Introduction

In the field of AR, achieving efficient text input remains a significant challenge. Although state-of-the-art head-mounted displays (HMDs) are equipped with reliable hand-held controllers and hand-tracking, they are rarely optimized for text-heavy tasks that demand high input bandwidth and performance. Current typing speeds in virtual environments range from 5.31 to 15.44 words per minute (WPM) by popular typing strategies in commercialized HMDs [1], [2], [3], often limited by collision-based input methods that require exaggerated mid-air movements. Bare-hand typing exacerbates this issue due to the lack of haptic feedback, resulting in poor key confirmation and diminished typing accuracy. Additionally, gesture-based input methods, whether using bare hands or controllers, causes significant muscle fatigue in the shoulders and forearms [4]. These limitations highlight the need for more efficient text entry solutions specifically designed for AR environments.

Many researchers have explored methods to improve typing performance with both speed and accuracy in virtual environments. These approaches include using controllers for discrete taps or continuous strokes, incorporating tools like rays [1], [2], buttons[5], and joysticks [6], [7], as well as bare-hand input techniques, such as two-thumb or ten-finger typing [8], [9], [10]. While these methods build on familiar input skills, their performance is often limited, typically reaching between 13.7 and 21.9 words per minute (WPM), due to the constraints of cursor-based typing and limitations of hand-tracking technologies embedded in commercialized HMDs. Some efforts have turned to external devices like physical keyboards [11], [12], [13], [14] and smartphones[15], [16], [17], [18] to enhance performance by leveraging user proficiency with traditional input tools. Although these devices can improve typing performance, their reliance on external hardware disrupts the immersive and fluid experience that AR and VR aim to provide. This trade-off between high typing efficiency and seamless interaction remains a key challenge in AR and VR contexts.

To address these challenges, we focused on three key studies for PropType's design and development.

The first study involved observing how users naturally interact with various objects for typing, offering insights into ergonomic factors and user adaptations to different surfaces. In this study, participants had two conditions: walking and sitting. I asked participants to imagine that they were in an AR typing scenario, and that they needed to type on the surface of the object. For each object, participants typed 25 phrases from the MacKenzie phrase set, while describing their motivations for their strategy, their experiences, and their expectations. Upon completing the exploration phase, they completed a questionnaire to provide their preferences and subjective feedback.

After typing on all objects, participants ranked the objects by preference. table1 shows the mean rankings. I also collected subjective feedback on the preferred form factors for typing with props as part of the interview for each object. Participants consistently favored small, easy-to-hold props with rigid surfaces that provide clear tactile responses during tapping, supported by the rankings. **table**

I also computed the agreement rate **(define**) for the object orientation (determined visually) and typing strategy. After analyzing the agreement and rankings, we selected four of the objects in the first study, with a range of surface.

The second study evaluated typing reachability and efficiency across four distinct props, each representing a range of sizes and shapes. For each of the four objects, we displayed a grid of sphere following the objects' surface. At a time, one random button was highlighted. I instructed participants to - as quickly and as accurately as they could - touch the sphere with their fingertip. The time taken for this was measured, and for each of the objects, a simple polygon was selected as the viable area for typing based on the mean performance for those points. **typing pic**

From the customized keyboard layouts, I tested PropType's overall typing performance by asking participants to type randomly selected MacKenzie phrases. We achieved high accuracy and speed (xxxxx) demonstrate the system's practical use in AR environments.

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