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Evaluating the Psychophysiological and Learning Effects of Reading-While-Listening for 6th Graders Learning Science Online

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Abstract

Reading-while-listening (RWL) is a form of audio-assisted reading. It is a method that combines simultaneously reading and listening to the same text to enhance reading comprehension, vocabulary. Though the positive effects of RWL have been documented, the literature does not give a detailed picture of the psychophysiological mechanisms behind it. This thesis by articles studies the effects of reading-while-listening on the reading comprehension and engagement of pre-teens online (6^{th} graders) by using psychophysiological measures.

Following a literature review, we hypothesized that RWL would be beneficial to learning outcomes and students' visual and emotional engagement compared to reading-only (RO). Additionally, we hypothesized that RWL would lead to a higher cognitive load. To test our hypotheses, a mixed-methods approach was utilized. We incorporated quantitative measures such as reading assessments, eye movement data and data related to emotional valence, and qualitative data gathered through interviews and observations.

A within-subjects experiment was conducted in a lab with 19 participants who were in 6^{th} grade, aged 10-12 years old, who had to read different science texts with and without audio support. Thus, all participants were exposed to the two reading conditions. The experiment ended with a third task in which participants were allowed to choose how to read the last text to observe their behaviour.

The findings suggest that reading-while-listening does not impact pre-teens' comprehension abilities. In fact, the interviews revealed that the participants did not necessarily find it easier to answer reading questions after RWL compared to RO. However, RWL was conclusive in increasing the engagement levels among participants. More specifically, it led to higher emotional valence and ambient-focal visual attention. The interviews confirmed that the auditory input appeared to increase interest and motivation, as the multi-sensory experience created a more enjoyable reading environment compared to traditional reading.

It is important to note that individual differences may influence the effectiveness of reading-while-listening in several ways. For instance, some participants with learning disabilities did not benefit from the audio support because they already had developed their own reading techniques. Personal reading preferences, and prior reading abilities may impact the extent to which 6th graders find the RWL method beneficial. In conclusion, reading-while-listening can be a valuable tool for young students as it keeps them engaged with the learning materials. Educators and parents can consider it as being a method for struggling readers or those who may benefit or like this multi-modal approach. Further research is needed to explore the long-term effects and to better understand individual differences in response to this method.

Keywords: Online Learning, Science Learning, Reading-while-listening, Audio-assisted Reading, Comprehension, K-12

Research methods: Semi-structured interviews, within-subjects experiment, eye-tracking study

Résumé

La lecture en écoutant est une forme de lecture audio-assistée. C'est une méthode qui combine simultanément la lecture et l'écoute du même texte pour améliorer la compréhension écrite et le vocabulaire. Bien que les effets positifs de la lecture en écoutant aient été documentés, la littérature ne donne pas une image détaillée des mécanismes psychophysiologiques derrière cette technique d'apprentissage. Cette thèse par articles étudie les effets de la lecture en écoutant sur la compréhension de lecture et l'engagement en ligne des pré-adolescents (6e année) en utilisant des mesures psychophysiologiques.

Suite à une revue systématique de la littérature, nous avons émis l'hypothèse que la lecture en écoutant serait bénéfique pour la compréhension de lecture et l'engagement visuel et émotionnel des élèves par rapport à la lecture seule/traditionnelle. De plus, nous avons émis l'hypothèse que la lecture en écoutant entraînerait une charge cognitive plus élevée. Pour tester nos hypothèses, une approche mixte a été utilisée. Nous avons incorporé des mesures quantitatives telles que des évaluations en lecture, des données sur les mouvements oculaires et des données liées à la valence émotionnelle, ainsi que des données qualitatives recueillies au moyen d'entretiens et d'observations.

Une expérience intra-sujets a été menée dans un laboratoire avec 19 participants âgés de 10 à 12 ans, en 6e année, qui devaient lire différents textes de science avec et sans support audio. Ainsi, tous les participants ont été exposés aux deux conditions de lecture. L'expérience s'est terminée par une troisième tâche dans laquelle les participants devaient choisir entre la lecture seule ou accompagnée de l'audio.

Les résultats suggèrent que la lecture en écoutant n'a pas d'impact sur les capacités de compréhension de lecture des préadolescents. En fait, les entretiens ont révélé que les participants n'ont pas nécessairement trouvé plus facile de répondre aux questions de lecture après avoir écouté le texte comparé à la lecture seule. Cependant, la lecture en écoutant a augmenté les niveaux d'engagement parmi les participants. Cela a conduit à une valence émotionnelle plus élevée et à une attention visuelle focale ambiante. Les

entretiens ont confirmé que l'apport auditif semblait accroître l'intérêt et la motivation des participants que la lecture traditionnelle.

Il est important de noter que les différences individuelles peuvent influencer l'efficacité de la lecture en écoutant de plusieurs manières. Par exemple, certains participants ayant des troubles d'apprentissage n'ont pas bénéficié du support audio car ils avaient déjà développé leurs propres techniques de lecture. Les préférences personnelles en matière de lecture et les capacités de lecture antérieures peuvent aussi avoir un impact sur l'efficacité de la lecture en écoutant. En conclusion, la lecture en écoutant peut être un outil précieux pour les jeunes étudiants car elle les maintient engagés dans le matériel d'apprentissage. Les éducateurs et les parents peuvent la considérer comme une méthode destinée aux lecteurs en difficulté ou à ceux qui pourraient bénéficier ou apprécier cette approche multimodale. Des études supplémentaires sont nécessaires pour explorer les effets à long terme et pour mieux comprendre les différences individuelles en réponse à cette méthode.

Mots-clés : apprentissage en ligne, apprentissage des sciences, lecture en écoutant, lecture audio-assistée, compréhension de lecture, primaire, secondaire

Méthodes de recherche : Entretiens semi-structurés, expérimentation intra-sujets, suivi oculaire

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List of abbreviations

List of abbreviations used throughout this thesis.

Abbreviation	Definition
RWL	Reading-while-listening
RO	Reading-only
LO	Listening-only
UX	User experience
K-12	Kindergarten to 12th grade

Preface

This thesis was written in fulfilment of the requirements for the Master of Science in Management (M.Sc.) in User Experience in a Business Context. It is fully written in English and its structure is composed of two articles.

The first article is a literature review. It outlines the research objectives, the current state of the literature of the topic and the research opportunities for future studies.

The second article is a scientific article reporting the results of the experiment conducted over the spring of 2022 and is in preparation for submission to the International Journal of Child-Computer Interaction (JCCI). A digital poster of the study, which included preliminary results, was also published in the online conference ACFAS[1] (ACFAS, 2023). This project was funded by NSERC, Prompt and Alloprof.

[1] Sindayigaya, Q., Léger, P.M., Sénécal, S., & Patrick Charland. (2023). Comprendre l'impact neurophysiologique de la lecture en écoutant : la compréhension de textes de science en 6e année. ACFAS. https://www.acfas.ca/evenements/congres/90/contribution/comprendre-impact-neurophysiologique-lecture-ecoutant

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Introduction

1.1 Context

In recent years, technology has rapidly progressed and has revolutionized the field of education, particularly with the rise of online learning platforms. In 2022, over 520,000 educational apps were available to download (Educational App Store, 2022). Additionally, the COVID-19 pandemic led to the closure of schools and further led to an inevitable increase of online platforms as an alternative for traditional classroom teaching (Aurini & Davies, 2021). In Canada, during 2020, the weekly instructional hours between teachers and their students ranged from one to twelve hours for kindergarten to Grade 9. For Grade 10 to 12, the weekly instructional hours dropped from two to three hours (Campbell, 2020; Gorbet et al., 2020). Many K-12 (kindergarten to 12th grade) teachers have said to have lost contact with their students during the pandemic. A survey conducted by the Canadian Teachers Federation (2020) with 18,000 teachers found that only 64% of teachers said they were in ‘’regular contact’’ with half of their students. To keep students engaged despite school closures and as an emergency response to the pandemic, K-12 teachers turned to technology to assist students in their learning. Though schools have now reopened since then, the digital landscape continues to evolve. Researchers, educators, designers, and other online learning specialists are continuously exploring innovative techniques to increase learning outcomes and accommodate to the diversity of students’ needs. One such method that is believed to enhance reading comprehension in the context of online learning is the integration of reading-while-listening (RWL).

Reading-while-listening refers to the practice of simultaneously reading a text while listening to an audio track or spoken narration. Text readers, for instance, are a form of reading-while-listening. Theoretically, according to the theory of multimedia learning, this approach enhances comprehension by presenting both visual and auditory formats rather than one modality alone, which provides learners with different ways of understanding the same information (Mayer, 1997). In other words, the audio is believed to be providing additional support to readers. RWL has been shown to enhance comprehension of children with learning disabilities and struggling readers (Schiavo et

al., 2021). By reading the text for the student with the right pronunciation and at a slow pace, the information is easier to decode. Thus, reading-while-listening can help with text decoding, vocabulary acquisition, and overall text comprehension (Chang, 2009; Chang & Millet, 2014, 2015; Brown et al., 2008; Webb & Chang, 2012, 2014). This is important when reading texts that contain words that are not used daily such as science-related words. In the past years, studies have found that the audio component in reading-while-listening provides additional support for young students learning science and math (Johnson & Mayer, 2012; Mason et al., 2013, 2015). Adding audio can aid comprehension and can allow readers to understand more complex texts and new school subjects. Moreover, past studies have argued that reading-while-listening exposes young readers to proper intonation, expression, and punctuation which helps their comprehension (Clinton, 2022). By hearing the right narration, children can develop a better sense of how written language is transformed into meaningful oral expression.

Online education offers unique opportunities and challenges compared to traditional face-to-face instruction. Students in online settings often experience limited non-verbal cues, reduced social interaction, and less assistance. Therefore, investigating the efficacy of reading-while-listening approaches becomes crucial in designing effective online instructional strategies that promote deep understanding and engagement.

While reading and listening individually have long been studied in educational research, the combined effect of engaging in both activities simultaneously still has unanswered questions. Firstly, there is no study to date has investigated the effects of RWL by using a combination of both quantitative and qualitative data to measure factors such as emotional valence and cognitive load. Both objective and subjective measures have to be taken into consideration to better understand how K-12 students feel about RWL compared to RO. This is potentially limiting our understanding of its true impact on learners. Several studies have looked at the impact of RWL on cognitive load. However, the user experience is a combination of both objective and subjective realities. Thus, it is important to study both experienced and inferred measures.

Secondly, the incorporation of ambient-focal visual attention measures has yet to be explored, leaving untapped potential in understanding the cognitive mechanisms at play during RWL. Ambient-focal visual attention has previously been linked to one's emotions in a study by Biele et al. (2013). They explored how the interaction with computer devices could be enhanced by considering both the user's emotional state and their eye movement patterns. Researchers hypothesized that a positive mood would lead to exploratory eye movements during interaction with a digital interface. To test this hypothesis, they recorded both the users' eye movements and brain activity throughout the experiment. Results confirmed that a positive mood changed the dynamics of visual attention, causing a shift from ambient to a more focal attention mode, meaning that users were more visually focused when they were in a good mood (Biele et al., 2013).

Lastly, the scarcity of research on RWL within the realm of K-12 science texts shows the need for further investigation into its efficacy as an educational tool within this specific context. Studies that have incorporated RWL as a learning technique mostly focused on language learning as they were focused on vocabulary gains for second language (L2) learners. For instance, Pellicer-Sànchez et al. (2020) conducted a study on how multimedia input (written text and images) was processed by second-language learners with and without audio (i.e., with and without RWL). A total of 30 participants had their eye movements recorded during the processing of a multimedia story text in the RO and RWL conditions (Pellicer-Sànchez, 2020). Their reading comprehension was then evaluated using a multiple-choice comprehension test. For first language (L1) learners, studies that have used eye-tracking to analyze how learners' process both text and pictures in the context of science and maths learning do exist (e.g., Johnson & Mayer, 2012; Mason et al., 2013, 2015) but they have not been done with and without RWL.

Several researchers have presented arguments as to why learning science at an early age is important. According to Fortus et al. (2022), there are five reasons why learning science at an early age is important: (1) To encourage future generations to major in science fields by enhancing their interest and curiosity towards STEM subjects and therefore, contribute to the innovation and economy of society; (2) To foster the development of skills and knowledge that can be important to one's life, regardless of

their career path, such as maintaining a healthy life; (3) To promote self-efficacy, critical thinking and other cognitive abilities necessary for learning; (4) To promote the ways in which science has improved and is improving our lives; and (5) To foster appreciation of science by emphasizing its cultural aspect such as highlighting science-related achievements and success stories of minorities in science (Fortus et al., 2022). In summary, science is not only needed for those who aspire to follow STEM careers as everyone can benefit from it. However, science learning is often considered difficult for young children because science often involves the use of abstract concepts that may not be always intuitive to grasp. For instance, concepts like gravity or photosynthesis can be difficult to grasp for children who are still developing their cognitive and language abilities. Plus, scientific vocabulary can be complex and unfamiliar, making it difficult for young learners to comprehend and retain new words. They are often context-bound, which means that they are rarely used in a non-science context as well. Moreover, science learning often involves understanding complex processes that may not have straightforward, tangible examples, making it harder for children to create mental representations of the learned vocabulary.

Addressing these gaps not only promises to shed new light on the multifaceted aspects of RWL but also holds the potential to unlock novel insights that could shape the future of educational practices and learning methodologies. In this study, we seek to bridge these gaps in the literature, offering a comprehensive and in-depth analysis of RWL's impact using a mixed-methods approach, while focusing on its potential applications within K-12 science education.

1.2 Research objectives

The primary objective of this thesis is to better understand the effects of reading-while-listening. The goal of this experimental part is to bring answers to the research gaps that have been found in the literature review.

The main research question of this thesis is: To what extent does RWL compare to RO in the context of learning sciences online when evaluating visual attention, cognitive load, emotional valence and reading comprehension? To answer this question, a

comprehensive review of the literature was done. The objective of this review was to collect, synthesize and analyze existing articles related to RWL and its effects on processes that affect the reading experience. We classified our findings into four distinct categories: (1) the benefits of RWL, (2) the challenges of RWL, (3) the impact of RWL on science achievement, (4) the psychophysiological processes involved in RWL which was separated into three different sub-sections: emotions, visual attention and cognitive load. Finally, we concluded this review with a discussion of the main relevant points, the limitations and avenues for future research.

For the experimental study, the objectives were to evaluate to what extent RWL differs from RO when comparing students' opinions on RWL and RO, visual patterns, cognitive demands and emotions. The following research questions were developed:

In the context of online science learning,

1) What are the differences in visual patterns (i.e., ambient-focal attention) during the RWL mode compared to the typical RO mode?

2) To what extent does RWL impact experienced and inferred cognitive load?

3) To what extent does RWL increase reading comprehension?

4) What are students' attitudes and opinions towards reading-while-listening when taking into account their emotions and verbal feedback?

Following the development of these four research questions, seven different hypotheses were formulated.

H1: We hypothesized that RWL would increase students' reading comprehension scores.

H2: We hypothesized that their cognitive load would increase in the RWL condition compared to the RO condition

H3: We hypothesized that high perceived and experienced cognitive load levels would reduce reading comprehension scores.

H4: We hypothesized that learners would find the RWL condition to be more pleasurable (i.e., generate more positive emotions) than the RO condition.

H5: We hypothesized that positive emotions would increase reading comprehension scores.

H6: We hypothesized that RWL would lead users to generate more visual exploration behaviours compared to the RO condition.

H7: We hypothesized that increasing visual attention would lead to higher comprehension scores. In other words, both variables would be positively correlated.

To answer our research questions and test our hypotheses, both quantitative and qualitative data were used to gather data on the learners' experience. The methods used to collect data included the use of self-reported questionnaires and eye-tracking. We concluded this article with a discussion of the main results, possible alternate explanations, the study strengths and limitations, its theoretical and practical contributions, and avenues for future research.

1.3 Theoretical and practical contributions

From a theoretical standpoint, this research aims at studying the impact of reading-while-listening on the reading comprehension and engagement of 6th grader by using eye-tracking methods, self-reported questionnaires, and semi-structured interviews. The results of this research can provide insights into the cognitive processes involved in the process of multimodal information when the information is new to the learner and seen as more difficult to understand as it is the case for science. More specifically, in the case of reading and listening simultaneously, we were interested in its effects on perceived and experienced cognitive load, emotional valence and visual attention. Secondly, this thesis can also shed light on how pre-teens feel when reading and listening at the same time. By analyzing the learners' visual attention and emotions, we can see how engaged students are when their brain integrates the same visual and auditory information. Lastly, this thesis contributes to the literature by informing us on how young learners with and without learning disabilities process new information simultaneously in the context of online

learning and whether it affects their learning performance. This understanding can contribute to theories of comprehension and inform educational practices. Moreover, our approach combined different research methods to include both the objective and subjective experience of young learners. Practically, the findings can inform the design and implementation of reading-while-listening on educational websites, softwares and applications that target young readers. By understanding the benefits or challenges of reading-while-listening, educators and other learning specialists can create effective instructional materials to enhance comprehension skills in early childhood, when comprehension skills continue to develop.

1.4 Structure of the thesis

This thesis is structured with two distinct articles. Each article addresses a specific aspect of the research topic. The first article is a comprehensive literature review which synthesizes and analyzes existing theories and studies related to reading-while-listening. It serves as a way to examine the current state of the literature, identify gaps and highlight the need for further studies. The second article is an experimental study conducted with 19 pre-teens to address the current research gaps found in the literature. This second article focuses on collecting primary data to compare reading-while-listening and traditional reading in the context of online learning. Lastly, the thesis will conclude by summarizing the findings, practical and theoretical contributions, and limitations of both articles. Potential avenues for future research in the field will also be discussed.

1.5 Article 1: Reading-while-Listening: A Review of its Effects on Primary School Students

1.5.1 Article information

The first article is a literature review which presents the results of the ongoing research on reading-while-listening, its benefits and its challenges. The main goal of this article is to identify research gaps within the literature and present the current state of the literature on the subject. In addition to this, the review presents the effectiveness of reading-while-listening, its effects on different cognitive processes

and the theoretical frameworks that are used to explain the mechanisms behind its effectiveness in the field of K-12 education and online learning. A summary of the review is provided below.

1.5.2 Article summary

The aim of this literature review article is to present the current state of the research in reading-while-listening as it is a popular and increasingly researched approach to language learning and comprehension. It focuses on its benefits, challenges, and identifies the current research gaps within the existing literature.

Simultaneously reading and listening in the context of online learning has several well-documented benefits. Firstly, recent studies have shown that RWL improves comprehension compared to passive reading or listening alone, especially for learners with disabilities that impair reading comprehension. The combination of visual and auditory input allows learners to better process and retain information. Secondly, RWL facilitates the development of pronunciation and listening abilities. The audio input reinforces correct pronunciation, aiding learners in better grasping phonetic nuances. RWL creates an immersive environment, mimicking real-life language usage scenarios. This enhances learners' exposure to natural language patterns and improves their ability to comprehend native-like speech. Additionally, the joint engagement with written and spoken language exposes learners to new words and expressions, fostering vocabulary expansion and contextual understanding. Lastly, RWL engages multiple modalities, thereby enhancing learning outcomes for a diverse range of learners.

However, RWL faces some challenges. Simultaneously processing written and auditory information can overwhelm learners, leading to a higher cognitive load and mental exhaustion. Moreover, individual learners may have different language proficiency levels, making it challenging to create RWL materials that suit everyone's needs adequately.

Research gaps also remain on the topic of RWL. Firstly, very little is known on its long-term impact as many studies focus on the short-term gains of RWL. There is a lack of longitudinal research to investigate its sustained impact on language proficiency and

retention. Plus, most on the studies that support the use of RWL as a reading strategy to improve learning outcomes compared to traditional reading were made by using storybooks rather than exploring its effects with other school subjects such as science.

The ongoing research on reading-while-listening (RWL) suggests that this learning method is useful as it offers benefits such as an enhanced comprehension, improved pronunciation, and increased vocabulary acquisition. However, challenges include an increase in cognitive load and individual differences in learning preferences. Furthermore, there are several research gaps such as the long-term impacts of RWL and comparisons with other learning strategies. As technology evolves, it is important to continue exploring the potential of RWL to optimize language learning outcomes.

1.6 Article 2 : The Psychophysiological Impact of Reading-While-Listening: Evaluating 6th graders' Comprehension in Science

1.6.1 Article information

The second article of this thesis is an empirical study. A poster of the study was submitted and accepted at *L'Association canadienne-française pour l'avancement des sciences* in May 2023 (ACFAS, 2023)[2]. It is currently in preparation for submission to the International Journal of Child-Computer Interaction (JCCI).

Following the literature review, a within-subjects experimental design was used to address the gaps found. The data collection was completed, in May 2022, by the student of this thesis with the collaboration of the business partner involved in this project. The article contains the results of the experiment and a thorough discussion of what was found. Finally, the article concludes with a conclusion which highlights the limitations of the study, its strengths, its contribution to the literature and avenues for future research in the field. A summary of the second article is provided below.

[2] Sindayigaya, Q., Léger, P.M., Sénécal, S., & Patrick Charland. (2023). Comprendre l'impact neurophysiologique de la lecture en écoutant : la compréhension de textes de science en 6e année. ACFAS. https://www.acfas.ca/evenements/congres/90/contribution/comprendre-impact-neurophysiologique-lecture-ecoutant

1.6.2 Article summary

The aim of this second article was to empirically evaluate the differences between reading-while-listening (RWL) and reading-only (RO) in the context of online learning of science and technology. More specifically, to what extent does RWL compare to RO when looking at factors such as emotional valence, visual attention, reading comprehension and cognitive load.

Nineteen participants were recruited through an online newsletter sent to their parents. All participants were French-speaking 6th graders. They were evaluated through eye-tracking technology and self-reported questionnaires. After completing a baseline task and three reading tasks, they were interviewed individually on their experience. Each reading task was different (i.e., required students to read while listening or not) to compare their scores across conditions. After analyzing the different scores, results indicated that, compared to RO, instructing students to simultaneously read and listen to science texts led to a decrease in visual attention, an increase in emotional valence and an increase in experienced cognitive load. There was no statistical difference in reading comprehension scores. Moreover, it was found that cognitive load, visual attention and emotional valence did not have a significant impact on reading comprehension alone. Interviews revealed that though students found RWL fun and different, they would not use it regularly as they do not have reading difficulties or already have their own way of overcoming their struggles such as using reading techniques taught in class. In conclusion, these results implied that though RWL had benefits such as increasing pleasure while learning, it remained largely unused by students. Lastly, despite the higher mental effort required to process verbal and visual information, RWL did not negatively impact reading comprehension.

Some study limitations must be considered to make sense of the results. Firstly, we couldn't assess reading comprehension with longer, more-detailed questions that would require students to answer with their own words. Instead, multiple-choice questions were used which limited the variability in scores as they were only four multiple-choice questions per task. Secondly, most participants were already excellent readers as we

observed no difference between the reading comprehension scores of the baseline task and other the other tasks.

Nonetheless, this study contributed to better understanding the effects of reading-while-listening in the context of online science learning. The study contributed to the understanding of how students process information when reading text and listening to auditory content simultaneously. By investigating the effectiveness of reading-while-listening in online science learning, the study supported existing principles of multimedia learning theory. Lastly, the study offered insights into individual differences in learning preferences and modalities. Some students appreciated this approach more than their peers for different reasons. Understanding these individual differences can help tailor instructional strategies to meet the diverse needs of 6th-grade learners. Practically, developers and educators can use these insights to create multimedia content that aligns with the cognitive processes and preferences of 6th graders.

1.7 Personal contributions

The experimental study presented in this thesis has been completed at the Tech3lab, a laboratory that focuses on the study of user experience, in Montreal. The following Table 1 presents a breakdown of my contributions to the present research project as the percentage of work completed for each step.

Table 1

Personal contributions

Step	Contribution
Research questions development	Defining the research question and identifying the research gaps - 80% • Due to my previous experience with K-12 education and learning environments, my supervisors suggested the possibility of working on the impacts of reading-while-listening in the context of online learning with a business partner. • My supervisors contributed by helping me refine my research question.
Literature review	Reviewing the literature to identify past studies, constructs, and measures to test the hypotheses - 100% Selecting the appropriate constructs and measures to be used in the experiment - 80% • My supervisors gave feedback on the selected constructs and measures and offered alternatives when needed. • They recommended books and articles to guide my reflection.
Ethics	Completing the CER form, submitting it and doing subsequent modifications - 100%
Experimental stimuli development	Creating the stimuli – 90% • Our partner provided me with the audio tracks , the images and the texts that had to be integrated onto the web pages. • I took care of building the 5 webpages with unique URLs. • I created the online questionnaires.

Experimental design	Creating the experimental protocol and design - 80% • My supervisors provided feedback on the protocol and the experimental design.
Participant recruitment and participant management	Creating the recruitment forms - 90% • I wrote the recruitment forms. The partner corrected and adapted the form so that it could be integrated in the newsletter sent to the parents and on their website. Soliciting and recruiting participants - 40% • The partner was in charge of recruiting participants and managing their schedule because they sent the newsletter to the parents through their system. • I provided the inclusion and exclusion criteria for the recruitment. Schedule management - 20% • A research assistant scheduled the participants at the desired time according to their preference. • I informed the assistant when cancellations occurred. Managing participant compensation - 100%
Pre-tests and data collection	Responsible for the pretests - 80% • My supervisors and two laboratory technician pre-tested the experimental design with children and teens a few day/weeks before data collection. • I pre-tested with adult participants. Responsible for data collection - 60% • During the data collection, I was assisted by a research assistant whose responsibility was to put time markers and save the data while I took care of the stimuli and the script given to the participants.

Data extraction and transformation	Extracting and cleaning the data from questionnaires and video recording data - 50% • A research assistant transferred the video recording data to our laboratory Sharepoint account. • I was responsible of cleaning the questionnaire data and formatting them. • A laboratory technician extracted the facial expression and eye-tracking data. • A research assistant and I created areas of interest on Tobii for the eye-tracking data.
Statistical analysis	Formatting data to be analyzed - 90% • The laboratory statisticians reviewed the format of the data after my first version to make sure it was compatible with their softwares. Conducting the statistical analysis - 80% • The laboratory statisticians helped me with the quantitative analyses. • I analyzed the qualitative data from the interviews.
Thesis redaction	Writing the articles – 100% • My supervisors gave feedback after each iteration.

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Chapter 2

Reading-while-Listening: A Review of its Effects on K-12 Students Reading Online

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Abstract

Reading-while-listening (RWL) is a learning method that couples the use of written text and its audio version to enhance comprehension. This approach is mostly used on websites, digital applications, and e-books. RWL responds to the needs of individuals with reading difficulties as it offers to different ways to process information and capitalizes on the benefits of both reading and listening modalities. With the advancement of educational technology, there has been a focus on how to provide students with techniques that could improve their overall learning outcomes without the physical assistance of an adult. This review explores the theoretical foundations, potential benefits and challenges, and practical applications of reading-while-listening across various educational contexts for children and pre-teens (K-12 level). The current literature suggests that the integration of reading-while-listening can promote deeper understanding, improve memory retention, and enhance overall learning outcomes. However, this review revealed that several gaps still exist. Firstly, longitudinal research is needed to better understand to what extent RWL impacts psychophysiological processes compared to reading-only (RO) as children develop better cognitive processes and reading strategies throughout their grade years. Secondly, there is little evidence that RWL is effective in the context of school subjects that are not related to language learning and story reading. Lastly, the evidence is still mixed when looking at eye patterns produced during RWL compared to RO.

2.1 Introduction

It is not uncommon for people of all age groups, including children, to use the Internet for educational purposes. In Canada, 98% of families with children under the age of 18 used the Internet in 2020 (Statistics Canada, 2021). As the Internet becomes more sophisticated, so do educational websites, which are now using a wide array of stimuli to capture their learners' attention. These websites are often referred to as being ''multimedia''. In the literature, multimedia refers to presenting both pictures and words (Mayer, 2014). More specifically, words can be printed words or spoken texts (i.e., audio tracks). Pictures, on the other hand, can either be static or with motion. Examples of static graphics include photos and illustrations while graphics with motion include animations and videos. In the context of online learning, multimedia learning is defined as "building mental representations from words and pictures" (Mayer, 2014). It can happen in different contexts such as e-learning, gaming, simulations, and virtual reality environments, that let learners process information in both verbal and visual form (Alemdag & Cagiltay, 2018). This article will focus on e-learning.

Reading online differs from traditional reading (i.e., reading paper books). Firstly, compared to traditional reading, online reading offers more flexibility as the information can be conveyed in different forms. For instance, verbal information can be presented with videos with subtitles which is a multimedia material (Pellicer-Sánchez et al., 2020). Though books can have pictures and text on the same page, the possibilities in terms of design are limited. With websites, the experience can be more interactive and personalized because there are several ways to share the same information (i.e., videos, slideshows, interactive graphs, or maps, etc.). Naturally, this flexibility impacts the reading process in different ways. For instance, reading strategies such as concept identification, information-seeking, and critical evaluation are impacted by multimedia materials and how the information is presented (Afflerbach & Cho, 2009; Coiro & Dobler, 2007; Coiro, Sekeres, Castek, & Guzniczak, 2014; SchmarDobler, 2003; Zang & Duke, 2008; Yamaç & Öztürk, 2019).

Reading comprehension can be impacted by multimedia materials. One of those materials is reading-while-listening (RWL). Reading-while-listening is a multimedia technique which involves having learners read silently while simultaneously listening to

the same text (Schmitt et al., 2010). Research has shown that reading-while-listening is beneficial for comprehension and fluency (Chang 2009; Chang & Millet, 2013, 2015), vocabulary learning (Brown et al, 2008; Webb & Chang, 2014) and offers a positive experience to learners (Brown et al., 2008; Chang, 2009; Tragant et al., 2016; Tragant & Vallbona, 2018).

When looking at cognitive processes, reading-while-listening (RWL) helps students with phonemic awareness, word recognition, spelling, and decoding abilities, which are often lacking in students with poor reading comprehension skills (Schiavo et al., 2021; Schmitt et al., 2010; Schmitt, 2011). However, not all learners with decoding issues struggle with comprehension. Untreated decoding deficits can affect reading comprehension and academic success (Flynn, Zheng, & Swanson, 2012). Other factors like inattention or hyperactivity problems can also impact reading comprehension (Miller et al., 2013). RWL has been found to significantly improve comprehension scores, especially for children and adolescents with learning disabilities (Keelor et al., 2020; Silvestri et al., 2021). It facilitates word identification for struggling readers (Silvestri et al., 2021; Staels & Van den Broeck, 2015) and improves literal and inferential text comprehension (Grimshaw et al. 2007). The bimodal condition of RWL helps students' comprehension by providing textual and contextual clues to the storyline.

Lastly, RWL also impacts visual patterns, which in turn can impact the reading experience. In a recent study by Pellicer-Sànchez et al. (2018), 5th and 6th graders and adult participants were presented with an illustrated text in two different conditions: RO and RWL. In the RWL condition, both children and adults exhibited fewer and shorter fixations and spent more time looking at the images compared to the RO condition. Comprehension scores were unaffected by the condition. Similar visual patterns were found by Serrano and Pellicer-Sánchez (2019) with 5th and 6th graders. Participants read an illustrated texts in their second language of instruction and spent more time looking at the images. The authors explained these results by claiming that RWL is more advantageous than RO because the visual input is supported by the spoken words as they provide auditory support and context. RWL also aids in matching spoken words with their written form.

A few reviews of the literature have been done on the effects of reading-while-listening. In a recent synthesis of the literature surrounding the effects of RWL on visual behavior and verbal learning, researchers noted that RWL was studied as early as the late 70's with audiobooks (Gerbier et al., 2018). It was said to be a promising technology for struggling readers as it was found to improve not only reading comprehension, but also word recognition, word meaning acquisition, reading fluency (van der Leij, 1981 as cited in Gerbier et al., 2018) and reading (Carbo, 1978; Chomsky, 1976; Gamby, 1983 as cited in Gerbier et al., 2018).

Since then, several experimental studies compared RWL with reading only (RO) or listening only (LO). For instance, Steele et al. (1996) found that reading comprehension and recall were increased by the RWL method, but not word recognition, in 9-12 years old students with reading difficulties. The RWL method was also preferred compared to RO and LO. Another study by Reitsma (1988) found that reading fluency was only increased when 7 years old children could use audio assistance when they needed it rather than when forced to use RWL for the entire text, suggesting that children's preferences and individual differences must be taken into consideration when developing such techniques. In contrast, Shany and Biemiller (1995) found that RWL was as good as requesting assistance to increase fluency and comprehension scores in 3rd and 4th grade students. Finally, in a study by Montali and Lewandowski (1996), RWL was found to be better for reading comprehension than both RO and LO for struggling readers in Grade 6 to 9. However, there was no statistical difference for good readers. Both good and struggling readers preferred RWL over the RO and LO conditions, showing that though RWL does not always lead to an increase in comprehension, it is still appreciated by K-12 students.

Following these past results, Gerbier et al. (2018) conducted an exploratory study with 40 French children in Grade 3 to 5. They were instructed to read short stories in their native language while simultaneously listening to the narrated version of the same text. In the RO condition, the text color used was black and it was shown on a white background just like most texts in books or online. In contrast, in RWL condition, the text was grey, but turned black as the narrator spoke. Children were thus able to follow the text and its

audio simultaneously. Subsequently, participants completed unexpected memory tests to assess word recall. The results of the study by Gerbier et al. indicated that the synchronization of text and audio had no significant effect on recall of how the words were written but had a negative impact on the recall of their meaning. Nonetheless, children with reading difficulties preferred the RWL condition. Additionally, the study recorded the children's eye movements during reading in both conditions. RWL was characterized by fewer but longer fixations on words and fewer regressive compared to the RO condition. This suggests that students paid more attention during the RWL condition as they had to follow the pace of the narrator.

A meta-analysis was conducted by Clinton-Lisell (2021) on RO and LO and its effects on comprehension across various age groups. Based on their analysis of 46 studies, the overall difference between reading and listening comprehension was not different ($g = 0.07$, $p = .23$). In a self-paced context, reading was found to be more beneficial than listening ($g = 0.13$, $p = .049$) rather than experimenter-paced ($g = -0.32$, $p = .16$). These findings give valuable insights in understanding how different modalities influence comprehension.

Lastly, in the most recent review of the literature by Singh and Alexander (2022), researchers investigated how audiobook listening and print reading influenced comprehension performance, the importance of individual differences, features of the text, and contextual factors of the reported results. The review regrouped 32 articles on elementary, secondary, and college students who engaged with RWL either through audiobooks or traditional print on paper or screens. The majority of the studies on RWL took place in classrooms with audiobooks. It was found that presenting audio only (i.e., listening only), on average, increased comprehension more effectively than printed text with young students. The effect size ranged from $g = .28$ to $g = .58$. However, for struggling readers and English learners, the combination of audio and text was found to be more beneficial for comprehension than text alone. For those specific groups, the effect size ranged from $g = .32$ to $g = 1.67$. However, few studies compared LO to RO directly, targeted older students without learning difficulties (grade 6-12) or used expository texts.

Though RWL has also been perceived positively in various studies (e.g. Brown et al., 2008; Chang, 2009; Lightbown, 1992; Tragant et al., 2016; Tragant & Vallbona, 2018), several research gaps remain. Firstly, none of these studies have looked at the difference between older students with and without learning difficulties in the context of science learning specifically. It is important to consider science learning because it provides students with a basic understanding of the natural phenomenon in our world and encourages the development of critical thinking and problem-solving skills. These skills are important later in life to be able to understand and engage in discussions and make informed decisions. Early science learning also helps students answer fundamental questions about the universe, life, and the environment. Lastly, it is important to build science knowledge early to foster interests in science disciplines later in life. From a sociocultural perspective, science is seen as an important subject as well.

Secondly, they mostly focused on quantitative data and did not take into consideration the qualitative aspect of RWL. Qualitative data collected from individual interviews, focus groups or any research method that involves open-ended questions will allow researchers to have an in-depth understanding of their participants' thoughts, feelings and opinions. Qualitative data add context to participants' answers. It becomes easier for researchers to detect the nuance in people's answers and ask further questions when misunderstandings occur. This is especially true for special populations such as children where their experienced may depend on so many factors such as their home environment, their understanding of the questions being asked and their personal opinions towards technology.

Thus, the main research question of this article is: What is currently known about reading-while-listening and to what extent does reading-while-listening impact psychophysiological (cognitive, attentional, and emotional) processes of older primary school students? Evaluating psychophysiological effects are important for several reasons. It offers a way to understand how our external stimuli can guide cognitive processes such as memory or emotions. Psychophysiology focuses on the interaction between the person and the environment, assuming that this information can shed some light on the human mind. It offers tools for mining information about nonconscious and

non-reportable processes, it can substantially contribute to our understanding of cognition, emotions, and behavior, which are difficult to capture via traditional self-report methods.

To answer our research question, we conducted a literature search, saved relevant studies and, from these, collected quantitative and qualitative data from our population of interest. Next, we classified our findings into four distinct categories: (1) the benefits of RWL, (2) the challenges of RWL, (3) the impact of RWL on science achievement, (4) the psychophysiological processes involved in RWL which will be separated in three different sub-sections (emotions, visual attention and cognitive load). Finally, we ended this review with a discussion of the main relevant points and a conclusion.

2.2 Method

This section highlights the methodology used to identify, select, and synthesize relevant studies pertaining to RWL.

2.2.1 Literature Review

A literature review was conducted. It was evaluated as being suitable for the aims of this study which was to synthetize the published articles available about reading-while-listening and its effects on the learning experience of primary school students. To find scientific articles, Web of Science and Google Scholar were used as sources. Web of Science is an online platform that gives access to several databases that provide scientific articles, academic journals, conference proceedings and other documents such as books from various fields. As for Google Scholar, it is a search engine that provides a way to look for articles, theses, conference proceedings and other scholarly material online.

Articles of interest had to be written in English, published in a peer-reviewed journal after 2008 and had to mention K-12 students as we were only interested in studies done with primary school children.

The first search term was [‘’reading-while-listening’’ OR “RWL”]. In addition to this first pair of terms, two AND statements were added. The first AND statement used was [‘’reading comprehension’’ OR “comprehension”]. The second AND statement used

was [‘’K-12’’ OR “children” OR ‘’primary school’’ OR ‘’students’’]. Figure 1 illustrates the screening process.

Our first search yielded 179 results, which were all exported to an Excel spreadsheet for further screening. For the first screening phase, all articles that were not empirical studies were removed from the list. Secondly, all abstracts were read to ensure that the studies were relevant to RWL and its effects on K-12 students. Articles that did not focus on K-12 learning and did not mention the differences between RWL and RO or LO were suppressed. This process resulted in 165 items being suppressed from the original list of 179 items. Lastly, 6 items were added to our analysis through snowballing and further searches on Google Scholar. In total, 20 articles were thus used for the analysis.

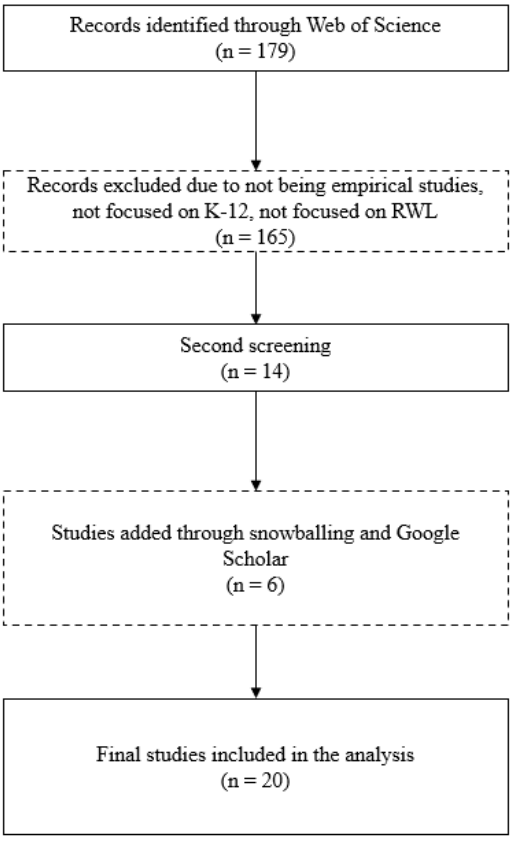

Figure 1

Screening process for the literature review

2.3 Results

The results section of this review presents a comprehensive synthesis of the findings from the included studies. The main objective of this section is to provide a clear and structured account of the evidence gathered. This section is organized into four different main sections and three sub-sections to facilitate a coherent presentation of the data.

2.3.1 Context

The following Table 1 presents the authors, the year of publication, the dependent and independent variables used and the main conclusions of each of the 20 studies. The earliest study was published in 2009 while the most recent was published in 2023.

#	Authors and year of publication	Age or grade	Experimental conditions	Main conclusions
1	Chang & Millett (2015)	10th grade	RO vs. RWL	Reading rates and reading comprehension improved in both conditions. The improvement was still observed for up to three months without additional treatment. The RWL group's improvement in reading rates and comprehension levels was higher than the RO group.
2	Dore et al. (2018)	4 to 5 years old (Preschool)	(1) parent reading, (2) independent reading with audio and (3) independent without audio	E-books using audio narration favored comprehension. Reading with a parent led to better recall.
3	Gerbier et al. (2018)	3rd to 5th grade	RWL with vs. without audio–visual synchronization	Poor readers preferred e-books with audio narration. RWL did not lead to higher orthographic and semantic learning.
4	Hawkins et al. (2015)	4th grade	RO vs. RWL	There was no difference between RO and RWL conditions on reading fluency. The RWL condition led to higher comprehension scores.
5	Hsieh & Huang (2019)	7th grade	E-book (RWL) vs. paper book	For low-proficiency students, e-book had a positive impact on listening comprehension.
6	Knoop-van Campen et al. (2018)	11 years old	(1) Reading-only (RO), (2) Listening-only (LO) (3) RWL	Children with dyslexia dedicated more time learning in the text condition. There was no difference in learning performance. No difference was detected in working memory across conditions.
7	Knoop-van Campen et al. (2022)	8th grade	Dyslexic vs. typical students (both groups used RWL)	In open-ended assignments, the addition of audio led students to distribute their attention across the entire text rather than concentrating on a single section. RWL increased reading time in students with and without dyslexia but did not affect reading comprehension performance.
8	Knoop-van Campen et al. (2023)	5th grade	RO vs. RWL	Both children with and without dyslexia used linear navigation strategies in both conditions.
9	Lee (2020)	1st grade (6 to 7 years old)	E-book reading with audio narration vs. recorded word explanations	Recorded word explanations resulted in greater word learning while e-book reading led to more incidental word learning.
10	Mestres et al. (2019)	5th grade	RWL, RO and control group	Students in the two intervention groups obtained higher vocabulary gains than those in the control group but did not present superior scores in reading or listening comprehension or reading fluency. RWL was the most appreciated mode.

11	O'Toole & Kannass (2018)	4 years old	(1) a print book read aloud by a live adult, (2) a print book narrated by an audio device, (3) an e-book read aloud by a live adult, and (4) an e-book narrated by an audio device	Children learned more words from the e-book and from the audio narrator. Attention predicted learning, but only in the print book condition.
12	Schiavo et al. (2021)	8 to 10 years old	RWL tool with dyslexic children vs. non-dyslexic children	Children with dyslexia increased their comprehension scores the most.
13	Serrano & Pellicer-Sanchez (2022)	10-11 years old	RO vs. RWL	Readers spent more time processing the text in the RO condition, while more time was spent processing the images in the RWL mode. Comprehension scores were similar for the readers in the two conditions.
14	Serrano (2023)	10-11 years old	RO vs. RWL	The vocabulary gains between RWL and RO were not statistically significant in the present study, RWL consistently showed higher gains.
15	She & Chen (2009)	7th grade (12 years old)	Two (interaction modes: animation/simulation) by Two (sensory modality modes: narration/on-screen text) factorial design	The group that received animation with narration allocated a greater amount of visual attention (number of fixations, total inspection time, and mean fixation duration) than the group that received animation with on-screen text.
16	Tragant et al. (2016)	10-11 years old	RO with teacher vs. independent RWL	Students preferred RWL and progressed as much in reading than their peers in the RO group with teacher.
17	Verlann & Ortlieb (2012)	10th grade	RO vs RWL	RWL led to significant reading comprehension improvement over RO.
18	Webb & Chang (2015)	10th grade	Extensive reading program through RWL vs. regular curriculum	The RWL group gained more vocabulary than the group in the regular curriculum. Gains were maintained 3 months later.
19	Yang, et al. (2022)	8 years old	Reading with audio-assistance, reading with visual-assistance, and silent reading	Reading comprehension was impacted by attention and cognitive load levels.
20	Yow & Priyashri (2019)	4 to 6 years old (preschool)	Single-language and dual-language e-books (with and without enhancing features)	Children paid more attention to their dominant language text. Enhancing features with synchronized dual-channel (visual and audio; RWL) inputs and attention-guiding cues effectively directed children's attention to print in both their dominant and nondominant languages.

Table 1

Context of the 20 selected studies

To analyze the differences between RWL and RO or LO, we classified each study within one or many categories depending on their results. In total, four categories were created: The general benefits of RWL in K-12 education, the current challenges of RWL in K-12 education, the impact of RWL on science achievement and the psychophysiological processes involved in RWL (e.g., cognitive load, visual attention and emotions).

2.3.2 The benefits of RWL in K-12 education

RWL has several benefits. Following the analysis of the 20 studies we collected, two main benefits were found. Firstly, RWL can help increase the written and oral vocabulary of students that are learning a first or second language in grade school. Secondly, RWL can also help foster vocabulary skills of children as young as preschool age. This section goes over the benefits of RWL in K-12 education.

Firstly, one of the benefits of RWL includes its positive effects on written and oral vocabulary for students that are learning a first or second language at a young age. For instance, Tragant et al. (2016) collected data from 28 students aged 10-11 years old, who spent 60% of their instruction time at school in a reading-while-listening program. Findings revealed that students in the intervention group displayed positive attitudes toward learning English and made comparable progress in their oral and written skills than students in the comparison group. A second, but smaller study also confirmed the effectiveness of RWL with four fourth-grade students (Hawkins et al., 2015).When comparing reading passages aloud to an adult, who would correct the student and provide feedback (1) and listening to recorded passages using an MP3 player (2), three out of four participants had better comprehension scores in the MP3 condition (the RWL condition). These results surrounding the positive effects of RWL on vocabulary gains and comprehension were also found in prior studies (Chang & Millet, 2015; Webb & Chang, 2014). The audio support seems to segment long texts into meaningful chunks, read slowly, making it easier for students to pay attention to difficult passages. Plus, allowing learners to encounter words in both their written and spoken form may make it easier to associate form and meaning (Webb & Chang, 2014).

Through this review of the literature, we found evidence that RWL is also as useful for preschool children to increase their vocabulary, though most studies evaluated its effectiveness by using e-books. E-books unlike traditional books, allow preschoolers to read independent of an adult by using the audio narration feature which represents a form of RWL. In a study by Dore et al. (2018), researchers found that reading aloud to children was effective to help them remember elements of a storybook. The team of researchers was initially interested in comparing preschoolers' comprehension of an e-book in three conditions: (1) parent reading, in which parents read the e-book to their children, (2) independent with audio, in which children see the e-book independently with audio narration (RWL), and (3) independent without audio, in which children see the e-book independently but do not have audio narration available (RO). Results indicated that preschoolers could understand some content from e-books using audio narration, indicating that using e-books independently may be a good learning activity for children that do not yet know how to read. However, results also indicated that children recalled the most information when reading with their parent compared to the other conditions. As more preschool children are interacting with technology and continue to use it in their school years with and without adult supervision, these findings give some insights on how to build reading skills for younger children through technology such as when using RWL. Authors have although noted that there may be important emotional benefits when reading with a parent at the preschool age. It is possible that children experience more positive emotions during e-book reading with a parent due to the physical proximity and intimacy involved, which may be a limitation of RWL in this regard. Nonetheless, positive results regarding the vocabulary gains involved in RWL has been replicated in another study, suggesting once again that RWL can be beneficial to children as young as four or five (Lee, 2020; O'Toole & Kannass, 2018). Lee (2020) explored how e-book reading, combined with audio narration and recorded word explanations, impacted the acquisition of new vocabulary among first-grade students attending low-socioeconomic elementary schools. A total of 100 first graders participated in this study. The results showed that the recorded word explanations led to significantly better word learning outcomes compared to the second condition, in which children did not have explanations provided to them. Furthermore, engaging with e-books facilitated vocabulary acquisition. Similar to these

findings, O'Toole and Kannass (2018) found that four years old children acquired more words when reading with an e-book that had simultaneous audio support (i.e., RWL).

To sum it up, RWL offers various advantages, revealing two principal benefits. To begin with, RWL demonstrates its potential to enhance the written and spoken vocabulary of students studying a first or second language in elementary school. Furthermore, RWL can effectively nurture vocabulary development in children as young as those attending preschool.

2.3.3 The challenges of RWL in K-12 education

The second aspect of RWL that we evaluated was the challenges associated with its use. Through this review, we found that the effectiveness of RWL depends on several factors such as motivation, technology acceptance, technology expertise, cognitive load, attention and other individual differences. Secondly, there is also a lack of longitudinal studies to verify the long-term effectiveness of RWL. Additionally, this learning technique does not always yield better learning results when compared to reading-only (RO). Lastly, though it is believed to support struggling readers, part of this population may not have access to RWL for socioeconomic reasons. To be able to use RWL, students need computers or e-books among other technologies that may not be available to them during their K-12 education years. This sub-section discusses such challenges in depth.

According to Knoop-van Campen (2022), longitudinal studies are needed to evaluate and quantify the benefits of RWL in the long-term as children develop more reading skills, reading strategies and develop their psychophysiological processes naturally (Knoop-van Campen, 2022). However, we were unable to find a study that followed students' progress across a long time period. Moreover, Knoop-van Campen (2022) found that variables such as expertise in using RWL or digital competences in general might influence the efficacy of RWL, especially when considering acceptance and motivation to use such tools as control variables. Though they did not measure those control variables, they noted that other moderator factors, such as measures related to visual attention and cognitive load, should be considered. In the same vein, Tragant et al. (2016) also highlighted the fact that future research should investigate how varying

durations of reading with audio support can further impact children's vocabulary and reading fluency. Little is known on how much RWL is necessary to be effective. Perhaps, a daily use of audio support is more effective than once during the school year. Moreover, Tragant et al. (2016) shared the same opinion concerning moderating factors in their study. They noted that individual differences may play a role in how young students can benefit from RWL in the long-term. For instance, learners with higher proficiency levels, motivation, and literacy skills may particularly benefit from this learning approach.

Additionally, as mentioned in the section above, another challenge concerning RWL is that it does not always lead to higher comprehension or vocabulary scores (e.g., Hsieh & Huang, 2020). Some studies have found that RWL had no effect on the memorization of the orthographic form of new words and even had a negative effect on the short-term memorization of pseudowords (Gerbier et al., 2018). These results were replicated in a study by Knoop-van Campen et al. (2018), in which researchers aimed to examine the redundancy and modality effects in multimedia learning in dyslexic children to investigate whether written and/or spoken text with pictures would benefit learning performance. Results revealed that children with dyslexia did not increase their vocabulary knowledge regardless of the modality used. However, they spent more time reading in the text condition, compared to the audio condition and the combined text-and-audio condition. Even if the groups used differed on their working memory abilities, they had similar results on reading performance scores, suggesting that the modality used did not have a positive or negative influence on learning regardless of the children's abilities (Knoop-van Campen et al., 2018).

Lastly, children from low-socioeconomic backgrounds are often the ones who are the most likely to struggle with reading as parents may not have the means to provide for reading materials, offer parental support while reading or have access to technologies that support RWL such as e-books or a computer (Lee, 2020). These potential struggling learners are at a disadvantage as the access to technologies that provide RWL may not be available in their environment. Lee (2020) explored the impact of RWL through e-book reading (RWL) and RO on the acquisition of new vocabulary among first-grade students attending low-socioeconomic elementary schools. Using a within-subject design, students

read two e-books, and their performance in learning seven words with RWL was compared to the learning of seven words without audio explanations. Results indicated that RWL enhanced word learning compared to the no explanation condition for all groups, but more so for struggling readers from low-socioeconomic backgrounds. Furthermore, RWL contributed to unintentional word learning. These findings suggest that children from low-income families can expand their vocabulary through e-book RWL. However, they may not always have access to e-books to begin with as explained before.

To summarize, the second dimension of this review focused on the challenges associated with it. Our review highlighted that the efficacy of RWL could be impacted by several factors, including students' motivation, acceptance of technology, proficiency in using technology, cognitive load, attention, and other individual differences. Additionally, longitudinal studies are needed to evaluate the long-term effectiveness of RWL. Furthermore, it should be noted that RWL does not consistently outperform RO in terms of learning outcomes. Lastly, while RWL is believed to provide support for struggling readers, poor readers from low-socioeconomic may face barriers to access RWL due to socio-economic constraints.

2.3.4 The impact of RWL on science achievement

RWL can be used in different contexts (e.g., at home or at school) and for different subjects (e.g., mathematics, science, languages, etc.). For instance, if a student wants to learn English as a second language, RWL might be helpful to learn the pronunciation and intonation of new words. Similarly, it could be possible to use RWL in the context of mathematics to better understand theorems at a slower pace. Thus, we were interested in seeing for which school subject(s) has RWL been used for across the 20 selected studies.

According to our results, three studies explored the perceptions of young learners exposed to scientific content with two different modes of input (RWL and RO; Tragant et al., 2019; Serrano, 2023; She & Chen, 2009). The results of all three studies indicated that RWL was not detrimental for science learning and could, in fact, support vocabulary knowledge. For instance, in the case of Tragant et al. (2019), the study also showed that

the RWL condition was more appreciated than the RO as it was chosen the most by the participants, supporting the idea that RWL can enhance the learning of science. Researchers explained this result by considering the possibility that new technology has a certain appeal as it is novel and enjoyable. Despite these positive results for RWL, students learned similar amount of vocabulary regardless of the intervention program they were in (Tragant et al., 2019). The study done by Serrano (2023) showed that RWL led to improvements in vocabulary acquisition for the first half of the school year. The remaining 16 studies were focused on storybook comprehension and first or second language learning.

In conclusion, it is evident that there is a notable gap in the research pertaining to the impact of RWL on other subjects than language learning and story comprehension. While the RWL approach holds promise and has demonstrated potential benefits, it remains largely unexplored when it comes to subjects like science, mathematics, arts, etc. This gap represents a valuable opportunity for future research to analyze the efficacy of RWL in other contexts.

2.3.5 The psychophysiological processes involved in RWL

RWL is a multifaceted process that engages a network of psychophysiological mechanisms such as emotions, cognitive load and visual attention, for instance, because it requires the learner to read and listen simultaneously to the information presented. Understanding the underlying psychophysiological processes is therefore important as it sheds light on the association between RWL and human cognition. The following section will be divided into three sub-sections cognitive load, visual attention and emotions.

Cognitive load

Due to the nature of RWL, readers are required to simultaneously process both auditory and visual information, resulting in a potential impact on their cognitive load as they have to process two modalities rather than one in the case of RO. The results of this section highlighted the importance of considering cognitive load as a dependent variable when evaluating the effectiveness of RWL.

Out of the 20 studies collected, two studies focused on the interplay between simultaneous visual and auditory reading and cognitive load. The first and most recent study of our dataset was done by Yang (2022). Eight years old Mandarin-speaking children were recruited and read English texts in three different modes, using a between-participants design. Data was collected on cognitive load, comprehension scores, and attention levels. The analyses showed that RWL had no significant influence on reading comprehension. However, the extraneous cognitive load accounted for 78% of the variance in the reading comprehension scores in the RWL mode and accounted for about 44% of the variance in the loss of visual attention, showing the importance of cognitive load as a potential control variable.

Given that e-books might place additional demands on children's cognitive processing abilities, another team of researchers conducted a study to examine whether multimedia elements in e-books, such as audio narration and tracking animations, could effectively guide the attention of Mandarin-speaking preschoolers toward the printed text in their language (Yow & Priyashri, 2019). Results showed that during the visual input and audio narration condition (i.e., RWL), children better integrated information and had a reduced cognitive load compared to the animation condition. Animations are more complex than RWL as they integrate moving images, text and sounds, all at the same time, whereas RWL only requires children to read and listen. However, when compared to RO, RWL leads to higher cognitive load levels (Yang et al. 2022). The main explanation for this is because RWL requires the processing of two modalities while RO only requires the processing of one modality. Consistent with the results found by Yow & Priyashri (2019), increasing the number of modalities to be processed inherently increases cognitive load levels.

To conclude, RWL inherently demands that readers process both sound and visual data at the same time. This could potentially increase their cognitive load because they’re dealing with two types of information instead of just one, as in the case of RO. The findings of this section show that as more modalities are being processed, cognitive load levels increase. Thus, RWL should lead to higher mental resources being used than RO.

Visual attention

When readers are asked to use RWL, their attention is divided between the auditory and visual input. It is therefore interesting to investigate how students' gazes behave in the context of RWL when compared to RO to analyze whether they follow a linear reading pattern or if they look at other things around the text such as images while the audio plays. According to the data collected, some studies found no differences in the average fixation time between RO and RWL. The evidence was mixed though as some studies found a difference in fixation duration. This sub-section summarizes the results on visual attention.

In their study, Serrano and Pellicer-Sánchez (2019) wanted to analyze the processing behavior of children in RO and RWL with multimedia materials. Results showed that the RWL condition caused differences in how young learners processed the text and pictures. While there were no differences in the average fixation duration between RO and RWL, learners spent more time and fixated more on the text in the RO mode. The RWL condition made learners pay more attention to images instead. Similarly, Schiavo et al. (2021) found that struggling readers exhibited a linear visual pattern while reading the lines of text with audio, while typical readers might have felt slightly distracted or annoyed by the constraints imposed by this reading modality and exhibited non-linear visual patterns. That did not, however, lower their performance.

Visual patterns may however depend on the task that the child has to perform after using RWL or reading text only. A study revealed that during open-ended assignments, students tended to distribute their attention more evenly across the entire text when audio support was there than not (Knoop-Van Campen et al., 2022). In the RO condition, visual patterns were characterized with more saccades at different areas and were therefore, more random. Similarly, a study done with French children in third and fifth grade found that the RWL condition led to fewer but longer fixations on words, and fewer instances of backward eye movements (regressive saccades) compared to the RO condition, thus supporting the idea that RWL leads to less random eye movements and more visual focus (Gerbier et al., 2018).

However, as previously mentioned, the evidence is still mixed. Mestres et al. (2019) found that there were no significant differences in eye movements when comparing students in two intervention groups (RWL and RO). More recently, Knoop-van Campen et al. (2023) recently found no results in visual patterns as well. Their study aimed to investigate the extent to which this form of external regulation affects navigation patterns in individuals with and without dyslexia, specifically in children and adults. Findings revealed that both typical and dyslexic children exhibited a predominantly linear reading approach in both conditions. These results imply that RWL has a minimal effect on the visual reading patterns of children.

To conclude, when readers are tasked with employing RWL, their focus is split between auditory and visual stimuli. Consequently, it becomes intriguing to explore gaze patterns when using RWL in comparison to RO. The data gathered revealed a discrepancy in findings; while some studies observed no distinctions in the average fixation duration between RO and RWL, others reported varying fixation durations.

Emotions

The last cognitive component that we were interested in was emotions felt during RWL by grade school students as it is important to not only consider learning performance but also whether RWL is seen as a positive and therefore, potentially reusable, or not. Results showed that RWL was seen as novel and made following texts easier for children.

In total, three studies have evaluated the emotions expressed by K-12 students in RWL and RO conditions. In one of those studies, researchers examined the impact of synchronizing written texts with its audio counterparts during RWL tasks (Gerbier et al., 2018). A group of 40 French children (third and fifth graders) participated in the study by reading short stories in their native language while simultaneously listening to a narrator reading the same stories aloud. The results revealed that children generally favored RO condition, except for those with lower reading abilities, who tended to prefer the RWL condition because they could follow the text easily (Gerbier et al., 2018). Another reason why RWL may lead to positive emotions is due to the novelty effect (O'Toole & Kannass, 2018). Children tend to view e-books as an enjoyable and pleasurable tool to learn. Similar

results were found in another study on science learning though researchers did not ask why students preferred the RWL mode than the RO mode (Tragant et al., 2019).

In conclusion, the final cognitive aspect we investigated pertained to the emotions experienced by grade school students while engaging in RWL. This aspect is crucial as it goes beyond assessing learning performance and evaluates the actual need for RWL from the students' perspectives. Our findings indicated that RWL was viewed as a novel and beneficial approach, simplifying text comprehension for children.

2.4 Discussion and conclusion

The current review of the literature was done to provide a comprehensive summary of the existing literature on the effects of RWL on K-12 children when compared with traditional reading (RO) or listening only. Through this process, consistencies and inconsistencies were found in the empirical studies that were analyzed. This section discusses the main results and the interpretation we made of them, but also offers avenues for further research by identifying gaps.

Firstly, RWL does seem to have a positive impact on struggling readers and those with learning disabilities such as dyslexia (Knoop-van Campen et al., 2022, 2023; Schiavo et al., 2021). As it engages both the visual and auditory senses simultaneously, RWL can enhance comprehension and retention of information, making it easier for young learners to understand and remember what they've read (Pellicer-Sànchez et al., 2020; Chang, 2009, 2013, 2015; Brown et al., 2008; Webb & Chang, 2014). Struggling readers who have dyslexia often have difficulties in decoding words and recognizing phonetic patterns (Schiavo et al. 2021). RWL can provide correct pronunciation and fluid reading, helping children with dyslexia overcome the challenges associated with decoding. This can improve their overall reading fluency. The positive effects of RWL can be seen in children as young as 4 years old (Lee, 2020; O'Toole & Kannass, 2018). However, it is not a perfect solution that fits everyone. Some studies did not observe a difference in reading comprehension scores when comparing RWL to RO (Knoop-van Campen et al., 2018; Gerbier et al., 2018).

RWL also comes with several challenges. Firstly, its long-term effects are not well understood with samples that involve K-12 children with and without reading difficulties (Tragant et al., 2016, 2018). Additionally, it is not always accessible to children from low-socioeconomic backgrounds whose parents may not have the resources to expose their children to RWL technologies (Lee, 2020). Plus, many potential moderating variables may impact the effectiveness of RWL. Variables such as motivation, knowledge of digital environments, technology acceptance and others may influence the relationship between RWL and learning outcomes (Tragant et al., 2016, 2018). One of the gaps in the literature also include the fact that most of these conclusions have been reached when RWL and RO were compared by using storybooks. Perhaps, the conclusions previously cited would have been different depending on the school subject being used.

From a psychophysiological standpoint, RWL does lead to more positive emotions, a heightened cognitive load and linear visual patterns, in general (Clark & Mayer, 2016; Mayer, 2017). However, not all studies found the association between RWL and a linear visual pattern while reading as the evidence is still mixed (O'Toole & Kannass, 2018).

This review contributed to the literature by highlighting the current benefits and challenges of RWL. This is important because by summarizing the current benefits and challenges, researchers can identify gaps in the literature and areas that require further investigation. This information can guide the direction of future studies, helping researchers prioritize research questions and hypotheses. Teachers, educators, and practitioners can use this information to make informed decisions about incorporating reading-while-listening activities into their instructional strategies. Understanding the benefits and challenges helps them optimize teaching methods and support learners effectively by providing additional support to students who may struggle with this task. It can lead to the development of inclusive teaching practices that cater to diverse learning needs. Practically, speech therapists, language educators, and professionals working with individuals with reading or language disorders can also use this information to design evidence-based interventions that target specific challenges associated with reading-while-listening.

Some limitations must be considered. Firstly, we were only able to use studies that were in Web of Science and Google Scholar and to which we had access through our institution access. Negative or null findings might have been not as readily available, leading to an incomplete picture of the effectiveness of certain reading strategies such as RWL. Moreover, most studies were done in English, Mandarin or Spanish. It could be possible that conclusions would have been different with a sample of children who speak other languages. Lastly, some studies relied heavily on quantitative research, potentially overlooking valuable qualitative insights that can provide a richer understanding of reading strategies such as the learners' thoughts and feelings while using a reading strategy such as RWL.

Future research should evaluate the longitudinal effects of RWL compared to RO as K-12 students may differ from their older selves both cognitively and in terms of personal preferences for reading strategies. Longitudinal studies with large sample sizes, if possible, are needed to quantify the benefits of RWL on a prolonged usage. It remains important to control for variables such as text difficulty, student's motivation and reading comprehension level as they could all impact the relationship between RWL and reading comprehension (Schiavo et al., 2021). Additional studies are needed to answer the previous gaps raised. For instance, little is known concerning the effectiveness of RWL when used in a context other than storybooks reading or language learning. Learning mathematics or sciences could lead to different results as they involve more than reading words.

In conclusion, the goal of this literature review was to provide a summary of the past research done surrounding RWL for the past 15 years. We identified, evaluated, and synthesized several studies' results to gather empirical evidence on the benefits and challenges of RWL at the K-12 level. Our findings helped better understand the effects of RWL on learning performance, emotions, cognitive load, visual attention and the challenges that this technique faces. Though this review provided some answers, there are still some gaps surrounding the research around RWL. Firstly, there is a lack of research on RWL and its effects on science or mathematics learning. Most of the studies found were done with story books or language learning materials. Science differs from other

subjects because it involves learning new and complicated words that are not commonly used, it uses its own jargon to describe phenomenon and several concepts may be new to children. For instance, children with developmental language disorders can struggle to learn new words which can make it difficult for them to understand scientific concepts that rely on specific vocabulary and syntax. Secondly, eye-tracking studies need to also consider qualitative information to better put in context the quantitative data collected. For instance, if certain areas of interest are more explored visually by learners while they are in the RWL condition, understanding why could give more information to researchers as to why that is. Lastly, almost all studies forced learners in different conditions such as RWL, RO or LO, but in most natural settings, such as at home, students are not forced to use RWL to better understand a given text. It is therefore important to explore why and when students naturally use this technique.

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Chapter 3

The Psychophysiological Impact of Reading-While-Listening: Evaluating 6th graders' Comprehension in Science

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Abstract

The aim of this study was to evaluate to what extent does reading-while-listening (RWL) compared to reading-only (RO), in the context of science reading, at the 6th grade level. The factors of interest were cognitive, emotional and attentional processes during reading with and without auditory support. They were evaluated through eye-tracking technology and self-reported questionnaires. Reading comprehension scores were also analyzed to see in which condition did students perform best. Lastly, students' overall opinions and preferences were recorded through semi-structured interviews. Results indicated that, compared to RO, instructing students to simultaneously read and listen to science texts led to a decrease in visual attention, an increase in emotional valence and an increase in experienced cognitive load. There was no statistical difference in reading comprehension scores. Interviews revealed that students though students found the audio mechanisms fun, they would not use it regularly as they do not have reading difficulties or already have their own way of overcoming their disabilities. In conclusion, these results implied that though RWL had benefits such as increasing pleasure while learning, participants did not show a significant intention to reuse it. Despite the higher mental effort required to process verbal and visual information, RWL did not negatively impact reading comprehension.

Keywords: Reading-while-listening, reading comprehension, eye-tracking, online learning, primary school, user experience, education technology, assistive reading

3.1 Introduction

The average use of Internet for educational purposes have increased among primary and secondary school students. For instance, prior to the COVID-19 pandemic, 94% of 15-year-old Canadian students reported using Internet at home (Statistic Canada, 2020). On another a nation-wide survey has revealed that 80% of Grade 4 students used a digital device (e.g., a computer or a tablet) at home for school work purposes at least once a month (Statistics Canada, 2020). However, as the Internet gains popularity with young students for learning purposes, so does the need for better multimodal web interfaces that can be both engaging and resourceful for their users. Due to the flexibility of web interfaces, many ways of representing the information exist. Online lessons can contain videos, reading-while-listening mechanisms, or images, among other means (Tare et al., 2020). The main issue with having all these modalities is that it is difficult to select the right one depending on the subject and the learners' age or level.

One of the goals of these multimodal interfaces is to facilitate the reading comprehension of their users. Auditory input has been used by learning specialists to improve the students' reading comprehension in different ways. One of them is the reading-while-listening technique which involves having learners read silently while simultaneously listening to the same text (Schmitt et al., 2010). The sound is generated by a human voice or a computer-generated voice. Studies have supported the hypothesis that learners assimilate the information better when the narration is done by a human voice and when it corresponds to what is being displayed on the screen (Mayer, 2017). Reading-while-listening tends to help students with undeveloped phonemic awareness, word recognition, spelling and decoding abilities (Schiavo et al., 2021) (Schmitt et al., 2010). Those deficiencies have been shown to characterize students with poor reading comprehension skills (Schmitt et al., 2010). However, reading comprehension is not limited to those skills only. For instance, not all learners with decoding issues have comprehension difficulties. Nonetheless, decoding deficits that remain untreated may

impact a student's reading comprehension and, eventually, their academic success (Keelor et al., 2020) (Flynn, Zheng, & Swanson, 2012). Similarly, reading comprehension can be impacted by other factors such as inattention and/or hyperactivity problems (Miller et al., 2013). Indeed, symptoms of attention-deficit/hyperactivity disorder, also known as ADHD, have been shown to have an independent negative effect on text comprehension (Miller et al., 2013). They may consequently function as moderators when researcher evaluate the effect of adding auditory input to texts on reading comprehension (Grunér et al., 2017).

Despite these factors, reading-while-listening (RWL) has been shown to significantly increase K-12 and secondary school students' overall comprehension scores compared to the typical unimodal (i.e., text only) mode of representation (e.g., Keelor et al., 2020; Silvestri et al., 2021) The gains are generally more important for children and adolescents with dyslexia and other learning disabilities. Indeed, Giusto and Ehri (2019) have proposed that reading-while-listening through text-to-speech (TTS) systems were predominantly helpful for readers who struggle with decoding written texts but have no problem understanding spoken language. Reading-while-listening systems seem to facilitate word identification for struggling readers as they synchronize texts with auditory input (Staels & Van den Broeck, 2015) (Silvestri et al., 2021). Moreover, recent studies have found that text narration significantly improved literal and inferential text comprehension compared to reading only with 9–11 years old pre-adolescents (Grimshaw et al. 2007). Results found that the bimodal condition better helped students' comprehension due to the use of correct intonation and word emphasis which may both have served to provide textual and contextual clues to the storyline.

However, students differ in their learning design preferences, cognitive abilities and learning strategies, thus making web design for learning purposes complicated (Chen & Huang, 2014). For instance, Leu et al. (2011) argued in a recent commentary on online reading comprehension that designing effective learning systems is especially complex due to the individual differences between learners. Nonetheless, it is important to study the use of multimodal web interfaces for primary school students in the context of science learning. Indeed, though there is no one design fits all solution, digital tutoring solutions

have been shown to support students with and without reading difficulties alike by adapting to their individual reading competencies and learning needs in a recent meta-analysis on computer-assisted instruction to improve online reading comprehension (Stetter & Hughes, 2010; Ma et al., 2014).

Several questions remain unexplored concerning the design of multimodal web interfaces for primary school students. Firstly, to our current knowledge, no study has focused on exploring how the integration of auditory input impacted the ambient-focal visual attention of young learners in the context of science learning at the primary school level. Exploring the similarities and differences in eye movement patterns can be done in various ways such as analyzing saccades, fixations or visual heatmaps (e.g, Krstić et al., 2018). However, no study has looked at analyzing the changes in visual inspection and ocular exploration behaviors. As mentioned previously, science learning relies on a diversified array of visual displays, text formats and other types of media to be understandable (Alvermann & Wilson, 2011). It is therefore important to consider that ocular behaviours may differ depending on the media presented to the learner. Visual attention has also been used to infer conclusions on cognitive load. Thus, eye movement patterns should not be ignored in multimodal learning studies. Secondly, though eye-tracking studies with minors in the context on online reading exist, few studies have paired quantitative data with qualitative data to better understand children's experience on multimodal interfaces. Kristic et al. (2018) have noted that factors such as motivation and reading strategies are important variables for understanding students' reading achievement. This conclusion remains true in the context of autonomous learning (i.e., studying at home) as children do not have their teacher's assistance while studying. Factors such as engagement, motivation, affect and satisfaction can be evaluated through qualitative verbatim. Grunér et al. (2018) noted that a qualitative approach is essential to examine the opinions of children with and without reading difficulties when using audio input while reading. Though many scales exist to quantify learners' satisfaction or emotional valence, qualitative data gives researchers details on one's experience and thoughts such as what do they like about the reading-while-listening technique, and what technological improvements could enhance their experience and encourage them to reuse the technology? Thus, past studies have highlighted the need for qualitative data to better

examine whether auditory input while reading is an accommodation that fits young students' learning preferences and strategies (Schmitt et al., 2010; Chen & Huang, 2013; Greene et al., 2014). Lastly, though students of all age groups are encouraged to use assistive technologies to compensate for their reading difficulties, not all of them will use these technologies when studying on their own (Schiavo et al., 2021). Exploring which factors are correlated with the reuse of reading-while-listening mechanisms is important in understand which user profile is more likely to prefer the added auditory support while reading.

The main objectives of this study were to, first, evaluate children's engagement towards reading-while-listening by looking at their ambient-focal visual attention patterns and by assessing their emotions and cognitive states in comparison to typical online reading without auditory input. Secondly, we evaluated the learning experience of reading-while-listening. More specifically, this study aimed at uncovering whether reading-while-listening was considered useful and efficient to students in the context of science learning. The following research questions have been developed:

In the context of online science learning,

1) What are the differences in visual patterns (i.e., ambient-focal attention) during the reading-while-listening mode compared to the typical reading-only mode?

2) To what extent does reading-while-listening impact experienced and self-perceived cognitive load?

3) To what extent does reading-while-listening increase reading comprehension?

4) What are students' attitudes and opinions towards reading-while-listening when taking into account their emotions and verbal feedback?

To address the research gaps and the proposed research questions we have developed an experiment in which students were asked to read and read-while-listening as the eye-tracker captured their eye movements. In addition to this, their opinions were taken into consideration through semi-structured interviews and post-task questionnaires. This study

was designed to help researchers better understand the engagement, emotions, and thoughts of students with and without reading difficulties as they interact with different modalities to complete reading comprehensions tasks. Practically, it could give instructional designers insights on the expected behaviour of younger students and how to effectively design web pages for science comprehension.

3.2 Research Framework and Hypotheses

3.2.1 Theoretical Framework

The cognitive theory of multimedia learning, also known as CTML and developed by Mayer (2001), best explains the cognitive processes involved in online learning with diverse media. The theory supports the idea that instruction works when the learner is guided to select relevant information, to organize it into a comprehensible cognitive representation, and to integrate the representation with other pertinent knowledge. According to the CTML, the main goal for instructional designers is to motivate learners to engage with learning material by using the relevant cognitive processing without overloading their working memory (Mayer, 2001 as cited in Ibrahim, 2012; Mayer 2009).

To reach this goal, instructional designers are encouraged to follow three key elements as they create learning materials:

(a) assist learners in reducing extraneous processing, which refers to any cognitive processing that deviates from the instructional objective and has the potential to perplex the learner;

(b) aid learners in handling necessary processing, which refers to ‘’any cognitive processing required to mentally represent the incoming material and is caused by the intricacy of the material’’ (Mayer, 2005; Sweller, 1999);

(c) help learners in handling generative processing which is ‘’any cognitive processing aimed at making sense of the incoming learning material, including organizing it and integrating it with prior knowledge’’ (Mayer, 2005; Sweller, 1999).

In the context of reading-while-listening, the cognitive theory of multimedia learning is relevant in explaining how it could help students learn better through what the theory calls ‘’dual coding’’. By simultaneously presenting written text and an audio track, learners can build robust mental representations of the material as they are engaging with the material through two channels: the auditory and visual systems (Moreno & Mayer, 2002; Paivio, 1991 as cited in Kormos et al., 2022). This repetition is thought to increase retention and recall of the information. More specifically, RWL has been thought to facilitate word recognition and the retrieval of word meaning (Ferrand & Grainger, 1993).

The Cognitive Load Theory (Chandler & Sweller, 1991; Sweller & Chandler, 1994), or CLT, is, by default, part of the CTML as it presents working memory as a cognitive system with limited capacity to selectively focus on and process incoming sensory data. CLT is also used to explain the way in which a learner’s cognitive resources are used during learning tasks. The theory suggests that instructional design should not overload the learner’s capacity for processing information or working memory. Baddeley’s (1986) theory of visual and auditory working memory states that working memory capacity can be increased by using auditory and visual input together rather than using one or the other alone. However, the information relayed by each channel should not be understood when presented alone. Instead, the two channels need to be processed together to be fully understood. Multimedia instruction’s strength is that is allows for this integration to happen. Visual information can be supported with narration, for instance. Similarly, CTML states that the redundancy of information through the visual and auditory channels should be avoided (Mayer, 2017). The redundancy effect occurs when the same information is presented simultaneously by the visual and auditory channels despite the fact that it can be fully understood in isolation, as either visual or auditory information (Mayer, 2017). Redundancy is discouraged because it can increase cognitive load. However, it is not necessarily a bad instructional strategy. Indeed, redundancy may be beneficial for novice learners as they may need assistance to make sense of the information through different media.

Experienced learners usually do not gain from redundance, nor do they lose knowledge from it (Kormos et al., 2022). For instance, several studies have found that

vocabulary knowledge increased when learners were instructed to read and listen simultaneously (Dupuy & Krashen, 1993; Pitts et al., 1989; Grabe & Stoller, 2002; Pigada & Schmitt, 2006; Song & Sardegna, 2014; Hossain & Hassan, 2022). In a recent study by Hossain and Hassan (2022), in the reading-while-listening condition, participants were able to enhance their vocabulary knowledge as they had sufficient time to process each word and received cues from the proper use of intonation. These cues helped them to make more accurate deductions about the meaning of unfamiliar words.

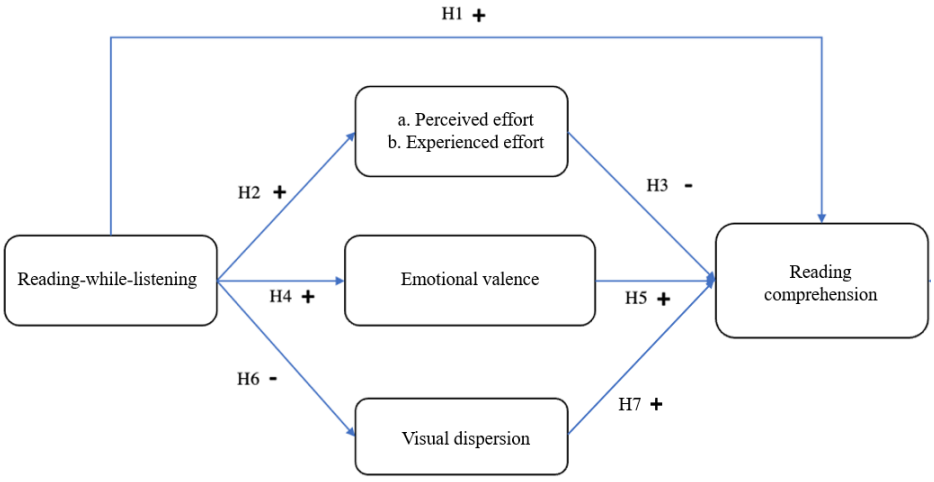
However, it is important to note that as with any other instructional method, the effectiveness of reading-while-listening also depends on several factors, such as the individual characteristics of the learner and the quality of the instructional materials. For instance, in a study conducted by Silvestri et al. (2021) found that in comparison to all the other groups of the study, the dyslexic group experienced the greatest advantage in text comprehension while using RWL. This is because both the intrinsic and extraneous processing loads were better aligned with their cognitive reading profile, which resulted in more efficient processing for text comprehension. According to Schnotz and Kurschner (2007), the goal of the CLT model is to find the best fit between an instructional model, the learner's cognitive architecture and the required task. There are three types of cognitive load that affect one's learning experience: the intrinsic load, the extraneous load, and the germane load. The intrinsic load relates to the level of complexity of the learning material while the extraneous load is the cognitive load created by the instructional material or the learning environment, and germane load is defined as being the mental effort required to process and integrate new information into existing knowledge. This highlights the importance of taking into consideration the profile of the learners instead as the results may vary depending on characteristics such as being dyslexic or not. In respect to the extraneous load, it is relevant to manipulate the learning format for math and science content as they are often associated with a higher intrinsic load (i.e., complexity of the content) (Schrader & Rapp, 2016). One way to reduce the load induced by complex content is to narrate instructions or explanations alongside graphics (Mousavi et al., 1995). By reducing some of mental effort required from the visual channel to the auditory channel, more important information can be selected and processed (Mayer, 2009).

3.2.2 Proposed Model and Hypotheses Development

To respond to the current gaps in the literature, the following model was built below (see Figure 1). The model serves as the guiding framework for our investigation of reading-while-listening and its psychophysiological impact. The model was inspired by the CTML and CLT, which were presented in the previous section. The rationale behind each hypothesis is available below.

Figure 1

Model of the present study



Hypothesis 1: Direct Effect of Reading-while-listening on Reading comprehension

Though some studies pointed out the lack of significant differences in students' comprehension performance between the RO and RWL mode (e.g., Serrano & Pellicer-Sánchez, 2019; Chang, 2009; Chang & Millett, 2015), RWL has been shown to not have a detrimental effect on comprehension (e.g., Diao & Sweller, 2007). More importantly, RWL has been shown to greatly support children with reading difficulties (e.g., Keelor et al., 2020; Hodapp & Rachow, 2010; Wood et al., 2018). Auditory systems can give poor readers the opportunity to listen to the right pronunciation to words, improve their visual and verbal information processing, and increase the cognitive resources that can be

allocated to comprehension. A recent study by Hsieh and Huang (2020) examined the impact of incorporating e-books into instructional material on the development of reading and listening skills in secondary school students with varying levels of English proficiency. The results showed a positive impact on listening comprehension, particularly for low-proficiency students. The study utilized an experimental group that employed an e-book in their English class, while a control group used a print version with equivalent content. The six-week e-book intervention was followed by an achievement test and focus-group interview. Thus, the possible positive effects of reading-while-listening on reading comprehension should not be overlooked. Following the results of these studies, we hypothesized that reading-while-listening would increase students' reading comprehension scores (H1).

Hypothesis 2: Direct Effect of Reading-while-listening on Cognitive Load

Working memory is a cognitive mechanism that allows us to hold and process information in our mind for a brief period of time to execute a task. This involves actively manipulating the information rather than simply passively retaining it. According to the Cognitive Load Theory, working memory is constrained by a finite capacity, and the amount of information it can hold varies among individuals. Additionally, information held in working memory is temporary, and without rehearsal or further processing, it tends to decay over time (Baddeley & Hitch, 1974; Baddeley, 2003). Interference can also affect working memory, as new information can disrupt the retention of previously held information, and vice versa. Lastly, working memory is specialized for processing certain types of information, like verbal or spatial data, which can make multitasking more difficult when multiple types of information are involved (Baddeley, 2003). As RWL involves processing two different channels of information at the same time, it poses a threat to the cognitive load levels. Altogether, the fact that it introduces a redundancy effect makes it more likely to increase the users' cognitive load. Redundancy happens when learners are presented with information that is either unnecessary or is repeated from multiple sources (Clark, Nguyen & Sweller, 2006; Sweller, 2005). The negative effects of redundancy have been documented in various studies (e.g. Kalyuga, Chandler, & Sweller 2000, 2004; Sweller & Chandler, 1994). As further explained by Mayer (2005),

by presenting different types of information to the user, their working memory will be challenged due to its limited capacity. Thus, we believe that this mental challenge will be seen as an increase of the users' cognitive load. As RWL requires learners to process the information from both their auditory and visual channels, we hypothesized that their cognitive load would increase in the reading-while-listening condition compared to the reading-only condition (H2).

Hypothesis 3: Direct Effect of Cognitive load on Reading Comprehension

The Cognitive Load Theory argues that high cognitive load can reduce retention and lead to errors in information retrieval. When the brain's working memory is overloaded with too much information at once to encode or too many tasks to perform, the ability to process and store information becomes significantly impaired as the working memory's capacity reached its limits (Chandler & Sweller, 1991; Just & Carpenter, 1992). This phenomenon is known as the split-attention effect. It also occurs when people must split their attention between multiple sources of information. It has been shown to be a major challenge for instructional designers who create platforms that integrate different sources of media such as texts, videos, images, and audio tracks (e.g., Chandler & Sweller, 1991, 1992; Sweller & Chandler, 1991, 1994; Sweller et al., 1990; Tarmizi & Sweller, 1988; Mousavi et al., 1995). Seigneuric et al. (2000) have investigated the impact of high levels of cognitive load on information retention with fourth graders. The first goal of this experiment was to assess the relationship between working memory capacity and reading comprehension in French fourth graders. They found that children's reading comprehension was predicted by their working memory capacity and that cognitive load decreased comprehension (Seigneuric et al., 2000). The relationship between working memory and comprehension skills is contingent on tasks that require the processing and storage of sentences (Seigneuric et al., 2000; Cain et al., 2004) and words (de Beni et al., 1998). In other words, when a learner is faced with different tasks that demand reading related skills at once, their working memory capacity will decrease and so will their comprehension. For these reasons, we hypothesized that high perceived and experienced cognitive load levels would reduce reading comprehension scores (H3).

Hypothesis 4: Direct Effect of RWL on emotions

Reading-while-listening can be perceived as more enjoyable for students. Tragant et al. (2019) compared a group of students who were exposed to 18 sessions of reading-while-listening to a group who were exposed to the same number of sessions through reading-only, and a control group. The subjects of the reading sessions (i.e., Dangerous Weather, Recycling, Amazing minibeasts, etc.) were roughly similar to topics students would cover in their science classes that year. There were 24–25 students of age 10 to 11. Results showed that learners perceived the RWL and the RO sessions differently. In fact, RWL was more liked among the participants than RO. A similar conclusion was in previous research by Tragant et al. (2016) who also found that students in the RWL group reported a very positive experience (Tragant et al., 2019). Despite the expected higher mental resources needed to process the simultaneous visual and auditory information, participants rated the RWL condition more favorably in terms of pleasure since it's more dynamic and less ''boring''. Similarly, we hypothesized that learners would find the RWL condition to be more pleasurable (i.e., generate more positive emotions) than the reading-only condition (H4).

Hypothesis 5: Direct Effect of Emotions on Reading Comprehension

Though scarce, recent studies have found that learners' emotions influence their reading comprehension performance. The available evidence on the impact of achievement emotions on learning from text is limited, but the results are consistent (Prinz et al., 2019). State emotions, which are experienced in the moment, have been found to have an effect on comprehension (Goetz & Hall, 2013; Pekrun et al., 2017). Greater interest and less boredom after reading the first part of a text have been linked to increased persistence and better comprehension, while experiencing greater anxiety after reading a text has been associated with poorer comprehension (Ainley et al., 2002a, b; Miesner & Maki, 2007). Similarly, learners with higher test anxiety have been found to achieve poorer comprehension (Miesner & Maki, 2007). Zaccoletti et al. (2019) have studied positive and negative achievement emotions. Negative-activating and negative-deactivating emotions were found to be linked to poorer comprehension, while positive

emotions tended to have a positive effect on comprehension. Overall, the available evidence suggests that positive achievement emotions typically facilitate comprehension, while negative achievement emotions impair it, regardless of whether the emotions are activating or deactivating (Zaccoletti et al., 2020). Thus, we hypothesized that positive emotions would increase reading comprehension scores (H5).

Hypothesis 6: Direct Effect of Reading-while-listening on Visual Attention

Eye-tracking has been employed in various studies to examine how learners process multimedia elements such as text, audio tracks and images while learning science and math (Johnson & Mayer, 2012; Mason et al., 2013, 2015). Eye-tracking studies on reading have revealed that children, compared to adults, generally have slower reading speeds, more fixations, longer fixation durations, less skipping, and more saccades (Rayner, 1998, 2009; Whitford & Joanisse, 2018). As for the impact of reading-while-listening, recent studies have supported the idea that it leads to explorative visual patterns which is characterized by short fixations and long saccades. For instance, some studies have found that young learners exhibited inconsistent reading patterns while watching videos and reading subtitles at the same time. Their visual patterns were characterized by a higher rate of skipping, fewer fixations, and longer latencies (d'Ydewalle & de Bruycker, 2007). Moreover, a recent eye-tracking study has supported the same hypothesis as young learners significantly spent more time and had higher fixation rates in the RO mode than the RWL mode. Instead, the RWL condition led learners to fixate images for longer rather than the text zones (Pellicer-Sánchez et al., 2020). To explain these results, Serrano and Pellicer-Sánchez (2019) have argued that when printed texts were simultaneously presented with the same auditory information, learners were more likely to look at pictures to support their comprehension as it allows them to better integrate the verbal and nonverbal sources of information. Therefore, it is not unlikely that the RWL condition will lead users to visually explore the page. Thus, we hypothesized that reading-while-listening would lead users to generate more visual exploration behaviours compared to the reading-only condition (H6). Visual exploration is characterized by short duration fixations followed by long saccades. This is also known as ambient reading. On the other

hand, long duration fixations followed by shorter saccades indicate focal information processing (Unema et al. 2005).

Hypothesis 7: Direct Effect of Visual Attention on Reading Comprehension

Part of being engaged is paying attention to the material being presented. In eye-tracking studies, visual attention can be categorized into two different categories: ambient and focal (Krejtz et al., 2016). Ambient attention involves a scanning pattern across stimuli, often observed in the initial phases of scene perception. It is characterized by brief fixations and extended saccades. Inversely, focal attention is distinguished by longer fixations and shorter saccades, indicating a more concentrated processing of stimuli. Greater focus on the stimuli suggests deeper engagement and active information processing (Krejtz et al., 2016). Eye-tracking devices have been used in research to gain data on the relationship between visual attention and different types of stimuli (e.g., Pellicer-Sanchèz et al., 2020). They allow researchers to examine the cognitive effort required in processing the visual informational. For instance, when examining the average fixation duration on images and text while silent reading, research has shown that the average fixation duration on images (260–330 ms) is longer than the fixation duration on text during silent reading (225–250 ms) because valuable information is gained from a wide field of view (Rayner, 2009). In the context of reading-while-listening, very few eye-tracking studies have been conducted with elementary school students on the effects of visual attention on reading comprehension. A review of the literature by Alemdag and Cagiltay (2016) has found that there is a lack of data to support the relationship between eye movements and students' learning outcomes (Chen et al., 2015; Lai et al., 213; Scheiter & Eitel, 2015). Among the 58 studies reviewed by the researchers, half of them (n = 29) studied the direct relation between eye tracking measurements and learning performance, including reading comprehension, but through measures of visual search efficiency, not ambient or focal visual attention. Though visual attention through an ambient-focal distinction was not evaluated, visual search efficiency was positively correlated with learning performance which could be used as a close proxy. Visual search efficiency is different from ambient-focal attention as it is defined as how fast the reader can locate important visual information when corresponding words are heard or read. Past

studies have found that visual search efficiency can be enhanced in multimedia environments by using regular on-screen text (i.e., bolded, italicized or capitalized words lead to more visual attention) or by pairing words with their corresponding narration like RWL does (Tabbers et al., 2004 as cited in Alemdag & Cagiltay, 2016). Nonetheless, the correlation between visual attention and reading comprehension has further been observed in other eye tracking studies. Some found that spending less visual attention was associated with poor learning performance improvement which highlights possible effects of attention on comprehension (e.g., Ozcelik et al., 2010; Scheiter & Eitel, 2015). We therefore hypothesized that increasing visual attention (i.e., focal processing) would lead to higher comprehension scores. In other words, both variables would be positively correlated (H7).

3.3 Methods

This project was approved by the Ethics Research Committee of our institution under the title ‘’Multimodal interfaces for science lessons: Impacts on learners' comprehension, cognitive and emotional engagement’’ (project number: 2022-4922) on May 3rd, 2022. This submission included the approbation for a data collection with minors with assent and consent forms from the participants and their parents.

This study used a within-subject experimental design. The independent variable was the modality used during the reading tasks (RWL or RO). The dependent variables were reading comprehension, emotional valence, cognitive load and visual dispersion. There were two control variables: the presence of a professionally diagnosed learning disability and the text topic. Both the order and the topic of the first and second tasks were counterbalanced.

3.3.1 Participants

Participants were recruited through a newsletter sent to their parents in April 2022. The newsletter was sent by email by a non-profit organization in education. As part of our partnership with the organization, only the parents that were subscribed to the newsletter were contacted. To be able to participate in the study, children had to be completing their

6th grade in a primary school in the province of Quebec. They also had to be able to speak and read French fluently. Due to the technical limits of the eye-tracker, participants were excluded from the study if they wore glasses because the eye tracker loses reliability when eyewear (i.e., contacts or glasses) is worn. In addition to this, participants could not take part in the study if they suffered from epilepsy or had any visual impairment such as myopia or hyperopia.

Thus, out of the 31 parents who completed the online form to participate in the study, 19 were selected on a first-come first-served basis, on whether they fitted the inclusion and exclusion criteria and, on their availabilities to come to the lab located in Montréal, Québec. A total of 19 participants took part in this study. Table 2 summarizes the descriptive statistics of the sample. 9 boys (47.37%) and 10 girls (52.63%). 3 participants were born in 2009 (13 years old; 15.79%), 14 were born in 2010 (12 years old; 73.68%) and 2 were born in 2011 (11 years old; 10.53%). Out of all participants, 12 had not been diagnosed with a learning disability by a professional (63.16%) while 7 had (36.84%).

Table 1

Descriptive statistics

Variable	*N*	*%*
Gender		
Boys	9	47.4
Girls	10	52.6
Year of birth		

2009	3	15.8
2010	14	73.7
2011	2	10.5
Learning disability diagnostic		
No	12	63.2
Yes	7	36.8

3.3.2 Material

Apparatus

For stimulus presentation, a 21.5″ Lenovo Thinkvision monitor was used (model name T2224pD). It was set at its default image settings (1920x1080 resolution with 1000:1 image contrast ratio and a 16:9 aspect ratio). Participants were seated from 60 to 70 cm away from the monitor. The screen was recorded during the experiment. The computer's operating system was Windows 11 Enterprise. Data from the self-reported questionnaires used in this study were recorded on the May 2022 version of Qualtrics (Qualtrics, Seattle, USA). All reading comprehension quizzes were done on the online platform Typeform on the May 2022 version (Typeform, Barcelona, Spain).

Experimental stimuli

This section shows the different experimental stimuli that were shown to the participants and the instructions that were conveyed to them during the one-hour experiment.

Children were exposed to two different conditions: the reading-while-listening condition and the reading-only condition. The RWL condition was built by adding small audio players on the left side of the reading page while the RO condition only had the original text. Both conditions are illustrated in the figures 2 and 3. The order was randomized to control for any "sequence effect" or a "carryover effect". This refers to the influence that the order in which experimental conditions or treatments are administered can have on the outcome of the study.

The three science texts used during this experiment were selected by the education professionals with whom we partnered for this study. The first topic was *The animal cell*, the second topic was *The internal structures of the Earth*, and the last topic was *The technological systems and their components*. These topics were all secondary one level to ensure that students were not highly familiar with their content beforehand. To ensure the quality of the topics, all selected topics were part of the secondary one provincial science curriculum and were, therefore, imposed by the Ministry of Education (MES) of our province to all first-year students. As for the reading comprehension questions of each topic, they were selected from a government approved science learning book, *Univers*, which was used in all secondary one classrooms across the province at the time of the study (Bélanger et al., 2020; Ministère de l'éducation, n.d.). This was to ensure the quality of the comprehension questions for each topic.

Figure 2

Reading-while-listening condition with the animal cell topic

Note. Participants were obliged to read the text while listening to the narration.

Figure 3

Reading-only condition with the animal cell topic

Instruments

Eye-tracking data was recorded using the software Tobii Pro Lab v.181 (Tobii, Stockholm, Sweden). The eye-tracker employs an infra-red light to detect the gaze of the

participant. It is a non-intrusive eye-tracking technique known as the pupil centre corneal reflection (PCCR) (Vasseur et al., 2019). In summary, the infra-red light is reflected by the eye and recorded by a camera, which captures the reflections generated by the light on the cornea and in the pupil. The software automatically calculates the vector formed by the angle between the cornea and pupil reflections. The direction of the gaze is then calculated by combining the direction of this vector with other geometrical features of the reflections. Fixations, saccades and other eye data was automatically recorded by the software. Scripts were coded manually by our team to calculate the *K* coefficients, following the methodology described in Shiferaw et al. (2019) and Krejtz et al. (2016). The methodology is described in the following section on the operationalization of the measures.

A facial emotion recognition software was used to assess the participants' emotional valence. The webcam placed on top of the monitor recorded the participants' facial expressions. The videos were then retrieved and analyzed in FaceReader v8.0 (Noldus, Wageningen, Netherlands). FaceReader allows to capture one's emotional valence in real time by calculating emotional valence as the intensity of positive emotion minus the intensity of negative emotions. This calculation renders a score between 0 (negative) to 1 (positive) (Ekman & Friesen, 1978; Loijens & Krips, 2018).

The Observer XT software (Noldus, Wageningen, Netherlands) allowed us to synchronize the facial expressions and eye-tracking data. Data was post-synchronized using Cobalt Photo Booth (Courtemanche et al., 2022).

Interview

To gain an in-depth understanding of why participants did or did not like reading-while-listening, why they decided to reuse it or not, whether they would reuse it in the future or promote it to friends and if so, why or why not, semi-structured interviews were judged to be useful. Semi-structured interviews allow the interviewer to probe further into the topic to gain a comprehensive understanding of the subject matter. By doing so, the researchers may help participants generate new ideas or insights that they had not considered previously. The feedback gained can help construct new hypotheses for future

studies. In the context of this study, semi-structured interviews were used to validate or challenge our existing hypotheses with rich and detailed data. The interview guide used in this study is available in the Appendix A.

3.3.3 Operationalization of Measures

This section provides details on the measures used and their operationalization in the context of this study. Table 2 summarizes how each measure were operationalized based on the psychophysiological state they represented.

Table 2

Operationalization of the measures

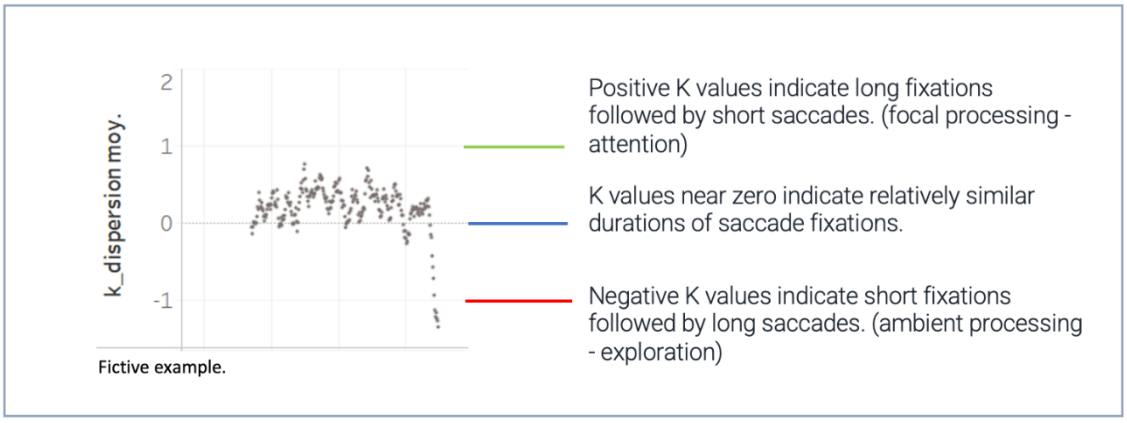
Measure	Psychophysiological State (Response to Stimuli)	Operationalization
Cognitive load	Cognitive load	Subjective or perceived cognitive load: NASA-TLX (Hart & Staveland, 1988) Objective or experienced cognitive load: PCPD from baseline (Attard-Johnson & Bindemann, 2019)
Visual attention	Visual attention dispersion	Focal-ambient K coefficients (Krejtz et al., 2016)
Emotional valence	Emotional valence	Emotional valence using FaceReader (Loijens & Krips, 2018)
Learning	Reading comprehension	Reading comprehension test results

Visual attention dispersion

Children's visual attention was assessed through visual attention dispersion. It was measured by using the ambient-focal coefficient K. This visual measure, developed by Krejtz et al. (2016), is also known as the K coefficient. This coefficient analyzes the changes in visual inspection behaviors and ocular exploration. The coefficient measures the changes in ocular exploration and inspection behaviors. The negative values indicate ambient viewing which occurs during the initial scene exploration whereas the positive values indicate viewing which is common during scene inspection (Krejtz et al., 2016). Positive values illustrate relatively long fixations followed by short saccade amplitudes as the attention is focused on very few areas of interest (Unema et al., 2005; Heitz & Engle, 2007). As for negative values, they illustrate relatively short fixations followed by long saccades as the attention is shared to all areas of the visual field in equal proportion (Unema et al., 2005; Heitz & Engle, 2007). See Figure 4 for a visual representation of each value. The values of the K coefficient that are close to zero designate a relative similarity between fixation durations and saccade amplitudes. The abscissa indicates time. Figure 4 summarizes what the positive and negative values of the K coefficient mean and how to interpret them.

Figure 4

The different levels of K coefficient



K is calculated as the mean difference between standardized values (z-scores) of each saccade amplitude (a_{i+1}) and its preceding i^{th} fixation duration (d_i). See equation (1) below.

$$K_i = \frac{d_i - \mu_d}{\sigma_d} - \frac{a_{i+1} - \mu_a}{\sigma_a} \quad (1)$$

Equation (1) is the K coefficient formula, where μ_d, μ_a are the mean fixation duration and saccade amplitude, respectively, and σ_d, σ_a are the fixation duration and saccade amplitude standard deviations, respectively, computed over all n fixations and hence *n Ki* coefficients.

Experienced cognitive load

Experienced cognitive load was measured through pupil dilatation, more specifically, by using the Percentage Change in Pupil Diameter (PCPD). It is one of the most used measures to infer the level of cognitive load or mental effort exerted during a task. As a response to cognitively demanding tasks, the pupils dilate. However, researchers must control for environmental factors such as the light levels in the room or the angle of the camera relative to the user as these factors can influence pupillary responses (Duchowski et al., 2018). Once controlled for, the dilatation of the pupil can be used as a valid measure to infer mental demands. The PCPD is the difference between the diameter of the pupil measured during a task and a baseline level, divided by the baseline level (Attard-Johnson et al., 2019). The baseline serves as an average value of pupil diameter taken before the experiment (Attard-Johnson & Bindemann, 2019). In other words, the baseline is essentially the pre-stimulus data of each individual as they all differ in pupil's size. The diameter is expressed in millimeters. We have used the guidelines by Karran et al. (2022).

Perceived cognitive load

The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) was used to measure the participants' subjective perceptions of their cognitive load (Hart & Staveland, 1988). The NASA-TLX is divided into six different factors and items:

mental demand (1 item), physical demand (1 item), temporal demand (1 item), overall performance (1 item), effort (1 item), and frustration (1 item). Each item has a possible score range from 0 to 100. The scores are then averaged to give a single task load index score (Hart & Steveland, 1988).

Emotional valence

According to Russell's (1980) circumplex model of emotion, emotion can be thought as being the sum of two distinct dimensions: emotional arousal and emotional valence. Arousal is a continuum varying from calm to excited while valence refers to a continuum from pleasure to displeasure (Charland et al. 2015). The possible values for both arousal and valence are comprised between -1 to +1. In respect to valence, pleasure refers to positive values while displeasure refers to negative values (Russell 1980). In the context of online learning, valence and arousal are implicit measures of emotional engagement. According to Ninaus et al. (2019), implicit measures are a more comprehensive way of measuring emotional engagement in learners during learning experiences. One of the commonly used measures is automatic facial expression analysis software, which has been favored in the context of learning and Information Systems (IS) (Charland et al., 2015; Bosch et al., 2014; Harley et al., 2015; Whitehill et al., 2014). This implicit measure is based on Ekman's (1993) work, which establishes a correlation between human facial expressions and six basic emotions (happiness, sadness, surprise, fear, disgust, and anger). Emotional engagement is inferred by measuring valence (positive or negative emotion) extracted from participants' facial expressions using automatic facial expression recognition software such as FaceReader v8.0 (Noldus Information Technology Inc, Netherlands), while the arousal level of the participants is measured using pupillometry.

Assessing learning performance through reading comprehension

Reading comprehension can be evaluated in different ways. One of them is through multiple-choice questions. Bloom's taxonomy is a framework that has been applied and used by K-12 teachers and college instructors to guide the design of learning objectives, instructional activities, and assessments (Anderson & Krathwohl, 2001).

Bloom and his collaborators argued that identifying the cognitive skills required to master a particular subject or topic was essential to design relevant assessments and learning activities that could help students develop those skills (Anderson & Krathwohl, 2001). The taxonomy is not only used to ensure that the curriculum is well-rounded, but also to design a quiz or an exam with questions that include the same or different levels of cognitive complexity. The framework elaborated by Bloom and his collaborators evaluated six major categories of learning: Knowledge, comprehension, application, analysis, synthesis, and evaluation (Anderson & Krathwohl, 2001). For each category, teachers can ask students to do actions that are already pre-determined by the framework. A list is available in the Appendix B. For instance, to test for comprehension, teachers are encouraged to ask questions in which students will have to explain in their own words the concept learned. To ensure that the reading quizzes were level-appropriate and evaluated the comprehension dimension, the questions were of the knowledge and comprehension categories established by Bloom. This means that questions started with the verbs ''select'', ''define'', ''show'', etc. In addition to this, to ensure that the questions respected the format and content used in real-life secondary 1 class, the reading questions came from a science book used by all students across the province. The book aligns with the provincial curriculum in science and technology.

3.3.4 Experimental protocol

Parents signed the consent form upon their arrival. Children then orally consented to the study. Once in the lab room, the eye-tracker was calibrated. Participants were asked to look at different points across the screen to ensure an accurate gaze point calculation. The participant's eyes were 60-70 cm away from the screen. During this experiment, two research assistants were present in an adjacent room and communicated the instructions to the child through external microphones. Cameras were also installed in the experiment room to ensure the child's security as they were alone. We have followed guidelines from Léger et al. (2018) on how to optimize eye-tracking studies with children and teenagers to increase data reliability.

Once all the tools were set up, the 60-minute experiment began with a baseline reading task. Participants were asked to read a pre-selected science text about hiccups at

their own speed. The baseline reading task was given to participants to allow them to get more familiar with the website, the software used and the experiment itself as they were primary school students. It also served as a control measure for the oculometry data as participants were asked to read a science text as they normally would at home. The text was chosen by learning specialists to ensure that it was appropriate for 6th graders according to governmental guidelines. The baseline text is available in the Appendix C. Then, participants were asked to answer three reading comprehension questions on the same computer through an online quiz platform without looking back at the text. The questions are available on the Appendix D. The three post-reading comprehension questions had been previously selected by the education specialists and were in a multiple-choice format. Each question had one correct answer among the four possible choices. The order of the questions could not be randomized due to the technical limits of the online platform. However, the four response choices were shown in a random order.

After the administration of the baseline task, the experiment began with a first reading task in the RWL or RO condition. Each reading task was followed by a multiple-choice comprehension quiz, which was comprised of three reading questions. As stated before, the order of the questions could not be randomized due to the limits of the platform used, but the order of the possible answers was. Children could only select one of the four possible answers each time and were not able to look back at the text to answer the questions. Following the end of each reading comprehension quiz, except for the baseline task, children were asked to complete a post-task questionnaire on their experienced cognitive load, pleasure, and arousal on a survey platform (i.e., Qualtrics). The topic of the chosen texts was different in each condition. The instructions for both tasks were given by the research assistant through the microphone.

For the third and last task, children were all asked to read a science text on technological systems and their components. Audio players were available on this webpage as well as shown in Figure 5. However, children were not obliged to use them unlike the RWL condition. Finally, the third reading task was followed by a multiple-choice reading comprehension quiz. Participants were asked three questions on the topic. However, unlike the previous tasks, they were permitted to go back in the text to help

them answer the questions, if they desired to do so. The format of the quiz did not change as children could only select one answer among four possible choices each time. This open reading task was always done last to test whether the usage of audio players would be repeated when given the chance. Figure 6 shows and summarizes the experimental procedure in a sequential manner and Table 3 summarizes the scenarios given to the participants during the three reading tasks.

Figure 5

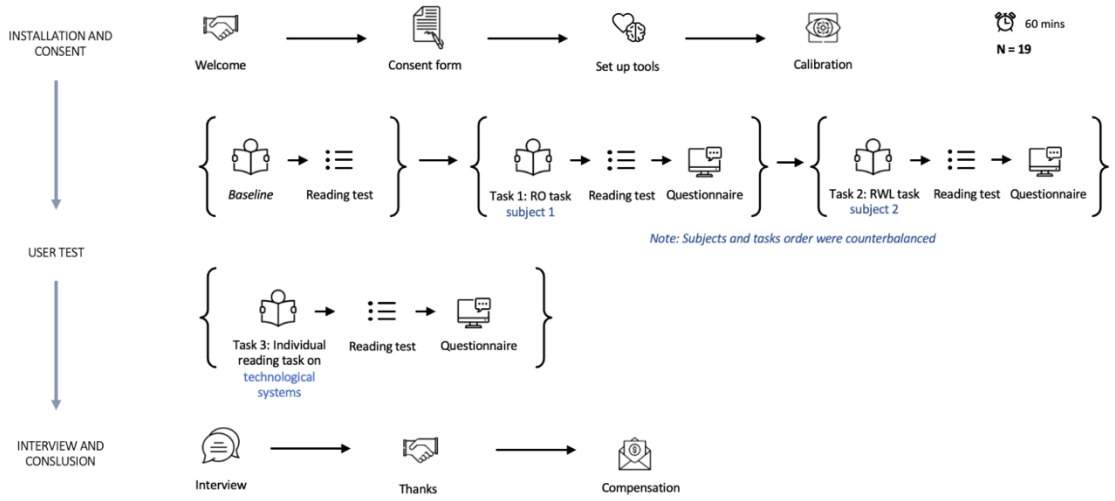
Technological systems reading task

Note. Part of the page shown to the participants during the third task. Participants were not obliged to use the audio players.

A post-experiment interview was conducted upon completion of all tasks and questionnaires. This semi-structured interview aimed at understanding the participants' overall experience with the learning platform, their opinions on the bimodal representation of the information and their online learning habits. The interview guide is available in the Appendix A. Each parent-child dyad was thanked for their participation with a $30 gift card and a physical educational game from a local library.

Figure 6

Experimental procedure



Note. Overview of the experiment.

3.3.5 Open task

In a lab setting, it is often difficult to obtain spontaneous natural reactions, especially with populations like minors, which may be influenced by the power imbalance between them and the researchers. Though lab experiments help standardize factors such as the participant's location, the material used and potential distractions, in-lab experiments can also influence the one's behavior and reactions. Participants may behave in ways that do not accurately reflect how they would respond in real-life situations. In

addition to this, participants may try to figure out what the experimenter wants and then respond according to the knowledge they have of the situation. Social desirability is also a problem as participants may respond in a way that they believe is socially acceptable or desirable. It is important to lower these biases as they pose a threat to the results validity. Thus, to better understand what happens in a normal setting, where children are free to use the resources that they need for their homework, we were interested in investigating the natural reactions of children when faced with RWL technologies (e.g., the frequency of usage of reading-while-listening mechanisms). This exploratory part will give insights on the re-use of audio-assisted reading technologies. The third and last task of this experiment was designed as a way to counter the biases mentioned.

The following Table 3 summarizes the scenarios that were presented to each participant through the microphone used in the lab.

Table 3

Task description with their respective scenario

Tasks	Scenario given to the participant
Task 1: Reading-while-listening (bimodal condition)	‘’You have a test to prepare for on the internal structures of the Earth/the animal cell. To prepare, your teacher suggests that you read the following page. You will then have to answer three multiple-choice questions for the test. It is important that you read the entire text to pass. Read the text at your own pace using all the audio buttons that I will show you. Let me know when you've finished reading and listening.’’

Task 2: Reading-only (unimodal text-only condition)	‘’You have a test to prepare for on the animal cell/the internal structures of the Earth. Your teacher suggests that you read the following text. You will then have to answer three multiple-choice questions for the test. It is important that you read the entire text to pass. Read the text at your own pace. Let me know when you've finished reading.’’
Task 3: Individual reading (open task)	‘’You have a homework due on technological systems. Please read the following text and answer the questions at the bottom of the page. This time, you will have the right to return to the text to answer your questions. You are free to use the audio buttons during your reading, but it is not mandatory. Notify me when you have completed your homework.’’

3.3.6 Statistical Analysis

Participants’ data were analyzed using STATA version 17 (StataCorp, Texas, USA) and the web version of Statistical Analysis System (SAS Institute, North Carolina, USA).

To test the hypotheses, linear regressions were conducted. We also considered doing post-hoc analyses with a mediation model to see whether cognitive load, visual attention and emotional valence could possibly impact the relationship between RWL and reading comprehension. The control variables remained the same in all the analyses. They were: (1) the presence of a learning disability diagnosis and (2) the topic of the text shown. To ensure the normality of the data, skewness and kurtosis values were taken into consideration. Skewness scores between ±2 points and kurtosis scores within ± 7 points were considered normal as supported in the literature (Hair et al., 2010; Bryne, 2010). Skewed data were normalized using a logarithmic correction with the following formula: log(variable).

3.4 Results

3.4.1 Descriptive Statistics

The descriptive statistics of the outcome variables are summarized in Table 4 for the overall sample. Both the average size pupil and average K coefficient data were normalized using the logarithmic correction. Though the skewness and kurtosis values of the pupil size variable are still out of the ‘’normal’’ limits despite being normalized, we couldn’t further correct the data without getting higher skewness or kurtosis values. Descriptive statistics of the outcome variables by subject and modality conditions are available in Table 5.

Table 4

Descriptive statistics of outcome variables for the overall sample (N = 19)

	M	*SD*	Skewness	Kurtosis	Min	Max
Reading comprehension*	0.32	0.47	-	-	0.000	1.000
TLX	33.82	16.94	-0.257	-0.763	0.000	65.250
Valence	-0.21	0.18	-1.030	0.581	-0.661	0.046
Pupil Size (normalized)	1.20	0.15	2.504	7.813	1.019	1.754
K coefficient (normalized)	0.51	0.11	1.432	4.977	0.301	0.934

Note. * Binary variable. Both the pupil size and K coefficient data were normalized using a logarithmic correction.

Table 5

Descriptive statistics of the outcome variables by topic and modality

	The Earth (RWL), *N* = 11		**Animal cell (RWL), *N* = 8**	
	M	*SD*	*M*	*SD*
TLX	26.02	12.57	41.41	14.52
Pupil size	1.15	0.08	1.28	0.21
Valence	-0.18	0.19	-0.19	0.14
K coefficient	0.47	0.08	0.47	0.07
Reading comprehension	0.27	0.47	0.25	0.46

	The Earth (RO only), *N* = 8		**Animal cell (RO only), *N* = 11**	
	M	*SD*	*M*	*SD*
TLX	33.67	20.25	36.18	18.72
Pupil size	1.26	0.20	1.14	0.07
Valence	-0.22	0.20	-0.25	0.18
K coefficient	0.56	0.11	0.55	0.14
Reading comprehension	0.25	0.46	0.46	0.52

Note. * Binary variable

3.4.2 Condition verification

Across experimental conditions, only the average pupil size mean scores were different between groups ($F(3,37) = 6.63$, $p = .001$). Though the data of this variable were corrected, the mean pupil score for the second condition was higher than all the other conditions ($M = 1.37$, $SD = .24$). The mean of the first condition was 1.12 with a standard deviation of .07. The mean of the third condition was 1.17 with a standard deviation of .05. Lastly, the mean of the fourth condition was 1.16 with a standard deviation of .08. We were unable to further correct the data without exceeding the normal skewness and kurtosis boundaries.

3.4.3 Intercorrelation verification

Out of all the correlation coefficients that were generated to measure the relationships between variables, none of them were significantly correlated. In addition, none of our correlation coefficients went above the .80 threshold.

3.4.4 Hypotheses validation: Fixed effects

The first step of the analysis was to determine whether RWL predicted reading performance scores (H1). The audio-assisted condition did not significantly predict reading comprehension scores ($z = -.62$, $p = .268$). The null hypothesis for H1 was not rejected. Thus, we were unable to conduct post-hoc analyses with a mediation model. Instead, we conducted one-tailed simple linear regressions because a mediation model requires a significant relationship between the dependent variable and the independent variable, in the first place, before adding mediating variables into the model. This condition was violated as we tested for H1. We were unable to demonstrate that RWL predicted reading performance scores.

3.4.5 Effects of RWL

Following the unsignificant results of the RWL condition on reading comprehension scores, one-tailed simple linear regressions were used to test whether adding audio to the text significantly predicted pupil size, TLX (subjective cognitive load) scores, *K* coefficients and valence scores, on average.

For pupil size, the overall regression was statistically significant ($\chi 2(1, N=19) = 65.23$, $p < .0001$). It was found that the reading-while-listening condition significantly predicted the average pupil size ($F(1, 17) = 11.63$, $p = .002$). Following these results, H2a was found to be supported. The pupil size was used to measure experienced cognitive load. We hypothesized that the experienced cognitive load would increase in the RWL condition compared to the RO condition (H2) which was found to be conclusive.

As for the perceived cognitive load that was captured by the TLX scores as part of the hypothesis H2b, the overall regression model was statistically significant ($\chi 2(1, N=19) = 5.97$, $p = .015$). However, reading-while-listening did not significantly predict the NASA TLX scores ($F(1, 17) = 0.10$, $p = .375$). Moreover, TLX scores were significantly predicted by the text topic meaning that the subject affected the perceived cognitive load ($F(1, 17) = 5.63$, $p = 0.030$). The animal cell condition ($M = 38.38$, $SD = 16.84$), on average, led to a higher mean than the Earth ($M = 29.25$, $SD = 16.20$) meaning that it was perceived as being more effortful. Nonetheless, the null hypothesis for H2b was not rejected.

For valence scores (H4), the overall regression was statistically significant ($\chi 2(1, N=19) = 16.49$, $p < .0001$). It was found that the reading-while-listening condition significantly predicted the average valence scores ($F(1, 17) = 3.23$, $p = .045$). The hypothesis for H4 was therefore supported meaning that RWL was found to be more pleasurable than RO.

For K coefficient scores (H6), the overall regression was not statistically significant ($\chi 2(1, N=19) = 0.21$, $p = .644$). However, it was found that the reading-while-listening condition significantly predicted the K coefficient scores ($F(1, 17) = 6.09$, $p = .012$). This result must be interpreted with caution as the overall model was not significant. It could be that the model does not appropriately represent the data. A lack of significance for the overall model may also be due to a variety of factors, such as a small sample size, insufficient power, or misspecification of the model. In the context of this study, the null hypothesis was not supported. Table 7 summarizes which hypotheses were supported or not depending on their research questions.

3.4.6 Effects on reading comprehension performance

For the second part of the analysis, we calculated the effects of cognitive load, emotional valence, and visual attention on reading comprehension since it was impossible to conduct a mediation analysis (hypotheses 3, 5 and 7). To calculate whether these variables still had an effect, we decided to run a regression analysis. None of the variables predicted reading comprehension scores. More specifically, it was found that perceived cognitive load (TLX scores) did not significantly predict reading comprehension scores (z = -0.68, p = 0.247). Experienced cognitive load (pupil size) did not significantly predict reading comprehension scores (z = 0.13, p = .447). Valence scores did not significantly predict reading comprehension scores (z = 1.43, p = .077). Lastly, it was found that K coefficient scores did not significantly predict reading comprehension scores (z = 0.38, p = .350). Thus, all null hypotheses for H3, H5 and H7 were kept. A summary of the GEE model is available in Table 6.

Table 6

Summary table of the effects of cognitive load, emotional valence, and visual or dispersion on reading comprehension scores

	B	*SE*	*95% CI*		*Z*	*p*
Intercept	-0.976	4.252	-9.310	7.358	-0.23	.409
Animal cell = 0	-0.720	0.763	-2.215	0.774	-0.94	.173
Diagnostic = 0	1.266	0.842	-0.385	2.917	1.50	.066
Text = 0	-0.579	0.993	-2.525	1.367	-0.58	.280

TLX	-0.016	0.024	-0.062	0.030	-0.68	.247
Pupil size	0.449	3.365	-6.146	7.044	0.13	.447
Valence	3.648	2.558	-1.366	8.662	1.43	.077
K coefficient	1.418	3.688	-5.811	8.647	0.38	.350

Table 7

Summary of the supported and unsupported hypotheses according to their research questions

Research question	Hypothesis	Supported
To what extent does RWL increase reading comprehension?	H1	No
To what extent does RWL impact experienced and inferred cognitive load?	H2a and H2b H3a and H3b	Yes No
What are students' attitudes and opinions towards reading-while-listening when taking into account their emotions and verbal feedback?	H4 H5	Yes No
What are the differences in visual patterns (e.g., fixations,	H6 and H7	Yes

saccades, etc.) during the RWL mode compared to the typical RO mode?

3.4.7 Exploratory data analysis

As previously explained, the third task was meant to predict what learners would do in their natural environment if audio players were available to them. The aim of the last task was to determine if they would they use the RWL without explicit instructions to do so. This exploratory phase of the experiment was done last in the experimental design to let participants better familiarize themselves with the audio-assisted reading and decide for themselves what they wanted. This section covers the results of this task.

While they were free to use it or not, 12 out of 19 (63.16%) participants re-used most or all of the audio buttons (equal or more than 60% of all audio buttons available). However, some participants explicitly mentioned in the post-experiment interviews that they thought they had to use them or that they had done it because they were in the lab (see section 3.6.2 for the results of the semi-structured interviews). Otherwise, they would have not done have it. Only one participant re-played the audio buttons while trying to answer the reading comprehension questions. Out of the 12 participants that have re-used the RWL technique for the last task, only four had a diagnosed learning disability (33.33%). Otherwise, the group of participants that re-played the audio players and thus re-used the RWL technique for the last task did not differ from the remaining nine participants that did not. Both groups expressed that they liked school and science equally when questioned with a 5-point Likert scale item on how much they liked each. We therefore asked them questions on their usage of the RWL technique in the subsequent interviews (see section 3.6.2).

3.4.8 Semi-structured interviews

Interviews were conducted at the end of the experiment to capture the participants' thoughts and feelings about their potential reuse of audio players and the process of reading-while-listening. The data was analyzed by conducting thematic coding, also known as thematic analysis. Thematic coding is a qualitative data analysis technique that involves identifying themes in participants' verbatims by examining the meaning of

words and sentence structure. Only relevant results are discussed in this section. Note that the following quotes from participants represent the general idea of what was said during the interviews.

To conduct the thematic coding, we first analyzed the responses of our 19 participants across the 12 questions asked by typing out the verbatims in Microsoft Word (Microsoft, Redmond, Washington, U.S.A.). The 12 questions were divided into three themes: General experience on the website (6 questions), future behaviors on the website (2 questions), and homework experience at home (4 questions). We attributed more questions on the general experience on the website because we were interested in collecting feedback on RWL and RO and the experiment had just ended, which means it was still in the participant's mind. Secondly, we highlighted the relevant thoughts and emotions expressed by the participants and attributed a code to each section. Once the coding was done for every verbatim section, the codes were regrouped in themes, which we were then able to write our conclusions from. A total of 5 themes were created: The usefulness of RWL, the participant's intention of reuse, the perceived benefits and inconvenience of RWL, and the use of multimedia materials while doing homework (online habits).

Following the analysis, 6 out of 19 participants found RWL to be helpful for them for various reasons. One reason was the fact that RWL offered a way to listen to words and sentences that were misunderstood. This helps learners understand how a word fits into the sentence structure and how its meaning contributes to the overall comprehension of the text. This is important for accurate communication and understanding in real-world language situations. For instance, to the question ''How did you find it, to have audio buttons on the website?'', a participant answered:

> *That's good, because like, let's say you don't really understand the meaning of the sentence, you can listen to it and read it at the same time, so that can help you.* (P04)

As previously stated, RWL allows for a better understanding of the pronunciation of certain words. This result reinforces this idea. However, another reason given for the re-

use of RWL was the fact that participants wanted to re-try it for fun or that they thought they had to re-do it since the previous tasks required them to. This type of reasoning must be considered when analyzing the behaviour of children or pre-teens in relation to new technology. When asked ‘’In the last task (the homework), you used the audio to read and listen. Why? Can you tell me more?’’, another participant replied:

> *Yes, it was more like checking how it works. [What were you checking?] Mmm like for example how it reads, the reading speed, or for example the audio quality. [And how was it, do you have any comments on that?] Uh yes um it's very good, on the other hand I find that if you misunderstood a little detail or that there's a little lag, you'll have to listen to all the big text again and if it's a big text, uh, it's... a little... yeah, so I suggest making a little slider for uh, to stop that.* (P08)

Another participant added:

> *In my head, I still had to listen to them, like in the second task I had to hear them. [So, if you were at home, would you use them?] No.* (P05)

Secondly, 9 out of 19 participants said they would not use them regardless of whether or not they used it for the last task. The main reason given being that it is not useful for them because they do not have reading difficulties or already have their own ways of dealing with them as they have learned strategies at home or in class to counter the possible effects of their difficulties.

One participant shared:

> *Uh, well, I would say that I won’t use it much, but there are people in my class who need it, so I find it practical. [Ok, why won't you use it a lot?] Because I don't need it, I have no difficulty with it [reading], and I'm able to read well.* (P03)

Another added:

> *Well, I find it good for the people it helps. Because you have people who, for whom it is more difficult to read. And so, for them it is better to hear because it is easier. [But for you?] No.* (P05)

This shows that individual differences must be taken in consideration when implementing educational technology solutions on a website as not all students with and without difficulties will use the technology the same way. Indeed, despite not having learning difficulties, some participants expressed that they would found it more difficult to read and listen at the same time. Perhaps because of the higher cognitive load required to manage both visual and auditory information simultaneously. When asked ‘’And what was the hardest for you during this test? Why?’’ a participant answered:

> *Remembering the information I heard. [Hmhm?] … [Do you have an example?] No. [And if I asked you, was it harder to remember the information you heard or read?] Heard.* (P06)

When asked ‘’If Alloprof revamps its website, is there anything you really want them to keep as it is now?’’ A student mentioned:

> *Please do not remove the texts to replace them with audio recordings because that would be more complicated for me.* (P05)

These examples further highlight the fact that individual differences and students’ opinions must be taken into consideration. Moreover, 5 participants mentioned that they would rather read by themselves for personal preferences reasons.

3.5 Discussion

3.5.1 Main results

The aim of the current study was to uncover to what extent does reading-while-listening impact 6th graders’ reading comprehension. More specifically, this study used psychophysiological tools to uncover to what extent does reading-while-listening impact young students’ visual attention, cognitive load and emotional valence in the context of science learning by using both quantitative and qualitative data. To our knowledge, few to no studies focused on visual attention by looking at a way to measure focal attention and visual exploration and precisely characterize visual patterns during a reading-while-listening task. Secondly, recent eye-tracking studies have expressed the need for more

qualitative research with children. Though this was not the entire focus of the present study, all participants were interviewed on their motivations, their habits and how they felt. Lastly, this study attempted to capture students' natural behaviors by letting them freely use the audio players.

Four distinct research questions were developed:

- What are the differences in visual patterns (e.g., fixations, saccades, etc.) during the RWL mode compared to the typical RO mode?
- To what extent does RWL impact experienced and inferred cognitive load?
- To what extent does RWL increase reading comprehension?
- What are students' attitudes and opinions towards reading-while-listening when taking into account their emotions and verbal feedback?

We hypothesized that RWL would result in less focus regarding students' visual patterns, but that it would lead to an overall positive emotional valence, a higher perceived and experienced cognitive load or mental effort. All those hypotheses were supported except for the perceived cognitive load, which remained the same in both the reading-only and reading-while-listening conditions. On the other hand, we also hypothesized that cognitive load would independently reduce reading comprehension scores and that positive emotions and visual attention would increase them. These hypotheses were not conclusive. Thus, the null hypothesis for H3, H5 and H7 were not rejected.

After analyzing our data, we found that reading-while-listening increased experienced cognitive load as supported by the pupil dilatation data. As expected, simultaneously reading and listening increased the demands on working memory as predicted by the CTL theory. According to the theory, RWL can increase cognitive load because it requires the brain to process two different streams of information simultaneously. When reading, the brain is engaged in visual processing, which involves interpreting and analyzing the words on the page. When listening, the brain is engaged in auditory processing, which involves interpreting and analyzing the sounds that are being

heard. This result is consistent with previous works that have evaluated the relationship between RWL and cognitive load. Moussa-Inaty et al. (2011) explored the effects of simultaneous reading and listening with Arabic-speaking university students who were learning English as a foreign language. Researchers instructed the students to learn English words and sentences through either reading alone or simultaneous reading and listening to the same spoken material (Moussa-Inaty et al., 2011). Subsequently, the students underwent tests in reading, writing, and listening skills. The outcomes of both the learning process and the tests supported the proposed hypothesis that reading-while-listening would increase the students' cognitive load. These results also align with another study in which five experiments were conducted to examine the effects of cognitive load management using explanatory notes in reading passages for readers with different levels of expertise. Researchers found that the text acted as a redundant source of information imposing an extraneous cognitive load which led to less gains in vocabulary (Yeung et al., 1998). When two modalities are used simultaneously, the brain must integrate and process the information from both streams, which is a harder task than processing one stream only. As the brain must handle additional demands, cognitive load is increased.

Interestingly, the changes in cognitive load were not enough to be perceived by the participants as the NASA-TLX scores were not statistically different depending on the experimental condition. This result could be explained by the fact that redundancy is not necessarily a negative phenomenon to all learners. For instance, Lightbown (1992) conducted a study comparing the effects of an extensive RWL instructional intervention to teacher-led instruction among primary schoolchildren. The results demonstrated that RWL was equally effective, if not more so, than teacher-led instruction in developing receptive and productive language skills, despite the increased cognitive effort it requires. In a subsequent study by Lightbown et al. (2002), a follow-up investigation after six years of extensive RWL intervention revealed that learners performed at par with comparison groups in receptive measures and oral production, although the approach was found to be less effective for written production.

Additionally, RWL was perceived as more pleasurable than RO as the emotional valence data suggested. This could be explained by the fact that audio players were new

on the website, and it felt like a new experience to many. On top of this novelty effect, combining reading and listening can lead to a more engaging and interactive learning experience for young students. Learners may find it more enjoyable than simply reading a text or listening to an audio recording separately. In other words, reading-while-listening can create a dynamic in which the learner feels immersed, making the learning process more motivating and interesting. These results on emotional engagement have been replicated in the past. However, most studies on the subject were made with adult learners in the context of audiobook or within a classroom. One of the rare studies that have looked at the relationship between emotional engagement and RWL through audiobooks with primary or secondary school students found that it could potentially foster positive outcomes such as a feeling of general wellbeing. In a short review of the literature by Best (2020), it has been reported that in a research project conducted by Moore and Cahill (2016 as cited in Best, 2020) with 31 secondary school students with reading difficulties, students reacted and commented positively to the one of the activities which involved having a story read aloud to them across several weeks while they could read the text simultaneously. In another study, participants were asked to read and/or listen to a story with the audiobook version (i.e., RWL condition) and the film adaption (i.e., audio and images condition) (Best, 2020). Participants filled self-reported questionnaires about their levels of engagement and had their physiological responses measured (i.e., heart rate and dermal sudation) to assess unconscious forms of engagement (Best, 2020). The results showed that though participants reported the movie condition to be more engaging, unconsciously, their physiological responses suggested that they were in fact more engaged with the audiobooks than the movie adaptations.

As for visual patterns, though both results were close to zero, the RO condition had a more positive result in terms of K coefficient than the RWL condition. During the RO condition, participants experienced longer fixations followed by shorter saccade amplitudes as their attention was divided on very few areas of interest compared to the RWL condition. As the K coefficient scores have shown, participants were more visually attentive in the RO condition and exhibited a focal processing of the information. As explained in the methodology section, in eye-tracking research, two general types of visual attention exist: ambient and focal.

Ambient attention involves a scanning pattern across stimuli as typically seen in the early stages of scene perception. It's marked by brief fixations succeeded by extended saccades. However, focal attention is characterized by prolonged fixations followed by shorter saccades, indicating a more concentrated processing of the stimuli. Increased focus suggests deeper attention and active information processing. As a reminder, a K coefficient score over 0 (positive score) indicates focal processing, which is characterized by short saccades and long fixations. On the other hand, a K coefficient under 0 (negative score) indicates an ambient processing of the information, which is characterized by long saccades and short fixations. Lastly, when K is equal to 0, this means the person exhibited either long saccades and long fixations or short saccades with short fixations.

One reason for this result is that reading-while-listening allows readers to look at different areas on a web page as the audio track still conveys the same information as the text. On the other hand, reading-only requires readers to visually focus on the words only. In a recent exploratory study conducted by Serrano and Pellicer-Sánchez (2019), the eye movements of young learners were analyzed while reading and listening to a text. The study revealed that when auditory text was present, the participants allocated more time and attention to the images than anything else on the page. An alternative interpretation of this result is the audio tracks might have been too slow or too fast for our participants, making them re-read the different passages. We did not, however, test that hypothesis.

Lastly, we found that participants' reading comprehension scores did not differ regardless of the experimental condition they were put in. This means that RWL did not lead students to learn more. It also did not significantly affect their learning performance in a negative way. In fact, both conditions led to similar results. One explanation for that has to do with the methodology and the sample used. The mean comprehension scores in both conditions were not different from the baseline meaning that our participants were already high achieving readers regardless of their learning disabilities or the lack of. Comprehension was also tested through short multiple-choice quizzes, making it harder to detect a statistical difference. Another possible explanation, which has been supported in previous studies, is that RWL does not always impact reading comprehension in a short

period of time (i.e., in non-longitudinal studies). However, RWL is not detrimental on comprehension either as shown in other recent studies (e.g., Chang & Millett, 2015).

3.5.2 Implications and practical applications

Practically speaking, this study demonstrated that whether instructional designers, teachers or design experts should provide auditive assistance technologies depends on individual differences. Indeed, even when students are diagnosed with learning disabilities, they do not necessarily find it useful to use reading-while-listening. They may already have their own techniques to overcome their difficulties. On top of that, reading-while-listening requires more mental effort than reading-only meaning that some students may feel overwhelmed and not use it. On the other hand, it is a pleasurable experience, and it does not reduce learning outcomes, meaning that it could still be available to students without interfering with their progress in subjects that are more challenging such as sciences. Some students may find it difficult to process both written and spoken sentences simultaneously and may benefit from focusing on one modality at a time instead. In summary, the decision to encourage reading-while-listening in the context of online learning of complex subjects such as sciences should be based on a careful consideration of the content being taught the students' individual needs and the learners' preferences.

3.5.3 Limitations

There are several limitations to this study. Firstly, our measure of reading comprehension was short and didn't have enough items to detect a statistical difference. Indeed, there were only three items per test and a total of three comprehension tests, making it harder to detect a difference if there was any. Moreover, we gave children multiple-choice tests instead of the short answer type of answer where they would openly write their own thoughts. This limited the depth of the analyses because students could have obtained good answers by luck. Thirdly, though recruiting children for lab studies is already difficult, it would have been better to recruit children of different profiles. Many children in our sample were good readers regardless of whether they had been diagnosed with a learning disability diagnosis or not. Our sample was therefore skewed from the

start with more academically successful students than not. That is also the reason why many participants expressed that though the auditory assistance was enjoyable, it was not necessary to better comprehend a text. Lastly, the lab environment also made it difficult to capture the natural behaviors of students for the last task, in which they were instructed to read the text and answer the questions as they would at home.

3.5.4 Future directions

Future studies should investigate the longitudinal effects of RWL as reading comprehension and more specifically, science comprehension, begins early in childhood and ends in adulthood. Though children with learning difficulties and neurological disorders are often the ones being cited as the users of auditive assistance in primary and secondary schools, it could be interesting to explore the exact user profile of those digital solutions and whether they are casual users or depend completely on such technology. Lastly, it could be interesting to go beyond typical RWL and start exploring the effects of other auditive assistance technologies such as speaking bots. With the rise of artificial intelligence, it is no surprise to expect a change in auditive assistance technologies that can now do more than read texts. How do children feel about these being used at home or in class? How does their use differ from traditional RWL? Such questions could be answered as future directions.

3.6 Conclusion

In conclusion, the present study aimed at understanding the effects of reading-while-listening. This study has provided further evidence on the benefits of RWL compared to the RO. The results of the present study demonstrated that the addition of auditory input led to positive emotional valence, an increase in experienced cognitive load and less visual attention. Nonetheless, despite increasing the emotional engagement of the learners, RWL has no impact on reading comprehension when it is evaluated through multiple-choice questions right after reading. These results suggest that though RWL is generally well perceived by primary school students, it does not improve students' retention of the information in such a short period of time. Practically speaking, it could be a waste of time and budget to implement audio tracks on a website if students are not

going to reuse them or if their learning performance does not increase significantly. Moreover, students with learning disabilities tend to already have methods to improve their learning experience whether it is through parental assistance, medication, reading techniques, etc. This study provided details on the experience of RWL through eye-tracking, self-reported questionnaires, and semi-structured interviews. Future studies should look at the longitudinal aspect of learning and knowledge acquisition and test whether RWL as a long-term technique could improve comprehension. Studies that incorporate parents are also welcomed.

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Chapter 4: Conclusion

4.1 Summary

The primary aims of this thesis were twofold. Firstly, we sought to assess children's level of engagement with reading-while-listening compared to reading-only by examining their patterns of ambient-focal visual attention and evaluating their emotional responses. Secondly, we aimed to determine the impact of reading-while-listening on reading comprehension compared to reading-only.

This last chapter is a summary of the methods that this thesis undertook to discover the gaps in the current literature and address them through an experimental study. The results of the experimental study and their implications are revisited. The chapter ends with a conclusion which highlights its theoretical and practical contributions, the limitations and the future studies that can be conducted.

4.2 Summary of the research question and the main findings

This thesis started with a review of the literature. This review delved into the current literature to uncover the potential advantages and disadvantages of RWL from different perspectives. We were more specifically interested on its effects on psychophysiological processes compared to reading-only and practical implementations of the RWL approach across diverse educational settings for children and pre-teens (K-12 level). Results indicated that RWL can foster a more profound comprehension, boost memory retention, and amplify overall learning results. However, this review identified several existing gaps. First, there was a need for long-term studies to thoroughly comprehend the extent to which RWL influences psychophysiological processes compared to RO, as children's cognitive processes and reading strategies evolve over their school years. Second, there was few evidence supporting the effectiveness of RWL in school subjects unrelated to language learning and story reading. Though language learning is important, the relevance of RWL should be studied with STEM subjects as

well. Finally, the findings remained inconclusive when examining students' eye movement patterns when evaluating RWL compared to RO.

Following the literature review that was done in the second chapter, gaps in the literature were identified. To fill the gap of knowledge surrounding reading-while-listening, an experimental study was designed. The study used a repeated-measure experimental design. The first independent variable was the subject used during the reading tasks. The second independent variable was the modality used during the reading tasks. The diagnostic of learning disabilities and the texts topics were considered as control variables.

This research had two primary goals. Firstly, it aimed to assess children's level of involvement when engaging in reading-while-listening, focusing on their visual attention patterns and emotional responses compared to the more common practice of online reading without auditory accompaniment. Secondly, the study sought to evaluate the educational benefits of reading-while-listening, with a particular focus on its utility and efficiency as a tool for students in the context of science education. The following research questions have been developed:

In the context of online science learning,

1) What are the differences in visual patterns (i.e., ambient-focal attention) during the RWL mode compared to the typical RO mode?

2) To what extent does RWL impact experienced and inferred cognitive load?

3) To what extent does RWL increase reading comprehension?

4) What are students' attitudes and opinions towards reading-while-listening when taking into account their emotions and verbal feedback?

Following the development of these four research questions, seven different hypotheses were formulated.

H1: We hypothesized that RWL would increase students' reading comprehension scores.

H2: We hypothesized that their cognitive load would increase in the RWL condition compared to the RO condition.

H3: We hypothesized that high perceived and experienced cognitive load levels would reduce reading comprehension scores.

H4: We hypothesized that learners would find the RWL condition to be more pleasurable (i.e., generate more positive emotions) than the RO condition.

H5: We hypothesized that positive emotions would increase reading comprehension scores.

H6: We hypothesized that RWL would lead users to generate more visual exploration behaviours compared to the RO condition.

H7: We hypothesized that increasing visual attention would lead to higher comprehension scores. In other words, both variables would be positively correlated.

Out of all the hypotheses, three were statistically significant (H2, H4, H6).

The study found that when students were instructed to read and listen to science texts at the same time, compared to reading only, there was an increase in visual dispersion, an increase in emotional valence, and a rise in cognitive load experienced. However, this did not statistically affect reading comprehension scores. From the interviews, it was clear that while students found the audio mechanisms enjoyable, they did not intend to use them regularly as they either did not have reading difficulties or had already developed their own strategies to manage their difficulties. RWL was found to be more pleasurable (i.e., generate more positive emotions) than the RO condition because it was new, engaged different senses and allowed for more flexibility than traditional reading. However, it led to higher cognitive load levels because reading and listening simultaneously can lead working memory to reach its limited capacity. Cognitive resources must be allocated to both the processing of visual and auditory information. In conclusion, RWL increased enjoyment in learning, there was no significant intention among participants to reuse it. Despite the increased mental effort needed to process both verbal and visual information,

RWL did not have a negative effect on reading comprehension. However, it led to visual patterns associated with exploration.

4.3 Theoretical and practical contribution

The present thesis makes theoretical and practical contributions to the fields of educational technology and user experience. This section highlights the key contributions and implications of the study.

Firstly, this study expands our theoretical understanding of the cognitive processes involved during reading-only and reading-while-listening by comparing the two. Following the results of our experimental study, this thesis provides insights on young users' emotions, visual attention, cognitive load, and learning performance. It was found that compared to reading-only was successful in increasing students' engagement as the positive valence scores and interviews suggested. However, it did not impact learning. Additionally, it led to less visual dispersion.

Building upon existing theoretical frameworks, such as the theory of multimedia learning, this study proposes that reading-while-listening, though cognitively challenging, does not negatively impact reading comprehension.

The wide array of measures used in this empirical study should also be noted as contributing to the refinement of existing knowledge within the literature. With eye-tracking measures evolving and becoming more precise, it becomes possible to advance the knowledge around visual attention and its relationship to other constructs such as reading comprehension. In this study, a relatively new measurement of visual dispersion was used as an example of such advancement. Moreover, qualitative data were collected through interviews which added more context to the quantitative results, regardless of their significance.

Practically, the findings of the following thesis have practical implications for specialists in the field of education and user experience. By identifying effective instructional strategies that students appreciate and are willing to use to support their learning, educational specialists can offer the right tools to the learners. In the case of

reading-while-listening, the experimental study supported the idea that individual differences must be taken into consideration when offering support to students with difficulty as they may already have their own reading strategies to succeed. Those strategies may include medication as well which, when used, can alter the way the brain processes audio-visual information in the context of learning. Nonetheless, this research project provided insights on the strengths and weaknesses of using the reading-while-listening method in the context of online learning.

In summary, this research project offered both practical and theoretical contributions to the fields of user experience and education. Together, these contributions contribute to the overall advancement of the field and have the potential to drive positive changes in theory and practice.

4.4 Research limitations

While the experimental study aimed to investigate various aspects of how RWL affected children's learning experience and cognition, several limitations should be acknowledged. These limitations pertain to the sample characteristics, recruitment method, language proficiency, and the lack of specific information regarding participants' schools and diagnosed learning disabilities.

Firstly, the sample used in this study was recruited solely through the newsletter sent to the parents. Therefore, it was impossible to select struggling students directly and randomly. It is possible that the sample was biased because, for the most part, parents of children with good grades in science or who already had a high interest in the subject signed up. This recruitment method may have introduced another bias as it primarily captured individuals who had access to Internet at home and were living close to the lab. Consequently, the findings may not be fully representative of the general population.

Secondly, all the children included in this study had to speak French to be able to participate. However, they did not necessarily have to go in a French school or speak French at home. We did not evaluate their level in French even though Montreal has

primary schools in both languages. This may have affected their comprehension, thereby limiting the generalizability of the study findings.

Additionally, the study did not ascertain the specific diagnoses of learning disabilities for the participants. Learning disabilities encompass a wide range of conditions with varying characteristics and educational implications. The lack of detailed diagnostic information hinders the ability to differentiate and analyze the specific effects of different types of learning disabilities on the outcomes measured in this study. Therefore, the absence of such data limits the ability to account for these contextual factors in the interpretation of the findings.

As for the experiment itself, some limitations must be considered. These limitations include the laboratory setting and he evaluation of the reading comprehension. For the laboratory setting, it is possible that children did not naturally because they were not in the comfort of their homes or because they felt pressured by the researchers or the environment (i.e., being in a university). As for the evaluation of the reading comprehension, it was done by asking three multiple-choice questions at the end of each task, which was not enough to evaluate their comprehension in depth. Right answers may have been due to chance. Instead, longer, open-ended questions could have been used. However, they are time-consuming and may lead to fatigue, especially with younger populations.

In conclusion, it is important to acknowledge these limitations, as they highlight potential sources of bias and restrict the generalizability and comprehensiveness of the findings. Future studies should aim to address these limitations by employing diverse recruitment methods, including multiple languages, collecting comprehensive information about participants' schools, and incorporating specific diagnostic criteria for learning disabilities to enhance the validity and applicability of the research outcomes.

4.5 Future research

This study provides valuable insights into the effects of reading-while-listening on children's learning experience. However, there are several avenues for future research that could enhance our understanding of this instructional approach and its potential benefits.

Firstly, long-term effects should be studied with a larger sample to better assess the efficacy and long-term impact of reading-while-listening. Future studies should employ a larger sample with children of similar or different reading struggles, with and without disabilities, that impact their reading skills. By increasing the sample size, researchers can obtain a more comprehensive understanding of the generalizability of the observed effects and explore potential individual differences in response to this instructional method.

Secondly, while this study focused on a specific age group (i.e., 6th graders), it would be valuable to investigate the effects of reading-while-listening on younger children as well as they are building their vocabulary and fluency skills. Exploring the effectiveness of this approach with younger learners could provide insights into its potential benefits during critical periods of language and cognitive development. This new sample of younger children could be followed in the context of a longitudinal study to understand the long-term effects of reading-while-listening.

Lastly, given the advancements in technology, future research should consider integrating AI components into reading-while-listening interventions. AI-based systems could adapt the reading material and audio content to individual learners, providing personalized and tailored experiences. Investigating the use of AI in conjunction with reading-while-listening could uncover novel approaches to optimize learning outcomes and engage children more effectively.

By addressing these areas of future research, we can further expand our knowledge of the effects of reading-while-listening on children's learning experience. These investigations will contribute to the development of evidence-based instructional strategies that promote effective learning and academic achievement in diverse educational settings.

Appendix A: Interview guide

Topic 1: Experience on Alloprof

I am now going to ask you questions about your experience with the 3 reading sheets: on the animal cell, on the Earth and on technological systems.

1. What did you find easiest while reading the 3 texts? Why?
2. And what was the most difficult? Why?
3. Which elements of the Alloprof website helped the most in answering the questions?
4. If Alloprof remade their website, is there anything you would really want them to keep the way it is now?
5. How did you find it, having audio buttons on the Alloprof website?
6. During the last task (homework), you used/did not use audio much to ____. For what? Can you tell me more?

Topic 2: Future Experiments

1. What would you do to prepare for your next exam?
2. Would you come back to the Alloprof website if you needed help before an exam? Why?

Topic 3: Homework experience

1. What do you do when you have difficult homework?
2. When you do homework, do your parents help you a little or a lot?
3. When you do your homework, do you use websites?
   - If no: go to the message below.
   - If yes: What do you like most/least about the websites you use when doing your homework?

That's it for me today. I thank you for your answers, and for your participation, it will help us a lot, and help Alloprof too. You can come with me, we will be able to join your parent in the waiting room.

Appendix B: Bloom taxonomy

Remember	Understand	Apply	Analyze	Evaluate	Create
Choose	Classify	Apply	Analyze	Agree	Adapt
Define	Compare	Build	Assume	Appraise	Build
Find	Contrast	Choose	Categorize	Assess	Change
How	Demonstrate	Construct	Classify	Award	Choose
Label	Explain	Develop	Compare	Choose	Combine
List	Extend	Experiment	Conclusion	Compare	Compile
Match	Illustrate	with	Contrast	Conclude	Compose
Name	Infer	Identify	Discover	Criteria	Construct
Omit	Interpret	Interview	Dissect	Criticize	Create
Recall	Outline	Make use of	Distinguish	Decide	Delete
Relate	Relate	Model	Divide	Deduct	Design
Select	Rephrase	Organize	Examine	Defend	Develop
Show	Show	Plan	Function	Determine	Discuss
Spell	Summarize	Select	Inference	Disprove	Elaborate
Tell	Translate	Solve	Inspect	Estimate	Estimate
What		Utilize	List	Evaluate	Formulate
When			Motive	Explain	Happen
Where			Relationships	Importance	Imagine
Which			Simplify	Influence	Improve
Who			Survey	Interpret	Invent
Why			Take part in	Judge	Make up
			Test for	Justify	Maximize
			Theme	Mark	Minimize
				Measure	Modify
				Opinion	Original
				Perceive	Originate
				Prioritize	Plan
				Prove	Predict
				Rate	Propose
				Recommend	Solution
				Rule on	Solve
				Select	Suppose
				Support	Test
				Value	Theory

Appendix C: Baseline text

Why do we have hiccups?

Our body is sometimes very mysterious. Some of his reactions may also intrigue us. For example, why do we get hiccups? There are many reasons why you may have hiccups. Luckily, there are also different ways you can use to stop it!

What are hiccups?

First of all, having hiccups is when you feel your upper body contracting while breathing and you make the “hic” sound. You can't decide to have hiccups. This is called a reflex. It's something you can't control, like when you put your hand near a hot pan in the kitchen and quickly pull it away so as not to burn yourself. You don't have to think about this gesture. Your body does it on its own, by reflex.

More specifically, hiccups are caused by the diaphragm. It's a muscle located just above your stomach that allows your lungs to empty and fill with air. When it contracts on its own, by reflex, this is what causes hiccups.

It doesn't last long and you can't control it. It’s a bit like a calf cramp!

There are several reasons why your diaphragm may contract, but the main culprit is... your stomach! In fact, most of the time, you have hiccups when your stomach is active, so after eating or drinking something. Here are some situations after which you might experience hiccups:

- Having eaten a large meal;
- Have drunk a soft drink;
- Having eaten something very cold and then another very hot food;

• Eating too quickly.

In these situations, your stomach becomes agitated: it swells and becomes a little bigger than usual. As it takes up more space in your body, it irritates your diaphragm, which is located above it. The diaphragm reacts and that's when the hiccups are caused!

Finally, know that laughing a lot can also cause your diaphragm to contract and therefore cause hiccups.

Appendix D : List of questionnaires

Pre-test questionnaire

Indicate what best describes your situation...

How often do you use the Alloprof site to do your homework?

Scale 1-5: Never, Rarely, Sometimes, Often, Always

How often do you use the Internet to do your homework

Scale 1-5: Never, Rarely, Sometimes, Often, Always

How much do you like school?

Scale 1-5: Not at all, a little, moderate, quite a bit, a lot

How much do you like science?

Scale 1-5: Not at all, a little, moderate, quite a bit, a lot

Post-task questionnaire

Have you ever seen this text in class?

Yes / No / I don't know or I don't remember

CSAT

Indicate your level of satisfaction with your reading of (text title).

Likert scale 1-5: Not at all satisfied, somewhat satisfied, neutral, satisfied, very satisfied.

Perceived usefulness

Likert scale (1 = "strongly disagree"; 7 = "strongly agree")

Indicate whether you agree or disagree with the following statements...

Using this website for my homework would help me complete my tasks more quickly.

Using this website could improve my performance during homework.

Using this website for homework could increase my productivity.

Using this website would increase my efficiency for my homework.

Using this website would make my homework easier.

I find this website useful for answering my questions.

NASA-TLX

Scale: 0 = negative to 100 = positive

How mentally demanding was the previous task?

How quickly did you feel you had to react?

How successful do you think you were on the previous task?

How much effort (physical or mental) did you have to make to perform the previous task?

During the previous task, how stressed, irritated, or unconfident did you feel?

Post-test questionnaire

Likert scale 1-5: Strongly disagree to Strongly agree

Indicate whether you agree or disagree with the following sentences.

When the teacher gives me instructions orally, I understand better.

When someone tells me how to do something in class, I learn it better.

I remember things I heard in class better than things I read.

I learn better in class when the teacher explains the material orally.

I learn better in class when I listen to someone.

I learn best when I read what the teacher writes on the screen.

I remember instructions better when I read them.

I understand better when I read instructions.

I learn better by reading than by listening to someone.

I learn more from reading text on the screen than from listening to my teacher.

Reading comprehension questionnaire

Hiccups

Indicate what other example of a reflex is mentioned in the text.

Answer: Remove your hand quickly from a stove to avoid burning yourself

Selects the correct aperture definition.

Answer: It’s a muscle located above your stomach

How does the stomach irritate the diaphragm? Choose the correct answer.

Answer: It swells, becomes a little bigger and takes up space

The animal cell

Identifies which component of the cell produces energy for the cell by converting sugars contained in food.

· Vacuole

· Mitochondria

· Nuclear envelope

· Cellular membrane

Select the correct definition of an organelle.

· Organelles are the constituents of the cell which are immersed in the cytoplasm.

· Organelles are flagella.

· Organelles are gametes, white blood cells or neurons.

· Organelles are animal and plant cells.

Indicate which of these statements is TRUE.

· All cells have the same characteristics and functions.

· There is only one type of cell: plant cells.

· Red blood cells are part of animal cells.

· The cell membrane directs cell division and contains chromosomes.

The internal structures of the Earth

Indicates which part of the Earth's structure corresponds to the following description:
"This is the hottest part".

· Earth's crust

· The lower mantle

· The inner core

· The upper coat

Indicates which structure of the Earth lies above the core.

· Continental plate

· Earth's crust

· Lower mantle

· Oceanic plate

Indicate which of these statements is FALSE.

· The mantle is part of the Earth's core.

· The mantle is made up of solid rocks and molten rocks.

· The lower mantle is the more viscous part of the mantle.

· The temperature of the mantle is much higher than that of the earth's crust.

Technological systems and their components

Select the correct definition of a technological system.

· A technological system is an organized set of components linked together.

· A technological system is a process that emits light.

· A technological system is an electrical assembly only.

· A technological system is a set of simple components. There is no complex system.

Determine which of the following subsystems is not part of the complex technological system of the bicycle.

· Wheel subsystem

· Braking subsystem

· Electrical subsystem

· Transmission subsystem

Complete the following sentence: “A component is a part (part, organ or device) of a technological system or a _____”

· Intermediate organ of movement transmission

· Subsystem

· Electrical mechanism

· Manual system