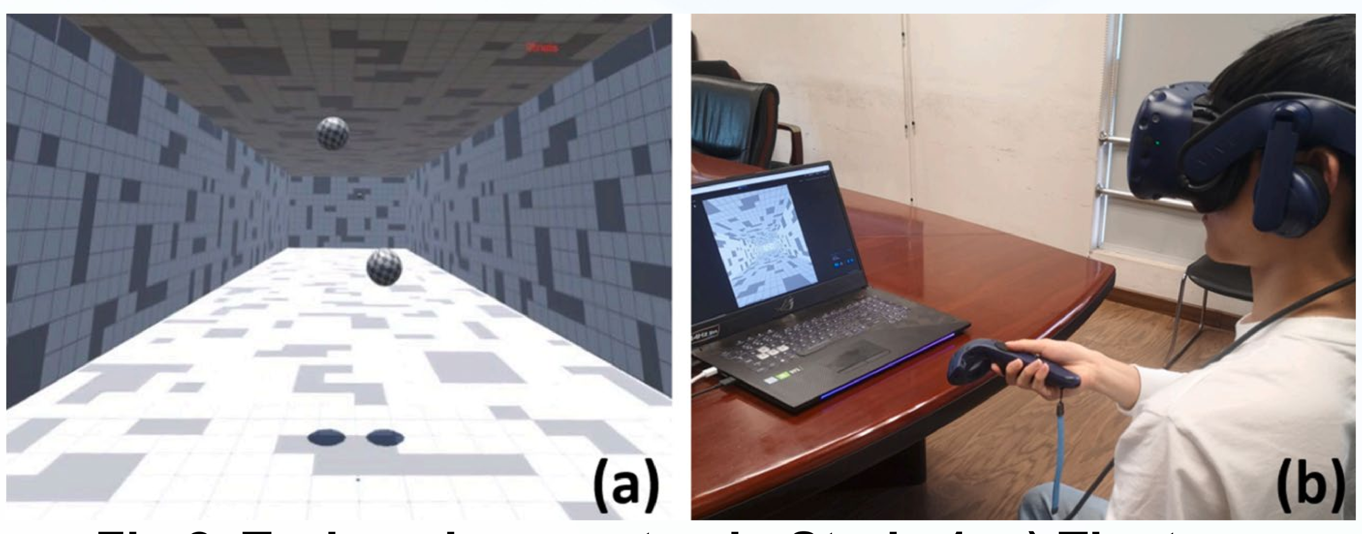

Fig 2. Task and apparatus in Study 1. a) The two-target-balls task; b) A participant took part in Study 1.

We found that target speed has the greatest impact on users perception, followed by shadow and direction movement (**Fig 3**).

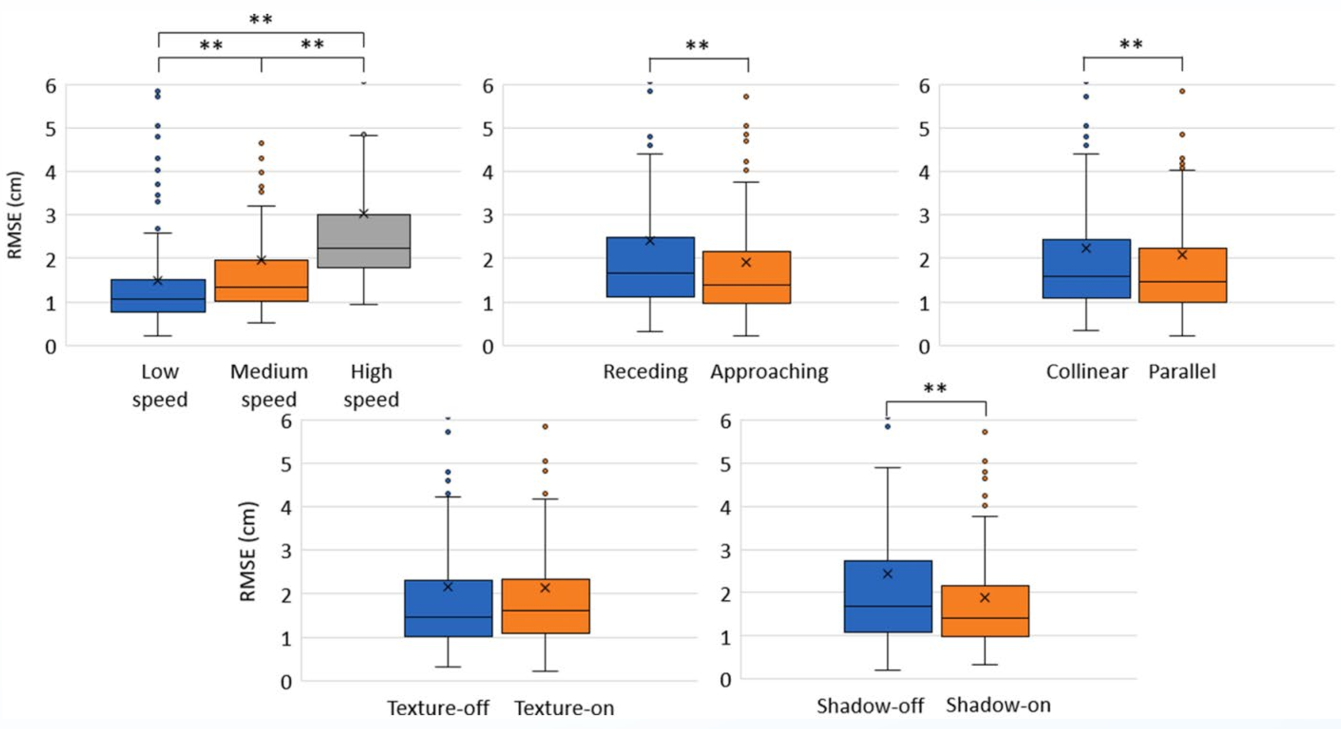

Fig 3. Boxplot diagrams represent analysis of RMSE for Speed, Direction, Alignment, Texture and Shadow.

The second study explores how the aforementioned factors affect user performance, which we define as the combination of movement time (MT) and error rate (ER). We discovered the influence of target speed on MT depending on the target's moving direction and initial distance having a significant impact on selection ER (**Fig 4**). Data of MT and the ER of motion-in-depth showed good fits with Jagacinski's model and a Ternary-Gaussian model, implying strong lawful regularities of MT and ER in this task (**Fig 5**).

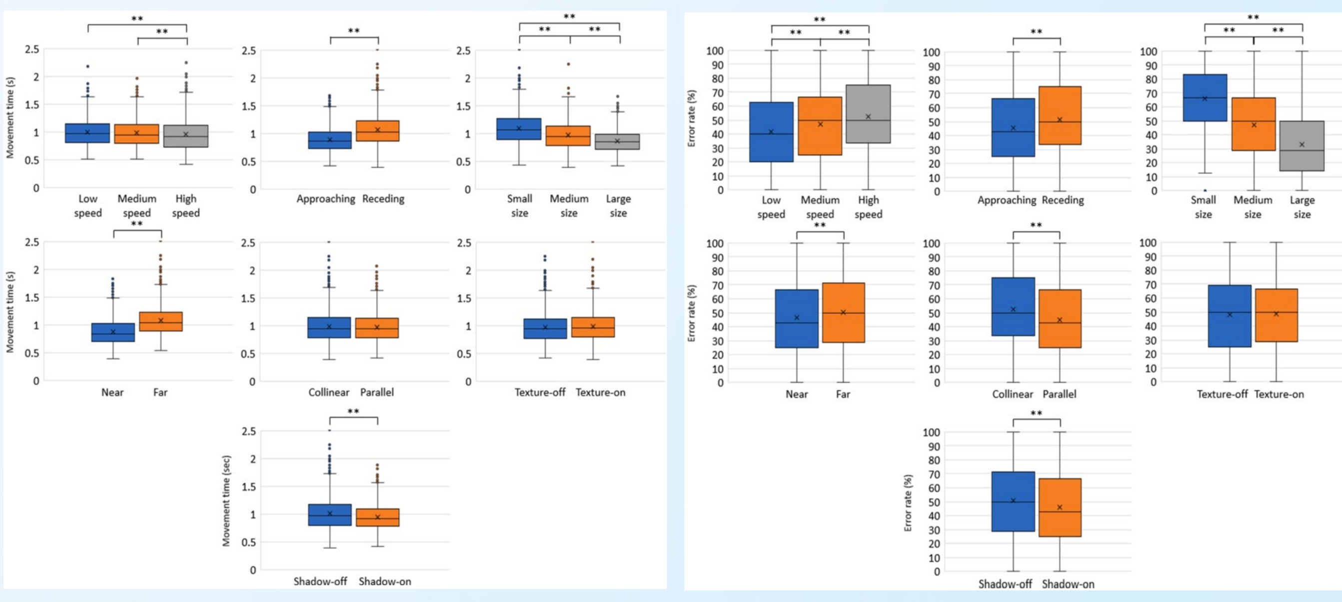

Fig 4. Boxplots of MT and ER for the seven factors of speed, direction, width, initial distance, shadow, texture and alignment

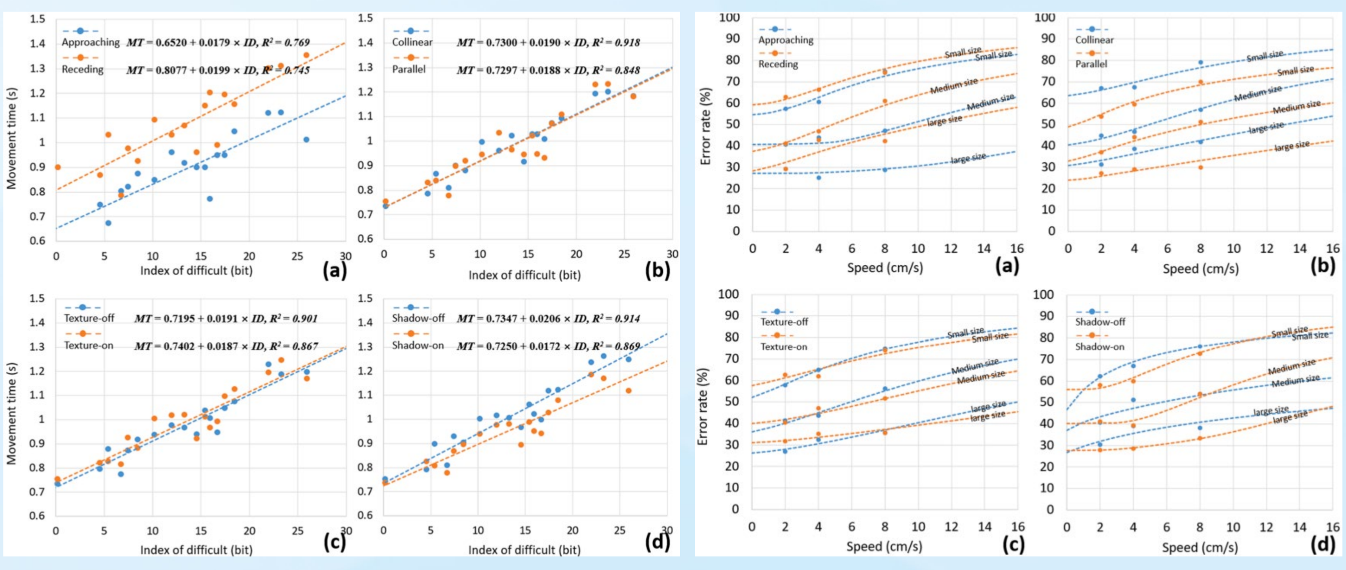

Fig 5. The good fits of Jagacinski's model and the Ternary-Gaussian model to the MT and ER data.

We conclude with implications derived from this study for future designs and advances our understanding of how users perceive and interact with moving targets in VR.