How does note-taking with digital pens on touch screens impact memory performance compared to using regular pen and paper?

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Introduction

Note-taking is a useful strategy adopted by many college students to facilitate their learning during lectures. Research has shown that note-taking not only helps students concentrate in lectures (Lin & Bigenho, 2011), but also assists memory retention (Hartley & Davies, 1978; Kiewra,1989).

The medium for note-taking has also evolved with the advancement in technology. The conventional note-taking strategy involves pen and paper, and notes are written by longhand. Since digital technology has become increasingly prevalent in classrooms, many students use their personal laptops and tablets to take notes. Nowadays, we observe numerous instances of a new form of note-taking. Students start to use digital pens (also known as digital styluses) to write directly on touch screens.

The various forms of note-taking attracted researchers' attention to study their impacts on learning. For example, Muller and Openheimer (2014) compared the learning outcome between laptop notetakers and longhand notetakers, and they found that typing notes with a keyboard was less advantageous than writing notes on paper due to passive lecture transcription. However, the newly developed digital stylus pens seem to convert the typing behaviour back to users' natural handwriting gesture. How might this new form of note-taking influence students' knowledge acquisition? Does note-taking with digital pens produce the same learning outcome as using traditional pen and paper? The proposed study aims to understand these questions. It will compare the memory performance between two methods of note-taking --- digital pens on touch screens versus regular pens on paper.

Background

This history of digital pens can be dated back to the 1990s', with the primary function of converting handwritings to texts on screens (Samsung, 2018). Due to technological constraints in managing the precision of digital writing, digital pens did not gain much popularity in the market (Samsung, 2018). In recent years, however, digital pens seem to become increasingly prevalent in our lives, especially among students. More and more students start to use digital pens to take notes during lectures on their touch screens.

One of the reasons why some students switch from keyboard to digital pens might be related to the improved tactile experience. In 2018, the Apple Pencil human interface guidelines introduced 9 design essentials that make the Apple Pencil works as intuitive as a real pen. For example, users can adjust the boldness of a stroke by applying various pressure and tilt, and they can erase the digital writing the same way as regular pens by scrubbing over the unwanted content (Apple Developer, 2018).

These positive features of a digital stylus seem to make it outperform than a keyboard in terms of note-taking. According to the research by Muller and Openheimer (2014), the downside of laptop note-taking is that it tends to produce "verbatim notes," which impairs the conceptual understanding of knowledge. Digital stylus pen might help students overcome this challenge by converting the passive typing behaviour back to the handwriting gesture, as if they are taking notes by longhand. This raises an interesting research question: does note-taking with digital pens produce similar learning outcome as note-taking with regular pens?

Exploring the impact of learning by different note-taking mediums will benefit from Muller and Openheimer's experimental framework (2014). They measured the memory performance in factual and conceptual test questions between laptop note-takers and longhand note-takers. The proposed research will adopt a similar approach to compare the memory retention between note-taking by digital pens and regular pens.

The results will be discussed through the lens of the Level of Processing Theory (LOP) (Craik &Lockhart, 1972) and attention. The LOP theory suggests that deeper information processing such as making meaningful associations predicts better memory retrieval (1972). Attention is also an insepeable component in the working memory to facilitate information manipulation (Engle, 2002). These theories will be applied to understand the potential differences in memory performance between two different note-taking methods.

Given the importance of note-taking in assisting learning in classrooms (Hartley & Davies, 1978; Kiewra,1989), the finding of this research will not only contribute to the existing literature in the field of Human-Computer Interaction and Cognitive Psychology, but also provide practical advice for current students when choosing their note-taking strategies. Moreover, the proposed research could also open up a new area of discovery. For example, future research could understand how different factors of digital writing such as writing speed, writing surface or tactile feedback might influence information processing.

Literature Review

Defining Digital Pens

Before diving into the literature review, it is important to clarify the definition of digital pens in the context of this proposal. Technically, there is a difference between a digital pen and a digital stylus. Digital pen is an umbrella term that refers to the input device that converts handwriting or drawing into digital format (PC Magazine Encyclopedia, n.d.). Some digital pens have more powerful functions such as scanning texts and audio recording other than basic writing and drawing. The digital stylus, on the other hand, is a type of digital pen. They are the ones that many students used to take notes because they have sensory ballpoints that register that pressure data to recreate the digital writings (History of Pencils, 2019). However, to make it less confusing in the context of this research, I will discount the difference between digital pens and digital styluses, and use them interchangeably to refer to the writing instrument on screen with writing and drawing as the primary functions.

The benefits of note-taking.

Note-taking is a complex cognitive activity that involves simultaneous comprehension, written production and mental coordination (Kiewra,1985; Piolat, Olive, & Kellogg, 2005). It depends on the functioning of working memory, which is the ability to process, manipulate and store information in a short period of time (Baddeley, 2000). Previous research highlighted the importance of note-taking in facilitating learning in academic contexts. For example, Di Vesta and Gray (1972) suggested that students can benefit from note-taking through the "encoding process" and "external storage (p8)". The encoding refers to the process of transcribing and making subjective associations while listening, and the external storage means the resource for later review and references. In other words, note-taking not only records the information, but also aids information processing by fostering meaningful connections.

Predictors of effective note-taking

Quality of Notes

Based on the review of the literature on note-taking and learning outcome, Piolat et al. (2005) identified that non-linear note-taking strategies (i.e. various combinations of summarizing, paraphrasing, graphs, concept maps etc.) predict better memory retention. However, given the fast-paced knowledge delivery in lecture settings, the non-linear note-taking strategies seem to be best achieved through the use of regular pen and paper. For instance, the content analysis of students' notes showed that laptop notetakers tend to produce more transcriptions of lectures (i.e. verbatim notes) than longhand notetakers (Muller & Openheimer, 2014). Consistent with Muller and Openheimer's findings, Luo, Kiewra, Flanigan and Peteranetz (2018) also found that laptop note-takers tend to produce more text-based notes, whereas longhand note-takers produce more image-based notes. These studies suggest that the quality of notes is more important than the quantity, and high-quality notes are best supported through the means of handwriting.

The importance of note quality in learning is consistent with the Level of Processing Theory (Craik &Lockhart, 1972). The theory suggests that there are two ways of information processing: *shallow processing* and *deep processing*. Shallow processing involves maintenance rehearsal, which means using repetitions to help remember information. Deep processing, on the other hand, involves elaborative rehearsal, which is making meaningful associations with the information. According to Craik and Lockhart (1972), the deeper information is processed, the more likely it can be remembered. In line with this theory, taking notes by longhand seem to support deep processing because note-takers can quickly make meaningful connections using drawings, marks and concept maps.

Attention

Another factor that predicts effective note-taking is attention (Peverly et al. 2007; Peverly, & Sumowski, 2012). Note-taking is a cognitively demanding task that requires simultaneous engagements of "listening to the lecture, determining gradations of importance in information, recording information while continuing to monitor the lecture, and inhibiting distractions (Peverly, Garner, & Vekaria, 2013, p7)." These tasks depend on the functioning of executive control of attention, which monitors the allocation of cognitive resources (Engle, 2002). Attention helps to focus on active tasks and also inhibit distractors in working memory (Peverly, & Sumowski, 2012). It is usually measured by the *Stroop Test* (Stroop, 1935), in which participants are instructed to respond to the colour of a word (e.g. red), rather than the word itself (e.g. Green). Researchers who studied the relationship between attention, note-taking and test performance found that sustained attention predicts a higher level of note-quality, which in turn predicts better test performance (Peverly et al. 2013).

It is important to discuss attention as a predictor for effective note-taking because it might be the factor that distinguishes the impact of digital pens on learning from regular pens. Digital pens are used to write on tablet screens, which are made by glasses with lower friction than paper. Gerth et al. (2016) compared the writing speed between writing on tablets and writing on paper, and they found that writing on tablets was actually faster than on paper due to the smooth surface of the tablets (2016). However, they also noticed that the downside of writing on low-friction screen was that it required a higher level of motor control of movement.

Summary and Hypothesis

The technological advancement grants pixel-level precision in digital pens, which makes the writing experience comparable to using regular pens. Moreover, using digital pens employs the same writing gesture as regular pens, which is unlikely for users to produce massive overlapping verbatim notes as the laptop notetakers. Therefore, it might seem reasonable to assume that note-taking with digital styluses would produce high-quality notes and facilitates deeper processing.

However, research also suggests that writing with digital pens requires extra motor control than regular pens (Gerth et al., 2016). In this case, the executive control may have to allocate more cognitive resources to the writing task itself, resulting in less attention given to a deeper level of information processing. Thus, based on the literature review, I predict that n**ote-taking with digital pens will be less effective than regular pens on learning.**

Method

The research will take place in a controlled experimental setting. As previously mentioned, the experimental framework will be adapted from Mueller and Oppenheimer's research (2014). There will be a pilot study conducted prior to the actual commencement.

Participants

The study plans to recruit 60-65 student participants from the University of Toronto, age ranged from 18-30. They will be recruited through social media posts, poster board and pre-class assignment. Students from all disciplines are encouraged to participate with the exception of upper year Psychology students who may be already familiar with the research topic and procedure.

The main recruitment criteria for this study will be students' experience of note-taking with either digital styluses or regular pen. For digital pen note-takers, they will be expected to have at least 6 months experience using Apple Pencil on iPad, or Microsoft Surface Pen on the Surface Book on a daily basis. For regular note-takers, regular pen and paper would be their habitual method of note-taking in lectures.

Ethical consideration

Since the proposed study involves human participants, the research ethic will be submitted, reviewed and approved by a University of Toronto Research Ethics Board (REB). The research risk involved in the study procedure might be the test component that measures participant memory performance; participants may feel a bit stressed to be tested. However, participants will be provided with full consent before the actual study. They will have the freedom to withdraw at any point during the study and they will be debriefed after the research.

Test Environment

The research will be held in a Psychology Lab located on the underground floor of Sidney Smith building. The lab is designed to have multiple independent rooms where participants can work individually in the space.

The room will be set up in a way that resembles the lecture room experience, with a few rows of long tables, chairs, projector screens etc. According to the test condition, the room will be presented with digital pens and touchpads, or ink-based ballpoint pens with sheets of paper.

Materials

Screener

A screener will be used in the recruitment stage to help select the participants who are suitable for the study. It will ask their field of study, the skill level of using digital pens, past experience in participating related studies. Questions that assessing their prior knowledge on primate social behaviour (i.e. the lecture topic used in the experiment) will also be asked to make sure the lecture material is new to them.

Digital and regular pens

The study will provide two models of digital styluses, Apple Pencil and Microsoft Surface Pen. They have the optimal performance on iPad and Surface Notebook respectively. The software that will be used to record notes is Microsoft OneNote, and it will be installed on both touchpads. The regular pen will be a standard black roller ball pen, accompanied by blank sheets of paper.

Lecture Materials

The lecture material will be selected from TED Talks on the topic of "The surprising science of alpha males (TED, 2017)." The talk uncovers the capacities of alpha males – "generosity, empathy, even peacekeeping", which is considered as interesting but not common knowledge.

Distractor task.

A 10-minutes Automated Ospan (Unworth, Heitz, Schrock, & Engle, 2005) will be used as the distractor task prior to the memory test. The function of this task is to prevent participants from rehearsing and studying the lecture material.

Memory Test Materials

The test will consist of a few short answer questions that assess participants' memory about factual and conceptual knowledge. A factual memory question example would be "where did the alpha male group live", a conceptual memory question would be "what is the parallel between humans and primates when choosing their leaders"

Post-study questionnaire

The questionnaire will have a similar structure as Luo et al.'s research (2018). It will collect the information about "demographics, lecture topic knowledge, typical note-taking completeness, note-taking medium preference, and attitudes about their experimental note-taking medium (p.953)."

Procedure

Once participants arrived in the lab, the researcher will provide consent form and explain the experiment procedure. All participants will be informed that there are three main components of the experiment: the lecture phase, the test phase and the final questionnaire. To reduce some potential anxieties associated with the test, the researchers will disguise the comparison component of the study and tell the participant that they are only interested in how note-taking influences learning. However, after the study, participants will be fully debriefed.

Lecture Phase (20minutes).

Upon finishing the introduction and informed consent, participants will be taken to the test room with all note-taking materials prepared (one at a time). The TED talk will be projected on a large screen at the front of the room, ready to be played. Participants will be instructed to take notes the same way as they do during regular lectures, either with digital pens or regular pens. If there are no further questions from the participants, the researcher will play the lecture and leave the room.

Test Phase (30 minutes).

When the lecture phase ended, the researcher will come into the room with the distractor task set up on the laptop. The researcher will explain how to complete the task, then take away participants notes and leave the room. Ten minutes later, the researcher will return with the actual memory test and instruct the participants to complete the test in 20 minutes.

Final questionnaire (5minutes)

Upon completing the memory test, researchers will come back to the room and collect the test responses. They will also instruct the participants to fill-in the post-study questionnaire. 5 minutes later, the researcher will come back and collect the questionnaire.

After these three phases, participants will be debriefed, thanked and dismissed.

Data Analysis.

The data that will be collected in this experiment will be participants' notes, memory test responses and questionnaire response. The main analysis will be comparing the memory test score between two groups: the digital pen note-takers and regular pen note-takers. There will be independent raters, blind to the purpose of this research, rate the memory test performance. A one-way ANOVA will be used to analyze the test scores between two note-taking strategies.

Statement of bias

Although the experimental procedure is carefully designed and controlled, there are still inevitable biases throughout the research. For example, there might be selection bias (Šimundić, 2013) during the recruitment phase because only users of Apple Pencil and Surface Pen will be selected. Although these two models have the optimal performance on the corresponding devices, the sample population may not be representative of the larger user group who may use other models of digital styluses. Related to the selection bias, there might also be volunteer bias in the recruitment stage (Šimundić, 2013). Only the students who are interested in this topic and willing to participate are selected for the research. These individuals might be more confident with their note-taking skills than others, resulting in a less representative research sample.

During the data collection phase. There might also be bias in the choice of the lecture material because it is selected by the researcher with her judgement of “interesting” and “not common knowledge”. Response bias (Šimundić, 2013) may also occur during the note-taking phase because participants want to take notes that they think the experimenter wants to see.

Finally, there is a limitation in the external validity of the research. Since the study aims to test the impact of different note-taking mediums on memory performance, it needs to control for note-review and memory rehearsal. Therefore, in the design of the experiment, participants will be given a memory test immediately after the lecture. However, this is not a natural way of testing in school. The results can only be used to understand how different note-taking mediums support working memory, rather than long-term information retrieval.

(Word count: 2991)

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