# Individual Differences and Group Effects for Keyboard and Stylus in Autobiographical Compositions and Summaries of Read Source Material for Students in Grades 4 to 9

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**Abstract**

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As new technologies for interacting with computers through written language become more widespread, it becomes increasingly important to understand which modes of computer interface are effective and for whom. For this study participants ranged from grades 4 through 9 and fulfilled diagnostic criteria for specific learning disabilities affecting letter, word, and sentence production. Students produced compositions alternating their use of either the stylus or the keyboard in a within-subjects design using two modes, each of which was repeated for three lessons in a row for three alternations for a total of 18 lessons (2 modes x 3 alternations of 3 lessons in a row). Total word count was assessed for each of the participants. This study employed two complementary methodologies. First, individual plots for word count were created to show individual growth over time and selected outcomes, including total correctly spelled, total misspelled, and total illegible to form a composite of total words produced. Second, hierarchical linear modeling and individual *t*-tests were used to analyze both individual and group differences. Individual plots indicated mixed effectiveness of mode of writing across time for individual participants, that is, individual differences in whether their written productivity was greater by stylus or keyboard. However, between groups analysis showed an overall effect of mode of writing. Students using keyboard were able to produce more words in specific lessons on their compositions than students who used the stylus. Also mean level of words produced by keyboard was significantly correlated with more outcomes for which there were treatment effects than was mean level of words produced by stylus. Implications for educators are discussed, especially the need to go beyond using laptops only for accommodations to use of laptops such as IPads integrated in explicit writing instruction in the classroom.

**Table of Contents**

# Chapter 1: Research, Definition and Diagnosis of Specific Learning Disorders, and the Use of Computers for Their Remediation.

## Introduction

In order to understand how the mode of writing affects a learning disabled student's ability to produce written language, it is perhaps first necessary to understand the nature of these specific learning disorders. Furthermore, with the development of new tools comes the necessity to develop novel skillsets for their effective use.

Language manifesting through the hand, eye, mouth and ear serves as a useful conceptual framework for addressing the development and the disability of language (Berninger, 2000). In this model we see these systems are interdependent; however they tend to follow a general developmental progression starting with language by ear. This is aural language and is the first that an infant would experience. This would be followed by language by mouth; often associated with the first spoken word. The third phase is represented by language by eye which is reading. The final stage is language by hand. Written language is partially predicated on the successful growth of other components of language. However, if specific language systems are not developing normally for a number of reasons,  certain technologies have been shown to be effective in helping developing children and youth circumvent these disabilities (e.g. through use of hearing aids, voice amplification, braille, and computer tools for production of written language).

## The Emergence of New Tools

Although researchers have investigated use of computers in writing for a quarter of century (e.g., MacArthur & Graham, 1987), the recent explosion of new technologies has raised the relatively unexplored issues of which modes of computer tools (e.g. stylus or keyboard) best support various kinds of writing activities and for whom. These issues are also timely because of the American Disabilities Act (1990), according to which individuals, including school age children and youth, are entitled to accommodations for their disabilities. For students with disabilities that affect their writing, accommodations often involve recommendations to use a computer. However, little research exists on the relative effectiveness of the various computer tools that might be used to produce writing with computers, especially laptops, either for students in general or for individual students with specific learning disabilities affecting written production of language.

The comprehensive second-order meta-analysis by Tamim, Bernard, Borokhovski, Abrami, and Schmid (2011), which represents a composite of meta-analyses addressing the overall effect of educational technology on student achievement measures based on 1,055 primary studies with 25 metanalyses, demonstrated the overall effectiveness of educational technology for students in general. They found that the average student in a classroom where technology is used averages 12 percentile points higher than a similar student who is participating in a non-technology enhanced classroom. While there are many other dimensions that factor into student achievement such as pedagogy, instructional approach, and treatment fidelity, these findings indicate that technology can generally be used to enhance education.

Particularly relevant to the present study, the authors found there was a more profound effect on achievement for students in K-12 grades than for students in higher education (Tamim et al., 2011). However, the field of writing research is experiencing a moment of transition in the face of emerging technologies for writing. With the development of these new systems comes a shift in the necessary cognitive abilities so that a computer user can adapt to both new demands and new affordances of writing tools. Because of this, the ability to analyze the effectiveness of these new technologies for evidence-based recommendations for both individual students and groups becomes increasingly more important. For the purposes of this study, complementary methods of analysis looking at individual and group differences may facilitate more methodologically diverse and therefore a comprehensive way of approaching the research questions. The focus will be on two modes of using computers for producing written language—the keyboard and the stylus—for purposes of composing written text.

Of note, a review of the relevant literature assessing effectiveness of educational technology for students with specific learning disabilities affecting writing and reading or for writing and reading instruction in general showed mixed results (Torgesen, Wagner, Rashotte, Herron & Lindamood, 2010). Other studies failed to find significant differences in both language and math outcomes for a variety of commercial interventions (Dynarski et al., 2007)

Still other meta-analysis detected meaningful effect sizes when looking specifically at the use of educational technology for reading outcomes (Cheung & Slavin, 2012). Other researchers indicate educational technology can yield more positive achievement outcomes for students with learning disabilities than for their non-learning disabled peers in a variety of contexts in mathematics education (Li & Ma, 2010). In some K-12 samples, the effectiveness of computerized interventions for students with dyslexia has not been shown to be more effective than more traditional teacher led interventions using similar material despite indicating an overall intervention effect (Torgesen, Wagner, Rashotte, Herron & Lindamood, 2010) This effect was also maintained over the course of a year on several measures of phonemic awareness.

However, for meta-analysis focusing specifically on middle school aged interventions, researchers demonstrated consistent effectiveness of a variety of digital technologies. These results further demonstrated that standardized measures from psychometric testing companies were less sensitive to the various treatments when compared to measures developed by the researchers themselves. Finally, if researchers developed their own technology specifically for the intervention, as is true for the present study, a greater effect size was demonstrated consistently across a variety of studies (Moran, Ferdig, Pearson, Wardrop, & Blomeyer, 2008).

User control in educational software may be less important than previously thought. Recent meta-analysis indicates that while using educational technology, user control of variables such as pacing, sequence of materials, choice of material type and amount may not have an effect on a wide variety of learner outcomes (Karich, Burns & Maki, 2014). Again, this meta-analysis did not account for students who were diagnosed with a learning disability and their patterns of effectiveness with regards to user control. Understanding user control also has implications for game based learning. In a game designed to teach letter-sound correspondences, researchers attempted to alter both the skill level of the game and a behavioral reward system to increase their effectiveness and time on task for the software. Researchers demonstrated no effect for either the reward system or the difficulty level (Ronimus, Kujala, Tolvanen & Lyytinen, 2014).

If user control does not demonstrate itself to be a worthwhile aspect of educational technology for language development, this would be counterintuitive given the extant body of research and understandings of learning theory more generally that placed constructivist and user directed learning as central (Bransford, Brown & Cocking, National Academy of Sciences, 2006). However, meta-analysis looking at constructivist education while using technology compared to more traditional education indicates that the constructivist education using technology is more effective. This effect is especially profound when constructivist measures are used to evaluate constructivist education instead of using traditional measures. (Rosen &

Salomon, 2007).

A variety of technologies have been demonstrated to be effective assistive technologies in composition for students with specific learning disabilities. These tools include voice dictation, word processing, spell checking, and word prediction. Early studies found discrepancies in the types of revisions made with traditional handwriting, word processing, and dictation. It is evident that students revise more often between iterations of compositions when handwriting, whereas they revise more within a composition when using a word processor. (MacArthur & Graham, 1987). One must bear in mind that there have been many advances in the technology and changes in instructional practices, and so further investigation may be necessary.

It is important to note that the computers used in this study are qualitatively distinct from many other previous attempts at software-based interventions for students with specific learning disabilities as they interface through touch and keyboard rather than just keyboard. This changes the usability dynamics for the student and presents a number of novel opportunities as well as challenges. With regards to preference, some evidence suggests that students prefer to use tablet computers as a part of their general education (Dündar, & Akçayır, 2013). It is important to note that distributing cognitive resources between teachers and their computers may have a negative effect on their ability to focus on the material. What’s worse is this may also have an effect on the students who sit near someone who is using a computer in class (Sana, Weston & Cepeda, 2013). For students with specific learning disorders that may also have difficulties with executive functioning, such as task switching and focusing, these issues may be even more significant. It is evident that in a research design should account for the type of setting participants experience the technology in, be it group work or individual work.

**Defining Specific Learning Disabilities**

Given revisions to the diagnostic criteria in the fifth and latest iteration of the diagnostic and statistical manual, the diagnoses currently understood as dyslexia, dyscalculia, and the disorder of written expression have been recategorized as simply "Specific Learning Disorder." (American Psychiatric Association, 2013) With the adoption of the latest DSM-V comes a new protocol for how and when specific learning disabilities are diagnosed. The significance of these decisions has educational, therapeutic and indeed legal ramifications that will be impactful for a generation of students in need of services. Diagnostic criteria for each of these conditions should carefully assess the nuanced distinctions between each of these domains.

However, this fifth version of the DSM has spawned considerable controversy and there is no consensus on this definition of specific learning disabilities (SLDs). The National Joint Committee on Learning Disabilities offers 5 criteria for understanding learning disabilities. First, in contrast to the DSM-V, it is assumed that they are heterogeneous both between and within individuals –that is to say co-occurring diagnoses have their own intervention needs that can be distinct from "pure" forms. Second, they result in significant disruption and use of listening speaking, reading, writing, reasoning and or math. Third, they are intrinsic to the individual (rather than related to acute pathology). Fourth, any of the diagnostic categories can be complicated by co-occurrence of executive functioning disorders, metabolic disorders, psychological disorders and a myriad of social and emotional challenges. Fifth, and finally, they are not caused by extrinsic forces such as poor instruction, although environmental factors can exacerbate its manifestation and be detrimental to the prognosis (NJCLD, 1982/1994).

Berninger and May (2011) considered the relevance of definition to identifying and implementing effective treatment. Specifically, they focused on two specific learning disabilities

(SLDs), which have not received as much attention as dyslexia, namely, dysgraphia and OWL LD. Dysgraphia is impaired legible automatic letter writing that is often associated with impaired storage and processing of letters (orthographic coding) in working memory, and finger sequencing that underlies formation of sequential strokes in letters. Oral and written language learning disability, or Owl LD, manifests as difficulties with morphological and syntactic coding and listening and reading comprehension and written expression of ideas (Berninger & May, 2011). In contrast, dyslexia, is a disability in word reading and spelling. Markers include, impaired pseudoword reading, spelling, phonological and orthographic coding, rapid automatic naming, and problems with executive functions that include inhibition and rapid automatic switching. What all these SLDs have in common, however, is difficulty in producing written language for various reasons.

**Psychoeducational Dimensions of Using Computers to Produce Written Language**

One study showed that the low-level language processing tasks interfere with the fluid production of higher-order language in undergraduate students in an exam situation (Connelly, Dockrell & Barnett, 2005). The authors suggested that if the lower order processing tasks could be automated, this would free up cognitive resources for higher order processing. Also in a population of college students, Grabowski (2008) found that the most consistent indicator of overall keyboard ability was speed of production. Keyboarding may allow them to generate text more quickly and thus allocate further resources towards higher level organization of writing.

While comparing a number of dimensions of writing quality and speed, Connelly, Gee and Walsh (2007) in UK showed that children who have not had explicit instruction in keyboarding have slower total times for keyboarding and also produce lower quality writing as compared to their handwritten versions. The authors noted that it was difficult to interpret the findings because the children had not had as much instruction in keyboarding as they had in handwriting.

In the past, some researchers found that cursive is the most effective way for students to express themselves (Harms, 1946; Horowitz & Berkowitz, 1964). Other researchers have found evidence that manuscript handwriting (printing) is a more effective means of written expression (Scott, 2009). One explanation for these seemingly contradictory findings is that there are individual differences among writers as to which mode of writing works best. Some studies that have documented such individual differences among students for manuscript (printing) handwriting, cursive handwriting, and keyboarding and handwriting (Berninger et al., 2006; Berninger & Amtmann, 2003).

Using handwriting activities in computerized environments has been shown to be useful for children for simple alphabet learning tasks (Fawcett, Nicolson & Morris, 1993). Possible applications of computerized media for this age group will be discussed further. It has been consistently indicated in grades 1 and 2 that fine motor ability was related to spelling and written expression in early grades. (Hooper, Costa, McBee, Anderson, Yerby, Knuth & Childress, 2011). It is also evident that for grades 1-5 there are developmentally stable individual differences exhibited for a number of measures including Listening Comprehension, Oral Expression, Reading Comprehension, and Written Expression. Furthermore, these measures were moderately correlated with each other. (Berninger, Abbott, Jones, Wolf, Gould, Anderson-Youngstrom, Shimada & Apel, 2006).

There is evidence that voice recognition might be useful as an alternative to handwriting. Quinlan (2004) found that speech recognition was helpful for students with dyslexia in that it decreased errors in expression, which occurred in written but not oral mode. It did however;

increase the total time taken by the student to express those ideas orally. Clearly, more research is needed to help educators assess which mode of writing is ideally suited to each student.

Past cross-sectional studies (Berninger, Yates, Cartwright, Rutberg, Remy, & Abbott, 1992; Graham, Berninger, Abbott, Abbott, & Whitaker, 1997) showed that handwriting, a transcription skill for translating internal language into visual symbols in the external world, contributed uniquely to composing. On-line experiments in a longitudinal study of second, fourth, and sixth graders found that (a) children composed more and faster (Berninger, Abbott, Augsburger, & Garcia, 2009) and expressed more ideas (Hayes & Berninger, 2010) in composing text when using handwriting than keyboarding; (b) advantages were not found for handwriting compared to keyboarding for spelling or writing alphabet from memory in those experiments; and (c) different neuropsychological processes contributed uniquely to printing, cursive, and keyboarding (Berninger et al., 2006).

There are a number of established models for assessment and intervention of reading disabilities. Development of morphological awareness is one consistently validated aspect of this. Meta-analysis has indicated that morphological instruction and intervention consistently yield improvement on literacy achievement across a variety of different domains and environments (Goodwin & Ahn, 2010). Other studies have validated this relationship. There is support for training of morphology in grades 4 and 5 and its effectiveness in learning new vocabulary (Bowers & Kirby, 2010), but also continuing work on phonological awareness (Blachman, 2000). Another study found that growth in phonological awareness skills is tied to growth in vocabulary (Metsala, 1999). Phonological awareness can be multifaceted and has been approached in many ways. It is evident that this type of intervention is useful for addressing word-level decoding problems (Snowling & Hulme, 2011). Low income students who were given a spelling program lasting two years performed better on phonological awareness assessments (Blachman, Tangel, Ball, Black, & McGraw, 1999).

One consistent measure that was found to be predictive of several writing outcomes is orthographic-motor integration, which is integrating access to letters in memory with the motor act of writing the letters. Jones and Christensen (1999) found that orthographic-motor integration accounted for 67% of variance in written expression. Christiansen (2004) then explored orthographic-motor integration and its correlation with both length and quality of text. Not surprisingly, there was a significant connection between the orthographic-motor integration of the students and their rate and quality on both written and typed measures, both of which were better in the controls.

This dissertation research extends research related to modes of letter production in typically developing writers (Alstad, Sanders, Barnett, Connelly, & Berninger, accepted pending revisions), which documented individual difference and developmental differences in whether manuscript non-connected handwriting, cursive connected handwriting, or keyboarding was most related to spelling and written composition. It also extends assessment research related to letter writing modes (Alstad et al., submitted) which showed that three specific learning disabilities —dysgraphia (impaired handwriting), dyslexia (impaired spelling), and oral and written language learning disability (impaired sentence construction)—exhibited different patterns of relative difficulty across the same three letter writing modes—manuscript or cursive handwriting and keyboarding.

# Chapter 2 - Design and Methods for Comparing Word Count for Both Stylus and Keyboard

## Methodological Approaches

Any methodology has tradeoffs in terms of the generality and specificity of its findings. While "pure" experimental design is still often held as the gold standard for generalizability of findings, it is not without criticisms surrounding utility and relevance to an individual in within his or her particular, contextualized environment.

It is evident that this field benefits from mixed methods research that accounts for both individual and group differences. Using only between groups analysis may not be adequate for this data for a number of reasons. If the students are fully stratified into all the groups that could potentially affect the dependent variable, the power of the analysis may be depleted beyond what is necessary to draw generalizable conclusions. Furthermore, given the population served, few of the stakeholders are interested in general findings; rather, they are concerned with educational applications that are person-specific, that is, which computer tool was most effective for each student.

This research addresses these questions using two complementary methodologies. First, individual development will be analyzed using single subject designs for growth across 18 lessons. Second, between groups analysis will be used to detect group differences. There is support for research using mixed models analyzing the effectiveness of educational technology, which demonstrate both effects within and between groups as well as pragmatic applications of these effects, or the lack thereof (Ross, Morrison & Lowther, 2010). This method also offers finer grained resolution for understanding individual participants and the complexities that influence both their writing and the ways they interact with technology.

**Participants**

These data represent the first cohort of a 5 year Learning Disabilities Research Center grant funded by the Eunice Kennedy National Institute of Child Health and Human Development (NICHD). Students were recruited from local schools surrounding the University of Washington and through self-referrals from parents. Students in Cohort 1 were in grades 5 (*n*=3); 6 (*n*=21); 7 (*n*=8); 8 (n=1) and 9 (*n*=1). They had an average age of 144 months. Participants were 82% male. The students ethnic breakup was varied including European-American(*n*=24); European American-Hispanic(*n*=2); European-American (*n*=2); Asian-American (*n*=1); Pacific Islander(*n*=1); European-American/Middle Eastern(*n*=1); European-American/African-African (*n*=1); European-American/Indian-Asian(*n*=1); European-American/Non-Specified (*n*=1).

Parental education level was varied. The mother's highest level of education represented high school graduate (*n*=1), college (*n*=15) and more than college (*n*=18). Father's highest level of education represented high school graduates (*n*=1); those that had less than a college degree, but more than a high school degree (*n*=2); College degree (*n*=14) and more than college (*n*=15).

Participants were given a comprehensive psychometric, diagnostic evaluation and assigned to one of three diagnostic categories, each of which is associated with impaired writing at different levels of language: dysgraphia (impaired subword handwriting), dyslexia (impaired word spelling), and oral and written language learning disability, OWL LD (impaired morphology and syntax) Individuals who exhibited mild or profound cognitive disabilities, autism spectrum disorders or seizure disorders were not included in the study.

**Procedures**

In the intervention phase, students completed 18 lessons over the course of the study.

Each lesson had three sets of learning activities. The first focused on handwriting. The second taught strategies for word reading and spelling. For example, students first performed a number of activities aimed at improving orthographic abilities as well as phonological, morphological and syntactic understanding. The third and culminating set included sentence and text composing. For the composing activities in the first six lessons, students were given writing prompts for autobiographical writing that was open-ended in nature, for example, “My Life at School”, “My Life before School”, “My Life after School”, “My Family” etc. For the last twelve lessons students read source material typical of the content area of curriculum (role of writing in the history of math--6 lessons or world culture and geography—6 lessons), took notes, and wrote written summaries.

Students were randomly assigned to order to start with one of two modes of writing—keyboard or stylus. They used one for three lessons in a row and then switched to the other for three lessons in a row for the first six lessons. For the next twelve lessons they used the same order of mode as for the first six and switch every three lessons. Participants first took notes while reading; after a period of 5 minutes, the reading material was removed; and they were prompted to write a summary about what they had read for a period of 15 minutes. If the students were idle for more than a period of 1 minute, they would be prompted to keep writing. After a period of 2 minutes, the program would time out and the student would be moved to the next activity.

**Instruments**

The tablet computers used in the study were the second generation of the Apple Ipad with 16 Gb of storage memory. The program was administered and tracked via web browser and hosted on offsite servers at the University of Washington School of Computer Science and

Engineering. Participants were given Boxwave brand styluses as these were determined to be the closest possible analogue to regular pen and paper. The IPads were elevated by stands to help the students focus on the screens; however students were allowed to hold the IPads in whatever way was comfortable to facilitate handwriting. For the composing activities in the last 12 lessons, the source material, which students read, took notes on, and then summarized, was displayed in another stand.

**Word Count Procedures**

In order to produce a consistent word count for the duration of analysis, coding criteria were developed. Approximately 8,000 pages of student compositions were analyzed for number of words produced that were correctly spelled and legible, incorrectly spelled but still legible, and illegible. These three counts formed a composite for the individual of number of words produced for each lesson. In order to count typed compositions, Microsoft word count function was used initially in conjunction with Spellcheck to establish an initial count followed by a manual count to detect any errors not detected by the software (e.g. homophone errors or erroneous substitutions of a properly spelled word).

In order to count handwritten compositions, manual count was performed of each page using a tally counter. This was complicated by the variability in quality of handwriting for each student. The method employed here serves a relatively specific purpose. The rational for these coding schemes was to target the spelling error that represented orthographic, phonological, or morphological misunderstanding specifically, rather than grammatical or syntactic errors.

First, it was important to establish criteria for assessing what an independent word would be counted as. Notes before the composition were not counted. Numbers were not counted as words. If there was an abbreviation of the material, it was not counted as a word. If slang was used, as in, words that depart from mainstream American English vernacular, they were counted. This was to account for micro and macro cultural differences in language usage. Following this logic, if a student used a foreign language in their composition it was counted as a word, provided it could be accounted for. Lastly, the word must be recognizable independent of its context in a sentence.

If it indeed was counted as a word by the above criteria, it is important to make clear what is then counted as a misspelling. Issues involving capitalization (e.g. “i went”), spacing (e.g. “togo”) and punctuation errors (e.g. “its”, “it’s”) were not counted as spelling errors. Homophone errors (e.g. “there”, “their”) were not counted as word spelling errors because they are sensitive to context related to syntax. If a student used nonstandard words such as slang, a variety of spellings were accepted. However, if names were misspelled, they would be rejected, that is, not used in the analyzes, as was also the case for repeat misspellings of the same word.

Finally, if the word was discrete from its neighbors, but was not readable independent of context, it was counted as illegible. All these word counts were compiled into spreadsheets for further analysis.

## Data Analyses for Detecting both Individual and Group Differences

### Single Subject Design Analyses

There is a growing body of research using single subject case design as a means of evaluating an individual subject’s response to a treatment. Efforts for creating rigorous methodologies that focus on an individual, which are empirical in approach, are being developed and indicate their utility in a variety of fields including educational psychology, literacy, and special education (Kratochwill, Hitchcock, Horner, Leven, Odom, Rindskopf & Shadish, 2013). In this review the authors explicate criteria for first identifying the appropriateness of this methodology, and second establishing if this methodology has met standards for evidence of a relationship between the independent variable(s) and the dependent variable as well as are relevant to the strength of that causal relationship.

For the individualized analysis of these participants, plots were constructed to display student progress over time. Individual charts were constructed for each mode of writing that they used. Visual analysis was used to assess effectiveness of modes of writing, type of writing prompt, and overall effectiveness through the course of the intervention. Visual analysis was conducted to assess effectiveness of the intervention for every student (For individual plots, see Appendix 1).

Graphs in Appendix 1 display results for individual students for the outcome of total word count. Students had been randomly assigned to order of stylus or keyboard; so to identify which mode was most effective for each student, the key should be used.

**Group Statistical Analysis Methodologies**

In addition to individual, single case design, within subjects repeated measures analyses methods were used to detect both growth in words produced and difference in mean word count between modes across the course of 18 lessons. In this process, word count was compared across 18 lessons to detect significant differences in composition length while comparing the two modes.

Preliminary exploratory analysis used hierarchical linear modeling. HLM provides a method for analyzing differences for individuals that are "nested" within groups. (e.g., students within their individual classrooms). It is robust to issues such as lack of homogeneity of variance and missingness that preclude other methodologies (Raudenbush & Bryk, 2002). Using this tool, one can assess the degree to which a student grew in word count over time.

In addition to modeling growth of the individual, significant differences for the type of writing the student is using were also of interest. To assess these between group differences, independent *t*-tests were used between the modes of writing on word count.

This total word count was broken down into three subgroups that formed the composite overall word count. These included, correctly spelled words that were legible (see Appendix 3), incorrectly spelled words that were legible (see Appendix 4) and illegible words.  Analysis was performed for number of illegible words produced, but the totals for number of illegible words were too small to perform meaningful analysis.

## Chapter 3: Results of the Dissertation Research Comparing Keyboard and Stylus

### Results of Individual Subject Analyses (see Appendix 1)

The total number of correctly spelled words, misspelled words, illegible words, and overall number of words produced is summarized for each of the 21 students in Appendix 1. Also for each student total word production in graphed by alternating use of stylus or keyboard for three lessons in a row. Analyses of patterns by visual inspection showed the following.

Student 1 (dysgraphia) did not show higher word productivity by keyboard until Lesson 8 and then maintained that advantage.

Student 2 (OWL LD) was highly variable, with initial greater word productivity for keyboard, but by end decreasing productivity by keyboard and increasing productivity by stylus.

Student 3 (dysgraphia) produced compositions only by stylus.

Student 4 (dyslexia) overall showed no clear advantage for either mode.

Student 5 (dysgraphia) overall had higher word production with keyboard.

Student 6 (dysgraphia) showed variability but overall produced more words by keyboard.

Student 7 (OWL LD) initially was more productive by keyboard, then stylus, and then keyboard.

Student 8 (OWL LD) towards the end was more productive by keyboard.

Student 9 (Dysgraphia) was variable but overall was more productive by keyboard.

Student 10 (dysgraphia) was variable but overall improved in both modes.

Student 11 (OWL LD) showed variability in which mode was most productive.

Student 12 (dysgraphia) showed better productivity by keyboard.

Student 13 (dyslexia) was more productive by keyboard in last 12 lessons.

Student 14 (dyslexia) overall was more productive by keyboard.

Student 15 (dyslexia) was more productive by keyboard.

Student 16 (dyslexia) overall was more productive by keyboard until last lesson when sizable improvement by stylus was made.

Student 17 (dyslexia) was more productive, with one exception, by keyboard.

Student 18 (dyslexia) overall was more productive by keyboard.

Student 19 (dyslexia) was in general, with some exceptions, more productive by keyboard.

Student 20 (dyslexia) was more productive by keyboard.

Student 21 (dysgraphia) was more productive by keyboard.

Findings from individual plots highlight the individual variability for each subject in their use of both the keyboard and the stylus overall and across lessons. Broadly speaking, there were general trends. First, there was a falloff in word count for many of the participants after the sixth lesson. This is not surprising as on lesson seven the students began the more structured formal note taking from writing prompt and students in grades 4 to 9 have had less experience with this kind of writing than with autobiographical writing The second difference from visual analysis was that many of participants showed more word productivity when writing by keyboard. However, there were individual differences among the students related to mode of word production, and these were not predicted by diagnostic status alone (dysgraphia, dyslexia, OWL LD).

**Results of Group Statistical Analyses**

Due to the higher degree of variability of word count within subjects as well as across the lessons, HLM failed to detect meaningful growth in word count during the duration of the study for this exploratory analysis. Due to the high degree of variability of production at their respective levels and the non-significance of growth models, one cannot state that there was systematic meaningful growth in word count at the individual level or at the group level. Furthermore, analysis of the same mode across sets of three lessons also did not find meaningful growth in word count. Holding genre of prompt constant did not account for growth in word count. Given these findings, it is evident we are not able to model growth over lessons for these data and consequently associate mode of writing with growth.

However, independent samples *t*-tests within a lesson showed that total word production for keyboard was significantly higher than for stylus for 12 lessons. These included lesson 1 $t(19) = 2.11$, $p < .05$; lesson 2 $t(20) = 2.22$, $p < .05$; lesson 3 $t(26) = 2.16$, $p < .05$; lesson 4 $t(27) = -2.26$, $p < .05$; lesson 5 $t(26) = -2.17$, $p < .05$; lesson 7 $t(29) = 2.22$, $p < .05$; lesson 8 $t(28) = 2.50$, $p < .05$; lesson 11 $t(28) = -2.71$, $p < .05$; lesson 13 $t(28) = 3.44$, $p < .01$; lesson 14 $t(31) = 2.45$, $p < .05$; lesson 16 $t(28) = -2.81$, $p < .01$ and lesson 1 $t(26) = -2.11$, $p < .05$. In no lesson was stylus superior to keyboard in terms of the mean total number of words produced. See graphs in Appendix 2 for overall independent samples *t*-tests results for group on each of the outcomes analyzed and total word production.

Further analysis was performed on the subtypes of words that formed this composite. Independent samples *t*-tests were performed on the number of correctly spelled words for each mode within each lesson. These analyses indicated that for 15 lessons keyboard outperformed stylus in terms of the number of correct words produced. Those included lesson 1 $t(18) = 2.87$, $p < .05$; lesson 2 $t(19) = 2.28$, $p < .05$; lesson 3 $t(26) = 2.78$, $p < .05$; lesson 4 $t(26) = -2.10$, $p < .05$; lesson 5 $t(25) = -2.19$, $p < .05$; lesson 7 $t(28) = 2.88$, $p < .01$; lesson 8 $t(27) = 2.97$, $p < .01$; lesson 9 $t(30) = 2.00$, $p < .05$; lesson 10 $t(27) = -2.16$, $p < .05$; lesson 11 $t(28) = -2.17$, $p < .05$; lesson 12 $t(29) = -2.22$, p < .05; lesson 13 $t(28) = 3.50$, $p < .01$; lesson 14 $t(30) = 2.94$, $p < .01$; lesson 16 $t(28) = -2.89$, $p < .01$ and lesson 17 $t(26) = -2.30$, $p < .05$. In no condition did stylus outperform keyboard in terms of mean number of correct words produced. See Appendix 3 for summary of results.

Yet other analyses involved comparing stylus and keyboard for the percent of misspelled words in independent samples t-tests. For the most part, no significant differences were found between keyboard and stylus on the percent of misspelled words. Again, in no instance did stylus outperform keyboard. See Appendix 4 for summary of results.

**Results of Correlational Analyses with Treatment Outcomes**

A final series of correlational analyses examined the correlation between word productivity while composing for each mode of letter production and each of the posttest measures for which treatment effects of the 18 computerized lessons were found. Overall the mean word productivity by each of the two modes ($N$=32) was significantly correlated, $r$=.536, $p$=.002. However, none of the correlations between mean word productivity by stylus was significantly correlated with any of the post-treatment outcomes for which treatment effects were found (Berninger et al., submitted). However, mean word productivity by keyboard was significantly correlated with each of the following:

Alphabet 15 seconds, $r$=.359, $p$=.047, $n$=31

Copy Best, $r$=.436, $p$=.013, $n$=32

Copy Fast, *r*=.530, *p*=.002, *n*=32

TOC Letter Choice, *r*=.498, p=.004, *n*=32

TOC Scrambles, *r*=.526, *p*=.002, *n*=31.

Thus, mode of letter production by keyboard was related to handwriting and word spelling measures. *That is, using the keyboard transferred to improved handwriting and spelling outside the computer environment when writing with pen and paper*. However, neither mode of word production was correlated with posttest scores on sentence combining which also showed treatment effects. When subword and word outcomes are evaluated, relationships with mode of computer tool use were found at levels of language smaller than syntax (multi-word units).

The same analyses were also conducted for dyslexics, dysgraphics, and OWL LD separately. For dyslexics, mode of letter production—keyboard and stylus-- was significantly correlated, *r*=.742, *p*=.002, n=15, as it also was for OWL LD, *r*=.954, *p*=.012, *n*=5, but not for dysgraphia, *n*=.528, ns., *n*=12. For dyslexics, significant correlations occurred with posttest treatment outcomes for which there were significant treatment effects for keyboard mode on Copy Best, r=.573, *p*=.026, *n*=15, Copy Fast, *r*=.731, *p*=.002, *n*=15, but for stylus mode on Alphabet 15 seconds, *r*=.605, *p*=.017, *n*=15 and Copy Fast, *r*=.594, *p*=.020, *n*=15. For dysgraphics, the modes were not significantly correlated, *r*=.528, *n*=12, but significant correlations occurred with posttreatment outcomes for which there were significant treatment effects for keyboard mode on TOC sight spelling, *r*=.889, *p*<.001, *n*=11, and WIAT 3 Sentence Combining, *r* =.622, *p*=.031, *n*=12, and for stylus mode on Sentence Combining, *r*=.751, *p*=.003, *n*=13. For OWL LD, the modes were significantly correlated, *r*=.954, *p*=.012, *n*=5. However, although keyboard mode was significantly correlated with TOC Spelling, *r*=-.985, *p*=.015, and for stylus mode with TOC Spelling, *r*= -.979, *p*=.021, n=4, in both cases the correlation was negative. Overall these correlational analyses showed that how mean level of word production as a function of computer mode of letter production is related to treatment-related written language skills depends on the diagnosis and writing task.

# Chapter 4 - Discussion of Results: Educational Applications and Theoretical Significance

## Educational Applications

These analyses did not demonstrate there was a significant growth in word count at the individual level. These findings support that across 18 lessons the length of a composition within a given time frame did not increase significantly. There are a number of factors that could contribute to this. For one, learning takes time. Had quality of composing been coded rather than just number of words produced, then significant growth over time may have been detected. With regards to statistical methodologies used in these analyses, multiple independent *t*-tests may increase the likelihood of type one error. This is due to the increase in family wise error rate when performing multiple hypothesis tests. However, while it would be possible to use Bonferroni-adjusted alpha levels, the within lesson results were very systematic, effect sizes were large, and it is unlikely that these are Type I errors. These results are in need of replication as a better indication that these statistical results are not reflective of Type I errors.

Nevertheless, keyboarding significantly outperformed stylus on several of the lessons, showing that students with SLDs affecting written language in the grade levels sampled can compose with keyboards. The design did not permit teasing apart effects due to students probably having had more prior experience with keyboard than with stylus. However, the focus of this research on individual differences in computer users by contrasting computer letter production modes shows that past research findings documenting advantages of the pen over keyboard based on means for groups need to be qualified based on findings when contrasting computer writing tools are considered and analyzed with both individual subject and group designs.

MacArthur (2009) argued that the tools by themselves have little impact on learning for students with learning disabilities. Effective instruction that supports the use of these tools for writing is also needed. Research is needed not only to identify effective instruction for using computer tools in writing instruction, but also for the role of different computer user modes for motivation, affect toward writing, and professional development of teachers for integrating computer tools with writing instruction (e.g., Pearson, Ferdig, Blomeyer & Moran, 2005). There are also implications for professional development, as new technology also requires concomitant training of professional educators to ensure its effective implementation in instruction.

MacArthur (2009) also noted four key recommendations for students with learning disabilities as they use word processing tools. First, they should be taught to type at least as fluently as they produce handwriting and vice versa. Also, students with specific learning disabilities that impact writing should use word processing from the beginning for some of their composing activities to prevent problems in written expression of ideas due to difficulties in letter production. Third, students need explicit instruction on how to revise using word processing. Finally, publishing using a variety of media is an effective way of giving students motivation for their writing. (MacArthur, 2009). Put another way, computers should be used not just for accommodations for students with specific learning disabilities but also incorporated into the instructional program as in the current study.

In an era when developing writers have many tools for producing written language, more research is needed in the most effective approaches for teaching students to use a variety of writing tools and potential advantages of being a hybrid writer who has expertise with multiple writing tools. Although research on phonological development is important for preventing reading disabilities (e.g., Kim, Woodruff, Klein & Vaughn, 2006; Torgeson & Barker, 1995), the benefits of teaching students multiple modes of written language production, including but not restricted to keyboarding and handwriting, deserves more research attention.

**Theoretical Significance**

It is a disconcerting prospect that through attempts to mitigate disability we may create technologies that allow previously necessary cognitive and linguistic abilities to atrophy. Some researchers have asked if smarter tools are offloading cognitive resources of the student on to the technology in such a way that important and interrelated cognitive abilities are being depleted (Sulzenbruck, Hegele, Rinkenauer & Heuer, 2011). This possibility falls into the broader discussion of assistive technology more generally as technology improves. To what extent should one use technology to fill in the gaps in general ability before it becomes clear using the technology is to the detriment of the independence and more general capabilities of the user?

At the same time, there is substantial research showing the value of explicit instruction in teaching handwriting to students with and without specific learning disabilities (e.g. Berninger & Richards et al., 2010). Research is lacking, however, on whether writing by stylus with a computer is the same as writing with a pen and paper outside the computer environment. So results of the current study for stylus do not generalize to writing with paper and pen. Future research might tease apart how writing by stylus with an iPad or pen and paper are the same and different.

## Chapter 5: Limitations and Future Directions for Research

There are a number of areas that could be expanded and should be explored in the future. On the one hand, there were a limited number of cases (trials of switching the stimuli) within the intervention of each subject. Ideally there would have been at least five alternating replications of each mode (Kratchowill et al., 2013).

On the other hand, traditional single subject designs with frequently alternating treatments may not be the most appropriate method for evaluating individual differences in mode of letter production in computerized writing lessons. The reason is that it has been well documented that students with specific learning disabilities have difficulty with switching attention (e.g. Berninger & Richards, 2010). Perhaps comparisons of students with specific learning disabilities using the same writing tool for a longer consistent block of time (e.g. first 9 lessons) and then a contrasting writing tools for a consistent block of time (e.g. last 9 lessons) with genre of writing consistent across all 18 lessons would have provided a more reliable estimate of individual differences.

Having a control condition that used pen and paper to serve as a comparison to stylus and keyboard would have given insight into the construct validity of word count as a dependent variable for orthographic production both using computers and non-computer writing modes. Stylus by itself is probably not a legitimate proxy for handwriting on paper given the current quality of technology. Many of the students complained about the way the stylus felt in their hand or the difficulty of holding it.

There are some order effects that are built into the study that could possibly be affecting the dependent variable. The order of the prompts students were presented with was in one sense, a logical incrementing of difficulty. It started with 6 lessons of self-directed, open ended writing, which is easier for developing writers. Then in the last 12 lessons they completed writing activities that made more grade-appropriate kind they might find in a writing class in middle or high school—reading or listening to source material, taking notes, and writing summaries, that is integrating writing with either reading or listening. Although changing writing tasks poses problems for research design, it does have ecological validity for the classroom where the nature of writing assignments changes frequently. These kinds of mismatches between research design and classroom applications pose challenges for the rapidly expanding field of translation science—how to translate research findings based on group analyses to individual students, given the individual differences they exhibit, and also the inherent nature of classroom instruction and learning that is not systematically controlled in the same way as experimental design.

In this intervention study, students also took notes. For future analysis, these notes could be incorporated into the analysis. The quality, length, and content of notes that the students took before producing the compositions should be evaluated for the relationship between letter production mode and quality of compositions the students are able to produce. The results might inform instructional practices for both students with and without specific learning disabilities, as instruction is often not devoted in upper elementary and middle school to strategies for taking notes on read source material to use in preparing written assignments in class or at home. With the demands of new media, information modalities and tools for writing, it may be that traditional note taking strategies are inadequate (Reimer, Beimhall, Cao & O'Reilly, 2009). It is evident there is a need for innovation in how these technologies are taught to developing writers.

In one sense, increase in computer usage for writing may have simplified the writing process. In another sense, there is a possibility that using new technology has not been entirely beneficial for writing development and the skills that are interdependent on them.

Learning to write, particularly to handwrite, builds on a variety of cognitive abilities for younger writers. And so, there are many questions that remain as to if these increases in ability are maintained with new writing tools and to what degree. One of these is whether there is an advantage to being a hybrid-writer who has been taught and developed expertise with multiple computer tools for writing. Future research might also investigate the contribution of handwriting and spelling instruction with a computer to transfer to better written composing with pen and paper, as was informally observed with some participants in the current study and documented in change in normed measures from pretest to posttest for the group.

There are several important details and distinctions surrounding educational software and games to consider in future research. Games for learning may show promise in fields like literacy education. This is also a timely subject to approach as there is a paradigm shift occurring in writing technology. The lack of cursive being taught in schools and the increase in emphasis on digital modes of input changes the educational dynamic for how students learn to read and write. Watts-Taffe & Gwinn (2007) note characteristics of learning environments that support effective literacy-technology integration.

Integrating conventional and new literacies

Critical thinking

Promoting learning to learn

Integration of literacy instruction with content-area instruction

Attention to social interaction and collaboration

Differentiation of instruction

Equity of access to technology

Emphasis on the classroom as a learning community

Multifaceted preparation for instruction coupled with flexibility

Preservation of fundamental features of exemplary print-based literacy instruction

This framework serves as a useful guide for developing technology that is relevant to both learning disabled students and typically developing populations and informs analysis of systems geared to these ends.

With the development of any software there are the increased costs associated with it. For many teachers and school districts, this can be a prohibitive expense. Interestingly, research indicates that the domain of learning game (2D, 3D, text-based, etc.) did not show significant discrepancies in effectiveness for learning outcomes assessing learning and retention. (Wouters et al, 2013). This was true across a variety of game budgets. This has implications for those wishing to develop a broader game-based learning curriculum in that it is harder to justify dedicating more resources to hardware and development of intensive features such as photorealism and 3D graphics. Eschewing the pervasive mindset that computer games should use cutting edge graphics allows for more low-tech options. Educators and developers may be more able to use simpler games for more precise, more localized and more specific purposes when superficial aspects of educational games are disregarded.

It is evident that there is an emerging and increasingly competitive market for attention in which formal education must inevitably compete. While thinking in terms of the economics is perhaps not a concept teachers are used to addressing, it seems that the way that the cost effectiveness of various technology supported instruction is an area in which they should become more informed and critical consumers.

It should be mentioned that neurological development co-occurs with each of the behavioral milestones in language. The tools available to researchers today enable them to understand how reading and writing work from a very basic and neurobiological level. It should be understood that from a perspective of neurological organization, no system is wholly insular with regards to language. While some systems are generally necessary for specific functions, these systems are interdependent and functionality can be relocated and other structures can be plastically appropriated for new tasks. Individual variability can and often does supersede broad generalities for how language is organized. Some of these tools that have consistently offered new insights are magnetic resonance imaging systems as they are capable of noninvasively looking at the living human brain. In a very general sense it is now possible to look at the human brain as it is functionally activated and as it is structurally organized. And technology tools for producing writing while the human brain is scanned are increasing understanding of the brain structures and functions underlying writing (Reitz, Richards, Wu, Boord, Askren, Lewis, & Berninger, 2013).

Educational technology continues to grow in relevance as media becomes more ubiquitous. Teachers who are able to stay abreast of the latest developments are better situated for trying to connect with their students. Teachers who are given the opportunity to be a part of the development process will likely inform decisions made by developers with pragmatic insights to refine these technologies for future generations. Ultimately the challenge is to apply the most appropriate technology supported tools for individual students for specific learning tasks, especially in written language. That is, what works for whom for what educational purpose?

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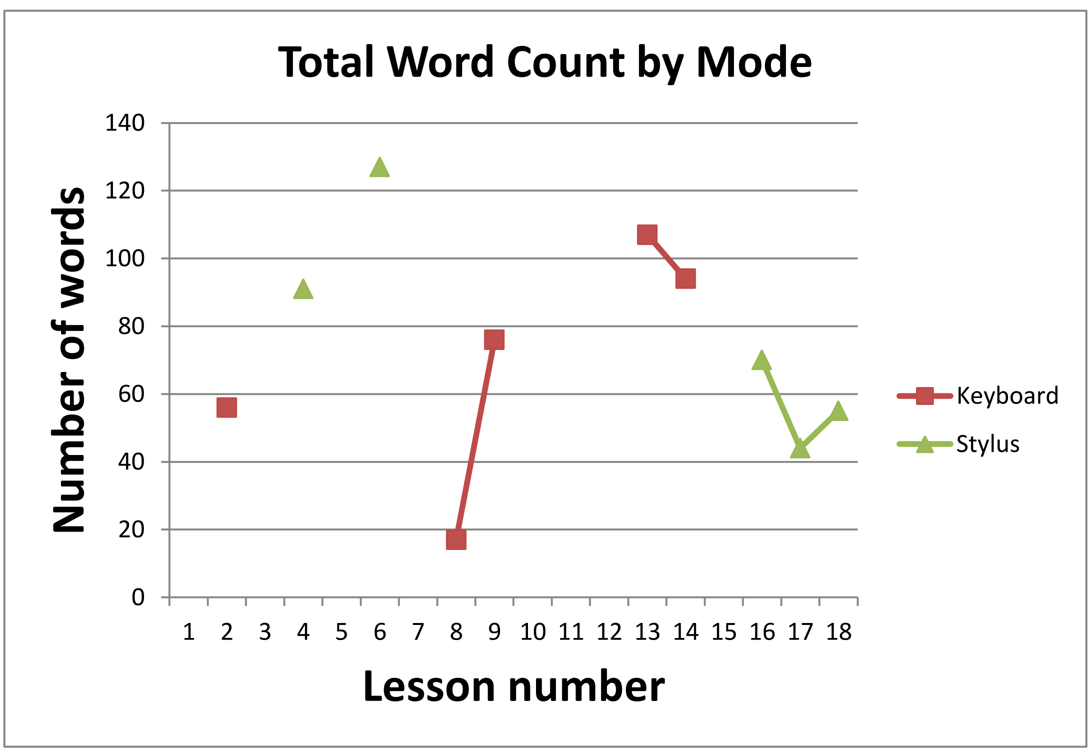
**Appendix 1**: Individual Graphs of Mode Used Across Lesson for Word Productivity

| | |
|---|---|
| Subject | 1 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 1 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboard | x | x | x | 0 |
| 2 | Keyboard | 54 | 2 | 0 | 56 |
| 3 | Keyboard | x | x | x | 0 |
| 4 | Stylus | 87 | 2 | 2 | 91 |
| 5 | Stylus | x | x | x | 0 |
| 6 | Stylus | 119 | 5 | 3 | 127 |
| 7 | Keyboard | x | x | x | 0 |
| 8 | Keyboard | 17 | 0 | 0 | 17 |
| 9 | Keyboard | 67 | 9 | 0 | 76 |
| 10 | Stylus | x | x | x | 0 |
| 11 | Stylus | x | x | x | 0 |
| 12 | Stylus | x | x | x | 0 |
| 13 | Keyboard | 94 | 13 | 0 | 107 |
| 14 | Keyboard | 85 | 9 | 0 | 94 |
| 15 | Keyboard | x | x | x | 0 |
| 16 | Stylus | 69 | 0 | 1 | 70 |
| 17 | Stylus | 39 | 3 | 2 | 44 |
| 18 | Stylus | 55 | 0 | 0 | 55 |
| | **Totals** | **686** | **43** | **8** | **737** |

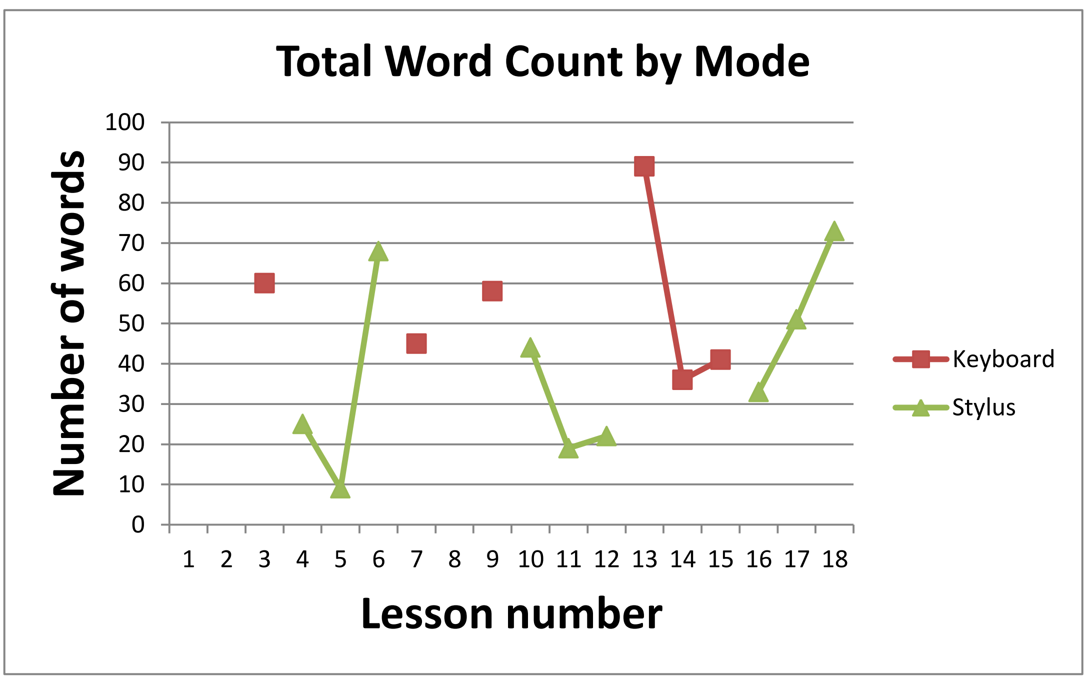
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | 56 | |
| 3 | | |
| 4 | | 91 |
| 5 | | |
| 6 | | 127 |
| 7 | | |
| 8 | 17 | |
| 9 | 76 | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | 107 | |
| 14 | 94 | |
| 15 | | |
| 16 | | 70 |
| 17 | | 44 |
| 18 | | 55 |



Subject
Cohort 1
Group OWL LD
Start Md 1

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboard | x | x | x | 0 |
| 2 | Keyboard | x | x | x | 0 |
| 3 | Keyboard | 60 | 0 | 0 | 60 |
| 4 | Stylus | 23 | 2 | 0 | 25 |
| 5 | Stylus | 9 | 0 | 0 | 9 |
| 6 | Stylus | 68 | 0 | 0 | 68 |
| 7 | Keyboard | 44 | 1 | 0 | 45 |
| 8 | Keyboard | x | x | x | 0 |
| 9 | Keyboard | 55 | 3 | 0 | 58 |
| 10 | Stylus | 31 | 12 | 1 | 44 |
| 11 | Stylus | 18 | 1 | 0 | 19 |
| 12 | Stylus | 21 | 1 | 0 | 22 |
| 13 | Keyboard | 85 | 4 | 0 | 89 |
| 14 | Keyboard | 32 | 4 | 0 | 36 |
| 15 | Keyboard | 37 | 4 | 0 | 41 |
| 16 | Stylus | 31 | 2 | 0 | 33 |
| 17 | Stylus | 46 | 3 | 2 | 51 |
| 18 | Stylus | 69 | 3 | 1 | 73 |
| | **Totals** | **629** | **40** | **4** | **673** |

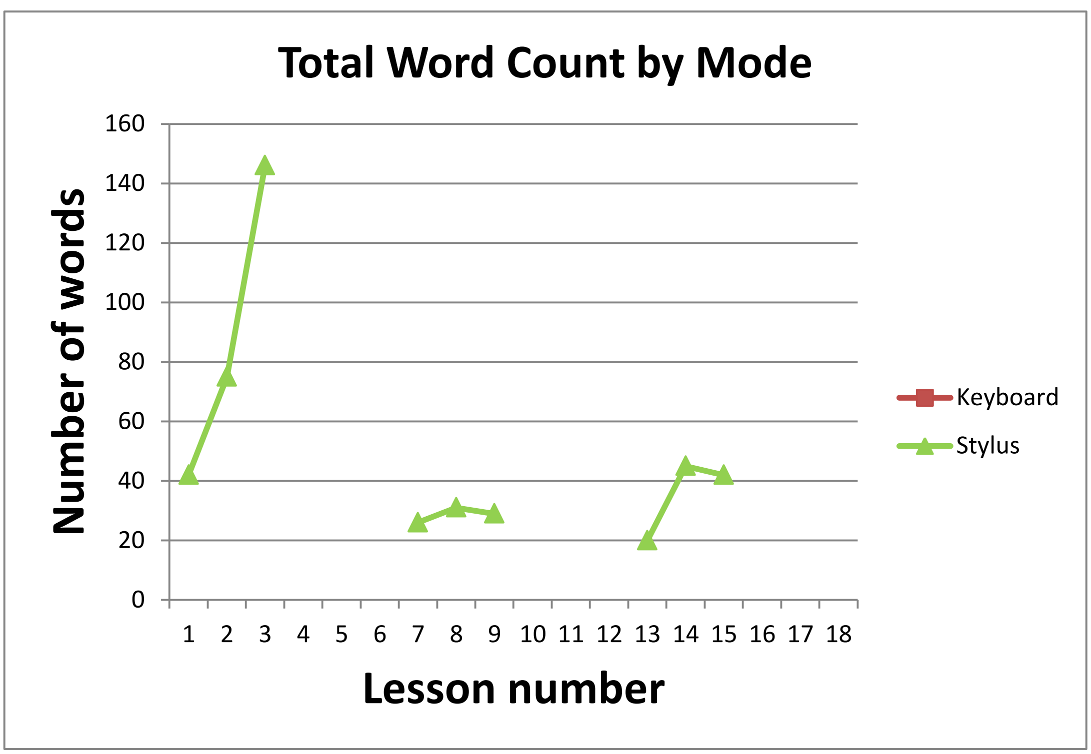
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | 60 | |
| 4 | | 25 |
| 5 | | 9 |
| 6 | | 68 |
| 7 | 45 | |
| 8 | | |
| 9 | 58 | |
| 10 | | 44 |
| 11 | | 19 |
| 12 | | 22 |
| 13 | 89 | |
| 14 | 36 | |
| 15 | 41 | |
| 16 | | 33 |
| 17 | | 51 |
| 18 | | 73 |



| | |
|---|---|
| Subject | 3 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | 34 | 7 | 1 | 42 |
| 2 | Stylus | 62 | 11 | 2 | 75 |
| 3 | Stylus | 101 | 38 | 7 | 146 |
| 4 | x | x | x | x | 0 |
| 5 | x | x | x | x | 0 |
| 6 | x | x | x | x | 0 |
| 7 | Stylus | 9 | 15 | 2 | 26 |
| 8 | Stylus | 13 | 18 | 0 | 31 |
| 9 | Stylus | 16 | 12 | 1 | 29 |
| 10 | x | x | x | x | 0 |
| 11 | x | x | x | x | 0 |
| 12 | x | x | x | x | 0 |
| 13 | Stylus | 12 | 8 | 0 | 20 |
| 14 | Stylus | 17 | 26 | 2 | 45 |
| 15 | Stylus | 19 | 21 | 2 | 42 |
| 16 | x | x | x | x | 0 |
| 17 | x | x | x | x | 0 |
| 18 | x | x | x | x | 0 |
| | **Totals** | **283** | **156** | **17** | **456** |

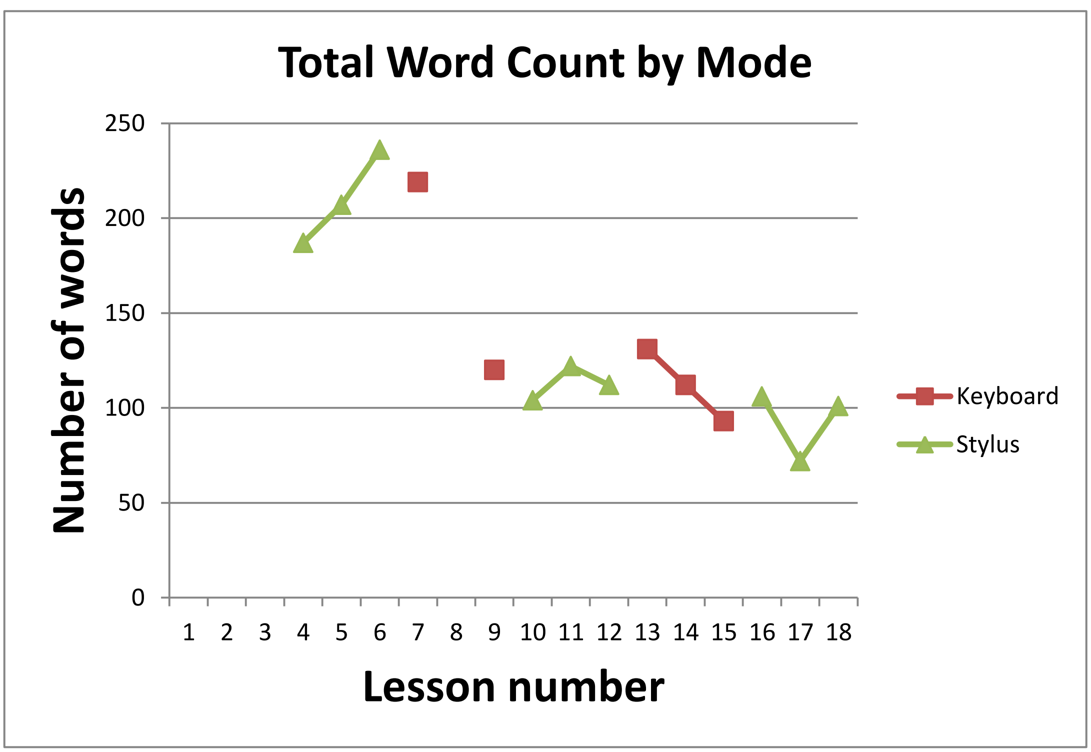
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | 42 |
| 2 | | 75 |
| 3 | | 146 |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | 26 |
| 8 | | 31 |
| 9 | | 29 |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | 20 |
| 14 | | 45 |
| 15 | | 42 |
| 16 | | |
| 17 | | |
| 18 | | |



| | |
|---|---|
| Subject | 4 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 1 |

| **Lesson #** | Mode | Correct | Misspelled | Illegible | **Total** |
|---|---|---|---|---|---|
| 1 | Keyboard | x | x | x | 0 |
| 2 | Keyboard | x | x | x | 0 |
| 3 | Keyboard | z | z | z | 0 |
| 4 | Stylus | 178 | 7 | 2 | 187 |
| 5 | Stylus | 186 | 12 | 9 | 207 |
| 6 | Stylus | 218 | 7 | 11 | 236 |
| 7 | Keyboard | 214 | 5 | 0 | 219 |
| 8 | Keyboard | z | z | z | 0 |
| 9 | Keyboard | 94 | 26 | 0 | 120 |
| 10 | Stylus | 89 | 8 | 7 | 104 |
| 11 | Stylus | 101 | 15 | 6 | 122 |
| 12 | Stylus | 96 | 10 | 6 | 112 |
| 13 | Keyboard | 118 | 13 | 0 | 131 |
| 14 | Keyboard | 98 | 14 | 0 | 112 |
| 15 | Keyboard | 88 | 5 | 0 | 93 |
| 16 | Stylus | 87 | 10 | 9 | 106 |
| 17 | Stylus | 63 | 9 | 0 | 72 |
| 18 | Stylus | 81 | 14 | 6 | 101 |
| | **Totals** | **1711** | **155** | **56** | **1922** |

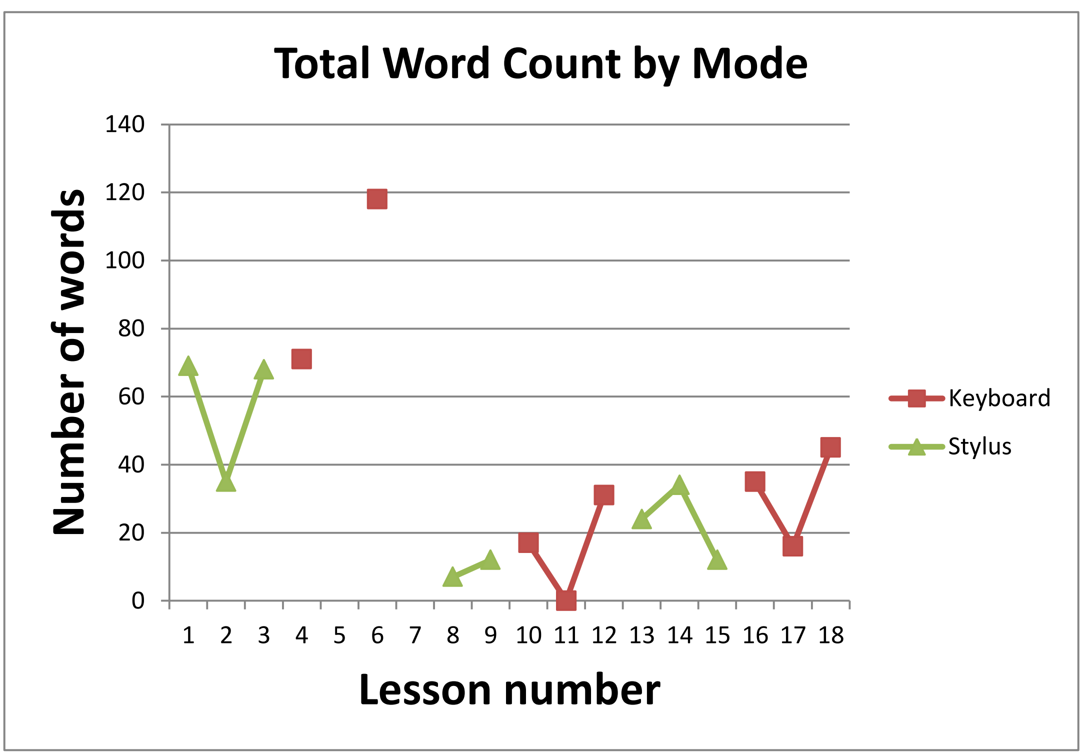
| **Lesson #** | **Keyboard** | **Stylus** |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | 187 |
| 5 | | 207 |
| 6 | | 236 |
| 7 | 219 | |
| 8 | | |
| 9 | 120 | |
| 10 | | 104 |
| 11 | | 122 |
| 12 | | 112 |
| 13 | 131 | |
| 14 | 112 | |
| 15 | 93 | |
| 16 | | 106 |
| 17 | | 72 |
| 18 | | 101 |



| | |
|---|---|
| Subject | 5 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | 65 | 4 | 0 | 69 |
| 2 | Stylus | 29 | 5 | 1 | 35 |
| 3 | Stylus | 54 | 11 | 3 | 68 |
| 4 | Keyboard | 68 | 3 | 0 | 71 |
| 5 | Keyboard | x | x | x | 0 |
| 6 | Keyboard | 105 | 13 | 0 | 118 |
| 7 | Stylus | x | x | x | 0 |
| 8 | Stylus | 7 | 0 | 0 | 7 |
| 9 | Stylus | 12 | 0 | 0 | 12 |
| 10 | Keyboard | 16 | 1 | 0 | 17 |
| 11 | Keyboard | 0 | 0 | 0 | 0 |
| 12 | Keyboard | 28 | 3 | 0 | 31 |
| 13 | Stylus | 11 | 12 | 1 | 24 |
| 14 | Stylus | 32 | 2 | 0 | 34 |
| 15 | Stylus | 10 | 2 | 0 | 12 |
| 16 | Keyboard | 33 | 2 | 0 | 35 |
| 17 | Keyboard | 16 | 0 | 0 | 16 |
| 18 | Keyboard | 45 | 0 | 0 | 45 |
| | **Totals** | **531** | **58** | **5** | **594** |

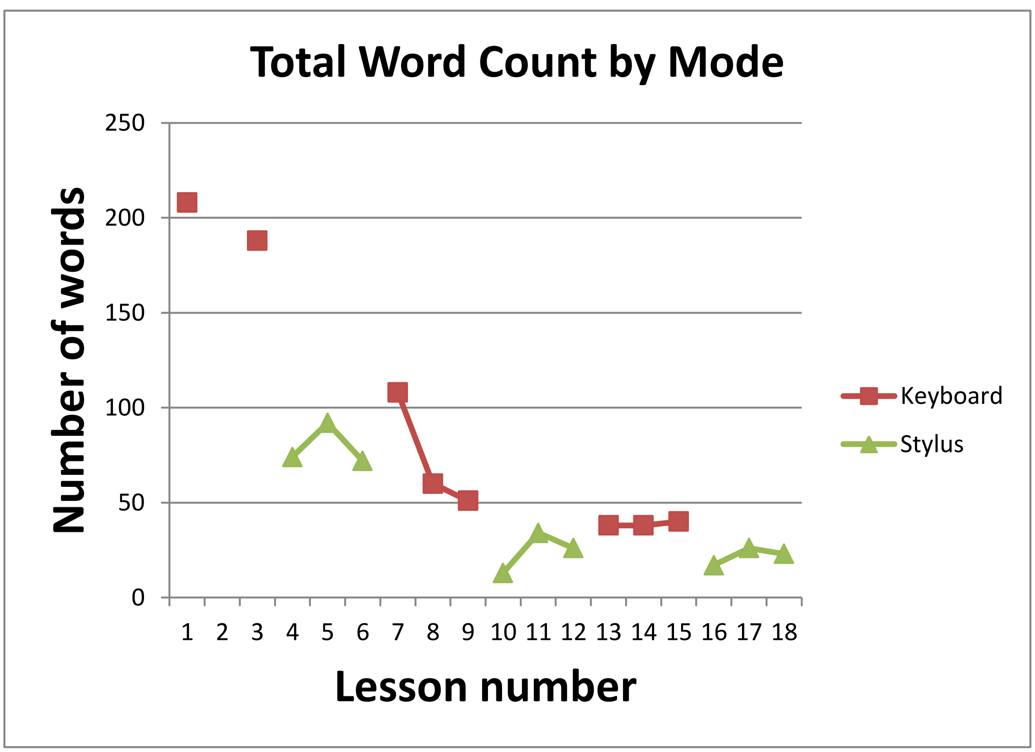
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | 69 |
| 2 | | 35 |
| 3 | | 68 |
| 4 | 71 | |
| 5 | | |
| 6 | 118 | |
| 7 | | |
| 8 | | 7 |
| 9 | | 12 |
| 10 | 17 | |
| 11 | 0 | |
| 12 | 31 | |
| 13 | | 24 |
| 14 | | 34 |
| 15 | | 12 |
| 16 | 35 | |
| 17 | 16 | |
| 18 | 45 | |



Subject 6
Cohort 1
Group Dysgraphia
Start Md 1

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboard | 202 | 6 | 0 | 208 |
| 2 | Keyboard | x | x | x | 0 |
| 3 | Keyboard | 180 | 8 | 0 | 188 |
| 4 | Stylus | 70 | 4 | 0 | 74 |
| 5 | Stylus | 88 | 4 | 0 | 92 |
| 6 | Stylus | 70 | 2 | 0 | 72 |
| 7 | Keyboard | 106 | 2 | 0 | 108 |
| 8 | Keyboard | 54 | 6 | 0 | 60 |
| 9 | Keyboard | 48 | 3 | 0 | 51 |
| 10 | Stylus | 13 | 0 | 0 | 13 |
| 11 | Stylus | 30 | 2 | 2 | 34 |
| 12 | Stylus | 24 | 2 | 0 | 26 |
| 13 | Keyboard | 36 | 2 | 0 | 38 |
| 14 | Keyboard | 37 | 1 | 0 | 38 |
| 15 | Keyboard | 37 | 3 | 0 | 40 |
| 16 | Stylus | 14 | 3 | 0 | 17 |
| 17 | Stylus | 24 | 2 | 0 | 26 |
| 18 | Stylus | 20 | 3 | 0 | 23 |
| | **Totals** | **1053** | **53** | **2** | **1108** |

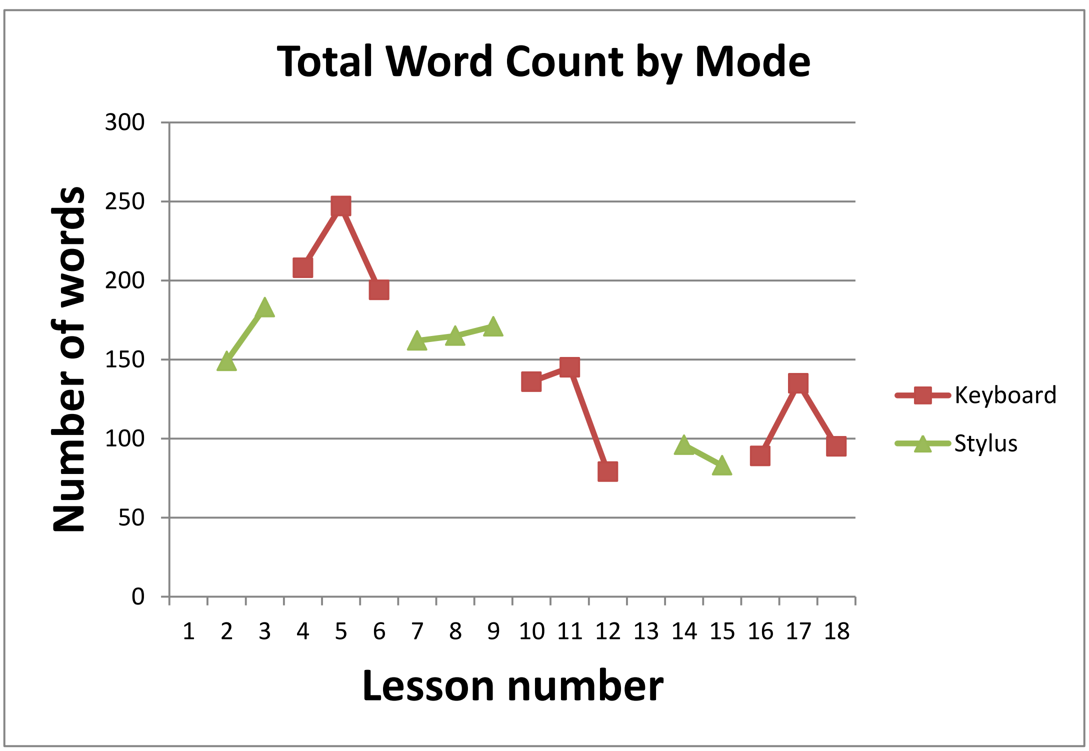
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | 208 | |
| 2 | | |
| 3 | 188 | |
| 4 | | 74 |
| 5 | | 92 |
| 6 | | 72 |
| 7 | 108 | |
| 8 | 60 | |
| 9 | 51 | |
| 10 | | 13 |
| 11 | | 34 |
| 12 | | 26 |
| 13 | 38 | |
| 14 | 38 | |
| 15 | 40 | |
| 16 | | 17 |
| 17 | | 26 |
| 18 | | 23 |



Subject 7
Cohort 1
Group OWL LD
Start Md 2

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | x | x | x | 0 |
| 2 | Stylus | 112 | 11 | 26 | 149 |
| 3 | Stylus | 146 | 18 | 19 | 183 |
| 4 | Keyboard | 190 | 18 | 0 | 208 |
| 5 | Keyboard | 228 | 19 | 0 | 247 |
| 6 | Keyboard | 172 | 22 | 0 | 194 |
| 7 | Stylus | 102 | 28 | 32 | 162 |
| 8 | Stylus | 104 | 17 | 44 | 165 |
| 9 | Stylus | 109 | 13 | 49 | 171 |
| 10 | Keyboard | 119 | 17 | 0 | 136 |
| 11 | Keyboard | 125 | 20 | 0 | 145 |
| 12 | Keyboard | 71 | 8 | 0 | 79 |
| 13 | Stylus | y | y | y | 0 |
| 14 | Stylus | 62 | 23 | 11 | 96 |
| 15 | Stylus | 48 | 15 | 20 | 83 |
| 16 | Keyboard | 86 | 3 | 0 | 89 |
| 17 | Keyboard | 125 | 10 | 0 | 135 |
| 18 | Keyboard | 83 | 12 | 0 | 95 |
| | **Totals** | **1882** | **254** | **201** | **2337** |

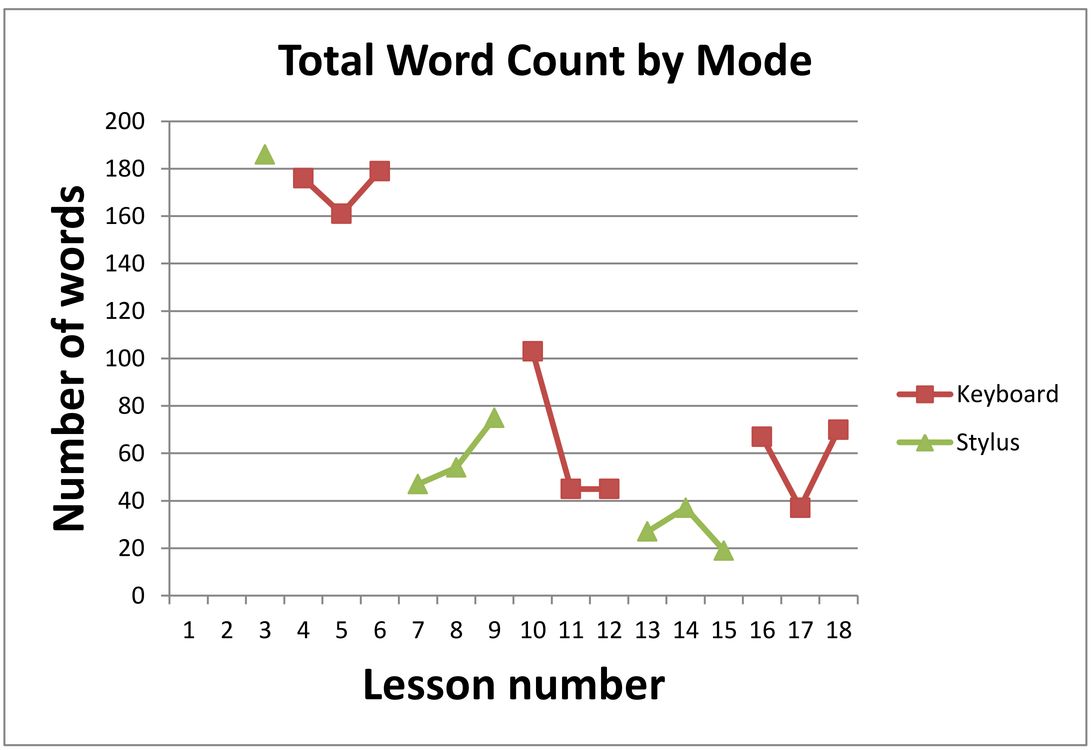
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | | 149 |
| 3 | | 183 |
| 4 | 208 | |
| 5 | 247 | |
| 6 | 194 | |
| 7 | | 162 |
| 8 | | 165 |
| 9 | | 171 |
| 10 | 136 | |
| 11 | 145 | |
| 12 | 79 | |
| 13 | | |
| 14 | | 96 |
| 15 | | 83 |
| 16 | 89 | |
| 17 | 135 | |
| 18 | 95 | |



| | |
|---|---|
| Subject | 8 |
| Cohort | 1 |
| Group | OWL LD |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | x | x | x | 0 |
| 2 | Stylus | x | x | x | 0 |
| 3 | Stylus | 136 | 15 | 35 | 186 |
| 4 | Keyboard | 162 | 14 | 0 | 176 |
| 5 | Keyboard | 133 | 28 | 0 | 161 |
| 6 | Keyboard | 175 | 4 | 0 | 179 |
| 7 | Stylus | 33 | 6 | 8 | 47 |
| 8 | Stylus | 38 | 11 | 5 | 54 |
| 9 | Stylus | 54 | 14 | 7 | 75 |
| 10 | Keyboard | 82 | 21 | 0 | 103 |
| 11 | Keyboard | 38 | 7 | 0 | 45 |
| 12 | Keyboard | 45 | 0 | 0 | 45 |
| 13 | Stylus | 15 | 3 | 9 | 27 |
| 14 | Stylus | 27 | 8 | 2 | 37 |
| 15 | Stylus | 13 | 3 | 3 | 19 |
| 16 | Keyboard | 50 | 17 | 0 | 67 |
| 17 | Keyboard | 28 | 9 | 0 | 37 |
| 18 | Keyboard | 57 | 13 | 0 | 70 |
| | **Totals** | **1086** | **173** | **69** | **1328** |

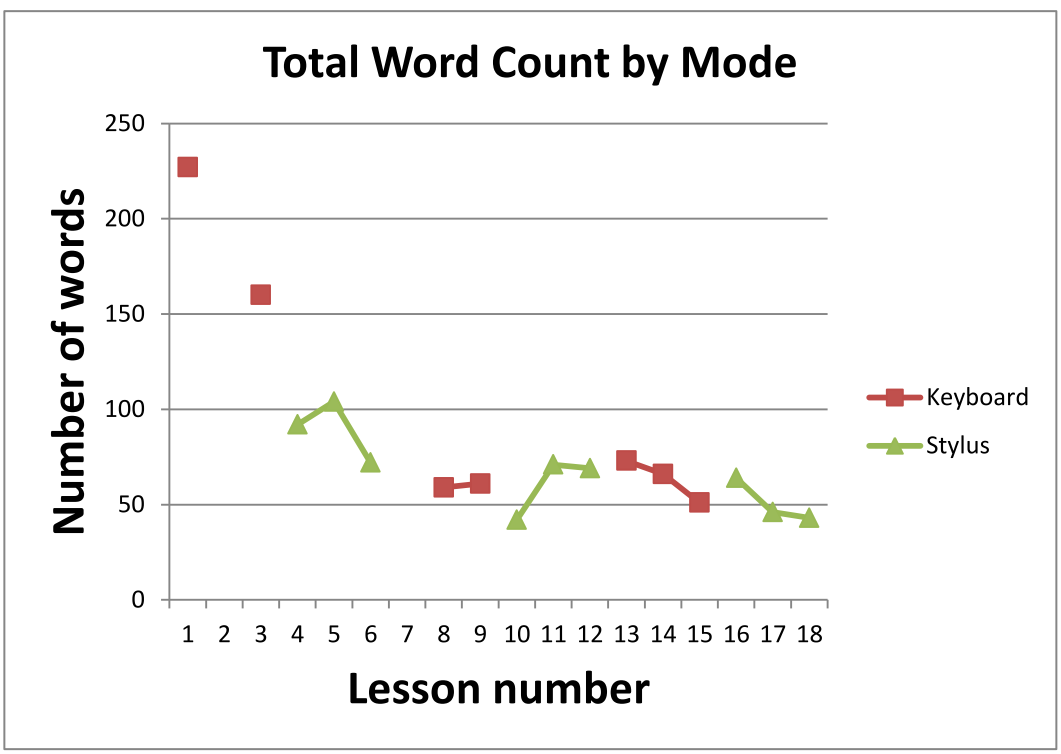
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | 186 |
| 4 | 176 | |
| 5 | 161 | |
| 6 | 179 | |
| 7 | | 47 |
| 8 | | 54 |
| 9 | | 75 |
| 10 | 103 | |
| 11 | 45 | |
| 12 | 45 | |
| 13 | | 27 |
| 14 | | 37 |
| 15 | | 19 |
| 16 | 67 | |
| 17 | 37 | |
| 18 | 70 | |



| | |
|---|---|
| Subject | 9 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 1 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboarding | 222 | 5 | 0 | 227 |
| 2 | Keyboarding | x | x | x | 0 |
| 3 | Keyboarding | 157 | 3 | 0 | 160 |
| 4 | Stylus | 88 | 3 | 1 | 92 |
| 5 | Stylus | 98 | 6 | 0 | 104 |
| 6 | Stylus | 66 | 1 | 5 | 72 |
| 7 | Keyboarding | x | x | x | 0 |
| 8 | Keyboarding | 55 | 4 | 0 | 59 |
| 9 | Keyboarding | 55 | 6 | 0 | 61 |
| 10 | Stylus | 36 | 6 | 0 | 42 |
| 11 | Stylus | 60 | 8 | 3 | 71 |
| 12 | Stylus | 57 | 7 | 5 | 69 |
| 13 | Keyboarding | 67 | 6 | 0 | 73 |
| 14 | Keyboarding | 64 | 2 | 0 | 66 |
| 15 | Keyboarding | 50 | 1 | 0 | 51 |
| 16 | Stylus | 55 | 9 | 0 | 64 |
| 17 | Stylus | 46 | 0 | 0 | 46 |
| 18 | Stylus | 36 | 5 | 2 | 43 |
| | **Totals** | **1212** | **72** | **16** | **1300** |

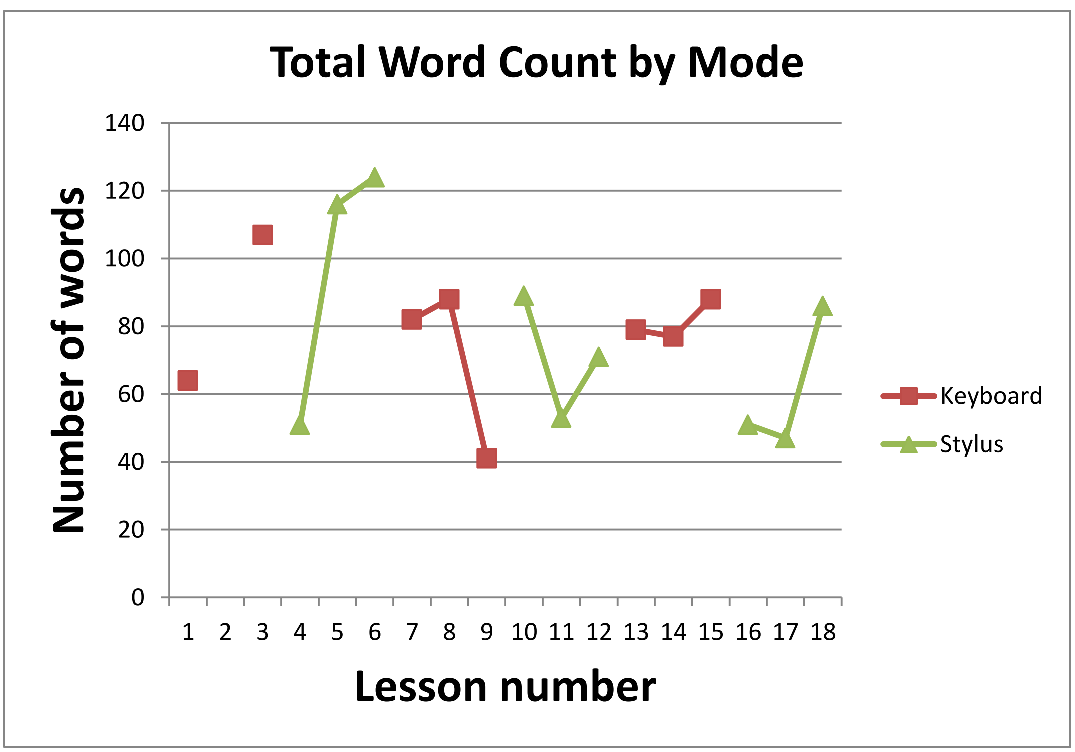
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | 227 | |
| 2 | | |
| 3 | 160 | |
| 4 | | 92 |
| 5 | | 104 |
| 6 | | 72 |
| 7 | | |
| 8 | 59 | |
| 9 | 61 | |
| 10 | | 42 |
| 11 | | 71 |
| 12 | | 69 |
| 13 | 73 | |
| 14 | 66 | |
| 15 | 51 | |
| 16 | | 64 |
| 17 | | 46 |
| 18 | | 43 |



| | |
|---|---|
| Subject | 10 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 1 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboard | 61 | 3 | 0 | 64 |
| 2 | Keyboard | z | z | z | 0 |
| 3 | Keyboard | 102 | 5 | 0 | 107 |
| 4 | Stylus | 50 | 1 | 0 | 51 |
| 5 | Stylus | 105 | 7 | 4 | 116 |
| 6 | Stylus | 115 | 8 | 1 | 124 |
| 7 | Keyboard | 77 | 5 | 0 | 82 |
| 8 | Keyboard | 86 | 2 | 0 | 88 |
| 9 | Keyboard | 37 | 4 | 0 | 41 |
| 10 | Stylus | 75 | 10 | 4 | 89 |
| 11 | Stylus | 46 | 2 | 5 | 53 |
| 12 | Stylus | 67 | 4 | 0 | 71 |
| 13 | Keyboard | 73 | 6 | 0 | 79 |
| 14 | Keyboard | 74 | 3 | 0 | 77 |
| 15 | Keyboard | 84 | 4 | 0 | 88 |
| 16 | Stylus | 42 | 6 | 3 | 51 |
| 17 | Stylus | 45 | 1 | 1 | 47 |
| 18 | Stylus | 78 | 8 | 0 | 86 |
| | **Totals** | **1217** | **79** | **18** | **1314** |

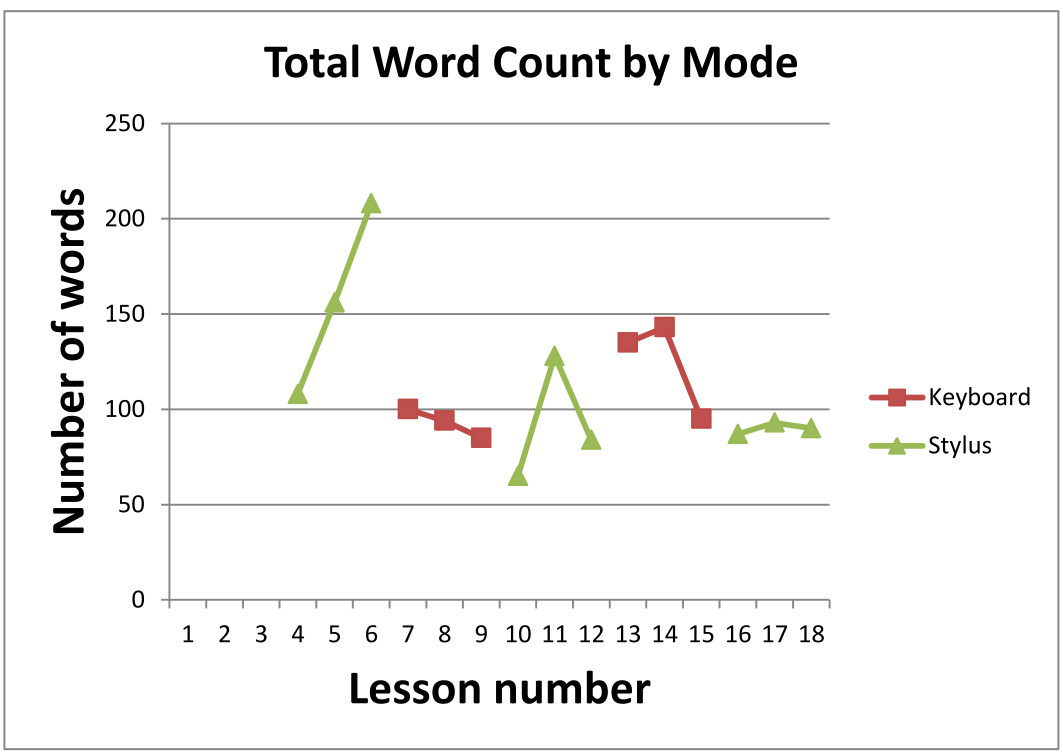
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | 64 | |
| 2 | | |
| 3 | 107 | |
| 4 | | 51 |
| 5 | | 116 |
| 6 | | 124 |
| 7 | 82 | |
| 8 | 88 | |
| 9 | 41 | |
| 10 | | 89 |
| 11 | | 53 |
| 12 | | 71 |
| 13 | 79 | |
| 14 | 77 | |
| 15 | 88 | |
| 16 | | 51 |
| 17 | | 47 |
| 18 | | 86 |



Subject 11
Cohort 1
Group OWL LD
Start Md 1

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboarding | z | z | z | 0 |
| 2 | Keyboarding | z | z | z | 0 |
| 3 | Keyboarding | z | z | z | 0 |
| 4 | Stylus | 99 | 9 | 0 | 108 |
| 5 | Stylus | 147 | 8 | 1 | 156 |
| 6 | Stylus | 202 | 4 | 2 | 208 |
| 7 | Keyboarding | 100 | 0 | 0 | 100 |
| 8 | Keyboarding | 94 | 0 | 0 | 94 |
| 9 | Keyboarding | 83 | 2 | 0 | 85 |
| 10 | Stylus | 62 | 2 | 1 | 65 |
| 11 | Stylus | 116 | 4 | 8 | 128 |
| 12 | Stylus | 79 | 2 | 3 | 84 |
| 13 | Keyboarding | 131 | 4 | 0 | 135 |
| 14 | Keyboarding | 135 | 8 | 0 | 143 |
| 15 | Keyboarding | 90 | 5 | 0 | 95 |
| 16 | Stylus | 80 | 6 | 1 | 87 |
| 17 | Stylus | 88 | 4 | 1 | 93 |
| 18 | Stylus | 84 | 6 | 0 | 90 |
| | **Totals** | **1590** | **64** | **17** | **1671** |

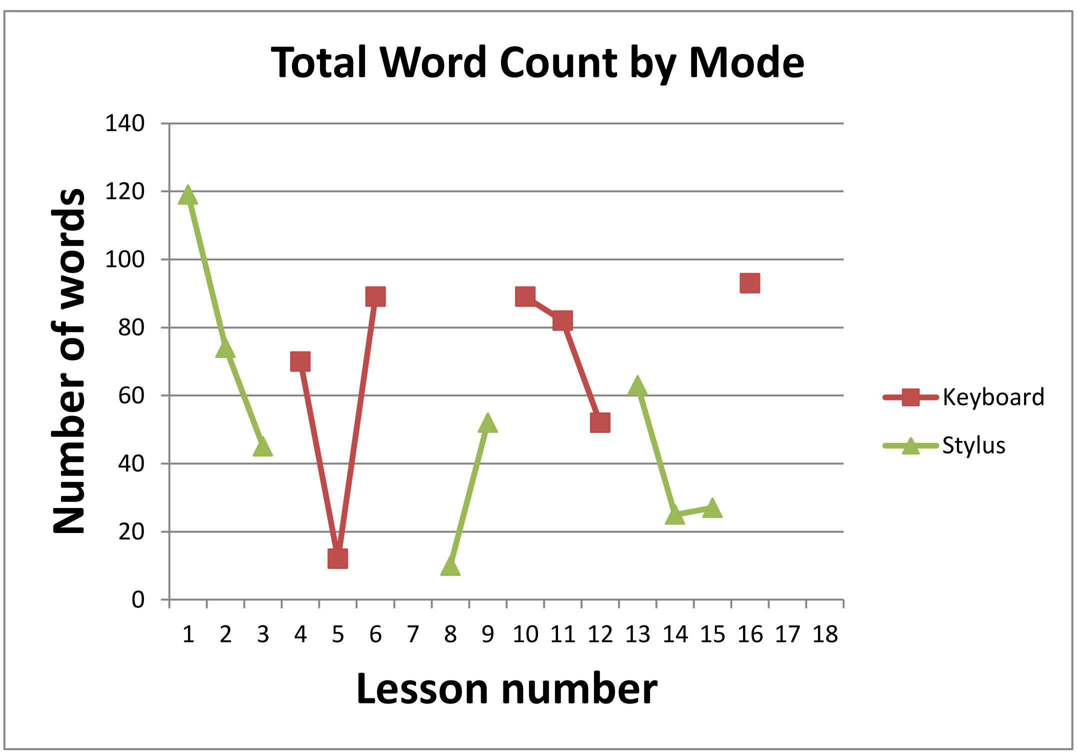
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | 108 |
| 5 | | 156 |
| 6 | | 208 |
| 7 | 100 | |
| 8 | 94 | |
| 9 | 85 | |
| 10 | | 65 |
| 11 | | 128 |
| 12 | | 84 |
| 13 | 135 | |
| 14 | 143 | |
| 15 | 95 | |
| 16 | | 87 |
| 17 | | 93 |
| 18 | | 90 |



| | |
|---|---|
| Subject | 12 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | 112 | 4 | 3 | 119 |
| 2 | Stylus | 69 | 3 | 2 | 74 |
| 3 | Stylus | 41 | 1 | 3 | 45 |
| 4 | Keyboard | 70 | 0 | 0 | 70 |
| 5 | Keyboard | 12 | 0 | 0 | 12 |
| 6 | Keyboard | 89 | 0 | 0 | 89 |
| 7 | Stylus | z | z | z | 0 |
| 8 | Stylus | 10 | 0 | 0 | 10 |
| 9 | Stylus | 47 | 3 | 2 | 52 |
| 10 | Keyboard | 89 | 0 | 0 | 89 |
| 11 | Keyboard | 81 | 1 | 0 | 82 |
| 12 | Keyboard | 52 | 0 | 0 | 52 |
| 13 | Stylus | 58 | 5 | 0 | 63 |
| 14 | Stylus | 24 | 1 | 0 | 25 |
| 15 | Stylus | 26 | 1 | 0 | 27 |
| 16 | Keyboard | 86 | 7 | 0 | 93 |
| 17 | Keyboard | x | x | x | 0 |
| 18 | Keyboard | x | x | x | 0 |
| | **Totals** | **866** | **26** | **10** | **902** |

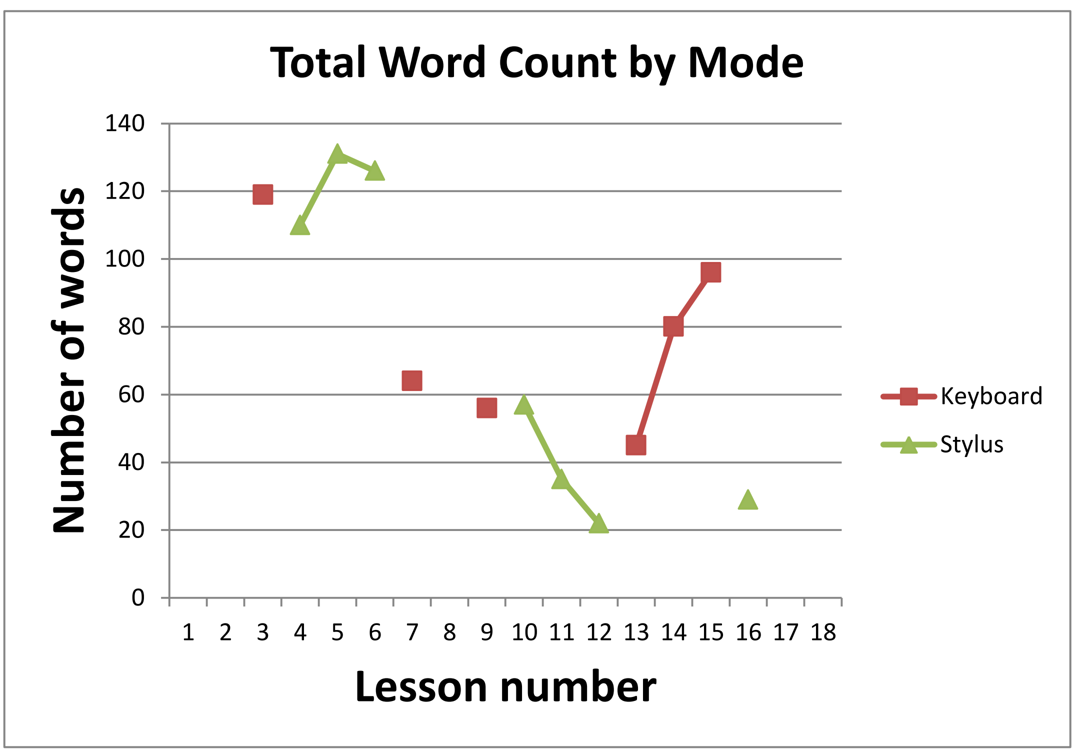
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | 119 |
| 2 | | 74 |
| 3 | | 45 |
| 4 | 70 | |
| 5 | 12 | |
| 6 | 89 | |
| 7 | | |
| 8 | | 10 |
| 9 | | 52 |
| 10 | 89 | |
| 11 | 82 | |
| 12 | 52 | |
| 13 | | 63 |
| 14 | | 25 |
| 15 | | 27 |
| 16 | 93 | |
| 17 | | |
| 18 | | |



| | |
|---|---|
| Subject | 13 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 1 |

| **Lesson #** | Mode | Correct | Misspelled | Illegible | **Total** |
|---|---|---|---|---|---|
| 1 | Keyboard | z | z | z | 0 |
| 2 | Keyboard | z | z | z | 0 |
| 3 | Keyboard | 119 | 0 | 0 | 119 |
| 4 | Stylus | 88 | 10 | 12 | 110 |
| 5 | Stylus | 92 | 25 | 14 | 131 |
| 6 | Stylus | 106 | 14 | 6 | 126 |
| 7 | Keyboard | 60 | 4 | 0 | 64 |
| 8 | Keyboard | x | x | x | 0 |
| 9 | Keyboard | 52 | 4 | 0 | 56 |
| 10 | Stylus | 44 | 9 | 4 | 57 |
| 11 | Stylus | 25 | 10 | 0 | 35 |
| 12 | Stylus | 16 | 3 | 3 | 22 |
| 13 | Keyboard | 41 | 4 | 0 | 45 |
| 14 | Keyboard | 70 | 10 | 0 | 80 |
| 15 | Keyboard | 83 | 13 | 0 | 96 |
| 16 | Stylus | 16 | 4 | 9 | 29 |
| 17 | Stylus | x | x | x | 0 |
| 18 | Stylus | x | x | x | 0 |
| | **Totals** | **812** | **110** | **48** | **970** |

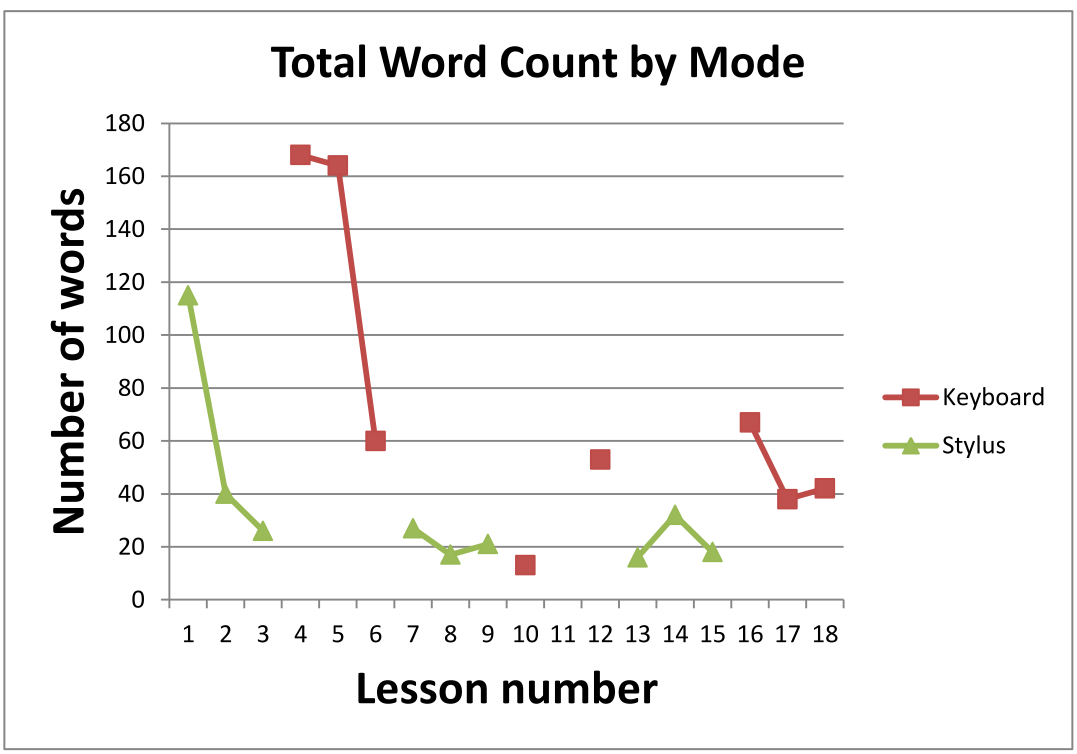
| **Lesson #** | **Keyboard** | **Stylus** |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | 119 | |
| 4 | | 110 |
| 5 | | 131 |
| 6 | | 126 |
| 7 | 64 | |
| 8 | | |
| 9 | 56 | |
| 10 | | 57 |
| 11 | | 35 |
| 12 | | 22 |
| 13 | 45 | |
| 14 | 80 | |
| 15 | 96 | |
| 16 | | 29 |
| 17 | | |
| 18 | | |



| | |
|---|---|
| Subject | 14 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | 105 | 10 | 0 | 115 |
| 2 | Stylus | 37 | 1 | 2 | 40 |
| 3 | Stylus | 25 | 0 | 1 | 26 |
| 4 | Keyboard | 157 | 11 | 0 | 168 |
| 5 | Keyboard | 141 | 23 | 0 | 164 |
| 6 | Keyboard | 54 | 6 | 0 | 60 |
| 7 | Stylus | 25 | 2 | 0 | 27 |
| 8 | Stylus | 13 | 3 | 1 | 17 |
| 9 | Stylus | 18 | 2 | 1 | 21 |
| 10 | Keyboard | 10 | 3 | 0 | 13 |
| 11 | Keyboard | z | z | z | 0 |
| 12 | Keyboard | 47 | 6 | 0 | 53 |
| 13 | Stylus | 16 | 0 | 0 | 16 |
| 14 | Stylus | 31 | 1 | 0 | 32 |
| 15 | Stylus | 15 | 2 | 1 | 18 |
| 16 | Keyboard | 62 | 5 | 0 | 67 |
| 17 | Keyboard | 37 | 1 | 0 | 38 |
| 18 | Keyboard | 42 | 0 | 0 | 42 |
| | **Totals** | **835** | **76** | **6** | **917** |

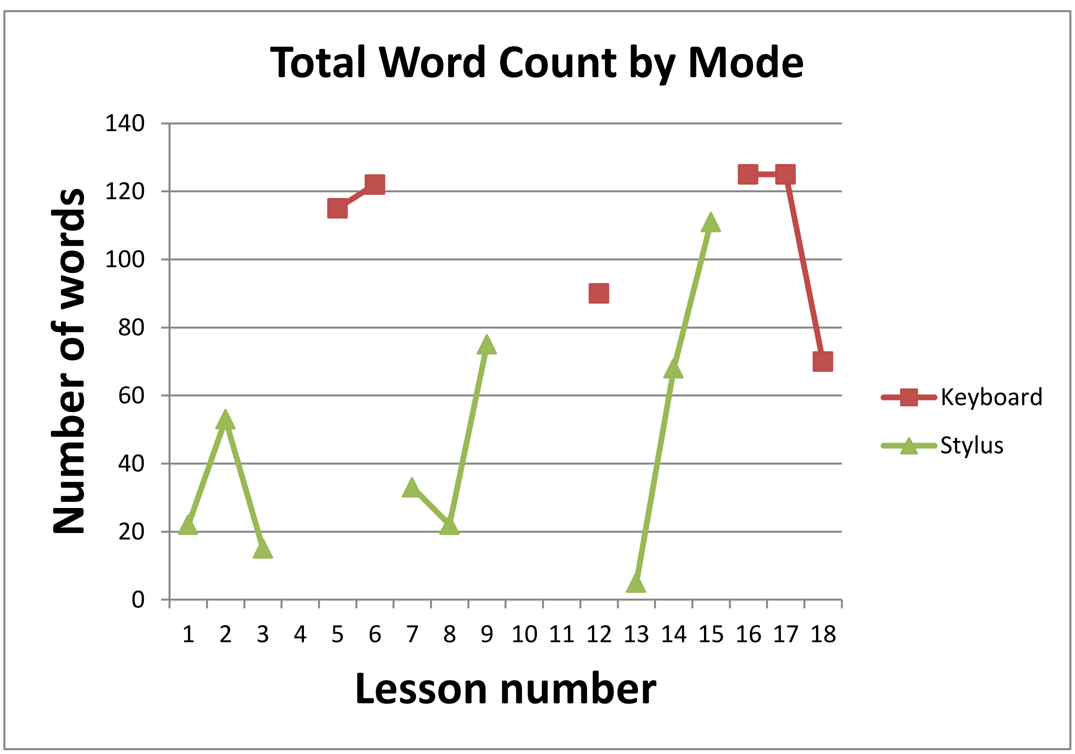
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | 115 |
| 2 | | 40 |
| 3 | | 26 |
| 4 | 168 | |
| 5 | 164 | |
| 6 | 60 | |
| 7 | | 27 |
| 8 | | 17 |
| 9 | | 21 |
| 10 | 13 | |
| 11 | | |
| 12 | 53 | |
| 13 | | 16 |
| 14 | | 32 |
| 15 | | 18 |
| 16 | 67 | |
| 17 | 38 | |
| 18 | 42 | |



| | |
|---|---|
| Subject | 15 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | 15 | 5 | 2 | 22 |
| 2 | Stylus | 44 | 4 | 5 | 53 |
| 3 | Stylus | 12 | 2 | 1 | 15 |
| 4 | Keyboard | x | x | x | 0 |
| 5 | Keyboard | 102 | 13 | 0 | 115 |
| 6 | Keyboard | 112 | 10 | 0 | 122 |
| 7 | Stylus | 26 | 5 | 2 | 33 |
| 8 | Stylus | 17 | 3 | 2 | 22 |
| 9 | Stylus | 63 | 9 | 3 | 75 |
| 10 | Keyboard | x | x | x | 0 |
| 11 | Keyboard | x | x | x | 0 |
| 12 | Keyboard | 87 | 3 | 0 | 90 |
| 13 | Stylus | 2 | 1 | 2 | 5 |
| 14 | Stylus | 48 | 14 | 6 | 68 |
| 15 | Stylus | 82 | 16 | 13 | 111 |
| 16 | Keyboard | 119 | 6 | 0 | 125 |
| 17 | Keyboard | 121 | 4 | 0 | 125 |
| 18 | Keyboard | 64 | 6 | 0 | 70 |
| | **Totals** | **914** | **101** | **36** | **1051** |

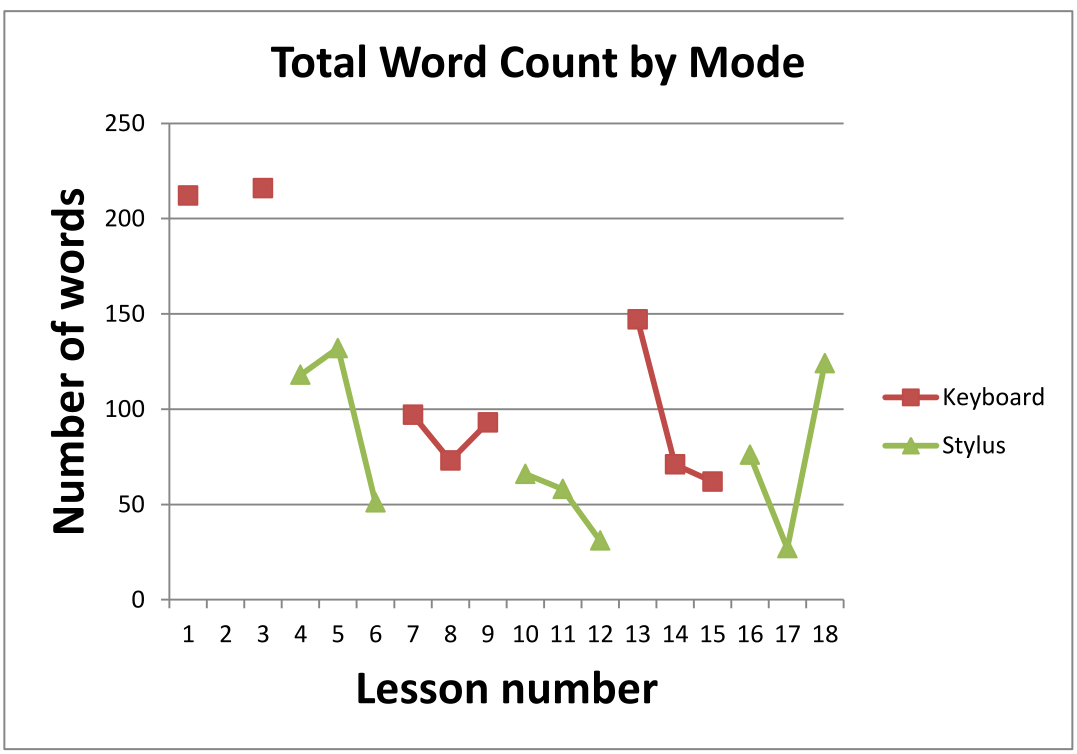
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | 22 |
| 2 | | 53 |
| 3 | | 15 |
| 4 | | |
| 5 | 115 | |
| 6 | 122 | |
| 7 | | 33 |
| 8 | | 22 |
| 9 | | 75 |
| 10 | | |
| 11 | | |
| 12 | 90 | |
| 13 | | 5 |
| 14 | | 68 |
| 15 | | 111 |
| 16 | 125 | |
| 17 | 125 | |
| 18 | 70 | |



| | |
|---|---|
| Subject | 16 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 1 |

| **Lesson #** | Mode | Correct | Misspelled | Illegible | **Total** |
|---|---|---|---|---|---|
| 1 | Keyboard | 199 | 13 | 0 | 212 |
| 2 | Keyboard | x | x | x | 0 |
| 3 | Keyboard | 210 | 6 | 0 | 216 |
| 4 | Stylus | 104 | 10 | 4 | 118 |
| 5 | Stylus | 110 | 15 | 7 | 132 |
| 6 | Stylus | 35 | 5 | 11 | 51 |
| 7 | Keyboard | 88 | 9 | 0 | 97 |
| 8 | Keyboard | 68 | 5 | 0 | 73 |
| 9 | Keyboard | 91 | 2 | 0 | 93 |
| 10 | Stylus | 46 | 11 | 9 | 66 |
| 11 | Stylus | 34 | 13 | 11 | 58 |
| 12 | Stylus | 23 | 4 | 4 | 31 |
| 13 | Keyboard | 137 | 10 | 0 | 147 |
| 14 | Keyboard | 65 | 6 | 0 | 71 |
| 15 | Keyboard | 56 | 6 | 0 | 62 |
| 16 | Stylus | 58 | 12 | 6 | 76 |
| 17 | Stylus | 23 | 1 | 3 | 27 |
| 18 | Stylus | 107 | 13 | 4 | 124 |
| | **Totals** | **1454** | **141** | **59** | **1654** |

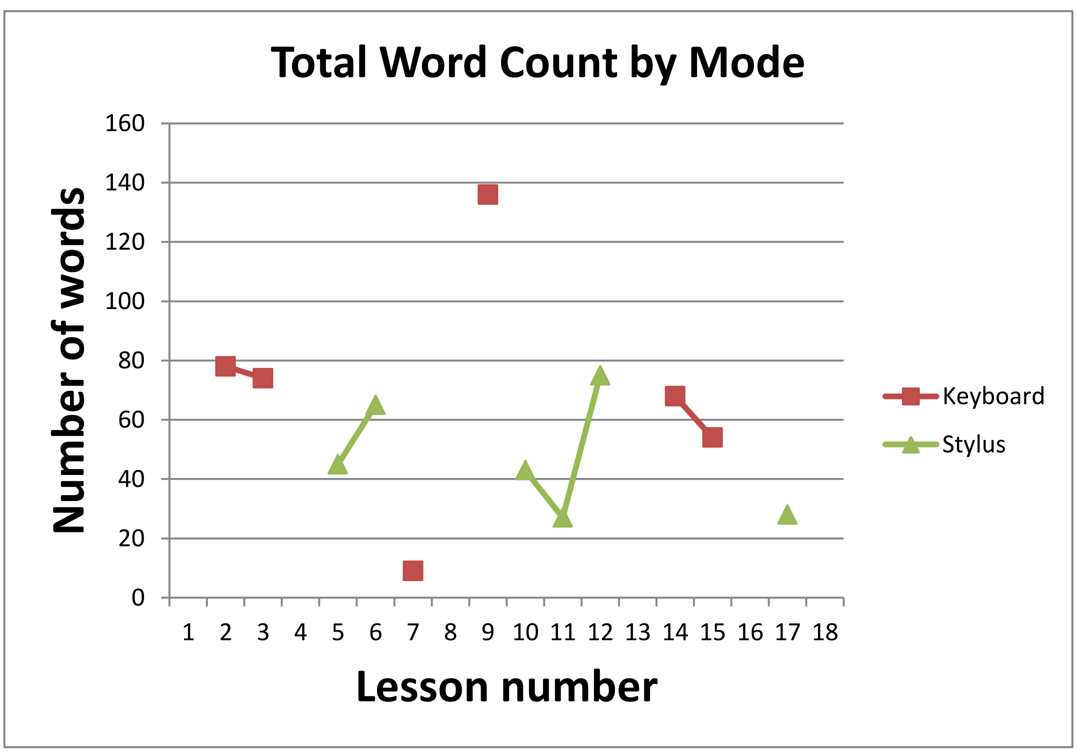
| **Lesson #** | **Keyboard** | **Stylus** |
|---|---|---|
| 1 | 212 | |
| 2 | | |
| 3 | 216 | |
| 4 | | 118 |
| 5 | | 132 |
| 6 | | 51 |
| 7 | 97 | |
| 8 | 73 | |
| 9 | 93 | |
| 10 | | 66 |
| 11 | | 58 |
| 12 | | 31 |
| 13 | 147 | |
| 14 | 71 | |
| 15 | 62 | |
| 16 | | 76 |
| 17 | | 27 |
| 18 | | 124 |



| | |
|---|---|
| Subject | 17 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 1 |

| **Lesson #** | Mode | Correct | Misspelled | Illegible | **Total** |
|---|---|---|---|---|---|
| 1 | Keyboard | z | z | z | 0 |
| 2 | Keyboard | 74 | 4 | 0 | 78 |
| 3 | Keyboard | 74 | 0 | 0 | 74 |
| 4 | Stylus | z | z | z | 0 |
| 5 | Stylus | 38 | 4 | 3 | 45 |
| 6 | Stylus | 54 | 7 | 4 | 65 |
| 7 | Keyboard | 9 | 0 | 0 | 9 |
| 8 | Keyboard | z | z | z | 0 |
| 9 | Keyboard | 136 | 0 | 0 | 136 |
| 10 | Stylus | 30 | 6 | 7 | 43 |
| 11 | Stylus | 22 | 1 | 4 | 27 |
| 12 | Stylus | 59 | 5 | 11 | 75 |
| 13 | Keyboard | x | x | x | 0 |
| 14 | Keyboard | 67 | 1 | 0 | 68 |
| 15 | Keyboard | 53 | 1 | 0 | 54 |
| 16 | Stylus | x | x | x | 0 |
| 17 | Stylus | 25 | 1 | 2 | 28 |
| 18 | Stylus | x | x | x | 0 |
| | **Totals** | **641** | **30** | **31** | **702** |

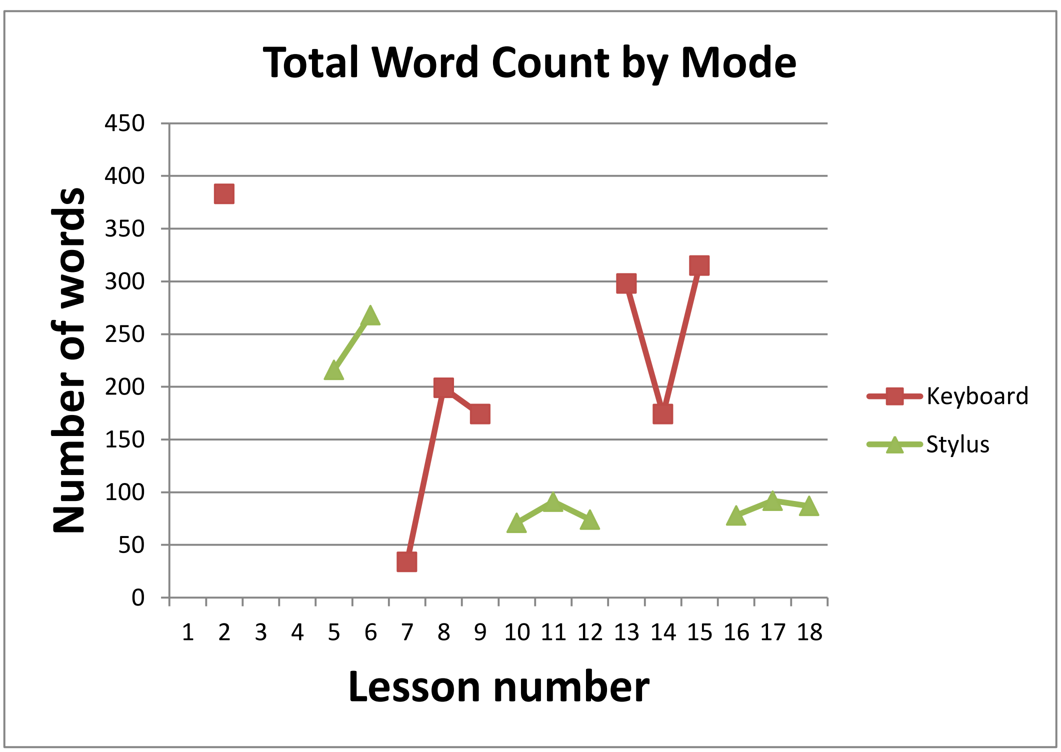
| **Lesson #** | **Keyboard** | **Stylus** |
|---|---|---|
| 1 | | |
| 2 | 78 | |
| 3 | 74 | |
| 4 | | |
| 5 | | 45 |
| 6 | | 65 |
| 7 | 9 | |
| 8 | | |
| 9 | 136 | |
| 10 | | 43 |
| 11 | | 27 |
| 12 | | 75 |
| 13 | | |
| 14 | 68 | |
| 15 | 54 | |
| 16 | | |
| 17 | | 28 |
| 18 | | |



| | |
|---|---|
| Subject | 18 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 1 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboard | z | z | z | 0 |
| 2 | Keyboard | 351 | 32 | 0 | 383 |
| 3 | Keyboard | z | z | z | 0 |
| 4 | Stylus | z | z | z | 0 |
| 5 | Stylus | 196 | 20 | 0 | 216 |
| 6 | Stylus | 251 | 16 | 1 | 268 |
| 7 | Keyboard | 32 | 2 | 0 | 34 |
| 8 | Keyboard | 196 | 3 | 0 | 199 |
| 9 | Keyboard | 156 | 18 | 0 | 174 |
| 10 | Stylus | 64 | 7 | 0 | 71 |
| 11 | Stylus | 84 | 7 | 0 | 91 |
| 12 | Stylus | 65 | 6 | 3 | 74 |
| 13 | Keyboard | 275 | 23 | 0 | 298 |
| 14 | Keyboard | 160 | 14 | 0 | 174 |
| 15 | Keyboard | 294 | 21 | 0 | 315 |
| 16 | Stylus | 69 | 9 | 0 | 78 |
| 17 | Stylus | 86 | 6 | 0 | 92 |
| 18 | Stylus | 79 | 8 | 0 | 87 |
| | **Totals** | **2358** | **192** | **4** | **2554** |

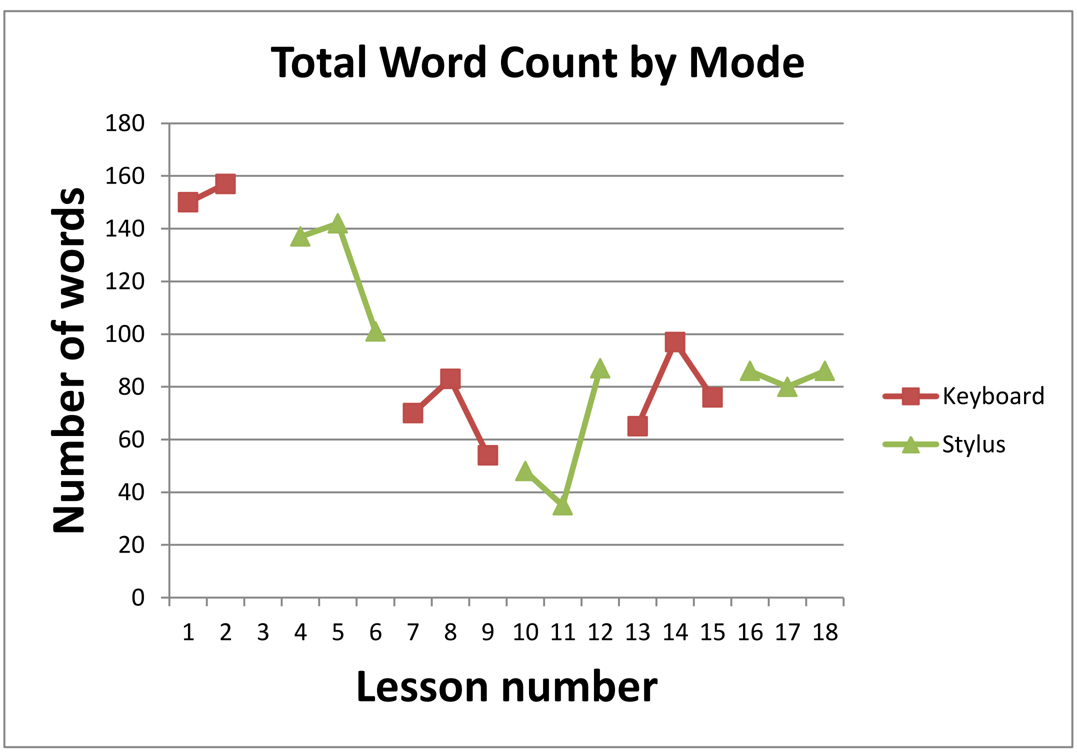
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | 383 | |
| 3 | | |
| 4 | | |
| 5 | | 216 |
| 6 | | 268 |
| 7 | 34 | |
| 8 | 199 | |
| 9 | 174 | |
| 10 | | 71 |
| 11 | | 91 |
| 12 | | 74 |
| 13 | 298 | |
| 14 | 174 | |
| 15 | 315 | |
| 16 | | 78 |
| 17 | | 92 |
| 18 | | 87 |



| | |
|---|---|
| Subject | 19 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 1 |

| **Lesson #** | Mode | Correct | Misspelled | Illegible | **Total** |
|---|---|---|---|---|---|
| 1 | Keyboard | 119 | 31 | 0 | 150 |
| 2 | Keyboard | 141 | 16 | 0 | 157 |
| 3 | Keyboard | x | x | x | 0 |
| 4 | Stylus | 98 | 27 | 12 | 137 |
| 5 | Stylus | 109 | 28 | 5 | 142 |
| 6 | Stylus | 81 | 18 | 2 | 101 |
| 7 | Keyboard | 61 | 9 | 0 | 70 |
| 8 | Keyboard | 82 | 1 | 0 | 83 |
| 9 | Keyboard | 50 | 4 | 0 | 54 |
| 10 | Stylus | 31 | 13 | 4 | 48 |
| 11 | Stylus | 29 | 6 | 0 | 35 |
| 12 | Stylus | 76 | 10 | 1 | 87 |
| 13 | Keyboard | 58 | 7 | 0 | 65 |
| 14 | Keyboard | 95 | 2 | 0 | 97 |
| 15 | Keyboard | 71 | 5 | 0 | 76 |
| 16 | Stylus | 70 | 11 | 5 | 86 |
| 17 | Stylus | 69 | 9 | 2 | 80 |
| 18 | Stylus | 72 | 12 | 2 | 86 |
| | **Totals** | **1312** | **209** | **33** | **1554** |

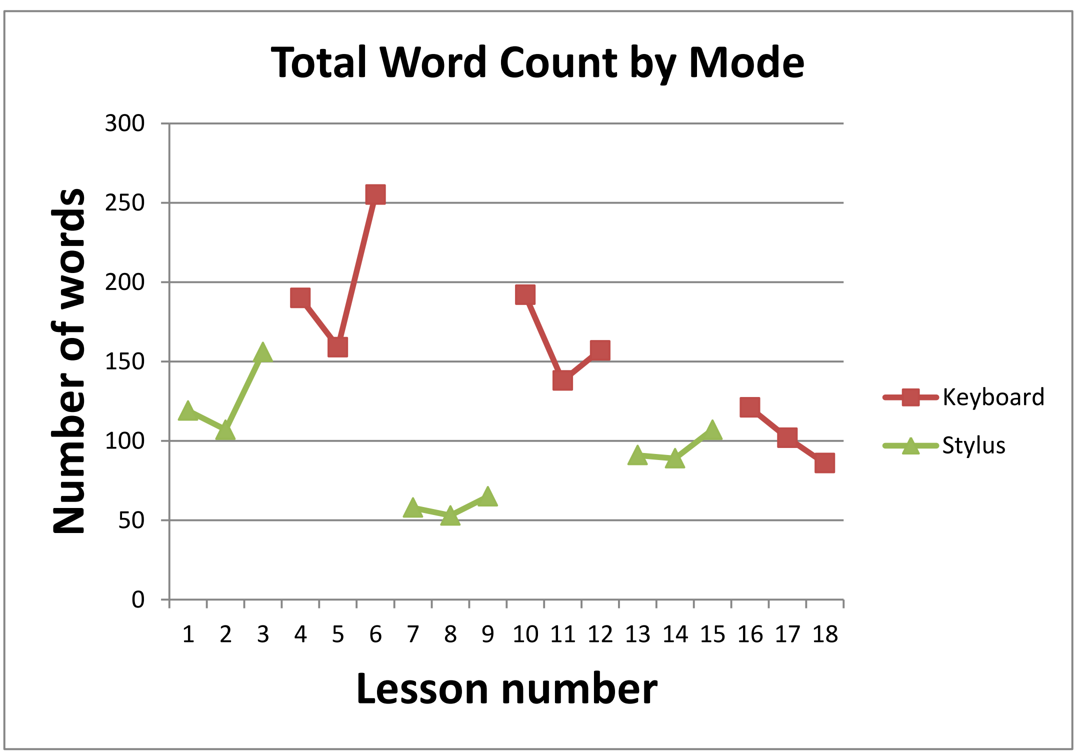
| **Lesson #** | **Keyboard** | **Stylus** |
|---|---|---|
| 1 | 150 | |
| 2 | 157 | |
| 3 | | |
| 4 | | 137 |
| 5 | | 142 |
| 6 | | 101 |
| 7 | 70 | |
| 8 | 83 | |
| 9 | 54 | |
| 10 | | 48 |
| 11 | | 35 |
| 12 | | 87 |
| 13 | 65 | |
| 14 | 97 | |
| 15 | 76 | |
| 16 | | 86 |
| 17 | | 80 |
| 18 | | 86 |



| | |
|---|---|
| Subject | 20 |
| Cohort | 1 |
| Group | Dyslexia |
| Start Md | 2 |

| **Lesson #** | Mode | Correct | Misspelled | Illegible | **Total** |
|---|---|---|---|---|---|
| 1 | Stylus | 115 | 4 | 0 | 119 |
| 2 | Stylus | 99 | 6 | 2 | 107 |
| 3 | Stylus | 147 | 8 | 1 | 156 |
| 4 | Keyboard | 185 | 5 | 0 | 190 |
| 5 | Keyboard | 147 | 12 | 0 | 159 |
| 6 | Keyboard | 248 | 7 | 0 | 255 |
| 7 | Stylus | 47 | 8 | 3 | 58 |
| 8 | Stylus | 47 | 3 | 3 | 53 |
| 9 | Stylus | 55 | 6 | 4 | 65 |
| 10 | Keyboard | 182 | 10 | 0 | 192 |
| 11 | Keyboard | 137 | 1 | 0 | 138 |
| 12 | Keyboard | 151 | 6 | 0 | 157 |
| 13 | Stylus | 90 | 1 | 0 | 91 |
| 14 | Stylus | 85 | 3 | 1 | 89 |
| 15 | Stylus | 105 | 2 | 0 | 107 |
| 16 | Keyboard | 113 | 8 | 0 | 121 |
| 17 | Keyboard | 95 | 7 | 0 | 102 |
| 18 | Keyboard | 83 | 3 | 0 | 86 |
| | **Totals** | **2131** | **100** | **14** | **2245** |

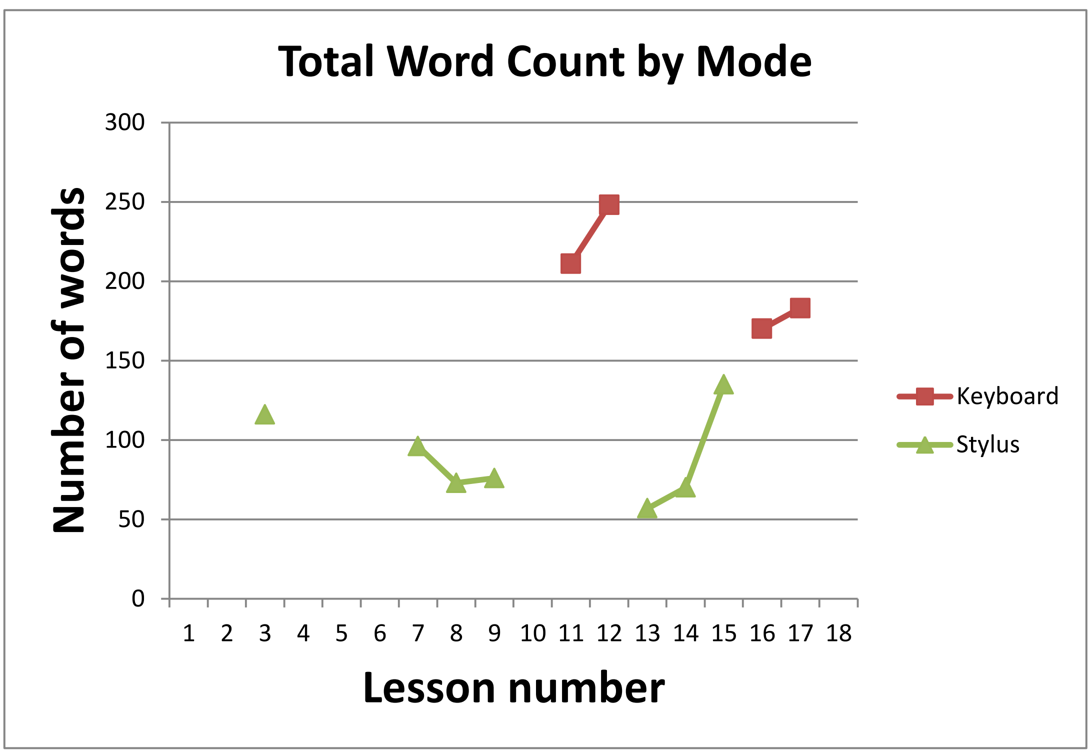
| **Lesson #** | **Keyboard** | **Stylus** |
|---|---|---|
| 1 | | 119 |
| 2 | | 107 |
| 3 | | 156 |
| 4 | 190 | |
| 5 | 159 | |
| 6 | 255 | |
| 7 | | 58 |
| 8 | | 53 |
| 9 | | 65 |
| 10 | 192 | |
| 11 | 138 | |
| 12 | 157 | |
| 13 | | 91 |
| 14 | | 89 |
| 15 | | 107 |
| 16 | 121 | |
| 17 | 102 | |
| 18 | 86 | |



| | |
|---|---|
| Subject | 21 |
| Cohort | 1 |
| Group | Dysgraphia |
| Start Md | 2 |

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Stylus | x | x | x | 0 |
| 2 | Stylus | x | x | x | 0 |
| 3 | Stylus | 106 | 4 | 6 | 116 |
| 4 | Keyboard | x | x | x | 0 |
| 5 | Keyboard | x | x | x | 0 |
| 6 | Keyboard | x | x | x | 0 |
| 7 | Stylus | 91 | 1 | 4 | 96 |
| 8 | Stylus | 69 | 2 | 2 | 73 |
| 9 | Stylus | 73 | 1 | 2 | 76 |
| 10 | Keyboard | x | x | x | 0 |
| 11 | Keyboard | 208 | 3 | 0 | 211 |
| 12 | Keyboard | 244 | 4 | 0 | 248 |
| 13 | Stylus | 56 | 1 | 0 | 57 |
| 14 | Stylus | 70 | 0 | 0 | 70 |
| 15 | Stylus | 130 | 1 | 4 | 135 |
| 16 | Keyboard | 157 | 13 | 0 | 170 |
| 17 | Keyboard | 181 | 2 | 0 | 183 |
| 18 | Keyboard | x | x | x | 0 |
| | **Totals** | **1385** | **32** | **18** | **1435** |

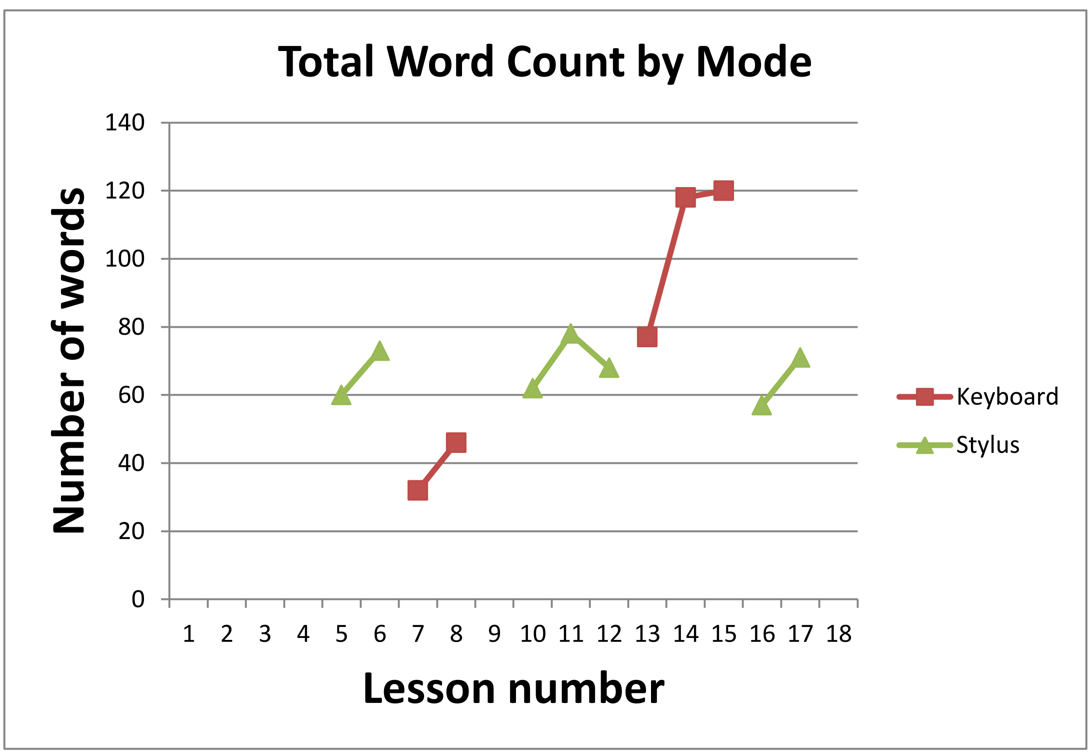
| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | 116 |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | 96 |
| 8 | | 73 |
| 9 | | 76 |
| 10 | | |
| 11 | 211 | |
| 12 | 248 | |
| 13 | | 57 |
| 14 | | 70 |
| 15 | | 135 |
| 16 | 170 | |
| 17 | 183 | |
| 18 | | |



Subject 22
Cohort 1
Group Typical OWL
Start Md 1

| Lesson # | Mode | Correct | Misspelled | Illegible | Total |
|---|---|---|---|---|---|
| 1 | Keyboard | x | x | x | 0 |
| 2 | Keyboard | x | x | x | 0 |
| 3 | Keyboard | x | x | x | 0 |
| 4 | Stylus | x | x | x | 0 |
| 5 | Stylus | 59 | 1 | 0 | 60 |
| 6 | Stylus | 71 | 1 | 1 | 73 |
| 7 | Keyboard | 30 | 2 | 0 | 32 |
| 8 | Keyboard | 43 | 3 | 0 | 46 |
| 9 | Keyboard | x | x | x | 0 |
| 10 | Stylus | 62 | 0 | 0 | 62 |
| 11 | Stylus | 77 | 1 | 0 | 78 |
| 12 | Stylus | 68 | 0 | 0 | 68 |
| 13 | Keyboard | 77 | 0 | 0 | 77 |
| 14 | Keyboard | 115 | 3 | 0 | 118 |
| 15 | Keyboard | 109 | 2 | 9 | 120 |
| 16 | Stylus | 57 | 0 | 0 | 57 |
| 17 | Stylus | 70 | 0 | 1 | 71 |
| 18 | Stylus | x | x | x | 0 |
| | **Totals** | **838** | **13** | **11** | **862** |

| Lesson # | Keyboard | Stylus |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | 60 |
| 6 | | 73 |
| 7 | 32 | |
| 8 | 46 | |
| 9 | | |
| 10 | | 62 |
| 11 | | 78 |
| 12 | | 68 |
| 13 | 77 | |
| 14 | 118 | |
| 15 | 120 | |
| 16 | | 57 |
| 17 | | 71 |
| 18 | | |



**Appendix 2.** Analysis of 18 Lessons Detecting Differences between Modes for Total Amount of Words Produced

| Lesson | Keyboard Mean | Keyboard SD | Stylus Mean | Stylus SD | t | df | Sig (2-tailed) |
|---|---|---|---|---|---|---|---|
| 1 | 174.50 | 77.32 | 109.18 | 64.25 | *2.11 | 19 | .048 |
| 2 | 154.10 | 92.04 | 89.58 | 38.17 | *2.22 | 20 | .038 |
| 3 | 156.93 | 68.77 | 105.07 | 57.56 | *2.16 | 26 | .040 |
| 4 | 158.33 | 83.99 | 104.71 | 43.04 | *-2.26 | 27 | .032 |
| 5 | 171.64 | 86.23 | 112.76 | 57.86 | *-2.17 | 26 | .039 |
| 6 | 163.25 | 102.26 | 132.20 | 71.06 | -1.01 | 30 | .319 |
| 7R | 94.28 | 56.95 | 53.31 | 39.93 | *2.22 | 29 | .034 |
| 8R | 96.13 | 66.79 | 45.87 | 39.91 | *2.50 | 28 | .018 |
| 9R | 77.79 | 45.78 | 53.79 | 42.52 | 1.53 | 31 | .135 |
| 10R | 80.27 | 52.98 | 54.16 | 22.04 | -1.90 | 28 | .068 |
| 11R | 95.73 | 54.61 | 52.95 | 32.36 | *-2.71 | 28 | .011 |
| 12R | 86.71 | 56.47 | 55.67 | 29.31 | -2.07 | 30 | .053 |
| 13R | 99.33 | 61.94 | 36.92 | 24.04 | **3.44 | 29 | .002 |
| 14R | 87.00 | 42.30 | 55.79 | 25.60 | *2.45 | 31 | .020 |
| 15R | 92.94 | 67.05 | 53.31 | 41.13 | 1.89 | 29 | .069 |
| 16R | 89.33 | 43.34 | 53.89 | 25.85 | **-2.81 | 28 | .009 |
| 17R | 82.70 | 54.80 | 50.44 | 26.71 | *-2.11 | 26 | .045 |
| 18R | 63.25 | 21.03 | 63.81 | 32.36 | .044 | 22 | .965 |

*p<.05; **p<.01; ***p<.001

**Appendix 3.** Analysis of 18 Lessons Detecting Differences Between Modes on Total Correctly Spelled Words

| Lesson | Keyboard Mean | Keyboard SD | Stylus Mean | Stylus SD | t | df | Sig (2-tailed) |
|---|---|---|---|---|---|---|---|
| 1 | 161.20 | 76.76 | 81.20 | 43.59 | *2.87 | 18 | .010 |
| 2 | 143.20 | 83.18 | 80.82 | 34.85 | *2.28 | 19 | .034 |
| 3 | 149.79 | 67.62 | 87.14 | 50.32 | *2.78 | 26 | .010 |
| 4 | 145.64 | 86.61 | 94.94 | 40.08 | *-2.10 | 26 | .045 |
| 5 | 158.50 | 91.44 | 97.88 | 53.24 | *-2.19 | 25 | .038 |
| 6 | 150.27 | 107.22 | 119.45 | 64.91 | -1.00 | 29 | .325 |
| 7R | 89.78 | 56.52 | 38.25 | 30.36 | **2.88 | 28 | .008 |
| 8R | 92.13 | 66.80 | 34.36 | 29.50 | **2.97 | 27 | .006 |
| 9R | 72.16 | 43.51 | 44.23 | 30.53 | *2.00 | 30 | .055 |
| 10R | 73.70 | 52.50 | 44.84 | 19.29 | *-2.16 | 27 | .040 |
| 11R | 78.64 | 59.78 | 43.68 | 28.69 | *-2.17 | 28 | .039 |
| 12R | 81.46 | 58.45 | 47.17 | 25.48 | *-2.22 | 29 | .034 |
| 13R | 91.67 | 57.63 | 29.08 | 27.23 | **3.50 | 28 | .002 |
| 14R | 80.79 | 40.68 | 44.31 | 22.09 | **2.94 | 30 | .006 |
| 15R | 83.11 | 64.09 | 44.31 | 38.05 | 1.94 | 29 | .062 |
| 16R | 80.08 | 43.39 | 44.89 | 23.30 | **-2.89 | 28 | .007 |
| 17R | 77.90 | 53.89 | 44.56 | 23.15 | *-2.30 | 26 | .030 |
| 18R | 57.13 | 18.37 | 55.63 | 28.15 | -.14 | 22 | .893 |

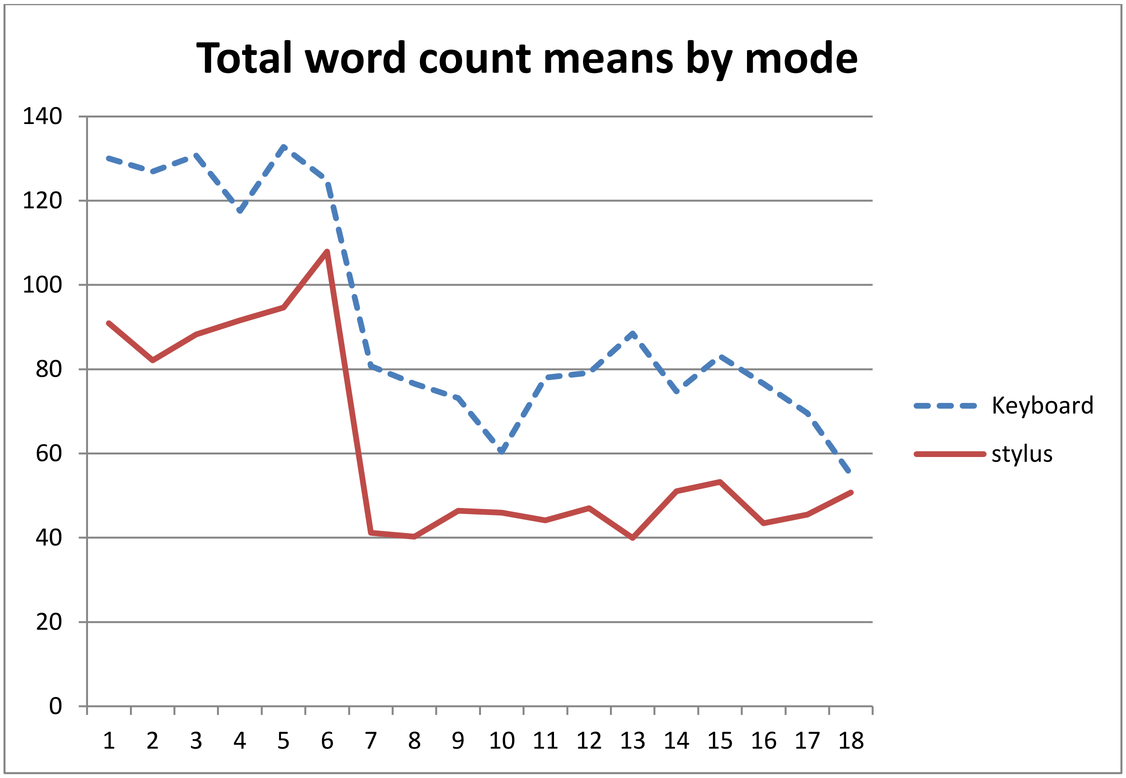
*p<.05; **p<.01; ***p<.001

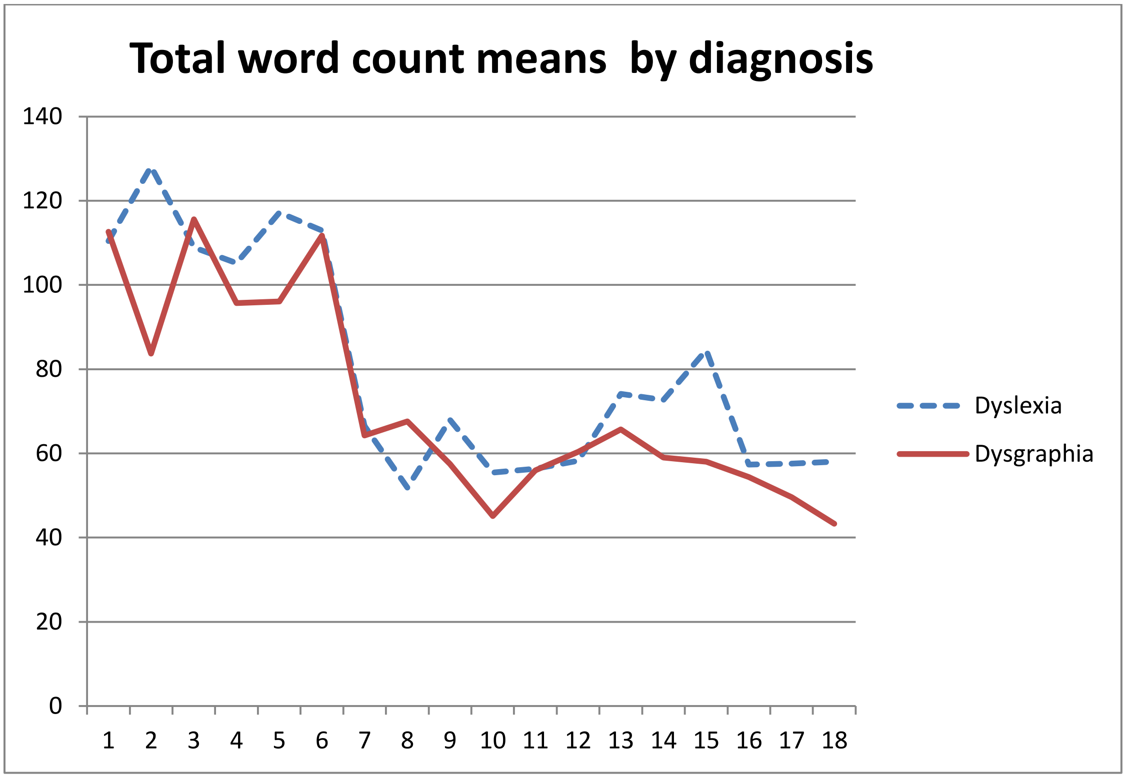
**Appendix 4.** Analysis of 18 Lessons Detecting Differences Between Modes on Total Misspelled Words

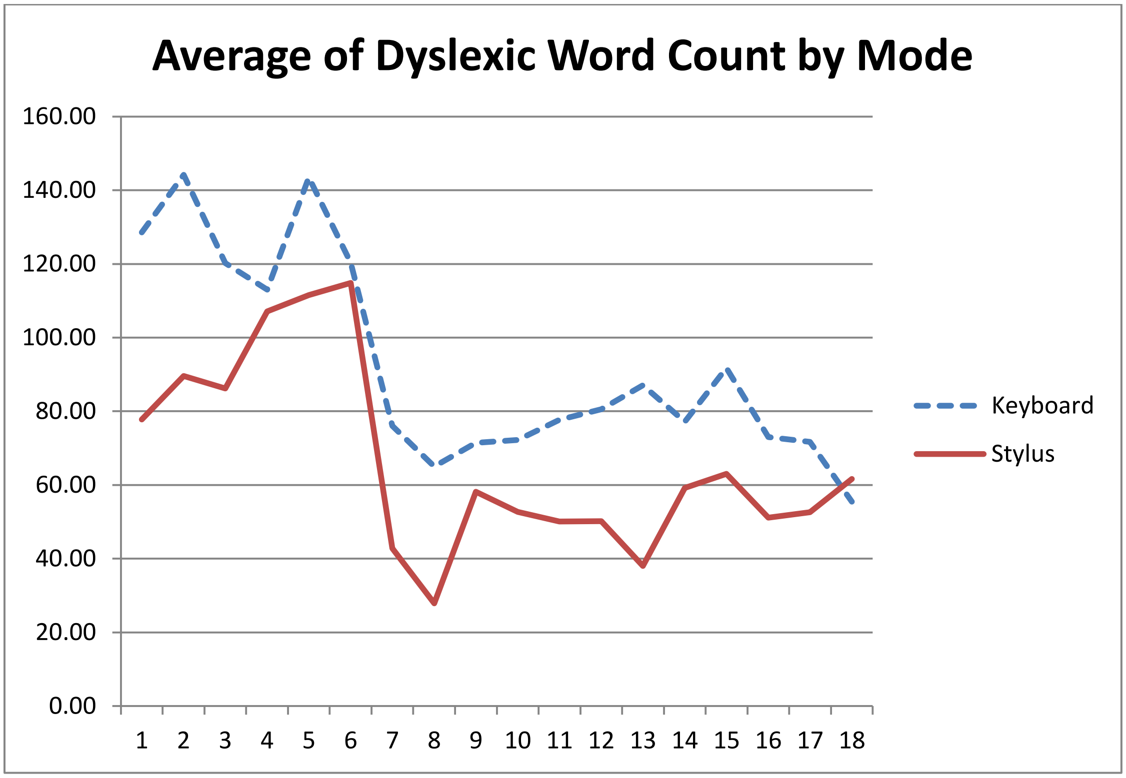
| Lesson | Keyboard Mean | Keyboard SD | Stylus Mean | Stylus SD | t | df | Sig (2-tailed) |
|---|---|---|---|---|---|---|---|
| 1 | 8.19 | 11.13 | 4.90 | 3.63 | 1.29 | 40 | .206 |
| 2 | 9.36 | 9.65 | 4.57 | 3.03 | *2.17 | 41 | .036 |
| 3 | 7.42 | 7.68 | 7.58 | 8.60 | -.07 | 48 | .945 |
| 4 | 5.68 | 6.04 | 5.79 | 5.58 | .07 | 49 | .946 |
| 5 | 10.95 | 9.59 | 9.10 | 8.04 | -.74 | 48 | .463 |
| 6 | 6.91 | 6.09 | 6.66 | 5.67 | -.16 | 52 | .876 |
| 7R | 5.00 | 5.79 | 5.68 | 6.99 | -.38 | 50 | .702 |
| 8R | 4.22 | 4.31 | 4.72 | 5.38 | -.37 | 50 | .713 |
| 9R | 4.63 | 5.26 | 5.17 | 3.93 | -.41 | 52 | .681 |
| 10R | 6.38 | 5.93 | 5.32 | 4.89 | -.70 | 50 | .486 |
| 11R | 6.18 | 8.00 | 4.53 | 4.13 | -.97 | 50 | .337 |
| 12R | 5.00 | 8.04 | 3.55 | 3.55 | -.87 | 49 | .390 |
| 13R | 6.90 | 5.73 | 3.36 | 3.71 | *2.51 | 49 | .015 |
| 14R | 5.67 | 5.14 | 5.43 | 7.04 | .14 | 51 | .890 |
| 15R | 8.41 | 12.49 | 4.13 | 5.48 | 1.53 | 50 | .132 |
| 16R | 6.86 | 7.51 | 4.97 | 3.74 | -1.18 | 49 | .242 |
| 17R | 4.70 | 3.87 | 3.86 | 4.02 | -.73 | 47 | .470 |
| 18R | 5.61 | 5.10 | 5.74 | 4.86 | .09 | 43 | .932 |

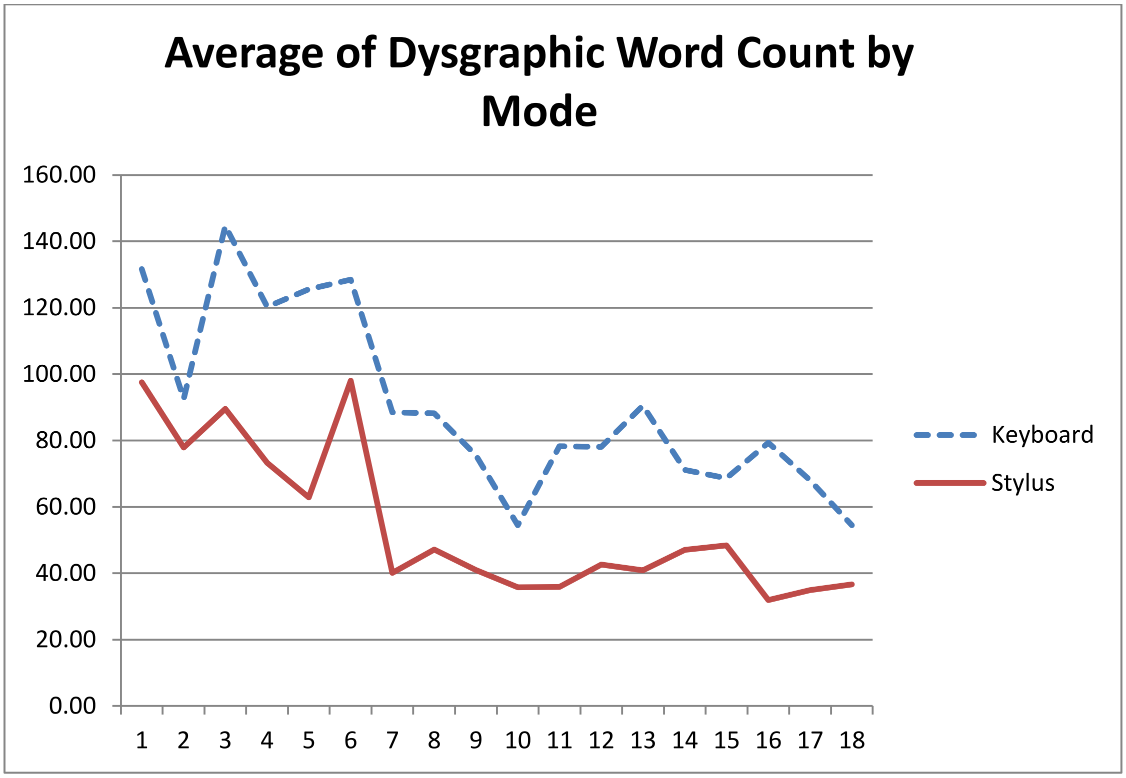
*p<.05; **p<.01; ***p<.001

**Appendix 5.** Analysis of 18 Lessons Detecting Differences Between Modes on Total Correctly Spelled Words




Total word count means by diagnosis
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Dyslexia
Dysgraphia


Average of Dyslexic Word Count by Mode
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Keyboard
Stylus


Average of Dysgraphic Word Count by Mode
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Keyboard
Stylus