A Systematic Review and Meta-analysis of Text Entry Studies

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Abstract

Text entry is a notably standardized research field in human-computer interaction, with established benchmarks and methodologies enabling rigorous comparisons across studies. Nevertheless, meta research in text-entry is scarce. This meta-analysis summarizes findings and effects from text entry experiments published from 1990 to 2024. Our records show that most text-entry experiments feature a baseline and an experimental UI, and that they mostly show that the experimental UI is superior ($g = 1.68$), with regards to text entry speed. We found that earlier text entry research focused mostly on the development of novel techniques, whereas recent text entry research, to a larger extent, adapts existing input methods to new devices, such as smartwatches or virtual reality headsets. We also find that text entry research often lacks statistical power ($M = 0.66$, $SD = 0.37$), relies on small sample sizes ($Mdn = 12$), and is mostly conducted with within-subjects designs (84%). Subjective evaluations of text entry systems beyond objective performance are rare. Our analysis found evidence for systematic publication bias in text entry research, as indicated by funnel plot asymmetry and a significant weight-function model adjustment. This underlines the research field's competitive culture of publishing research only if entry speed is beaten in comparison to some baseline.

CCS Concepts

• **Human-centered computing** → **Text input**; **Keyboards**; • **General and reference** → **Surveys and overviews**.

Keywords

text entry, keyboards, meta-analysis

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1 Introduction and background

Text entry has been a primary means of directing computers, since the beginning of interactive computing. Despite significant advancements in interaction techniques, direct text input remains one of the most frequent and essential activities in computing today [213]. Improving text entry through novel designs has therefore been a long standing research challenge [e.g., 111].

Text entry was once dominated by physical keyboards on desktop computers, but is now common on virtually all computing devices [213]. As text entry transitions beyond traditional computing devices to form factors such as large screens [67, 119], smartwatches [143], and extended reality (XR) [40], it faces new challenges requiring tailored solutions. While the QWERTY keyboard and its multilingual variants remain the standard, emerging device form factors demand interaction techniques that align with unique modalities. Addressing these challenges is crucial to ensuring efficient and seamless user experiences across disparate interfaces.

Given the centrality of text entry in human-computer interaction, evaluations of new text entry techniques require generalizable and comparable validation of their advantages and disadvantages beyond subjective experiences [114].

1.1 Standardized text entry evaluation

Evaluating the effectiveness of new interactive techniques is essential to verify their efficacy. MacKenzie and Tanaka-Ishii [117] emphasized the importance of reliable and validated evaluations for text entry techniques, proposing a standardized method to ensure consistent and comparable assessments. The canonical text entry experiment, proposed by the authors, compares input methods based on speed and accuracy (dependent variables). The experimental input techniques are often compared against a baseline that researchers hypothesize can be improved upon (independent variable). Participants transcribe provided text phrases, enabling controlled measurement of performance metrics such as typing speed and accuracy. This methodology is designed to ensure reproducibility and generalizability in assessing text entry techniques for mobile devices [117].

The primary measurements in text entry studies are typing speed [112] and error rate [164]. Typically, participants are presented with a set of strings for transcription and instructed to input them as quickly and accurately as possible [164]. Previous approaches, such as having participants type whatever came to mind, were criticized for their lack of internal and external validity [116]. To address these issues, a standardized set of phrases was developed for use in evaluations [116]. Researchers are advised to use this standardized phrase set to ensure the generalizability of their experiments [116].

Typing speed is commonly measured in words per minute (WPM) or, less frequently, in characters per second (CPS) [196]. Accuracy is typically quantified using the Character Error Rate (CER). Although other measures, such as usability, cognitive load, and subjective preferences, are relevant, they are less frequently reported [117].

As such, text entry research stands out as a particular standardized fields within human-computer interaction, and most of the

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text entry experiments rely on the experimental protocol described above [72]. For these reasons, text entry research is an obvious candidate for meta analytical research, for summarizing research trends and identifying short comings.

1.2 Concerns about Text entry measurements

The methods in text entry research have been rigorously standardized and canonically rely on speed and accuracy metrics. However, the practices of conducting standardized text entry experiments are not devoid of validity issues. Kristensson and Müllners [95] highlighted that the design and evaluation of text entry systems are unlike traditional HCI evaluation methods, being highly standardized. However, even metrics specifically developed for text input systems often require revision to ensure validity. For example, Soukoreff and MacKenzie [164] evaluated the proposed minimum string distances and keystrokes per character metrics and found that these approaches fail to adequately estimate accuracy in text entry studies. Similarly, Zhang et al. [211] criticized traditional performance metrics for their ambiguous interpretation and limited applicability to design decisions. To address these issues, they proposed the throughput metric as an alternative to better capture the trade-offs between speed and accuracy.

Mutasim et al. [128] demonstrated that testing novel and unfamiliar keyboard layouts by asking participants to repeatedly type the same phrase often leads to inaccurate estimates unless the training spans several days, which is different from general practice of conducting text entry experiments in a single session. Additionally, Yi et al. [200] emphasized the critical role of test sets in evaluating text entry techniques, showing that the clarity of words within phrase sets significantly affects measured text entry speed and error rates.

Kristensson and Müllners [95] also underscored the importance of considering the interplay between physical and cognitive parameters during typing, which are frequently uncontrolled in experiments, limiting the validity of design implications drawn from empirical results. To address this, they developed a computational model enabling systematic exploration of the design space for predictive text entry. Complementing this, Buschek et al. [19] argued that lab-based typing experiments may not accurately reflect general text entry behavior. They advocated for studying typing behavior "in the wild" and created an app to log text entry behavior outside controlled environments.

In the context of XR, Hincapié-Ramos et al. [67] pointed out that mid-air interactions are prone to fatigue. They suggested that evaluations of mid-air text entry systems should include a complementary metric, "consumed endurance", to better assess and design novel interactions involving repetitive input, such as mid-air text entry. Obukhova [132] highlighted the variability in participant numbers across text entry studies and the lack of theoretically validated effect sizes for a-priori analyses when planning experiments. To address this gap, the author analyzed the effect sizes of 21 highly cited typing experiments and developed an effect size ruler to guide researchers in determining appropriate sample sizes.

Finally, concerns about demand characteristics in text entry research have recently been raised [72]. Iarygina et al. [72] showed that participants increase their performance with experimental interfaces to align with their guess about the researcher's hypothesis.

1.3 Objectives

Despite the prominence of text entry as a study of research, there is a lack of evidence on whether text entry studies have biases and validation issues on a general level.

While text entry research in HCI has extensively explored various input methods – from traditional keyboards to mobile devices, wearables, large screens, and virtual reality – a lack of large-scale, systematic comparisons across studies, remains. These comparisons are vital for building theory, evaluating methodologies, and guiding innovation, as the current fragmentation limits generalizability and theoretical advancements.

To address these gaps, we reviewed 157 text entry studies in HCI, and conducted a meta-analysis of experimental methods of those studies that compare a novel technique to an existing baseline. This paper summarizes main findings, and helps indicate where the canonical way of text entry evaluation has potential validity issues.

2 Methods

2.1 Eligibility criteria

Following PRISMA guidelines [125], we queried the ACM Digital Library for text entry studies that empirically compared two or more text entry interfaces (see Figure 1). We searched the full texts of all papers from CHI, UIST, MobileHCI, IEEE VR, ISMAR, VRST, SUI, and TVCG, as these are the venues in which text entry studies are mostly published.

We limited the scope to include only papers that measured speed. This criterion was chosen because speed is the most commonly reported and standardized measure across the field. Additionally, we focused our search on studies evaluating keyboard-based input methods, excluding studies on trackball, mouse, or speech input, to maintain a consistent scope and ensure comparability.

We searched the relevant databases (query: `("TEXT ENTRY" OR "TEXT-ENTRY" OR "TEXT INPUT" OR "TEXT-INPUT") AND ("WORD* PER MINUTE" OR "WPM" OR "CHARACTER* PER SECOND" OR "CPS" OR "CHARACTER* PER MINUTE" OR "CPM")`) across the title, abstract and full texts of articles written in English and published in 1990 to 2024. From the search, we identified 460 unique articles. We then scanned the articles and included those that met the following criteria:

1. presenting novel research findings (this criterion excludes systematic reviews, posters, and commentaries);
2. presenting an empirical study with human participants;
3. reports entry speed (e.g, words per minute).

The eligibility criteria were met by 157 papers.

2.2 The source data and materials

From each article that met eligibility criteria, we manually extracted relevant data. We extracted information on the (1) experimental design, (2) speed and accuracy metrics, and (3) number of participants. If data were not stated in the text, where possible, we manually extracted data from figures.

In addition to analyzing the data collected as described above, we performed meta-analyses on the effect sizes of text entry speed for papers that include a comparison of new text entry methods with a baseline or an existing text entry technique. Among the articles

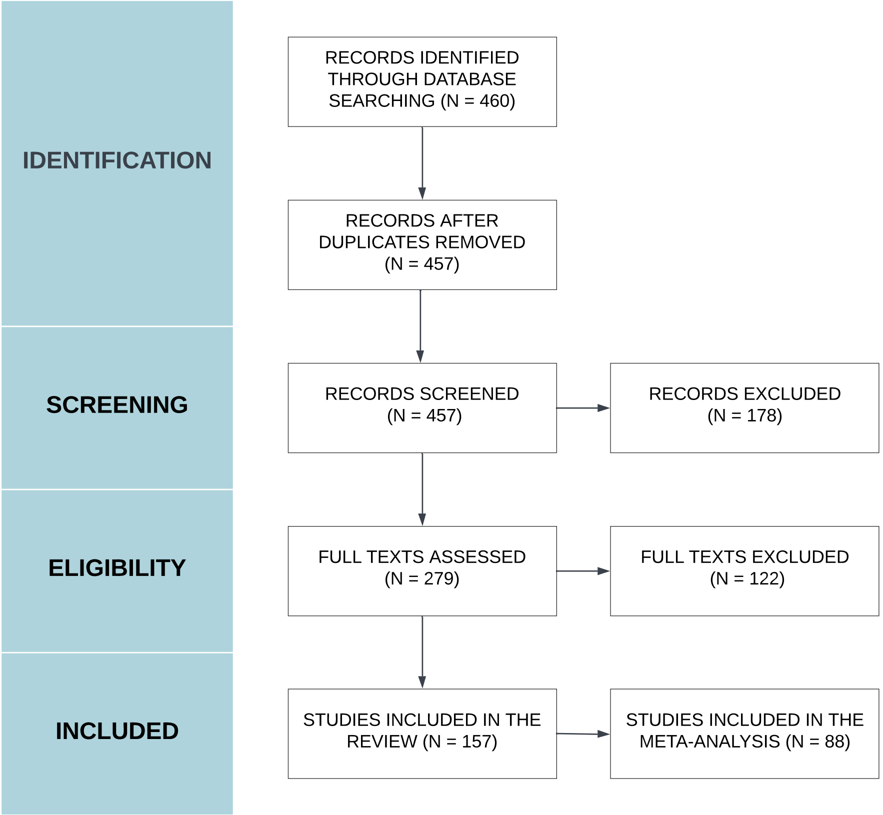

Figure 1: A PRISMA-style flow chart of the selection of studies for the analysis.

that met the eligibility criteria, 88 papers compare new text entry methods with a baseline, such as the standard QWERTY layout [12] or an existing text entry technique [24]. This baseline allows for evaluating new or alternative input techniques under controlled conditions. The effect sizes reported in this meta-analysis reflect the magnitude of performance differences between new text entry methods and their respective baselines. Thus, the meta-analysis does not include studies that test the same text entry method across different devices (e.g., computer and smartphone [209]), under varying postures (e.g., sitting, standing, and walking [7]), or examines variations of the developed method (e.g., input gestures [202]), as such studies do not provide a baseline for comparison.

Effect sizes enable comparisons between studies, assist in estimating the required sample size for future research, and help evaluate the significance of experimental findings [161]. We report Hedges' g, as it is more robust than Cohen's d when dealing with small sample sizes [65]. Effect sizes were calculated using means, standard deviations, and sample sizes, with per-condition sample sizes accounted for. When group-specific sample sizes were not reported, we assumed an even distribution of participants across groups. The data collected in the articles are available without reservation at OSF[1].

3 Review

In this section, we provide an overview of the research landscape on text entry methods across various device categories. We highlight the unique challenges and innovations within each category, as well as the performance metrics and evaluation methods used in these studies.

Mobile text entry. The majority of the studies investigated typing performance using mobile phones (N = 52) or tablets (N = 16). Text entry methods for mobile devices are diverse, and the design of keyboards for touchscreens has a crucial influence on the typing performance [155]. Even though the QWERTY keyboard layout reigns ubiquitous, there have been attempts to develop alternative layouts [204]. Such attempts include modifications of QWERTY [12], OPTI [118] layout, or splitted layouts for two-thumb fast text entry [136]. Another augmentation of mobile text entry is adding feedback to the keyboard, and researchers are studying how feedback, such as haptic or audio, affects typing performance [6, 38, 69, 133]. Multiple text entry studies investigated how postures influence text entry performance, and how the text entry methods could be adapted for postures or walking [7, 27, 49, 124]. Research in text entry also covers accessibility for people with impairments, like Parkinson disease [181] or visual impairments [13, 156, 171]. Text entry research on smartphones also concerns predictive text input

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[1] https://osf.io/be4y9/

and autocorrection models, aimed to improve movement accuracy and error corrections [30, 51, 115, 123].

XR. Researchers have also investigated multiple methods for improving text input in extended reality (XR). Text entry in XR presents unique challenges, such as the lack of tactile feedback, reliance on precise tracking or gaze-based input, and the physical demands of spatial interactions [92]. These factors can affect typing speed, accuracy, and user comfort, while also introducing considerations like fatigue, ergonomics, and motion sickness, making VR text entry distinct from traditional text entry research. Recent work has, therefore, investigated the adaptation of text entry methods for virtual reality. Such studies include the investigation of handheld controllers [14, 122], physical and virtual keyboards [34, 40, 93],and a variety of interaction techniques [60, 97, 162, 163, 166, 202].

Wearables. A considerable amount of research investigated text entry for wearable devices in light of such devices' tiny form factors. Such devices include chording keyboards [111], smartwatches [53, 70, 100, 127, 134, 199, 201], and external sensors [41, 52, 58, 90, 168, 188, 194, 195]. Zhang et al. [213] attempted to develop a text input solution suitable for any device.

Performance across devices. To provide an overview of performances across devices commonly used in text entry studies Figure 2 summarizes mean typing speeds.

Other metrics. All of the articles analyzed calculate the accuracy of the entry method in the form of an error rate, conforming to the standardized way of conducting text entry experiments. Approximately half of the papers (N = 94) augment the objective findings with some form of qualitative feedback. Out of those, 48 papers measure cognitive load in the form of NASA-TLX [62]. 23 articles analyzed the usability of the developed techniques by employing System Usability Scale (SUS) [17] or User Experience Questionnaire (UEQ) [98]. Finally, 27 papers measured preference between novel and baseline text entry methods.

4 Meta-analysis

In this section, we examine the effectiveness of experimental text entry methods compared to baseline approaches across various device categories. By calculating effect sizes, we evaluate the performance improvements facilitated by novel techniques and highlights trends, strengths, and potential biases in the reported research.

4.1 Effect of experimental text entry method

To assess how much the novel text entry methods outperformed baselines, we calculated weighted mean effect sizes for text entry performance across six device groups: desktop, tablet, mobile, smartwatches, XR, other devices (e.g., smart glasses, key cubes), as well as overall across all devices. These results enable comparisons of experimental manipulations across devices (see Figure 5).

All text entry studies in the sample report positive effect sizes; that is, the experimental interface is always superior to the baselines. An overall effect on speed, across all devices, was determined to $g = 1.86$, 95% CI [1.64, 2.09]. This indicates a large overall effect, reflecting significant improvement of the novel text entry technique over an existing baseline. These findings highlight that novel designs consistently outperform their predecessors, regardless of what the new and the old designs are.

Divided by device, the smallest effect was observed for studies concerning XR devices ($g = -0.30$, 95% CI [-0.43, -0.16]), indicating a small effect of the studied interventions or techniques with this technology. It is plausible that existing baselines for XR text entry are underdeveloped or poorly optimized, and XR techniques are often compared to text entry methods in real life [e.g., 93, 122]. Such a choice of a baseline, with which participants have experience, creates a high performance threshold for new techniques to surpass. Additionally, XR interfaces often demand novel interaction paradigms due to their immersive nature and the need to adapt to complex spatial and contextual factors, making them a complex environment for improvements. Other devices demonstrated a higher effect ($g = 1.65$, 95% CI [1.45, 1.84]), followed by mobile devices with an effect of $g = 1.12$, 95% CI [1.01, 1.24]. Comparatively, smaller effects were noted for desktop ($g = 0.80$, 95% CI [0.73, 0.87]), tablet ($g = 0.83$, 95% CI [0.74, 0.90]), and smartwatch categories ($g = 0.57$, 95% CI [0.47, 0.57]).

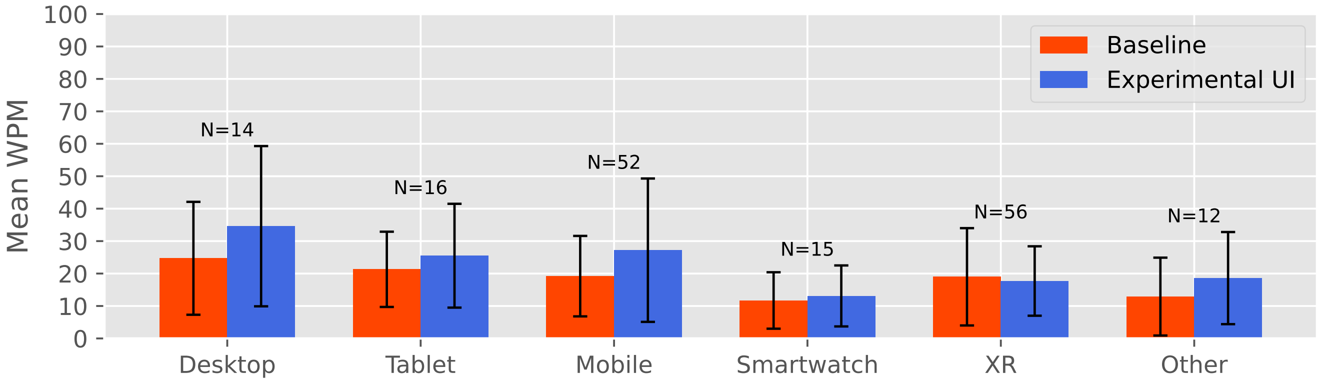

Figure 2: Mean performance divided by device. Bars show mean typing speed in WPM, and error bars show SDs. Experimental UIs outperform baselines in text entry studies across all form factors, except XR.

We analyzed the presence of publication bias in the results. Weight-function modeling and funnel provide evidence for publication bias. It is notable that only studies showing superior performance to baselines have been published. The details of the analysis can be found in Appendix A.

4.2 Participants and design

The 157 articles employed between 1 and 72 participants, with a median participant count of 15 ($SD = 9.35$). Summarizing only the research comparing the text entry method against the baseline (90 papers), we found a mean power for speed of 0.66. The power was calculated using R-function STATS::POWER.T.TEST, which takes the number of participants, mean difference, and pooled standard deviation as inputs. This indicates that, on average, the studies have a moderate probability of detecting true effects, which may suggest room for improvement in experimental design or sample size.

Among the studies, 25 papers employed between-subjects, and 132 papers employed within-subject design. Studies with a within-subject design yielded a higher weighted mean effect size ($g = 1.59$, 95% CI [1.47, 1.71]) compared to those using a between-subject design ($g = 1.25$, 95% CI [1.14, 1.37]). This could reflect the presence of demand characteristics, as participants may attempt to excel with new techniques, anticipating the outcomes the researchers hope to observe [72].

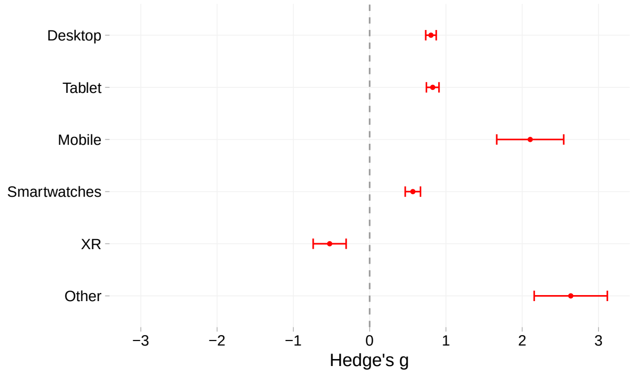

Figure 3: The weighted means of means of word-per-minute effect sizes, grouped by device, with 95% CIs of means. The effect sizes are derived from per-study comparisons of baseline vs. experimental interfaces.

5 Discussion

The findings from this review and meta-analysis provide an overview of 157 text entry experiments from over two decades of research. By consolidating findings, we have identified critical trends, methodological gaps, and areas for future exploration.

The reliance on speed and accuracy metrics remains a cornerstone of text entry research. While these measures offer standardized and comparable outcomes, they might fail to capture the nuanced trade-offs inherent in text entry tasks, and only a small proportion integrate the perception of new text entry solutions beyond objective performance, such as, among others cognitive load and usability. Expanding this practice can provide a richer, more holistic view of user experiences and inform the design of user-centric input methods.

Our analysis also demonstrated that within-subject designs yield higher effect sizes than between-subject designs. This finding might suggest that within-subject designs may more effectively capture subtle performance differences while reducing interparticipant variability [54]. On the other hand, it may indicate the presence of demand characteristics and the fact that participants try to give their best performance on new techniques because they guess what the researcher expects from them [135]. A text entry experiment, where demand characteristics were controlled, Iarygina et al. [72] showed that when participants think that the keyboard is developed by researchers, they systematically perform higher speeds and report higher user experience compared to the baseline conditions, even when the experimental and baseline conditions are identical.

The low statistical power observed across many studies emphasizes the need for larger sample sizes and robust experimental designs. Our analysis reveals a median participant count of 12 per study, far below the threshold recommended for detecting moderate effects with adequate power. Future research must prioritize a-priori power analyses and adopt strategies such as remote data collection to address these limitations [132].

Device-specific trends in text entry highlight opportunities for targeted interventions. The challenges of text entry on smartwatches, characterized by their constrained form factors, call for innovative approaches that prioritize accessibility and comfort. Similarly, XR text entry, with its reliance on mid-air interactions and spatial inputs, demands metrics that account for fatigue and endurance, such as consumed endurance. Addressing these unique device-specific considerations can drive the development of tailored solutions that enhance usability and performance.

Finally, we observed that the field is affected by publication bias, as only results demonstrating speeds superior to baseline methods tend to be published. This raises the concern that the reported superiority of a developed artifact may be influenced by the choice of baseline. Moreover, surpassing the widely adopted QWERTY layout–where users have extensive experience–is inherently challenging. Given these factors, researchers might consider focusing on additional evaluation metrics beyond speed, such as user experience and cognitive load.

6 Limitations

While this meta-analysis provides valuable insights into text entry research, several limitations should be acknowledged. First, the scope of included studies was limited to those reporting speed and accuracy metrics, which may exclude other valuable research focusing on qualitative aspects or alternative evaluation criteria as user experience or cognitive load. This focus potentially narrows the generalizability of our findings to broader aspects of text entry performance. Nevertheless, very few papers in text entry focus on such variables.

A further challenge arose from incomplete reporting in some studies, where precise numerical data for key variables were not provided and had to be inferred from figures or plots. While effort was made to estimate these values accurately, such inferences introduce potential inaccuracies that could affect the precision of effect size calculations and aggregated metrics. This limitation underscores the need for more consistent reporting standards within the field to improve the reliability of future meta-analyses.

In analyzing the data from 157 articles, significant heterogeneity in study design, methodologies, and measurement practices was observed. The variations spanned experimental procedures, device types, sample sizes, and statistical analyses, making it challenging to integrate findings into cohesive summaries. Consequently, the meta-analysis was performed only for studies that had a baseline for comparison. As such, the conclusions drawn should be interpreted with caution, recognizing that the source data reflects diverse scientific approaches.

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A Publication bias

To assess the possibility of publication bias in the field, we investigated a funnel plot created using the R package `metafor` [175]. Funnel plots show effect sizes against their standard errors, with asymmetry in the plot potentially indicating publication bias.

The funnel plot (Figure 4) indicates a possible publication bias, as shown by the concentration of studies on one side of the mean effect size (see Figure 4). It suggests that studies with non-significant or negative results are underreported. Considering the analyses of word-per-minute effect sizes, all studies with negative effect, belong to XR category. For the analysis of the funnel plot, we excluded six papers with extreme outliers (Hedge's $g > 5$).

To further assess the risk of publication bias, we employed weight-function modeling, using the R-package `weightr` [28]. This approach compares the fit of a publication-bias-adjusted model to that of an unadjusted model. A significant increase in fit may be indicative of publication bias. The results of the weight-function modeling revealed a significant increase in fit, suggesting the presence of publication bias. The likelihood ratio test comparing the adjusted and unadjusted models indicated a significantly better fit for the adjusted model, $\chi^2(1, N = 148) = 6.89$, $p = 8.65 \times 10^{-3}$. This suggests publication bias in the analyzed studies.

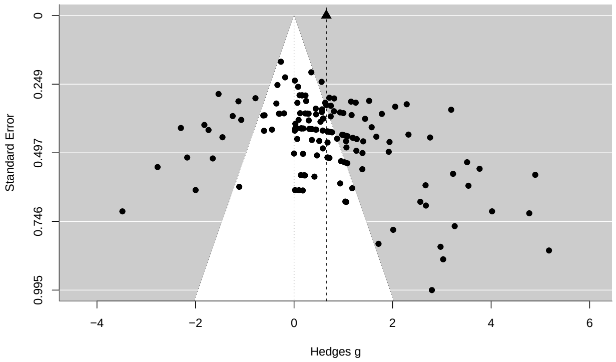

Figure 4: Funnel plot for text entry studies, comparing the effect size (Hedges' g) and precision (standard error) for the word per minute metric.

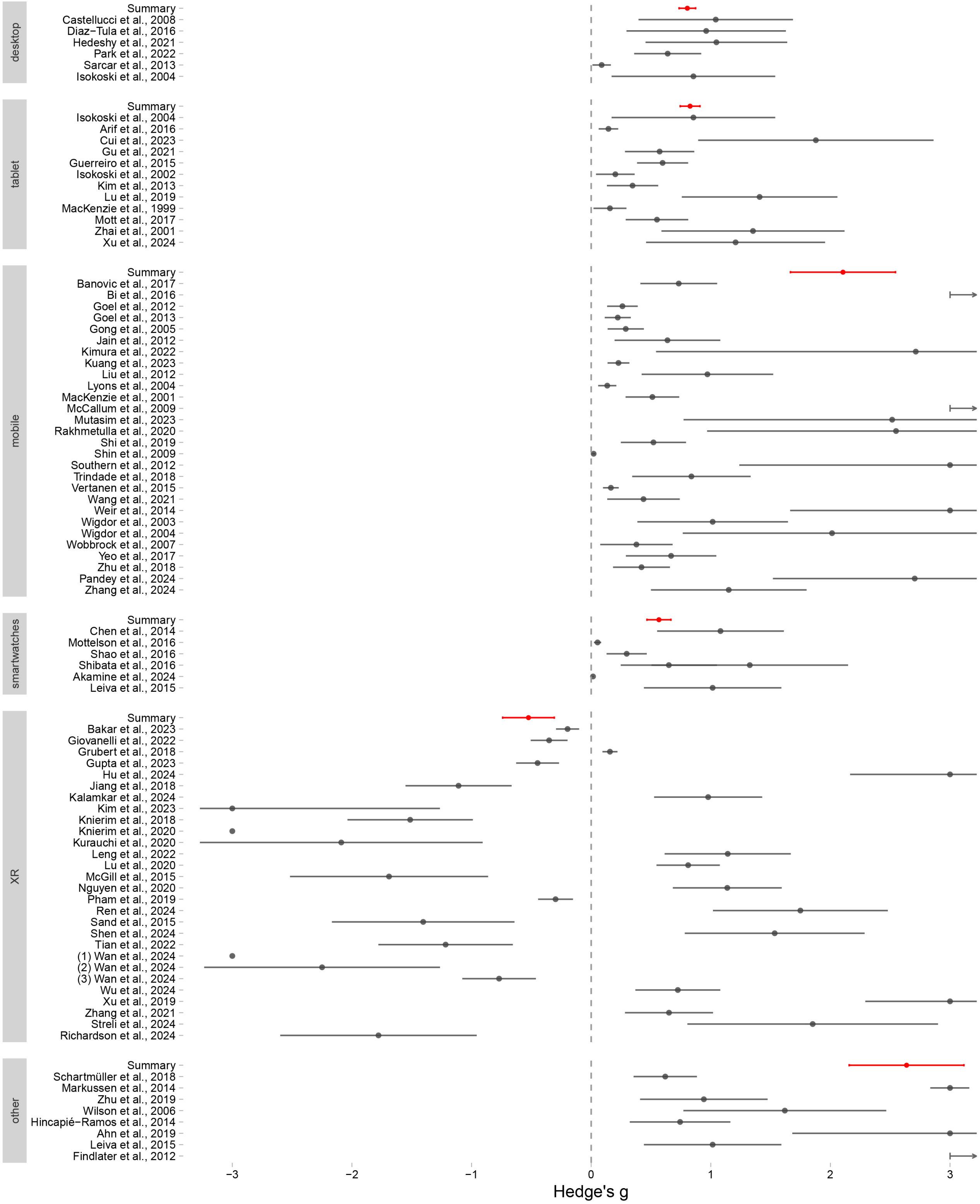

Figure 5: Word-per-minute effect sizes, grouped by device. The error bars show 95% CIs. The red dots denote the weighted means of means with a 95% CIs of means. The effect sizes are derived from per-study comparisons of baseline vs. experimental interfaces.