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APP–BASED HANDWRITING INSTRUCTION AND HANDWRITING LEGIBILITY OUTCOMES IN STUDENTS WITH LEARNING DISABILITIES: A CONTROLLED INTERVENTION EXPERIMENTAL STUDY USING HANDWRITING WIZARD, LETTERSCHOOL, AND LETRAKID

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ABSTRACT

Handwriting legibility is an important academic skill, but students with learning disabilities tend to have ongoing handwriting problems. This study investigated the possibility of mobile app-based handwriting instruction in handwriting legibility, compared results with traditional instruction and investigated differences in three handwriting apps. A quasi-experimental pre-test post-test control group design was adopted with one control group (n = 10) and three experimental groups (n = 10 each). Handwriting legibility was evaluated with the Handwriting Legibility Scale at pre-test and post-test, and analysis of data was performed through the use of nonparametric procedures. Results showed no baseline difference between groups (H (3) = 2.17, p = .538) were significant. Post-test comparison showed a significant result of group effect (H (3) = 13.66, p = .003), and a large effect size (η^2 = .30). Dunn post-hoc tests suggested that all three experimental groups had significantly higher scores than the control group, but differences between apps were not significant. Gain-score analysis indicated that there was significant variation between groups in the improvement (H (3) = 10.25, p = .017) and one app presented comparatively greater gains. A series of within-group Wilcoxon tests confirmed significant pre-to-post improvement in all the experimental groups (r = .80 - .89), but there was no meaningful change in the control group. The findings suggest mobile handwriting apps are effective supplementary tools to improve handwriting legibility among LD students and that may be meaningfully integrated into special education instruction

Keywords: *Handwriting legibility; learning disabilities; mobile apps; app-based instruction; special education; handwriting intervention; educational technology*

1. INTRODUCTION

Handwriting is a core academic skill that is an important part of early learning and continued educational success of students (Morris, 2024). As far as digital technologies are used in the classrooms, handwritten work is still a predominant form of academic expression especially in primary grades where students are required to provide written representations of their knowledge. Legible handwriting supports not only during academic performance, but also with student confidence, participation in the classroom and participation in learning activities. Conversely, problems in penmanship can impede student progress and contribute to frustration, lack of motivation and negative self-perceptions among students (Lhamo & Rigdel, 2025).

Students with learning disabilities (LD students) are especially susceptible to handwriting problems (Bray et al., 2021; Re et

al., 2023). Learning disabilities are neurodevelopmental disorders that are defined as chronic impairments in the acquisition and app of academic skills even when there are sufficient intelligence and educational opportunity (Thurston et al., 2021). Many of the LD students struggle with fine motor coordination, visual-motor integration, letter formation, spacing, and writing fluency; all these issues impact handwriting legibility directly. Research has consistently demonstrated that handwriting problems are more common and more chronic in LD students than in their typically developing peers, and often continue well beyond the early school years and influence performance in academic areas of all kinds.

The relationship between learning disabilities and handwriting difficulties is complicated and complex (Zaibi & Bezine, 2024). Handwriting involves integrating the cognitive, perceptual, and motor activities such as attention, working memory, visual perception, and motor planning. For LD students, deficits in one or more of these areas may interfere with the handwriting process resulting in poorly formed letters, variable spacing, and poor legibility. As a result, students may have problems expressing their ideas in written form, despite having enough conceptual understanding. These challenges make it difficult to make handwriting development accessible and developmentally appropriate for this population and the need for specific, engaging, and developmentally appropriate interventions for handwriting development.

Traditional instruction for handwriting that is so widely used often consists of repetitive paper-and-pencil activities (Ruini & Mortara, 2022) that may not provide the kinds of instruction that address the diversity of learning needs of LDs. Such approaches may be especially difficult for students needing more multisensory input, immediate feedback and persistence of motivation. In recent years, educational technology has become a promising avenue in aiding in skills development amongst students with a learning difficulty. Mobile apps, in particular, provide for an interactive, richly visual, and customizable learning environment that can facilitate handwriting practice by means of guided tracing, real-time feedback and progressive skill development.

Mobile handwriting apps aim to reach out to learners in a multisensory experience where visual, auditory and tactile elements are combined. These apps often include student practice in letter formation at a student's own pace, repetition of tasks if necessary, and immediate corrective feedback, something that may be particularly helpful for students with a learning disability. The portability and accessibility of mobile devices further increase their possibility for use in the classroom or at home. Despite the increase in accessibility of handwriting apps, empirical evidence looking at the effectiveness of these apps, particularly in comparison to traditional instruction, is scarce, and this is especially true in low-resource educational settings.

Although, according to existing studies, technology-based interventions can be used to assist with writing-related skills, there is a lack of controlled experimental studies directly comparing the effects of various mobile handwriting apps on handwriting legibility among LD students. Moreover, few studies have investigated such interventions in the context of the special education school setting where instructional resources and student needs may differ significantly from classrooms with general education students. Addressing this gap is necessary in order to inform evidence-based instructional practices and to guide educators in their choice of technological tools for instruction of handwriting.

The current study was designed to find out the effectiveness of handwriting interventions using mobile app to improve handwriting legibility for LD students. Specifically, the effects of 3 commonly used handwriting apps, compared with traditional handwriting instruction, were compared in a pre-test-post-test control group design. Handwriting legibility was the main outcome variable and the mode of instruction (mobile app-based intervention vs. traditional instruction) was an independent variable. By systematically examining the influence of mobile handwriting apps, the purpose of this study is to offer empirical evidence on the role of educational technology in supporting handwriting development in LD students and

to offer some practical implications for special education practice.

2. LITERATURE REVIEW

Despite the growing impact of digital gadgets in learning institutions, handwriting still remains a key part of early schooling and classroom communication (Bonneton-Botté et al., 2023). Even in primary-grade educational settings, written assignments continue to be the most widespread tool learners use to document information, perform assignments, and showcase their knowledge of academic concepts. Other than its practical use, handwriting is heavily linked with academic confidence, interest in the task and classroom involvement (Limpo et al., 2020). On the one hand, in case handwriting is readable and fluent, students can more clearly convey their thoughts, stay up to date with the classroom activity, and have a positive attitude towards studying (Fitjar et al., 2021). Handwriting problems can disrupt the completion of tasks, the achievement of assessments, written expression as well as self-perception in the long run leading to frustration and disengagement (Chung et al., 2020).

A significant amount of research has documented the fact that handwriting problems are specifically prevalent among the LD students and the fact that such problems are likely to continue without instructional assistance (Rodgers et al., 2023; Dionne et al., 2023). This group of students often has difficulties with fine-motor control, visual-motor integration, coordination in writing, and consistency in the letter formation, which subsequently impacts the legibility and fluency in written activities (Yakut et al., 2025). These challenges do not merely impound mechanical issues with writing, but they are tied inextricably with more general cognitive, perceptual, and motor activities that maintain the production of written language (Saile & Yasin, 2024). Consequently, the LD students tend to experience slow handwriting skills compared to their normally developing peers and can still have an impact on the academic performance in various disciplines.

The connection between handwriting performance and learning disabilities has thus been well investigated in the broader areas of special education, developmental learning studies as well as educational psychology (Teng et al., 2022). Research has placed emphasis on the fact that handwriting is not a single motor skill, but a complicated, modular procedure implicating attention, working memory, serial planning, perceptual organization and executive functioning (Suggate et al., 2023). Disruption in any of these underlying processes can result in a slow, stressful and incoherent handwriting output in students with sufficient conceptual knowledge of academic material (Bondi et al., 2022). This association has enhanced the case in support of intervention strategies beyond handwriting practices which regularity and has been in support of systematic, supportive and involving learning experiences responding to the varied needs of the learners.

The traditional handwriting teaching, despite its widespread use, has been criticized as being based on repeated paper and pencil drills and having little ability to give a student with handwriting difficulties personalized feedback or encouragement (Jamaluddin et al., 2024; Ghanamah, 2025). In the case of LD students, these instructional strategies might not be effective enough in overcoming issues with regard to involvement, endurance of tasks, or formation of regular writing patterns (Liu et al., 2024). This teaching drawback has prompted scholars and educators to investigate other teaching methods, such as technology-based and multisensory education settings, which might be more accommodative and accommodating to student variance.

Digitization of instruction in handwriting has been gaining popularity in recent years, in particular, with the use of mobile devices and educational apps (Raymundo & Cermak, 2025). Mobile handwriting apps provide practice conditions that are interactive, visually guided, and rich in feedback enabling learners to practice writing patterns, get instantaneous corrective feedback and have repetitive and structured practice (Hopcan & Tokel, 2021). These characteristics have been characterized to be consistent with the learning profiles of LD students who might experience advantages of multimodal delivery of instructions, scaffolding, and self-pacing learning. The availability and portability of mobile devices also add to their possibility of use within and

without the classroom to add to the possibilities of learning.

Despite the emerging studies whereby the technology-based handwriting interventions have been argued to have a positive effect on engagement and writing-related skills, research evidence on the effectiveness of these interventions has been mixed (Reganet al., 2024; Han & Wang, 2025). Numerous studies have concentrated on general writing outcomes (e.g. Cruz Cordero et al., 2024; Smitha & Renumol, 2025), small-scale classroom-based interventions, or short-term experimental interventions, whereas less have embraced controlled comparative designs or those outcomes in LD students. Fewer have compared more than one handwriting app in a similar research design or have investigated the instructional use of apps in handwriting teaching in a special school where resource access, teaching focus, and student requirements and needs are very different to those of an overall educational environment.

The gaps note the necessity of the systematic and empirically based research on the role of mobile handwriting apps in the context of handwriting legibility in LD students. Further investigation in the field is not only necessary to enhance the evidence-based instructional practice, but also to direct teachers on the use and incorporation of relevant technological tools in the handwriting teaching. The current research adds to this emerging research question by researching app-based handwriting teaching as a systematic intervention, comparing it to the traditional one, and determining the level to which the results differ among the various mobile handwriting apps.

3. STATEMENT OF THE PROBLEM

The handwriting legibility is a core academic skill, which aids in enabling students acquire skills in showing learning through the subject disciplines. Among LD students, the consistent handwriting problems tend to disrupt such aspects of academic performance, classroom activity, and written communication. Even after receiving special teaching, a lot of LD students still create written text that is hard to read, incomplete or inconsistent and this can have a harmful impact on the results of assessment as well as the confidence of the students.

Traditional paper-and-pencil approaches are often used in special education settings and might fail to support the needs of LD students, which are often varied in terms of cognitive and motor processes. These methods tend to be low in multisensory, paced differently, and lack immediate feedback, which is important with learners having problems with attention, visual-motor integration, and fine motor coordination. This means that development of the handwriting legibility can be gradual or minimal to a great number of students.

There has been a suggestion of using technology-based handwriting interventions as an alternative or complimentary measure to conventional instruction with the growing accessibility of mobile educational apps. Nevertheless, very little empirical studies have been done to investigate the effectiveness of mobile handwriting apps in enhancing the legibility of handwriting among LD students, especially when using in a controlled experimental design. Furthermore, not many studies have conducted the comparison of relative impacts of various mobile handwriting apps to handwriting performance. This gap in evidence poses a question to teachers and practitioners about the instructional usefulness of mobile apps in special education settings in handwriting intervention.

4. RATIONALE OF THE STUDY

The justification of the current research is based on the necessity to define effective, interesting and evidence-based instructional techniques to facilitate the development of handwriting in LD students. Considering handwriting is a complicated cognitive and motor process, interventions offering multisensory stimulation, guided learning, and continuous feedback could be of special use to this group. Handwriting apps run on mobile handwritings provide these features and can enhance student motivation and engagement in the process of performing handwriting.

Although mobile devices have been widely used in the education sector, there is a dearth of empirical studies that have assessed the effectiveness of mobile devices in training handwriting. The current literature usually concentrates on the general result of writing or does not have control groups, and it is hard to

manage whether the results of interventions are due to the application of the mobile apps. Moreover, there are not many comparative studies that analyse the different handwriting apps in a particular study.

This paper aims to fill these gaps through a purposive study of how the effectiveness of specific mobile handwriting programs will enhance handwriting legibility in LD students in a pre-test-post-test control group study. By contrasting the mobile app-based instruction with the traditional handwriting instruction, the study will be able to offer empirical data that will be used to inform the decision-making in instruction in the special education environment.

5. SIGNIFICANCE OF THE STUDY

The results of the research are predicted to have both theoretical and practical implications. Theoretically, the research is adding to accumulating literature on technology-assisted learning by giving concrete evidence on the role that mobile apps play in helping LD students develop handwriting. It also helps to get a better idea of how various teaching modalities can be used to affect the performance of handwriting in children with special educational needs.

As an empirical investigation, the study also provides useful information to teachers of special education, therapists, and school administrators who would want to use effective methods to help such students with handwriting problems. The findings can inform teachers about the right choice of technological solutions that can be used to complement the traditional handwriting instruction by determining the possible advantages of mobile handwriting apps. Also, the research can be used to guide the professional development programs by revealing the teaching environment within which the mobile apps can be used in the special education classes successfully.

On policy and institutional level, the study will offer evidence that can be used in decision making in the adoption of educational technologies in special education context, especially towards low-resource situations. The research can be used to inform evidence-based strategies of improving handwriting instruction among LD students by investigating the efficacy of available and widely used mobile apps.

6. OBJECTIVES OF THE STUDY

The objectives of the present study were to:

1. Test the efficacy of handwriting training using mobile app to enhance the legibility of handwriting in LD students.
2. Compare the mobile app-based instruction and the traditional handwriting instruction as far as the handwriting legibility is concerned.
3. Discover variations in the handwriting legibility results of students with the utilisation of varying handwriting software in handheld devices.

7. RESEARCH QUESTIONS

The following research questions guided the study:

1. Does handwriting training based on mobile app instruction cause handwriting legibility to increase in LD students?
2. Are there any notable differences in the outcomes of handwriting legibility of students exposed to mobile app-based instruction and traditional handwriting instruction?
3. Do handwriting legibility scores vary in students writing with various mobile handwriting apps?

8. RESEARCH HYPOTHESES

The following hypotheses were formulated for the study:

H_{01}: LD students who receive mobile app–based handwriting instruction will not demonstrate significantly higher handwriting legibility scores than those receiving traditional handwriting instruction.

H_1: LD students who receive mobile app–based handwriting instruction will demonstrate significantly higher handwriting legibility scores than those receiving traditional handwriting instruction.

H_{02}: There will not be a statistically significant difference in handwriting legibility scores of LD students between the experimental groups using different mobile handwriting apps.

H2: There will be a statistically significant difference in handwriting legibility scores of LD

students between the experimental groups using different mobile handwriting apps.

9. METHODOLOGY

The current research used a controlled experimental design to test the impacts of handwriting instruction via mobile apps to the handwriting legibility of LD students. The control group consisted of pre-test-post-test in order to compare the results of handwriting between the students implementing mobile app-based intervention and traditional handwriting training. The research was done in a special education school and the sample was selected, intervention was implemented and data was collected in a standardized manner in order to create uniformity in the intervention between groups.

The methodology is elaborated in the subsequent subsections, which are research design, participants and sampling procedures, the instruments used, intervention procedure and the data analysis techniques.

9.1 Study Design

The experiment was done using a pre-test-post-test control group experimental design to investigate the influence of handwriting instruction on handwriting legibility in the LD group using mobile apps. This design allowed to compare handwriting legibility results of students that encountered mobile app-based intervention and the traditional handwriting training and take into consideration the baseline performance variation. All groups were assessed using the same standardized assessment procedure to determine how much their handwriting had improved or not after the intervention period.

9.2 Population, Sampling and Sample

The study population was comprised of students who had learning disabilities and were attending a special educational school in Rawalpindi, Pakistan. A sample of 40 students consisting of 27 boys and 13 girls in this population was chosen to respond to the study. The sample was selected among primary-level grades and the sample of the participants was in formal special education services at the time of data collection. The students were only found eligible to be included in the study when they had handwriting difficulties as determined through the use of the SSHI-LD.

The participants were chosen through a random sampling approach among the qualified students. This method was employed in order to minimize selection bias and to make sure that all students that fit the inclusion criteria were given an equal chance to take part. Random sampling was deemed suitable due to the rather homogeneous educational environment and diagnostic features of pupils at the chosen school.

The criteria were that the students should have a known diagnosis of a learning disability, they should have handwriting problems as measured on the SSHI-LD screening procedure and they must be capable of engaging in organized handwriting training on mobile devices. The students were also left out of the study when they had comorbid sensory impairments or physical disability that would significantly influence handwriting performance, serious intellectual disabilities that inhibited participation in the instructional activities, and unreliable attendance within the duration of the intervention.

After the selection of the participants, all the students were pre-tested with the HLS in order to evaluate their baseline performance in handwriting. On the basis of pre-test scores, the participants were put into one of four categories so as to make a reasonable comparison across the groups. The groups were divided into one control group that used traditional handwriting teaching and three experimental groups that used handwriting teaching using various mobile apps. This presentation organization allowed the comparison of the traditional instruction and intervention based on mobile apps, and the exploratory comparison of the chosen mobile apps.

9.3 Instrumentation

The instruments used in collecting the data of the study were standardized and developed by the researcher. The participants have been screened prior to the intervention by the use of the Screening Scale of *Handwriting Issues in Learning Disabilities (SSHI-LD)*. The SSHI-LD was created to aid in identifying students with handwriting problems, which are usually linked to learning disability, and to determine the

eligibility of the students to participate in the research. The scale is made of the items on a five-point Likert scale and concentrates on the handwriting-related challenges that can be observed and applied to the classroom performance. The SSHI-LD was found to have content validity by undergoing professional review by three individuals in the area of special education, educational research and language education. Analysis of inter-rater reliability provided a coefficient of Cohen kappa of 0.76, which reflects great agreement. The outcome assessment did not involve the SSHI-LD, and it was only utilized in the screening process.

The level of handwriting legibility was measured by the use of the *Handwriting Legibility Scale (HLS)* that was the primary outcome measure of the study. The HLS is an aversive measurement instrument created to measure the handwriting legibility based on the major parameters which include the form of letters, spacing, alignment, and general reading (Barnett et al., 2018). The scale gives a composite score that indicates handwriting legibility as a whole and has been applied in past studies that review the performance of handwriting in learning situations. All subjects had the same standardized procedures of the HLS in the pre-test and post-test phases to achieve consistency between groups.

The instructional tools that were deployed to the participants of the experimental groups were tablet devices that were equipped with the selected mobile handwriting apps. These devices were only accessible during the scheduled intervention sessions and were not available to the participants outside an intervention period.

9.4 Intervention Procedure

The intervention was carried out during a time span of about ten weeks and comprised of a total of thirty instructional sessions. Each of the sessions was carried out in a school-based controlled and distraction-free environment to achieve uniformity in implementation. The SSHI-LD was used to establish that the students had handwriting difficulties before the intervention. After the screening, all the selected participants were tested in terms of their baseline performance in handwriting using the HLS.

They took part in one of four groups, with one control group and three experimental groups, according to the pre-test scores of the handwriting legibility so that there would be reasonable comparability of the groups. The control group (n = 10) was taught a conventional handwriting during the normal classroom lesson. The experimental groups were given mobile app-based handwriting, and each group used one handwriting app during the intervention period. In particular, HW group (n = 10), LS group (n = 10), and LK group (n = 10) had to use Handwriting Wizard app, LetterSchool app, and LetraKid app respectively.

The sessions of intervention were about 30 minutes. Session frequency was also modified at the intervention period to make the instructional intensity sufficient and provide adequate chances to practice handwriting skills. These modifications were made across the board in all the experimental groups, and the duration of sessions, instructional processes, and learning goals remained similar during the time of intervention.

The choice of mobile handwriting apps was informed by fixed guidelines, such as, its wide use in teaching, overall favourable pedagogical remarks, acceptance of teachers, the creation of suitable educational development companies, and the emphasis on learning manuscript or print handwriting. The chosen apps offered to offer the structured practice of handwriting in guided tracing exercises, visual and interactive feedbacks to assist in forming letters correctly and improving the overall handwriting legibility.

In every session, experimental group students were trained in handwriting activities with the help of a trained instructor using the same app they were assigned. The focus of instruction was on the regular letter formation, spacing, and alignment, and the students worked at a personal pace with the help of the app characteristics. At the end of the intervention period, the legibility of handwriting was once again measured among all participants using Handwriting Legibility Scale (HLS) with the same procedures as those that were applied during the pre-test stage. The normal teaching schedule was not altered except in the intervention sessions, and the control group

was not exposed to the mobile handwriting programs at all in the course of the research.

9.5 Data Collection and Analysis Procedure:

The data were collected in two steps; pre-intervention (pre-test) and post-intervention (post-test). In the pre-test stage, all qualified subjects were given a handwriting assignment in which they scored the task with the help of the Handwriting Legibility Scale (HLS). The pre-test was used as a baseline measure of the legibility of handwriting as well as to constitute similar groups. After administration of pre-tests, participants were divided into a control group and three-experimental groups with each experimental group taught using a different mobile handwriting app and the control group taught using the traditional handwriting training.

The intervention was applied during the specific study time under the control of instructional conditions. The same handwriting assessment procedure was used at the end of the intervention to assess the post-test using the same criteria of scoring and methods of administration to maintain the consistency between measurement points. Any form of scoring was done with care and was documented in a standardized data-entry template to reduce the possibility of recording error.

Preparation of data was initially done by accuracy checking, screening of scores and calculating of descriptive statistics of both groups at pre-test and post-test. Hypotheses on normality and homogeneity of variance were tested in order to select the right statistical procedures. Nonparametric analyses were taken up because normal tests were not always met within groups and over time. Baseline equivalence was evaluated by the Kruskal-Wallis test of pre-test results; the post-test group difference was evaluated with Kruskal-Wallis test and pairwise comparisons of the post-test with Dunn post-hoc with Bonferonni adjustment. To analyse the extent of change-related to the intervention even further, gain-score analysis and other post-hoc comparisons was carried out and within-group improvement was assessed by means of Wilcoxon signed rank tests. To test the robustness of the ANCOVA, a Quade rank-based ANCOVA was also conducted to readjust the performance at the post-test. To aid practical interpretation of results of the intervention, effect sizes were computed together with significance tests.

9.6 Ethical Considerations

Ethical standards were keenly followed during the study procedure. The school administration gave the approval of the research to proceed with data collection beforehand. Classroom teachers were also contacted to allow the intervention to be implemented in the normal instructional program.

Parents or legal guardians of students who were involved in the study provided informed consent after being informed about the aim of the study, the processes to be done, and the fact that participation was voluntary. Parental consent was taken before students were included in the study and their participation did not disrupt their normal educational services. The participants were told, in an age-sensitive way, that they could pull out of the study any time without any academic penalty.

All participants' anonymity and confidentiality were ensured. No personal identifiers were stored in the data files and all data were coded to make sure that individual participants were not identified. The data collected was meant to be utilized in the research alone and it was kept in a safe place only accessible to the researcher.

No physical or psychological harm was anticipated to be caused to participants during the intervention since the intervention included instructional exercises, which are present in normal classroom activities. The control group students kept on with the conventional handwriting training so that every participant did not suffer a lack of educational aid. The entire process was carried out in line with the ethical standards of conducting research on education among children and students with disabilities.

10. DATA ANALYSIS

The analysis of the data was done with the help of relevant inferential and descriptive statistics that were used to investigate the variation in handwriting legibility between groups and over time. Descriptive statistics were calculated before the inferential analysis to summarize the scores of handwriting legibility of each group at

pre-test and post-test and compare the overall distributions of the data. Follow-up analysis was done to compare the results of handwriting legibility between the control and the experimental group and to find out the differences between the experimental groups after the intervention.

10.1 Descriptive Statistics

Descriptive statistics were achieved to describe handwriting legibility scores in each group before and after the test and to understand the trends of central tendency and dispersion of scores before one could infer based on this information.

Table 1: Descriptive Statistics of Scores by Group and Time

Group	Time	n	Mean (M)	Median	SD	Variance
Control Group	Pre-test	10	14.00	14.00	1.33	1.78
Control Group	Post-test	10	14.30	14.00	1.49	2.23
HW Group	Pre-test	10	14.30	14.00	1.34	1.79
HW Group	Post-test	10	16.80	16.50	1.23	1.51
LS Group	Pre-test	10	13.50	13.00	1.51	2.28
LS Group	Post-test	10	17.20	17.50	1.69	2.84
LK Group	Pre-test	10	14.20	14.50	1.23	1.51
LK Group	Post-test	10	17.10	17.50	1.91	3.66

As Table 1 demonstrates, initial pre-test scores were generally similar in groups (Control: M = 14.00, HW: M = 14.30, LS: M = 13.50, LK: M = 14.20), which suggests that the handwriting legibility was reasonably similar in all groups initially. The mean score of the control group was not significantly different at post-test (M = 14.30), and all the three experimental conditions had significant increases (HW: M = 16.80; LS: M = 17.20; LK: M = 17.10). The highest average values of gains were in the LS and LK groups, respectively, and then HW. The standard deviations were moderate between groups and time points (with a range between 1.23 to 1.91), and thus indicated consistency and similar dispersion of scores across the period of the study.

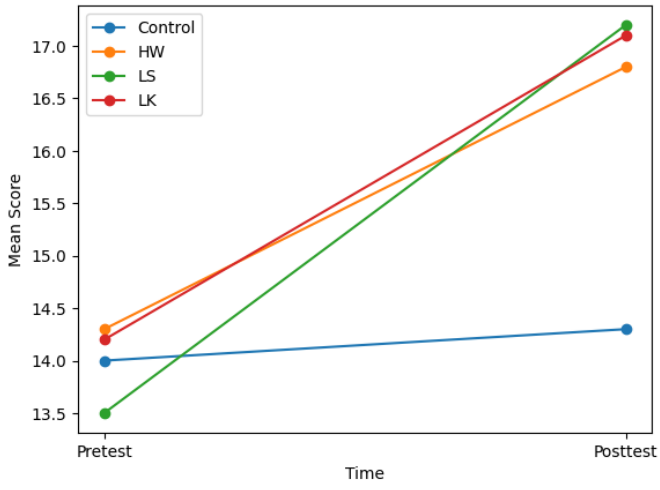

Figure 1. Pre-test and Post-test Mean Scores across Groups

Figure 1 presents the visual trend that indicates that the control group had relatively little improvement in handwriting legibility scores within the intervention period, particularly between pre-test and post-test. Conversely, the three experimental groups showed a distinct increase in the mean of scores over the time, which portrays significant improvement of handwriting legibility after receiving app-based

instruction. The growth was the highest among the LS and LK groups, and HW group, which is consistent with the statistical findings of the analysis section.

To test the normality assumptions in each group in pre-test and in post-test, the Shapiro-Wilk test was applied to test the distribution of handwriting legibility scores.

10.2 Normality Test

Table 2: Shapiro–Wilk Normality Test Results

Group	Time	W	p-value	Interpretation
Control Group	Pre-test	0.918	.344	Normality assumption met
HW Group	Pre-test	0.803	.016	Normality assumption violated
LS Group	Pre-test	0.845	.051	Normality assumption met
LK Group	Pre-test	0.924	.389	Normality assumption met
Control Group	Post-test	0.862	.080	Normality assumption met
HW Group	Post-test	0.924	.389	Normality assumption met
LS Group	Post-test	0.838	.041	Normality assumption violated
LK Group	Post-test	0.760	.005	Normality assumption violated

Table 2 demonstrates that the normality assumption was not always followed in groups and time points. The distributions of several of the groups such as HW-Pre (W = 0.803, p =.016), LS-Post (W = 0.838, p =.041), and LK-Post (W = 0.760, p =.005) showed significant deviation of normality, but not all group scores showed significant deviation of normality (e.g., Control-Pre: W = 0.918, p =.344). Considering these inconclusive findings, and following the plan of analysis, nonparametric statistical tests were used in further analyses.

10.3 Homogeneity of Variances

The Brown-Forsythe test was used to test whether the variances of groups are homogeneous; this is a powerful test which can be fitted to small sample sizes, and which does not assume that the distribution is normal.

Table 3. Brown–Forsythe Test of Homogeneity of Variances

Time Point	F (Brown–Forsythe)	df1	df2	p-value	Interpretation
Pre-test	0.046	3	36	.987	Homogeneity of variance met
Post-test	1.390	3	36	.262	Homogeneity of variance met

According to Table 3, Brown-Forsythe test showed no significant difference in variance among the groups during pre-test or post-test (Pre-test: F (3,36) = 0.046, p = .987; Post-test: F (3,36) = 1.390, p = .262). These findings demonstrate that the variances by groups were similar and it is possible to assume that the subsequent between-group analysis can be performed under a homogeneity assumption.

10.4 Baseline Equivalence

In order to ensure that the baseline comparability was achieved before the intervention, a Kruskal-Wallis H test was used to compare the pre-test scores on handwriting legibility among the four groups.

Table 4: Kruskal–Wallis Test (Pre-test Scores)

Time Point	Statistic	df	p-value	Interpretation
Pre-test	H = 2.17	3	.538	No significant baseline difference

Table 4 revealed that the Kruskal-Wallis test did not show significant differences in the pre-test scores, H (3) = 2.17, p =.538. These results prove that the groups were equal in the legibility levels of the handwriting before the intervention.

10.5 Intervention Effect

The post-test scores were analysed by another Kruskal-Wallis H test to determine whether there are any differences in handwriting legibility across groups after the intervention.

Table 5: Kruskal–Wallis Test (Post-test Scores)

Time Point	Statistic	df	p-value	Interpretation
Post-test	H = 13.66	3	.003	Significant group difference

As indicated in Table 5, the analysis showed statistically significant difference between the post-test handwriting legibility between groups, H (3) = 13.66, p =.003. It means that the intervention conditions were related to different post-intervention outcomes, which is why follow-up pairwise comparisons could be used to define the origin of these differences.

10.6 Post-Hoc Comparisons

Since the omnibus post-test result was significant, the Dunn's pairwise post-hoc tests with Bonferonni correction were conducted to determine which group comparison pairs interested in the overall effect.

Table 6: Dunn–Bonferroni Post-Hoc Comparisons (Post-test Scores)

Comparison	z	p (Bonferroni-adjusted) *	Interpretation
Control vs HW	2.76	.034	Significant
Control vs LS	3.13	.010	Significant
Control vs LK	2.98	.017	Significant
HW vs LS	0.36	1.000	not significant
HW vs LK	0.22	1.000	not significant
LS vs LK	0.14	1.000	not significant

As Table 6 reveals, all experimental groups were scored significantly higher than the control group in the post-test measure (Control vs HW: p =.034; Control vs LS: p =.010; Control vs LK: p =.017). Nevertheless, there were no important differences between the experimental groups themselves (all p >.05). The results show that instruction using apps was more effective than instruction using a traditional approach, despite the fact that the three apps yielded similar post-intervention results.

10.7 Effect Size

In order to supplement the significant tests and quantify the magnitude of group differences at post-test, the effect size of the Kruskal-Wallis analysis was estimated with eta-squared (η^2).

Table 7: Effect Size for the Kruskal–Wallis Post-test Comparison (Eta-Squared, η^2)

Time Point	Statistic	Value	Interpretation
Post-test	η^2	.30	Large effect

Table 7 shows that the eta-squared value was high to state that group membership has a large effect on post-test handwriting legibility (η^2 = .30), which implies that a high percentage of the difference in the results could be attributed to the instructional condition.

10.8 Gain Score Analysis

Gain scores (Post Pre) were calculated and compared with the help of Krustal-Wallis H test to assess the variation in the level of improvement among different groups of participants.

Table 8: Kruskal–Wallis Gain-Score Result

Time	Statistic	df	p-value	Interpretation
Gain Score	H = 10.25	3	.017	Significant difference in gain scores

As presented in Table 8, the analysis found a statistically significant difference in improvement of gain-score between the groups, H (3) = 10.25, p = .017. This implies that the change being pre-test to post-test was different among intervention conditions.

10.9 Post-Hoc on Gain Score

Since the gain-score analysis indicated that there were significant overall improvement differences, Dunn's pairwise post-hoc tests with Bonferonni correction were performed to identify what specific groups differed in terms of the number of improvements.

Table 9: Dunn–Bonferroni Post-Hoc Comparisons for Gain (Improvement) Scores

Comparison	z	p (Bonferroni-adjusted)	Interpretation
Control vs HW	2.06	.239	not significant
Control vs LK	2.27	.140	not significant
Control vs LS	3.02	.015	Significant
HW vs LK	0.21	1.000	not significant
HW vs LS	0.97	1.000	not significant
LK vs LS	0.76	1.000	not significant

Table 9 reveals that the LS group had significantly improved compared to the control group (p = .015). Even though there was also a higher improvement score in HW and LK groups than in the control group, adjustment statistically revealed that these differences were not statistically significant. There were no exhibited significant differences in improvement between the experimental groups (all p >.05), which shows that the magnitude of the improvements in the three apps is broadly the same.

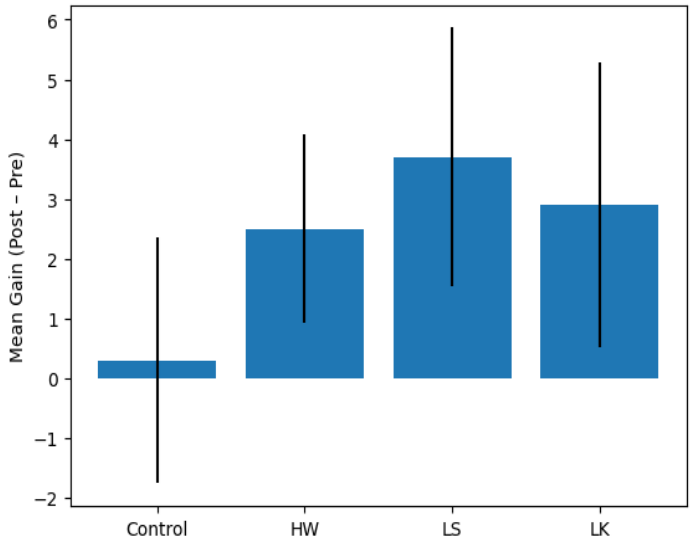

Figure 2. Gain Scores by Group as a Bar Chart with Error Bars (SD).

In Figure 2, the trend indicates that no significant change was observed in the control group, but the three experimental groups registered positive means that changed after the practice. The LS group had the greatest improvement, then the LK and HW groups which is in line with the gain-score and post-hoc statistical outcome. The error bars show that there is a degree of variability in groups, but the trend of the improvement is obviously more significant in the app-based instruction groups compared to the control group.

10.10 Baseline-Adjusted Comparison of Post-test Scores

Being a robustness analysis, a Quade rank-based ANCOVA was employed to compare post-test scores and statistically adjust pre-test performance to give a nonparametric estimate of group differences, which was adjusted by the baseline.

Table 10: Quade Rank-ANCOVA Result (Post-test Adjusted for Pre-test)

Comparison	Statistic	df	p-value	Interpretation
Post-test Adjusted for Pre-test	F = 1.81	3, 36	.162	Not significant

As seen in Table 10, the Quade analysis revealed that there was no significant difference in baseline-adjusted post-test, F (3,36) = 1.81, p =.162. This implies that the differences found in the group in the unadjusted analysis were lesser after pre-test variation was factored in.

10.11 Within-Group Improvements

In order to determine the significance of pre-to-post improvement in each group, Wilcoxon signed-rank tests were done individually in the control and each experimental group and the effect size (r) was determined to demonstrate the magnitude of improvement.

Table 11: Within-Group Improvement (Wilcoxon Signed-Rank Tests)

Group	W	p-value	z	Effect Size (r)	Interpretation
Control	18.00	.586	0.53	0.18	Not significant
HW	0.00	.007	2.67	0.85	Large improvement
LS	0.00	.002	2.80	0.89	Large improvement
LK	0.00	.012	2.52	0.80	Large improvement

As shown in Table 11, the three experimental groups showed significant change in handwriting legibility before to after with large effect sizes (HW: p = .007, r =.85; LS: p = .002, r = .89; LK: p = .012, r = .80). Conversely, the control condition did not demonstrate a significant change (p = .586), which means that meaningful improvement happened mostly in the conditions of app-based instruction.

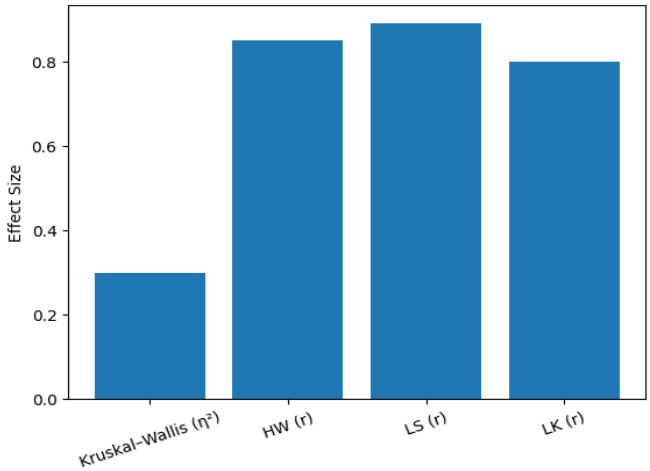

Figure 3. Effect Size Summary

Figure 3 indicates that the overall group effect at post-test reflects an effect of large magnitude whereas the within-group improvement effects of the three experimental groups are within the large range. This is the best outcome when it comes to the LS group, then the HW and LK according to which a significant intervention-related improvement is noted and supports the

trend of considerable gains in intervention-related areas found in the statistical results.

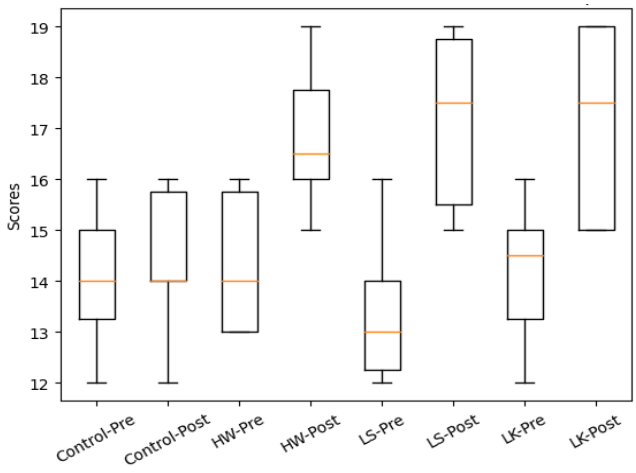

Figure 4. Boxplot of Distribution of Scores within Each Group across Time

Figure 4 boxplots show little difference in score distribution within the control group, which means that there had been no significant improvement over time. Conversely, in the experimental groups, the median and upper-range values distinctly increase between the pre-test and the post-test, which indicates a significant increase in handwriting legibility. The LS and LK groups reveal the most significant upward distributions shifts, then there comes the HW group which is also in line with the within-group Wilcoxon result and gain-score trends.

11. FINDINGS

As the results of the research show, the groups were generally similar in their handwriting legibility before the intervention. Although the control group had minimal or no significant improvement between pre-test and post-test, all the three experimental groups reflected observable enhancement after engaging in the use of the app in teaching handwriting.

A subsequent analysis revealed that the results of handwriting were significantly different between groups at post-test, and that students in the app-based instruction conditions performed better than students in the traditional handwriting instructions condition. Nonetheless, the three apps yielded relatively similar post-intervention results, which implies that all of them were effective to a relatively similar extent to assist handwriting legibility.

The time-based improvement was found to have improved more in students on the experimental groups than control group with one app reporting a relatively strong improvement. In spite of this, the general trend was indicative of significant improvement in all three conditions of the app and little improvement in the control group.

A robustness analysis performed to explain the differences at baseline performance revealed that some of the differences at the post-test period could be partly explained by baseline difference in handwriting. However, this alteration did not eliminate the general trend of an increase in regard to app-based teaching.

The within-group analyses also validated the hypothesis that students in the three experimental conditions had significant pre-to-post handwriting legibility improvement, whereas this was not the case in the control group.

Combined, these results imply that handwriting instruction through mobile apps put a positive influence on the improvement of handwriting legibility in LD students. These findings demonstrate the promise of interactive online resources as instructional aids and suggest that, although one app resulted in comparatively better gains than the other two apps, all three apps helped create more meaningful gains than in the case of traditional handwriting instruction.

12. DISCUSSION

This research investigated the capability of mobile app-based handwriting instruction to LD students, and the idea was to compare the results of this method with the results of handwriting instruction and contrast the possible variations among three handwriting apps. The results are valuable data that can be used to promote handwriting legibility in this category of population through app-based instructions and, in addition, the results can be used to compare the efficacy of various digital instruments.

In line with the first objective, the researchers established that, in line with the first objective, students who had undergone handwriting instruction using the apps exhibited significant gains in handwriting legibility between the pre-test and post-test but students in the control group did not exhibit significant changes in handwriting legibility between the pre-test and post-test. These findings indicate that mobile apps have the potential of being a viable instructional tool towards developing handwriting in LD students. The results are in line with previous studies that technology based and multisensory techniques can be used to improve the writing related skills with more engagement, instant feedback and repetitive structured practice (e.g., Zorzi et al., 2006; Rosenblum et al., 2004). The findings are also consistent with theoretical views on the significance of interactive, visually instructed, and task-oriented teaching systems among learners with motor-coordination and visual-motor integration problems, which are generally related to handwriting problems among LD students.

Regarding the second objective, the analysis demonstrated that students in the three experimental groups did better at post-test compared to those in the conventional handwriting training group. This trend shows that the app-based teaching was also widely more efficient than traditional paper-and-pencil training in the facilitation of handwriting legibility. The reason can be the existence of a structured, yet interesting practice environment where students can be given immediate corrective feedback, sequencing of tasks, and given the chance to learn at their own pace. The same studies that were conducted have indicated that technology-mediated handwriting interventions may be used to augment motivation and persistence, decrease task avoidance, and promote sustained practice - often challenging when using a traditional instructional format on its own. The current results thus add additional empirical evidence to the use of digital tools in teaching handwriting, especially in special education where it is possible that learners might be assisted by the other means of delivery.

The third objective was to understand possible variations between the three mobile apps to be applied in the study. Even though there was one app that had a relatively higher improvement in gain scores, the performance of the experimental groups was, generally, similar. This indicates that though particular design characteristics like visual scaffolding, tracing guidance or reinforcement mechanisms might contribute to the degree of improvement to some extent, all these three apps had common instructional attributes which were enough in order to contribute to meaningful handwriting improvements. These findings are consistent with previous studies that have shown that the success of handwriting aids based on technology tends to be less related to brand or platform and more to overlapping pedagogical characteristics like multisensory input, systematic repetition and explicit modelling of motor patterns. The fact that results are often similar across apps is also a sign that teachers have a certain degree of freedom to choose which tool to use, especially when such factors as the lack of resources, their availability, or cost are involved.

Simultaneously, the analysis of the baseline score adjusted indicated that initial performance difference might contribute to the noticed post-test differences. Instead of undermining the main results, this subtlety makes the process of handwriting development among the LD students more complex and emphasizes the significance of the interpretation of the intervention results in the context of the learner diversity. The overall trend in the pattern of results shows that app-based instruction helped significantly in improving handwriting, although the level and the trend of responses might differ among learners and apps.

In general, the study contributes to the body of literature by offering evidence on the use of mobile handwriting apps in special education under the form of controlled and school-based studies. It illustrates that those tools, in addition to facilitating quantifiable change, also provide a feasible substitute to the conventional handwriting lessons. At the empirical level, the results indicate that educators and counsellors can take into consideration the implementation of mobile handwriting programs as auxiliary learning aids among students who react well to interactive and visually instructive learning uses. Research-wise, the study underscores the fact that more studies need to be conducted to understand the interaction of particular app features, the degree of instructional intensity, and the unique characteristics of learners to influence the effects of handwriting.

Combined, the results indicate the conclusion that handwriting instruction through mobile app is an emerging potential strategy through which handwriting legibility can be enhanced among LD students, which has both a functional learning advantage and an instructional flexibility through the various app formats.

13. CONCLUSION

This research paper has reviewed the effectiveness of handwriting teaching using mobile apps among the LD students and comparisons were made with traditional handwriting teaching. This led to a significant increase in the legibility of handwriting of students receiving instruction through the app, but only slight or no improvement of handwriting in students in the control group. In the three apps, students were able to score higher at the post-intervention compared to the traditional instruction and this shows that mobile apps are more supportive and engaging in the learning process of acquiring handwriting skills.

Even though there was one app that seemed to produce comparatively higher gain score improvement, the overall post-intervention performance of the experimental groups was similar to a large extent. This implies that the instructional similarities of the apps such as guided tracing, multisensory feedback, structured repetition, and sequencing tasks in a given order were central to the facilitation of the development of handwriting and not a platform-specific attribute.

Combinations of the results suggest that mobile handwriting apps are a promising and efficient instructional tool in the case of LD students, and especially in the contexts where the latter might be supported by the interactive, graphical, and encouraging formats of practice. This research provides empirical evidence of the use of digital technologies in teaching handwriting and supports the possible potential of technology-assisted learning strategies in special education.

14. SUGGESTIONS

According to the results of the study, the following recommendations are suggested:

1. These apps may be incorporated by teachers and therapists in the framework of traditional instruction to offer more structured practice and engagement opportunities to LD students.
2. Frequently practicing handwriting apps under the supervision can assist the students in consolidating motor patterns, enhancing the formation of letters and staying motivated.
3. The features of the apps used in teaching should be known to the teachers so that they can use them appropriately, in line with the curriculum objectives and to be able to monitor learner progress.
4. Because of similar results of the apps, the preference should be made to the tools that provide multisensory input, corrective feedback, repetition and age-related design.
5. Self-paced practice is possible through mobile apps and might be especially helpful with students who need more time, repetition, and fine-motor assistance.

The recommendations can guide schools, experts, and policy-makers to make sound judgments on the incorporation of educational technology in handwriting teaching to learners with special needs.

15. LIMITATIONS OF THE STUDY

Despite the meaningful results that the study has provided, there are a number of limitations to consider. First, the sample size and setting

used was restricted to one school situation and that might limit the extrapolation of findings to wider or more diverse groups. Second, the intervention period was also rather brief and the retention or maintenance of handwriting gains in the long term was not studied. Third, the legibility of handwriting was assessed with the help of one measuring tool, and no other results like the writing speed, fluency, or functional writing tasks at the classroom level were involved. Fourth, there could have been differences in individual learning profiles of LD students, which could have contributed to responsiveness to the intervention; however, subgroup analyses were not performed. Fifth, the research failed to look at teacher fidelity or difference in the implementation practices, which could also influence the results. The follow-ups should consider these restrictions in the interpretation of the results and in the design of the follow-up studies.

16. RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the current results, future research can take into account the following directions:

1. Expand the sample size and increase the sample diversity in terms of schools, grade levels, and disability profiles to increase the external validity.
2. Test the long-term effects by making follow-ups to establish the sustainability of gains in handwriting.
3. Add other outcome variables, including handwriting speed, writing fluency, classroom writing performance and student motivation.
4. Compare various intensity levels of intervention, such as the frequency of sessions, sessions length, and teaching medium.
5. Explore individual responses to app-based teaching and learning, including varied or less varied responses depending on learning difficulty type or severity, fine-motor skills, or performance in handwriting (as a previous task).
6. Test teacher-mediated vs independent app, understanding the impact of instructional support, scaffolding or feedback practices.
7. Undertake qualitative or mixed methods research to encompass the perceptions of the students and teachers, the experiences of engagement and the difficulties faced in implementation.

This kind of research will further inform the idea of how mobile handwriting apps can be optimally incorporated into the special education practice and how the instructional benefit can be different among learners and situations.

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