Sub-study II

Frangou, S-M., Wikgren, J., Sintonen, S., Kairaluoma, L., & Vasari, P. (2019). The effect of writing modality on recollection in children and adolescents. *Research in Learning Technology, 27*:2239. https://doi.org/10.25304/rlt.v27.2239

Research in Learning Technology
Vol. 27, 2019

ASSOCIATION FOR LEARNING TECHNOLOGY ALT

ORIGINAL RESEARCH ARTICLE

The effect of writing modality on recollection in children and adolescents

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(Received: 21 February 2019; revised: 27 September 2019; accepted: 7 October 2019; Published: 28 10 2019)

We set out to assess the extent to which writing modality affects recollection in children and adolescents. We examined 10- to 11-year-old children's (N = 63) and 16-year-old adolescents' (N = 43) handwriting, keyboarding with a laptop computer and keyboarding with a touchscreen tablet computer or mobile phone in a within-subjects experimental design. Participants were instructed to write down stories dictated to them in the three writing modalities. Recollection of the stories was assessed using free recall of details in the stories. The results indicate that the writing modality affects recollection, handwriting leading to better recollection. However, currently, digital writing tools are inundating classrooms and workplaces around the globe, making their competent use a necessity in today's world. For example, in Finland, students are obligated to use a laptop in upper secondary education and in the national final examination. In light of the results, we highlight the importance of balancing the instruction and practice of different writing modalities. Given the limitations of this study, we suggest conducting a larger-scale study and further research on the educational and cognitive implications of using and learning to write using multiple writing modalities.

Keywords: handwriting; keyboarding; writing instruction; recollection

Introduction

Writing is communication through letters, words and sentences (Peterson and Grimes 2018) produced with writing mediums or tools (Haas 1996). Writing is an essential competence for social communication in the 21st century; however, the demands of contemporary society continually raise the bar for digital competence requirements, which also extends to the different modalities of writing. Keyboarding (i.e. typing) with different digital devices has taken precedence over writing with pen and paper (Mangen and Velay 2014), and literacy now encompasses much more than reading and producing linear text (Kallionpää 2017). Furthermore, digital tools are presently used in reading and writing instruction, and in Finland, information and communication

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Citation: Research in Learning Technology 2019, **27**: 2239 - http://dx.doi.org/10.25304/rlt.v27.2239
(page number not for citation purpose)

technologies (ICTs) are widely becoming part of the school infrastructure and a key component of literacy.

The Finnish National Core Curriculum for basic education was revised in 2014 and was implemented in 2016 in the teaching of all subjects (Vahtivuori-Hänninen *et al.* 2014). The new curriculum introduced multiliteracy skills to equip students with the necessary proficiencies to communicate and function in the digitised world, meaning also the competence to use different writing modalities. Furthermore, multiliteracy refers not only to reading and writing, but also to the ability to create and interpret different types of information with and through different modes of communication and media (Buckley-Walker *et al.* 2017). In upper secondary education in Finland and in the matriculation examination (the national examination on the upper secondary education syllabus), laptops are the main writing medium. This examination is currently undergoing the process of digitalisation (Kupiainen, Marjanen, and Ouakrim-Soivio 2018), and hence, students taking this examination can benefit only from a solid keyboarding competence.

Competence in writing with any modality could again have a connection to recollection. During the development of handwriting and keyboarding skills, improving basic transcription skills is essential, that is, to express oneself in writing, one must be proficient in the foundations of language, spelling and orthographic skills (Berninger and Swanson 1994). Handwriting proficiency is fully developed before 15 years of age (Accardo, Genna, and Borean 2013), but initially children are able to associate specific letters (characters) with their corresponding sound. They gradually become aware of the writing conventions of their own language while simultaneously developing finger dexterity (Dinehart 2015). Similarly, as keyboard proficiency develops, so does spelling accuracy and keyboarding speed with less focus on finding the correct keys (Rønneberg and Torrance 2019).

This is also consistent with the keyboarding research conducted by Christensen (2004), in which the texts produced by eighth and ninth graders via keyboarding improved considerably after keyboarding practice. Moreover, research has shown that when children learn keyboarding, they benefit from a new kind of motivation to express themselves, as their ability to edit improves and they no longer keyboard with an improvised, frustrating and time-consuming hunt-and-peck system (Rogers *et al.* 2003). As Berninger and Swanson (1994) and Klein (1999) put it, a competent writer by hand can concentrate on the writing topic at a higher level of planning while reviewing the produced text and does not need to concentrate on the graphomotor execution process of writing, which could also be the case in proficient keyboarding. More cognitive resources can be used to process the content, planning and monitoring of writing (Berninger and Swanson 1994; Rønneberg and Torrance 2019; Yeganeh Doost *et al.* 2017). Hence, in this study, we posited that the writing modality can be considered an encoding medium that can leave a significant memory trace. We asked: Do different writing modalities have differing influences on children's and adolescents' recollection?

Handwriting and keyboarding

Handwriting can be conceptualised as a skill that unites perceptual and motor skills. The component of perception is associated with the perceived letter shape, while the motor component deals with letter production (Vinter and Chartrel 2010).

Citation: Research in Learning Technology 2019, **27**: 2239 - http://dx.doi.org/10.25304/rlt.v27.2239

Hence, the development and coordination of fine motor skills, neuromotor processes and multiple cognitive processes are essential in handwriting (Dinehart 2015). At the same time, Erthal (1998) suggested that a good age to learn keyboarding is approximately eight or nine, as children at this age have the necessary competencies, including the ability to read, and the fine motor skills and hand–eye coordination needed to write in the visual space of the screen and in the motor space of the keyboard (Erthal 1998; Mangen and Velay 2010).

From theoretical and empirical research, several differences between keyboarding and handwriting are apparent, although both skills require practice to progress from novice to proficient levels. Yamaguchi and Logan (2014) studied the keyboarding process and identified three major forms of linguistic-level associations during competent automated keyboarding – the association between words and specific letters, the association between letters and specific keys and the association between specific finger and the correct keys to strike. Logan and Crump's (2011) cognitive model of typing dealt more with lower level cognitive functions, such as the location retrieval and graphomotor execution of keystrokes, than with higher level planning or reviewing of text, which is common in handwriting studies (Berninger and Swanson 1994; Flower and Hayes 1981). Cognitive process theory, introduced by Flower and Hayes (1981), clarifies the cognitive process model introduced by the authors a year earlier (Hayes and Flower 1980). The theory proposes that handwriting is a recursive action, which has three components. Firstly, in the writing process, writers are continually and simultaneously planning, translating and revising as they compose a text. Secondly, the writer's long-term memory stores various types of knowledge that can affect the outcome of the text, such as previous knowledge about the topic or knowledge about the reading audience. However, the ideas created in long-term memory are often disorganised and therefore require cognitive revision and structure before being written down. Thirdly, the task environment refers to relevant and related text produced thus far and how such text affects the writer in terms of framing the topic, goals and audience (Flower and Hayes 1981).

Empirical studies concerning keyboards have found keyboarding to be more productive compared to handwriting not only in terms of speed and legibility (Rogers and Case-Smith 2002) but also due to its features for organised notetaking, which enhance recall (Bui, Myerson, and Hale 2013). Keyboarding has also yielded benefits for poor (in speed or legibility) or disabled handwriters, which improves their written output (Rogers and Case-Smith 2002; Weigelt Marom and Weintraub 2015). Keyboarding on touchscreen devices follows the same principles as those for a conventional or laptop keyboard; however, the keys cannot be separated by touch, which can cause keyboarding accuracy to decline and slow down the writing process (Kim *et al.* 2014) by shifting the focus from the text to the keyboard. However, tablet computers with touchscreens were found to be effective instructional tools for children with specific learning disabilities, improving their handwriting, spelling and composing competences (Berninger *et al.* 2015).

In empirical research, handwriting has been reported to have multiple benefits, from improving orthography and structuring to enhancing composing and creative writing skills (Berninger and Swanson 1994; Christensen 2005). However, studies regarding the connection of keyboarding and handwriting to recollection are scarce and mainly concentrate on the accuracy of the letters. Research on children's letter, or character, recognition, including short-term and long-term retention, was conducted

by Longcamp, Zerbato-Poudou, and Velay (2005) and Longcamp *et al.* (2006). Similar research was also conducted on adults by Longcamp *et al.* (2008). These studies suggest that handwriting may enhance the recollection of letters, and in the case of children, this effect would become more pronounced with age. Concerning adults' word recollection, research by Mangen *et al.* (2015) with female university students reported that handwriting produced better recollection scores compared to keyboarding on computers and touchscreen devices; these findings were corroborated by Frangou *et al.* (2018) for handwritten text recall. Furthermore, a study by Mueller and Oppenheimer (2014) compared university students' recollection of handwritten and typed lecture notes, and found that handwritten lecture notes composed in one's own words (not verbatim) promoted a deeper understanding of the subject and its later recollection.

The current study context

In the current study, we compared three writing modalities – handwriting, keyboarding on a laptop and keyboarding on the touchscreen keyboard of an iPad (10- to 11-year-olds) and a mobile phone (16-year-olds) – and the recollection of short logical stories. Generally, recollection is understood as the retrieval of stored information from memory system (Tulving 1983). However, recollection in the current context refers to episodic memory because the written stories were logically composed and ordered (Tulving 1983). A story is recalled through story schemas, as put forward by schema theory (Mandler 2014). This means that a story generally has a structure, with setting, theme, plot (events) and resolution, which can be recalled in logical order (Mandler 2014). This study tested long-term retention, which is the broad aim of formal teaching, and exclusively measured the content knowledge of the written verbatim content of texts that needed no prior knowledge.

We conducted two experiments, one with 10- to 11-year-old Finnish children (N = 63) and another with 16-year-old Finnish adolescents (N = 43), to examine their recollection after handwriting, laptop keyboarding and touchscreen keyboarding (iPads for children and mobile phones for adolescents). Participants aged 10 or 11 were chosen because, at this age, children's writing competence is transitioning from learning to write to writing to learn (Sedita 2013). The 16-year-old participants were chosen because they were ninth graders, that is, at the very end of their basic education in Finland when students are assumed to have all the competences needed to communicate with digital devices and to function in contemporary society.

Methodology

Participant recruitment and data collection were conducted in accordance with the standards and guidelines of the University of Lapland Research Ethics Committee and the guidelines of the Finnish National Board on Research Integrity (TENK). The Municipality of Rovaniemi School Board gave permission to carry out the research in the schools, and prior to task performance demographic information of the participants was collected and consent forms sent to be signed by the participants and the participants' legal guardians. The first author was responsible for the data collection in the schools' premises that were familiar to the participants.

Citation: Research in Learning Technology 2019, **27**: 2239 - http://dx.doi.org/10.25304/rlt.v27.2239

Pilot experiment with 10- and 11-year-old children

Participants

A pilot experiment was conducted with 10–11-year-old children. From the participants (N = 29), 19 were 10-year-old children (11F, 8M) and 10 were 11-year-old children (4F, 6M). Four participants were left-handed and 25 were right-handed, and all were proficient Finnish speakers. The participants began keyboarding at the age of 5.62 (SD = 1.45) and used 5.00 (SD = 3.21) fingers for keyboarding. Touchscreen keyboarding began a bit later, at the age of 6.34 (SD = 1.32).

Similar to Frangou *et al.* (2018), the pilot experiment was conducted using three stories. Upon reflection of the day the participants wrote the texts, it became evident that the texts were too demanding in terms of content and length. Given the limitations of the pilot experiment in terms of scope, inconclusive results and a demanding assessment tool, a second study was designed. Therefore, experiment 1 replicated the pilot study, but with adjusted parameters.

Experiment 1 with 10- and 11-year-old children

Participants

Participants (N = 63) included 31 10-year-old children (17F, 14M) and 32 11-year-old children (20F, 12M) from one school who were all proficient Finnish speakers. Four participants were left-handed and 59 were right-handed. The age at which keyboarding began was 6.68 (SD = 1.50), while the corresponding age for keyboarding on a touchscreen device was 6.56 (SD = 1.43). The children used 4.89 fingers for keyboarding (SD = 2.68).

Material

The pilot experiment material had been too demanding with two stories from the Wechsler Memory Scale (WMS-R) logical memory subtest (Wechsler 1987) and a third story that had been created to be similar to the other two (story C, Appendix A). In experiment 1, the stories were revised and shortened to suit this age group. All three stories were 40 words long with a logical structure that required no prior knowledge. For score-recording purposes, a 20-item list of details, persons and occurrences was created from each (story A, B & C, Appendix B).

For the handwritten test, a pen and paper were provided. For laptop keyboarding, Asus Chromebooks were used; for touchscreen keyboarding, iPads (model MD510KS/A) were used. The quantitative data arising from the memory tests were analysed using descriptive statistics (Statistical Package for the Social Sciences [SPSS] 24 software).

Research design and procedure

An experimental within-subjects research design was used; therefore, all participants used handwriting, a laptop keyboard and an iPad touchscreen keyboard to write three different stories – one for each writing medium. At the beginning of the session, the participants were instructed to write down everything that was dictated to them and told that they would be asked to recall information from their written stories 1 week

later. As the three stories were dictated in random order, the children wrote them verbatim with a pen, laptop keyboard and touchscreen keyboard one after the other in small groups. Reading pace was adjusted according to the children's ability to write. After each writing task, the story was read aloud once again so that the children could determine whether their written text was correct. The writing modality sequence was also randomised to prevent the same method from being used first or last. One week later, the participants were individually asked to orally recall everything they remembered about their written stories, in a free-recall condition with as much time as needed. For score-recording, a 20-item list of details was used in which one point was earned for each recalled detail (a maximum of 20 points). One cue word concerning the story's theme (e.g., bear) from the item list was designed to be used if a child could not recall anything at all.

Experiment 1 results

The mean value for recollection scores after handwriting was 9.83 (SD = 3.97); the mean value for recollection scores after keyboarding was 8.83 (SD = 4.00); and for touchscreen keyboarding, this value was 8.98 (SD = 3.96). Interestingly, particularly in handwriting, a difference was found between the age groups; the 11-year-old participants' recollection score value in handwriting was 11.56 (SD = 3.35), while for the 10-year-olds it was 8.03 (SD = 3.79).

Firstly, we assessed the effect of the writing modality on time spent writing (Figure 1A). ANOVA with repeated measures for each modality as a within-subjects factor and age (10 and 11) and gender as between-subjects factors revealed a significant writing mode – age interaction [$F(2,118) = 63.79$, $p < 0.001$], the main effect of writing modality on time spent writing [$F(2,118) = 18.36$, $p < 0.001$] and the main effect of age [$F(1,59) = 399.33$, $p < 0.001$]. Further paired samples t-tests on both age groups separately indicated that in 10-year-old children, handwriting is more time-consuming than tablet writing [$t(30) = 23.87$, $p < 0.001$] or keyboard writing [$t(30) = 3.92$, $p < 0.001$]. It was also found that the 10-year-olds spent less time

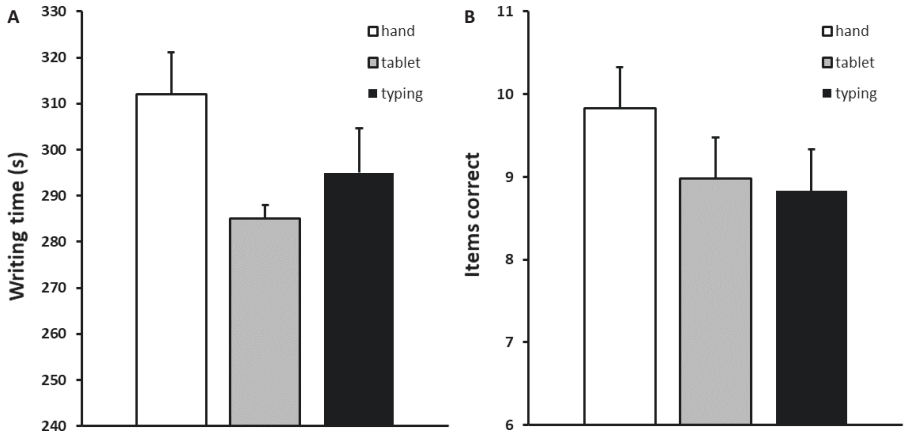

Figure 1. Results from experiment 1 with 10–11-year-old participants.

Citation: Research in Learning Technology 2019, **27**: 2239 - http://dx.doi.org/10.25304/rlt.v27.2239

writing with a tablet than with a keyboard [$t(30) = 4.87$, $p < 0.001$]. The pattern for 11-year-old participants was somewhat different. For them, writing with a tablet was the most time-consuming method, as indicated by significant differences from both handwriting [$t(31) = 14.86$, $p < 0.001$] and keyboard writing [$t(31) = 4.76$, $p < 0.001$]. The findings indicate that younger pupils spend significantly more time writing, especially handwriting.

A similar analysis run on the recollection scores (Figure 1B) yielded a significant main effect of age [$F(1,59) = 9.24$, $p < 0.01$]. Thus, the recollection scores were analysed for both age groups separately. A significant main effect of writing mode was found for the 11-year-old children [$F(2, 62) = 4.28$, $p < 0.05$)]; however, no such effect was found for the 10-year-olds [$F(2, 60) = .001$, $p = 0.99$]. To further analyse the differences among the writing modalities, paired samples t-tests were run between the writing modalities. The recollection scores for the 11-year-old children's handwriting were better than either of the other modalities – keyboard writing [$t(31) = 3.32$, $p < 0.01$] and touch screen keyboarding [$t(31) = 2.15$, $p < 0.05$].

Experiment 2 with 16-year-old adolescents

Participants

The participants of experiment 2 included 43 16-year-old adolescents (21M, 22F), representing all the students of this age group at one school. Six of the participants were left-handed and 37 right-handed, and all were proficient Finnish speakers. The participants started using keyboards at the age of 7.98 (SD = 2.02) and used 7.91 (SD = 1.45) fingers for keyboarding; they began using touchscreen keyboards at the age of 10.60 (SD = 1.14).

Material

The material for experiment 2 was identical to that for the pilot experiment with two stories from the WMS-R logical memory subtest (Wechsler 1987), which is designed to test episodic memory, and a similar one that was created for this study (story C, Appendix A). The three stories were each around 60 words long. For score-recording purposes, there was a 25-item list of details, persons and occurrences from each story (two from WMS-R and one created for this study). For each recalled detail, one point was earned, meaning that one could score a maximum of 25 points. Data analysis methods were identical to those used in experiment 1. For the handwritten test, a pen and paper were used, whereas the participants' own laptops were used for keyboarding and their own mobile phones were used for touchscreen keyboarding. On the mobile phones, only thumbs were used for writing.

Research design and procedure

The research design and procedure were identical to those used in experiment 1, with the exception that the 25-item lists were used for score recording and no cue words were given.

Experiment 2 results

The participants' mean score for recollecting handwritten texts after 1 week was 6.46 (SD = 3.82), for laptop-keyboarded texts 4.74 (SD = 2.43) and for touchscreen-keyboarded texts 5.44 (SD = 4.13). ANOVA with repeated measures revealed a significant main effect of writing mode on time spent writing [$F(2,82) = 77.39$, $p < 0.001$]. Time spent writing is depicted in Figure 2A. Paired samples t-tests indicated that handwriting was slower compared to both the mobile phone touchscreen [$t(42) = 18.52$, $p < 0.001$] and keyboard [$t(42) = 9.17$, $p < 0.001$]. Curiously, adolescents wrote faster with a phone, using only their thumbs, than with a keyboard [$t(42) = 3.68$, $p < 0.01$].

A similar kind of repeated measures ANOVA was run on recollection scores (Figure 2B). We found a significant main effect of writing mode [$F(2,82) = 4.19$, $p < 0.05$]. The ANOVA with repeated measures tests of within-subjects effects revealed the significant main effect of writing modality on recollection [$F(2,84) = 4.24$, $p = 0.018$]. The subsequent pairwise comparisons revealed that handwriting was significantly better recalled than laptop-keyboarded texts ($p = 0.011$) with Bonferroni adjustment. Recall scores were subsequently analysed with pairwise comparisons to determine differences between writing methods. The results indicated that handwritten material is better recalled than texts written on a laptop keyboard [$t(42) = 3.09$, $p < 0.01$]. A comparison between handwriting and mobile phone writing yielded a borderline significant difference in favour of handwriting [$t(42) = 1.76$, $p = 0.085$].

Discussion

The interrelation of learning and memory (Carroll 1993) emerged in this study through the degree of recollection by individuals after stories were written down using different writing modalities. Stories are generally not a subject that children are tasked with memorising at school; yet, stories represent a good source for writing without the need of prior knowledge and, in this way, equalise the starting point among children.

Our research provides valuable insight into writing modalities and their influence on recollection. A key finding is that handwriting resulted in better recollection than laptop keyboarding and touch screen keyboarding among 11-year-old children and 16-year-old adolescents. However, children aged 10 recalled almost equally well after

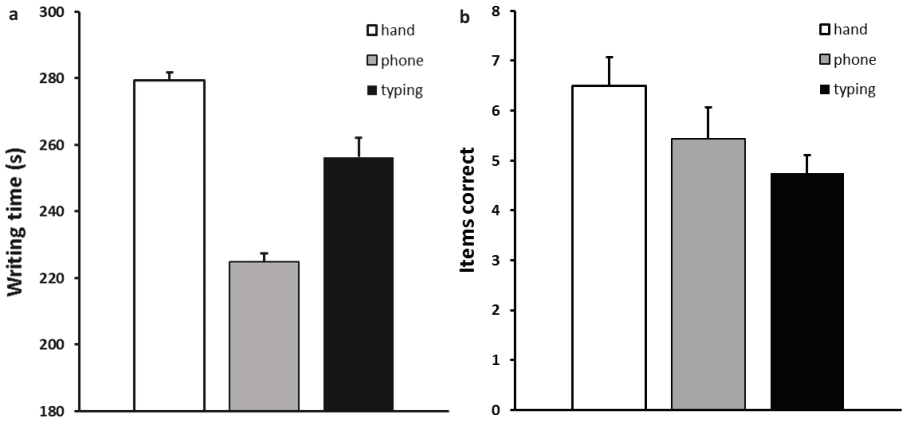

Figure 2. Results from experiment 2 with 16-year-old participants.

Citation: Research in Learning Technology 2019, **27**: 2239 - http://dx.doi.org/10.25304/rlt.v27.2239

writing with all three writing modalities. This leads to the question of the keyboarding proficiency of the 11- and 16-year-old participants, which would decrease the amount of attention needed to locate and strike the keys (Rønneberg and Torrance 2019) and would thereby enable the participants to concentrate more on the topic (Berninger and Swanson 1994; Klein 1999) and recall more of the text. Furthermore, for 11-year-olds, a difference was found between the recollection scores of handwriting and touchscreen keyboarding; however, for 16-year-olds the difference between handwriting and touchscreen was not significant. These results suggest that handwriting is likely to be the most proficient modality for this age group, with touchscreen keyboarding not far behind, the fast speed of keyboarding on mobile phones suggesting this as well. Furthermore, the 10-year-olds spent less time writing with a tablet than with a keyboard. This could demonstrate how familiar these age groups are with touchscreen devices, a finding consistent with those of Mangen et al.'s (2015) study, in which a positive correlation was found between recollecting words that had been written with a touchscreen device and the number of years spent using touchscreen devices.

The study design used in this research, that is, comparing three different writing modalities with similar texts for all three, seemed to work well. The texts were suitable for adolescents; however, the parameters for 10- to 11-year-old children were adjusted after the pilot experiment. The adjusted parameters worked well for this age group.

Study limitations

This research has some limitations that should be acknowledged. Firstly, to our knowledge, a test designed to measure recollection after writing with different modalities does not exist, and therefore, there were no empirical studies with which to compare this study. Furthermore, large-scale experimental research on different age groups would produce more generalisable results. Therefore, the confidence interval for means was calculated from the results of experiment 2 because the number of participants was 43, and the distribution of gender was close to equal. The confidence interval for means was calculated to determine an adequate number of participants for test standardisation. We are 95% confident that the number of participants for each age group needed to standardise the test is 262.

Were it possible to conduct this study on a larger scale, a control group for comparing the outcomes would have certainly yielded clearer results and would have helped make the appropriate adjustments to the texts. Lastly, the test used for this research generates only quantitative data and does not consider any possible individual differences, such as mnemonic abilities, experiences with different modalities or personal preferences; neither does it consider the writing participants' backgrounds or contexts.

Conclusion

This article addressed the question: Do different writing modalities have differing influences on children's and adolescents' recollection? The question is highly relevant in the era of widening digital, multimodal text worlds. Using experimental within-subjects research design, the current study investigated 106 Finnish children's and adolescents' recollection after handwriting and keyboarding on laptops and touchscreen keyboards and found that different writing modalities influence recollection;

handwriting was the best writing modality among 11-year-old children and 16-year-old adolescents.

The increase and variety of new writing modalities present challenges for the education system. To improve the writing skills of students, systematic keyboarding instruction, supplementary instruction in areas in need of more support and standardised and uncomplicated tests for monitoring the development of writing skills should be developed. As multiliteracy is viewed as a transversal competence within the framework of the new curriculum in Finland, good foundations, both in handwriting and keyboarding, are invaluable for future.

It is evident that further empirical research on the educational and cognitive implications is needed in writing research to understand the effects of technology together with modality on recollection in different age groups. The study design and pilot test developed during this research (Appendix B) may be a useful starting point for others who are considering developing new methods to research writing modalities; however, for other age groups the parameters need to be adjusted again. At the same time, more research is needed on the multiliteracy competences and adaptivity to new technologies that are expected in contemporary society. Furthermore, new writing research instruments are needed to evaluate students' diversifying literacy skills and their influence on recollection to provide educators with valuable information about the students' abilities and potential need for targeted interventions.

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Citation: Research in Learning Technology 2019, **27**: 2239 - http://dx.doi.org/10.25304/rlt.v27.2239

Appendix A

Story C, pilot experiment and experiment 2 (translation)

Large beasts of prey are **familiar** to the **border guards** of the **eastern division**. Border guard **Jacob Smith** has seen a **bear three times** during his **career**. The **previous case** happened 2 **years ago** when he was **patrolling** with his **dog** one **July morning**. They passed a **valley** when they **heard a sound**. A bear had **touched** the **barbed wire** and **came across** the **border**. The man decided to **whistle**, and the bear **turned right back**. The border guards of the **Lake District,** for example, meet bears about **five times a year**.

Each of these items earned one point if recalled:
Large beasts of prey, familiar, border guards, eastern division, Jacob, Smith, bear, three times, career, previous case, 2 years ago, patrolling, dog, July morning, valley, heard a sound, touched, barbed wire, came across, border, whistle, turned right back, Lake District, five times, a year.

Appendix B

Story A, experiment 1 (translation)

A **student** named **Leevi** from **Ranua** found a **small** and strange **animal yesterday on the way to school**. He drove on a **moped** to take it to a **zoo** where the **vet recognised** the animal to be a **rare reptile**. The **beautiful** reptile must certainly **have escaped** from a **pet shop** because it would not have been able to survive in **northern nature**. Here, it needs a **terrarium** and a **heat lamp.**

Each of these items earned one point if recalled:
Student, Leevi, Ranua, small, animal, yesterday, on the way to school, moped, zoo, vet, recognised, rare, reptile, beautiful, escaped, pet shop, northern nature, terrarium, heat lamp.

Story B, experiment 1 (translation)
During the **weekend, four men** went to **Norway** on a **fishing trip**. They did not stay in a **cottage**, but in a **caravan**. On **Sunday**, the **sun** was shining and the **fish were biting well**. Then the **boat's cap disappeared** and the boat was **filled** with water. Some nearby **Japanese tourists** came to **help** and the men started their **trip home, wet**.

Each of these items earned one point if recalled:
Weekend, four, men, Norway, fishing trip, cottage, caravan, Sunday, sun, fish, biting well, boat's, cap/cork, disappeared, filled, Japanese, tourists, help, trip home, wet.

Story C, experiment 1 (translation)
Bears are familiar to **old Emma** who **lives in the woods**. **Last summer** Emma saw a bear **three times**. **Last time** it happened when she went to **pick berries** with the **dog**. They walked on a **forest path** when she heard a **sound**. The bear was **stealing honey**. The bear was **startled** by the **barking** of the dog and **slowly walked away**.

Each of these items earned one point if recalled:
Bears, old, Emma, lives, in the woods, last (1 year ago), summer, three, times, last time, pick berries, dog, forest, path, sound, stealing honey, startled, barking, slowly walked, away.