Master Thesis

Short-Term and Long-Term Modality Effects in a Learner-Paced vs. System-Paced Multimedia Lesson for Children

University of Twente
Master Psychology in Learning Sciences

Student
Adiëlle Niebeek (S1791583)
m.g.a.niebeek@student.utwente.nl

Supervisors
Prof. dr. P.C.J. Eliane Segers
e.segers@bsi.ru.nl
Dr. Hans van der Meij
h.vandermeij@utwente.nl

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Summary

The modality effect holds that presenting information in audiovisual presentations provokes better learning outcomes than presenting it in visual-only presentations, because of an overload in working memory for the visual-only presentations. The modality effect has mostly been evidenced in system-paced conditions and directly after learning, whereas recent studies showed different results for learner-paced conditions and on long-term effects. Furthermore, the modality effect has scarcely been related to variation in working memory. Therefore, the present study investigated the effect of mode (audiovisual vs. visual-only) and pace (learner-paced vs. system-paced) of a multimedia presentation on children's retention and transfer. A group of 275 children from 5th and 6th grade of Dutch primary schools was randomly divided into four groups (system-paced audiovisual; system-paced visual-only; learner-paced audiovisual; learner-paced visual-only). They were tested for retention and transfer immediately after the lesson. Delayed retention and transfer was tested one day after the lesson. The present study revealed an interaction between mode and pace, suggesting a modality effect on retention when lessons were system-paced, and a reversed modality effect on retention when lessons were learner-paced. However, follow-up analyses did not show any significant differences between the modes in the two pace-conditions; a modality effect and reversed modality effect was not found. Auditory working memory did show a modality effect over time, in the sense that more forgetting took place in children with higher auditory working memory in the audiovisual compared to the visual-only condition. It can be concluded that in order to evaluate modality effects, working memory should be taken into account.

Keywords: *modality effect, children, working memory, system-paced vs. learner-paced, long-term outcomes*

Inhoud

Introduction

Digital media increasingly influence our daily lives. The use of digital media in education has led to more attention for the development of guidelines in designing multimedia instruction. An example of this is the design of lessons in which audio material is combined with visual material. Foundational studies on the effects of learning from an audio-visual presentation with pictures and spoken text versus learning from a visual-only presentation with pictures and written text showed better learning outcomes for the former (see Ginns, 2005, for a meta-analysis). This effect is called the modality effect and is often measured with retention tests and transfer tests. Retention tests are used to measure a learner's ability to remember newly acquired information, whereas transfer tests are used to measure a learner's ability to use newly acquired information to solve new problems (Mayer, 2014).

Several issues exist in research into the modality effect. First, modality effects in system-paced lessons (fixed order and pace, determined by the system) are not always replicated in learner-paced lessons (pace determined by the learner and a possibility to return to previous pages or to skip pages; Ginns, 2005). Studies that used learner-paced lessons often did not find a modality effect on the short-term (Van den Broek, Segers, & Verhoeven, 2014; Inan et al., 2015; Tabbers, Martens, & van Merriënboer, 2004). Some of these studies with learner-paced lessons even found an unexpected reversed modality effect (i.e., better retention or transfer scores for visual-only conditions) on the long-term. The difference in short-term and long-term findings shows a need for research into modality effects on the long-term. However, only a few studies tested for long-term modality effects. The results of these studies showed that the modality effect can change over time (Van den Broek et al., 2014; Segers, Verhoeven, & Hulstijn-Hendrikse, 2008; She & Chen, 2009; Witteman & Segers, 2010). Furthermore, most research on the modality effect focused on adults and little research has been conducted with children (but see Leahy & Sweller, 2011; Segers et al., 2008; Witteman & Segers, 2010). Therefore, the generalizability of the modality effect is not quite clear. Finally, although the theory of the modality effect is based on the theory of working memory, there has been little research into the role of working memory on the modality effect (but see Gyselinck, Jamet, & Dubois, 2008; Seufert, Schütze, & Brünken, 2009; Witteman & Segers, 2010). Following the theory, working memory capacity should be a moderator of the modality effect (Baddeley, 2002; Mayer, 2014), but such an effect has not been shown in any study.

The goal of the present study was thus to investigate the interaction between working memory and the modality effect in children by comparing short-term and long-term learning outcomes for audio-visual vs. visual-only learner-paced multimedia lessons with audio-visual vs. visual-only system-paced multimedia lessons.

Modality Effect

The modality effect holds that learning from an audio-visual presentation produces better learning outcomes than learning from a visual-only presentation. It can be explained in terms of working memory, in particular with the phonological loop and the visuo-spatial sketchpad (i.e., the verbal and the visual subsystems of working memory) and is an aspect of the Cognitive Theory of Multimedia Learning (CTML; Mayer, 2014). One assumption in CTML is that humans possess an auditory-verbal and a visual-pictorial channel. The difference between these two channels is conceptualized in the sensory modalities approach (auditory/visual) and the representation mode approach (verbal/pictorial). According to the sensory modalities approach, a distinction is made between information presented via the ears and information presented via the eyes. Concretely, one channel processes auditory material (such as spoken words or background sounds), whereas the other channel processes visual material (such as pictures, video, animation, or printed words). According to the representation mode approach, a distinction is made between information presented in verbal form and information presented in visual form. One channel processes verbal material (such as spoken or printed words), the other channel processes non-verbal or pictorial material (such as pictures, video, animation, or background sounds; Mayer, 2014). Since both channels have limited capacity, information should be divided onto both channels, which minimizes the risk over overloading one channel. Thus, when information is presented in audio-visual form, both channels are adopted, which leads to efficient use of working memory and therefore to better learning outcomes then when information is presented in visual-only form (i.e., the modality effect; Mayer, 2014). Moreover, learners are not able to process written text and pictures simultaneously, which entails split-attention (Low & Sweller, 2014). When information is presented in audio-visual form, it is possible to process text and pictures simultaneously.

However, Mayer's interpretation of working memory is not completely in line with Baddeley's interpretation of working memory, whose theory is a leading theory of working memory used in modality effect studies. The difference between Baddeley and Mayer is visible in their opinion on the manner in which written text is processed. Mayer states that written text is initially processed in the visual-pictorial channel and then transferred to the auditory-verbal channel. Conversely, according to Baddeley (2000), written text is processed in the phonological loop (see Schüler, Scheiter, & van Genuchten, 2011; Schüler, Scheiter, Rummer, & Gerjets, 2012). Baddeley substantiates his opinion on the manner in which text is processed with the explanation that the phonological loop serves two functions: "it can maintain material within the phonological store by subvocal repetition, and it can take visually presented material such as words or nameable pictures and register them in the phonological store by subvocalization" (Baddeley, 1992, p. 558).

Summarizing, this means that the modality effect is less likely to occur based on Baddeley's theory than based on Mayer's theory (Schüler et al., 2011; Schüler et al., 2012). Mayer's assumption that the visual part of the visual-pictorial channel might be overloaded when written text is presented with pictures due to the belief that written text is initially treated as visual images in working memory (i.e., visuo-spatial load explanation) is often used as main explanation for the modality effect. However, due to Baddeley's theory that both written and spoken text are processed in the phonological loop, the ground theory of the modality effect can be called into question. The present study adheres to the theory of Mayer.

Learner-Paced vs. System-Paced Multimedia Lessons

Research on the modality effect has shown overall robustness of the modality effect (Ginns, 2005). However, inconsistent findings reveal the need for the identification of boundary conditions. Based on CTML, the modality effect is expected to appear when material is complex, when graphics are dynamic rather than static, when learners have a low level of knowledge, when verbal segments are short, and when words are familiar (Mayer & Pilegard, 2014). Another important boundary condition concerns pacing of the material. The first studies on the modality effect were conducted with system-paced multimedia lessons (the pace and order of the lesson is fixed and set by the system). However, when multimedia material in subsequent studies was learner-paced (the pace of the lesson is defined by the learner and the learner has a possibility to return to previous pages or to skip pages), evidence for the modality effect was less strong, namely $d = -0.14$ (Ginns, 2005). Several studies, both in adults and children, even showed a reversed modality effect on transfer in visual-only conditions when material was learner-paced (Van den Broek et al., 2014; Inan et al., 2015; Segers et al., 2008; She & Chen, 2009; Stiller, Freitag, Zinnbauer, & Freitag, 2009; Tabbers et al., 2004; Witteman & Segers, 2010).

An explanation for a reversed modality effect in visual-only conditions when material was learner-paced might be the fact that written text is permanent information, whereas spoken text is transient information. Permanent information can be reread, whereas transient information must be maintained in working memory in order to be integrated with subsequent information. This results in decrease in learning, which is termed transient information effect (Leahy & Sweller, 2016). In addition, in learner-paced conditions learners can choose how much time they spend on studying the material. When learners receive enough time to study material, they can use beneficial reading strategies for written text. For spoken text this is more difficult, due to the fixed pace and order of the text (Van den Broek et al., 2014).

In order to understand the manner in which pacing affects the modality effect, research should compare learner-paced and system-paced conditions. However, besides the study by Izmirli and Kurt (2016), there has been little research into the modality effect that compares learner-paced conditions with system-paced conditions. In the study by Izmirli and Kurt, ninety-seven university students watched a learner-paced audiovisual, learner-paced visual-only, system-paced audiovisual, or system-paced visual-only lesson about computer-aided instruction. There were no significant differences between the achievements of the groups (Izmirli & Kurt, 2016). There is no research into the modality effect that compares learner-paced conditions with system-paced conditions with children as participants.

Short-term vs. Long-term Modality Effects

In order to learn, information must be remembered over time. Only few studies incorporated long-term learning outcomes in their research into the modality effect. Regarding retention, these studies showed inconsistent results. Van den Broek et al. (2014) found no modality effect on the short-term, while they found a reversed modality effect on the long-term (d = 0.56). Segers at al. (2008) found a modality effect on the short-term (d = 0.55) and Witteman and Segers (2010) found a reversed modality effect immediately after the intervention (d = 0.23) and no significant differences between conditions a day later and a week later. Regarding transfer, Segers et al. (2008) and Witteman and Segers (2010) showed that after a day, learners in written text conditions acquire better scores on transfer than learners in spoken text conditions. Thus, the modality effect for transfer reversed on the long-term (d = 0.55; d = 0.12).

An explanation for this latter effect might be that written text activates auditory and visual traces in memory, which may improve retention (Nelson, Balass, & Perfetti, 2005;

Witteman & Segers, 2010). Such double sensory processing could provide more retrieval cues that facilitate later recall (Van den Broek et al., 2014, p.440). Note, that this assumption would not be supported by Baddeley's theory, which claims that text activates auditory traces only (Baddeley, 2000).

Another explanation for different findings in short-term testing and long-term testing, is that long-term testing is executed after at least one night of sleep and sleep supports consolidation of newly acquired memories (Wilhelm, Diekelmann, & Born, 2008). Memory traces are preferentially consolidated during sleep and this leads to improved performance after a night sleep (Ashworth, Hill, Karmiloff-Smith, & Dimitriou, 2014; Wilhelm et al., 2008). For this reason, testing participants a day after the intervention or experiment is considered long-term testing. The findings that the modality effect might even be reversed on long-term tests, shows a need for research into delayed modality effects.

Modality Effects in Children

Most research into the modality effect has been conducted with adults, mainly with university-students. A typical feature of university is that primary schools are extremely heterogeneous. Therefore, it is intriguing to investigate the modality effect with children. Ginns (2005) reviewed 43 results of the modality effect. Although he found a strong modality effect for studies with junior high school students (d = 0.72) and senior high school students (d = 0.85), the studies with children showed a weaker modality effect (d = 0.51). The latest study reported in Ginns (2005) was from 2002. Six years later, Segers et al. (2008) studied the modality effect with children in a within-subject design. One hundred and twenty-eight primary school children watched learner-paced lessons in four different formats. There was one lesson with written text only, one lesson with written text and pictures, one lesson with spoken text only, and one lesson with spoken text and pictures. The children were tested for retention and transfer immediately after the intervention and one week later. A short-term modality effect was found for retention, with better results for spoken text and pictures than for written text and pictures. For transfer, a modality effect was found on the short-term. However, on the long-term the modality effect was reversed (Segers et al., 2008).

Another study that investigated the modality effect with children is the study by Witteman and Segers (2010). They tested the modality effect for eighty primary school children. The children watched a learner-paced lesson with spoken text and pictures or written text and pictures. For retention, they found a reversed modality effect immediately after the intervention and no significant differences between conditions a day later and a week later. For transfer, they found a reversed modality effect one day after the intervention, while there were no significant differences immediately after the intervention and one week later. Regarding working memory, they found a general effect for auditory- and visual working memory on retention scores. Children who scored higher on working memory tests scored higher on retention and transfer questions. However, they did not find a moderation effect for working memory (Witteman & Segers, 2010).

Furthermore, Leahy and Sweller (2011) conducted two experiments with children from primary schools. In their first experiment, twenty-four children watched a system-paced audiovisual or visual-only presentation. The authors only tested for transfer and they only tested the children immediately after the intervention. They found a reversed modality effect (i.e., the group presented with the visual-only presentation was superior). They stated that this reversed modality effect could have been caused by too long sentences. Therefore, in their second experiment, they broke the longer sentences into shorter segments. Sixty-four children watched a system-paced audiovisual or visual-only presentation. This time, the authors again only tested for transfer and found a modality effect immediately after the intervention, which confirms that length and complexity of text influences the modality effect (Leahy & Sweller, 2011; Low & Sweller, 2014).

The results of these studies indicate that there might be a difference between the modality effect with adults and the modality effect with children; studies with children often show a reversed modality effect on retention or transfer. One difference between adults and children that might affect the modality effect is that according to Baddeley, Gathercole and Papagno (1998), children have underdeveloped phonological loops. According to Baddeley's theory about working memory (2000), the phonological loop is responsible for storing and rehearsing text information. For spoken text this is more demanding, due to the transient nature of spoken text, which reveals the prerequisite of a high phonological loop capacity for processing spoken text (Schüler et al., 2012). Therefore, children might have less advantage of spoken text over written text than adults.

Working Memory and the Modality Effect

Although the theory of the modality effect is largely based on the theory of working memory, there exists little research that investigates the influence of working memory on the modality effect (but see Gyselinck et al., 2008; Seufert et al., 2009; Witteman & Segers, 2010). Studies into the modality effect showed that learning from an audiovisual lesson resulted in better learning outcomes than learning from a visual-only lesson (Ginns, 2005), and it is likely that this effect can be moderated by working memory. Namely, it can be expected that the influence of mode on retention and transfer scores is different for learners with high working memory span than for learners with low working memory span. For instance, children with high working memory span are able to remember more, which would logically lead to higher retention scores and indirectly to higher transfer scores (you have to remember information to be able to transfer it to new situations). Furthermore, Mayer's explanation is that audiovisual lessons are better than visual-only lessons, because both channels are adopted. Therefore, following Mayer's explanation, a moderation of auditory working memory and a moderation of visual working memory would be visible in audiovisual lessons, whereas a moderation of visual working memory would be especially visible in visual-only lessons. Following Baddeley's explanation, primarily a moderation of auditory working memory would be a visible in audiovisual and visual-only lessons.

Two studies that investigated the influence of working memory on the modality effect with adults are the studies by Gyselinck et al. (2008) and Seufert et al. (2009). In the study by Gyselinck et al. (2008), fifty-six university students watched either an auditory or a visual system-paced multimedia lesson. The authors incorporated individual differences in working memory capacity in the study and divided the group into an experimental condition (who watched the lesson while performing two concurrent tasks) and a control condition (who watched the lesson without performing concurrent tasks). The concurrent tasks were a spatial tapping task and an articulatory task. In the spatial tapping task participants had to move their hands anticlockwise between four buttons, in the articulatory task participants had to repeat the sequence 'ba, be, bi, bo, bu' at a rate of about one syllable per second (Gyselinck et al., 2008, p. 366). No overall modality effect was found. However, when the authors only selected participants with high auditory working memory they found a modality effect on transfer and when they only selected participants with high visual working memory they found a reversed modality effect on transfer. Therefore, they suggested that the modality effect appears to depend on individual differences. A remarkable finding is that, although abovementioned findings might suggest that learners with high auditory working memory benefit from audiovisual lessons and learners with high visual working memory benefit from visual-only lessons (which confirms Mayer's theory), the authors found that storage of verbal information did not depend on the modality of presentation; verbal working memory (i.e., the phonological loop) was involved in the comprehension of text, either written or spoken (which confirms Baddeley's theory on working memory; Gyselinck et al., 2008).

In the study by Seufert et al. (2009), seventy-eight university students watched a learner-paced multimedia lesson on the structure and function of a cellular molecule responsible for the energy of our cells. Forty students were assigned to the visual-only condition and thirty-eight students were assigned to the audiovisual condition. Working memory capacity was measured per student. The authors found a modality effect for audiovisual conditions on retention, but no interaction of working memory capacity on this modality effect. However, they found an interaction between working memory capacity and the modality effect on transfer. Results show that participants with low working memory capacity performed low in the visual-only condition, whereas participants with high working memory capacity performed low in the audiovisual condition. Therefore, the authors concluded that the modality effect can be moderated by memory characteristics, such as capacity and strategy skills. Furthermore, they explained the low scores in the audiovisual condition for learners with high working memory capacity by suggesting that high capacity learners use the phonological loop for inner self-explanation (e.g., they process pictures in the phonological loop with their inner voice) and if the text information is presented in spoken form it is processed in the phonological loop as well, which causes interference (Seufert et al., 2009, p. 39). This explanation shows linkage with both Baddeley's theory and Mayer's theory. In addition, the low scores in the visual-only condition for learners with low working memory capacity could be caused by the fact that learners with low working memory capacity have less capacity to process information (Mayer, 2014).

Present Study

The above review of the literature makes clear that the modality effect has boundary conditions relating to learner-pacing vs. system-pacing and to short-term vs. long-term. Furthermore, it is plausible that there exists a moderating role of working memory on the modality effect according to the CTML, yet it has scarcely been studied. To the best of my knowledge, no research exists that investigated the modality effect in children, in learner-paced vs. system-paced multimedia lessons on short-term and long-term while examining the influence of working memory on the modality effect. Therefore, the goal of the present study was to investigate the modality effect with children on short-term and long-term, in learner-paced and system-paced conditions, while examining the interaction between individual working memory and this modality effect.

The first question of the present study was whether there would be a modality effect for retention and transfer on short-term and long-term and whether this would be different for learner-paced vs. system-paced conditions. The second question was whether working memory would be a moderator for this effect in both conditions. Since studies on the modality effect with children showed conflicting results for learner-paced conditions on short-term, it is difficult to formulate a hypothesis on a modality effect in learner-paced conditions on short-term. The first hypothesis was that there would be modality effect for system-paced conditions on short-term and long-term. The second hypothesis was that there would be a reversed modality effect for learner-paced conditions on short-term and long-term. Previous studies show conflicting results for transfer and retention. Most reversed modality effects were found for transfer. Therefore, it is expected that effects would be most apparent for transfer.

Since the modality effect is based on theory of working memory by Baddeley (2000) and Mayer (2014), a difference was expected between scores on retention and transfer for participants with high working memory capacity and participants with low working memory capacity. Therefore, the third hypothesis was that working memory is a moderator for the modality effect or reversed modality effect.

In the present study, a group of 275 children from fifth and sixth grade of Dutch primary schools were presented with one out of four multimedia lessons (i.e., system-paced audiovisual; system-paced visual-only; learner-paced audiovisual; learner-paced visual-only). They were tested for retention and transfer immediately after the lesson and the next day. Auditory- and visual working memory was measured and finally, word-reading ability and reading comprehension were measured to make sure that any group differences could not be ascribed to variation in reading ability.

Method

Participants

Participants were 275 children from six Dutch primary schools (147 female). Their age ranged from 9.25 to 12.67 ($M_{age} = 10.95$; $SD = 0.69$). The schools are located in Noord-West Veluwe and were selected by convenience sampling. The socioeconomic status of the schools could be classified middle to high (Sociaal en Cultureel Rapport, 1998). Only participants from the 5^{th} and 6^{th} grade of primary school participated in this research, which resulted in a total of thirteen classes. Parents were informed about their child's participation in the study and gave active consent. Originally, 283 children were to participate in the present study. Three participants were excluded on beforehand, as their parents did not give consent for their child to participate and records of five participants were excluded due to technical issues or due to unfinished post-tests. The remaining 275 participants had no relevant prior knowledge on the subject, their native language was Dutch, and they were able to use a computer. Participants were randomly assigned to one of the four conditions of a 2 x 2 design with modality (audiovisual vs. visual-only) and pacing (learner-paced vs. system-paced lesson) as between-subject factors. This resulted in the following conditions: audiovisual+learner-paced (n = 70); audiovisual+system-paced (n = 70); visual-only+learner-paced (n = 66); visual-only+system-paced (n = 69). In order to check whether variables would have to be controlled for in the model, a MANOVA was conducted for prior knowledge, learning eagerness, word reading ability, reading comprehension, auditory working memory, visual working memory, and age. However, auditory- and visual working memory will always be included as moderating variables in the main analysis, to answer the second research question. Prior knowledge and learning eagerness was measured by a forced choice question. Choices ranged from very much to very little (prior knowledge) and very nice to very stupid (learning eagerness) on a five-point scale. Scores for reading comprehension were provided by the schools. Word reading ability was obtained from the Doorstreepleestoets [Cross-Out Reading Test] (Van Bon, 2007). Participants received a sheet full of existing and non-existing words. They had to read the words one-by-one and cross-out the non-existing words in one minute. The total score was the number of read words minus the number of mistakes (with a mistake being an existing word crossed-out or a non-existing word not crossed-out). There was a total of 120 items. The reliability of this test has been checked in previous studies (Van Bon, 2006). Test-retest reliability varied from 0.78 to 0.83 and parallel-test reliability varied from 0.77 to 0.84. Finally, reading comprehension scores were derived from the biannual reading comprehension tests from Cito (Cito – Productoverzicht, 2018). Children received a score ranging from A-E, with A being the score for the highest 25% and D and E being the score for the lowest 25%. The MANOVA showed, that the four groups did not differ in terms of prior knowledge (p = .310), learning eagerness (p = .319), reading comprehension (p = .711), and age (p = .893). The covariates that were not significantly different between groups were left out of further analyses. The only statistically significant effect was an effect of word reading ability, $F(1, 271) = 6.82$, p =

.009, $\eta_p^2 = .025$. Therefore, this variable will also be included in the main analysis. Since abovementioned variables were measured to make sure that any group differences could not be ascribed to variation in prior knowledge, learning eagerness, word reading ability, reading comprehension, and age they were not described in the next section. To increase motivation, participants were told on beforehand they could win a toy for good performance.

Materials

Auditory working memory. Auditory Working Memory Capacity (AWMC) was measured with a Digit Span Test (Wechsler, 1992), in which children heard a sequence of randomly ordered digits with one second between each digit. Recognizable patterns were avoided (i.e., 2, 4, 6, 8). The researcher read the sequence out loud and the children had to recall this sequence. There were two different sequences with the same length and after every two sequences with the same length, the sequence increased with one digit. The first two sequences started with three digits. When both trials of one length were wrong, testing was terminated. There was a maximum of 12 items and the last correctly mentioned item represented the score (e.g., when the last correctly mentioned item was 6, the child's score was 6). Cronbach's alpha for the Digit Span Test was fair, $\alpha = 0.64$ (Berg, 2008).

Visual working memory. Visual Working Memory Capacity (VWMC) was measured with a Corsi Block Tapping Test (Corsi, 1972 as cited in Kessels, Van Zandvoort, Postma, Kappelle, & De Haan, 2000). The children saw nine blocks being tapped on in a different sequence with one second between each tap. Again, recognizable patterns were avoided. The researcher tapped the blocks in silence and the children had to imitate the sequence. There were two different sequences with the same length and after every two sequences with the same length, the sequence increased with one block. The first two sequences started with two blocks. When both trials of one length were wrong, testing was terminated. Scores for VWMC were represented by the number of correctly repeated sequences. The last correctly mentioned item represented the score. There was a maximum of 16 items. Cronbach's alpha for the Corsi Block Tapping Test was fair, $\alpha = 0.64$ (Berg, 2008).

Intervention materials. The materials for the multimedia lesson were adapted from the work of Mayer and Moreno (1998) and the work of Witteman and Segers (2010). The present study used Mayer's original multimedia lesson on the formation of lightning, translated for Dutch primary schools by Witteman and Segers (2010). The multimedia lesson consisted of 16 slides with text about the formation of lighting (e.g., "Cool moist air moves over a warmer surface and becomes heated.”). Regarding previously mentioned boundary conditions to the modality effect, the multimedia lessons were designed in such a manner that the boundary conditions were controlled of. The program used for this multimedia lesson is Microsoft Office PowerPoint. In the audiovisual condition, the slides contained a static graphic and narration. In the visual-only condition, the slides contained a static graphic and written text below the static graphic. The narration was a recording of the voice of the researcher, who was raised in the area of the schools. The materials were informally piloted with twenty-eight primary school children. Participants in system-paced conditions had limited time for each slide: the time per slide in the audiovisual system-paced condition was similar to the time per slide in the visual-only system-paced condition (i.e., total length of written text was 226 words and total length of the lesson was 140 seconds, which is the same as in the study by Mayer and Moreno). The time for the slides was similar to the time the narration sounded plus one second in which the participants were already able to see the graphic (i.e., the text or narration appeared one second after the graphic appeared and disappeared at the same time). Participants in the learner-paced conditions were free to browse the slides and listen to, look at or read the learning material as often as they felt necessary. They used the arrow keys on the keyboard to go back or forth, and they clicked the sound icon on the top left side of the screen to play the narrative again. The intervention materials can be found in Appendix A.

Retention and transfer tests. Following Mayer and Moreno (1998), retention was measured with the written open question: “Please write down an explanation of how lightning works”. This retention question was presented to the participants immediately after the lesson. The day after the first tests, participants were presented with a second test containing the same retention question. Transfer was measured with three open-ended written transfer questions, following Witteman and Segers (2010). They were presented to the participants immediately after the lesson. The day after the first tests, participants were presented with a second test containing three new open-ended transfer questions. The first transfer question of the immediate test was: “What could you do to decrease the intensity of lightning?”. The second transfer question of the immediate test was: “How do clouds form?”. The final transfer question of the immediate test was: “What does air temperature have to do with lightning”. The first transfer question of the delayed test was: “Suppose you see clouds in the sky but no lightning. Why not?”. The second transfer question of the delayed test was: “Why does lightning often hit the highest point?”. The final transfer question of the delayed test was: “What causes lightning?” (Mayer & Moreno, 1998; Mayer, Heiser, & Lonn, 2001;

Witteman & Segers, 2010). Participants answered the retention and transfer questions by typing their answer in a block below the question. They were allowed to take as much time they needed. Scoring was performed by the first researcher who assigned points when the elements from the correction form were mentioned. For the retention question the maximum achievable score was 15 points per testing moment and the maximum achievable score for each transfer question was 2 points (i.e., 6 points in total for transfer) per testing moment. To test for interrater reliability, a second researcher checked 10% of the sample (randomly assigned across conditions). The inter-rater reliability was high, $\kappa = 0.93$, $p < 0.001$. Scoring forms can be found in Appendix B.

Procedure

The experiment took place during class time. At the start of the experiment, the participants made the Doorstreepleestoets [Cross-Out Reading Test] individually in their classroom. Subsequently, participants were tested for auditory- and visual working memory individually in an empty room in school. After that, four participants at a time were taken back to the empty room. They received a laptop and entered an online environment by Qualtrics in which they were asked for their gender, date of birth, and which language they primarily spoke at home. They were seated apart from each other on separate tables. They received the forced question on learning eagerness and the forced question on prior knowledge after which the participants were randomly assigned to one out of four multimedia lessons on the formation of lightning (i.e., system-paced audiovisual; system-paced visual-only; learner-paced audiovisual; learner-paced visual-only). The system-paced lessons lasted 140 seconds, in the learner-paced lessons children used approximately the same amount of time. All participants were then told which condition they entered. When they received an audio-visual condition, they were told to use the headphones to listen to the narrative. When they received a learner-paced condition, they were told to use the left and right arrow keys on the keyboard to move on to the next slide or to go back to the previous slide. In addition, they were told to click the sound icon on the top left side of the screen to play the narrative again. After watching all slides, the participants closed the window and immediately returned to the online environment in which they conducted the post-test. One day after, they conducted the delayed test. Both tests contained four pages. The first page showed the retention question, a block in which participants could write down their answer, and a button to move to the next page. The second page showed the first transfer question, a block in which participants could write down their answer, and again a button to move to the next page. The same applies to the other two transfer questions. After the participants answered all questions, a pop-up window appeared, which instructed them to close the learning environment and to return to their class. All tests were anonymous; however, the researcher has access to a file which links the participant number to a name.

Analytical Approach

This study has a 2 (audiovisual/visual-only between-subjects factor) X 2 (system-paced/learner-paced between-subjects factor) X 2 (post-test/delayed test within-subjects factor) design with retention and transfer scores as separate dependent variables. Auditory- and visual working memory are incorporated as moderating variables. Knowledge represents the learning effect, T1 is the post-test, and T2 is the delayed test.

In order to test the hypotheses, four General Linear Model (GLM) Repeated Measures analyses were used. For retention, two GLM Repeated Measures analysis were conducted with mode (audiovisual, visual-only) and pace (learner-paced, system-paced) as between-subject factors and time (immediately, one day after) as within-subject factor. For the first GLM Repeated Measures analysis, covariates were auditory working memory and word reading ability. For the second GLM Repeated Measures analysis, covariates were visual working memory and word reading ability. The aim of these analyses was to test for differential effects of mode and pace on retention across time. For transfer, the same analyses were conducted. In every GLM Repeated Measures analysis, the design consisted of main variables and interaction between these variables. Post Hoc analyses were conducted as follow-up in order to identify the nature of the effect. Before the tests were conducted, it was checked whether the assumptions were not violated. The assumption of independence was met, as well as the assumption of additivity and linearity. In order to test the assumption of normal distribution, skewness and kurtosis was measured. Retention scores were a little right skewed, with skewness of 0.75 (SE = 0.15) and normally tailed, with kurtosis of 0.31 (SE = 0.29). Transfer scores were a bit right skewed as well, with skewness of 0.40 (SE = 0.15) and normally tailed, with kurtosis of -0.23 (SE = 0.29). However, due to the large sample the central limit theorem, an approximately normal distribution can be assumed. Box’s M test indicated that the assumption of homogeneity of variance had been met for all four GLM’s: GLM retention with auditory working memory, $F(9, 833702) = 0.33$, $p = .966$; retention with visual working memory, $F(9, 833702) = 0.33$, $p = .966$; transfer with auditory working memory, $F(9, 833702) = 0.42$, $p = .925$; and transfer with visual working memory, $F(9, 833702) = 0.42$, $p = .925$. Furthermore, Mauchly's tests indicated that the assumption of sphericity had not been violated.

Results

Table 1 summarizes the mean scores, standard deviations and maximum scores for retention and transfer at T1 (test immediately after the lesson) and T2 (test one day after the lesson) and all relevant variables for the four conditions. Table 2 shows the bivariate Pearson correlation matrix of all relevant variables.

Table 1.

Mean Scores (Standard Deviations) and Maximum Scores of All Relevant Variables Over Groups

		System-Paced		Learner-Paced	
		Audiovisual	Visual-Only	Audiovisual	Visual-Only
Retention	T1	4.21 (2.25) 11	4.09 (2.43) 11	4.31 (2.42) 10	4.33 (2.21) 9
	T2	3.96 (2.37) 9	4.13 (2.50) 11	3.94 (2.37) 10	3.83 (2.52) 10
Transfer	T1	1.46 (1.38) 6	1.20 (1.37) 6	1.54 (1.25) 5	1.56 (1.38) 5
	T2	1.21 (1.06) 4	0.99 (0.99) 4	1.26 (1.18) 6	1.20 (1.03) 4
Learner Characteristics	Prior Knowledge	2.50 (0.86) 4	2.54 (0.78) 4	2.71 (0.85) 5	2.55 (0.85) 4
	Learning Eagerness	3.40 (0.62) 4	3.64 (0.80) 5	3.50 (0.78) 5	3.56 (0.73) 5
Cognitive Characteristics	Word Reading Ability	57.06 (17.82) 97	65.42 (19.73) 115	64.09 (20.72) 109	60.17 (19.57) 97
	Reading Comprehension	3.56 (1.19) 5	3.49 (1.16) 5	3.67 (1.09) 5	3.50 (1.35) 5
	Auditory Working Memory	4.87 (0.72) 6	4.94 (0.87) 8	4.81 (0.79) 7	4.82 (0.74) 6
	Visual Working Memory	4.91 (0.74) 7	4.93 (0.63) 6	4.89 (0.77) 7	4.83 (0.80) 7

Table 2.

Bivariate Pearson Correlation Matrix of All Relevant Variables

			1	2	3	4	5	6	7	8	9
1	Retention	T1									
2		T2	.680**								
3	Transfer	T1	.264**	.233**							
4		T2	.279**	.332**	.247**						
5	Learner Characteristics	Prior Knowledge	.090	.135*	.216**	.160**					
6		Learning Eagerness	.036	.124*	.128*	-.021	.239**				
7	Cognitive Characteristics	Word Reading Ability	.134*	.174**	.015	.026	-.019	.000			
8		Reading Comprehension	.245**	.309**	.083	.206**	.107	-.021	.141*		
9		Auditory Working Memory	.240**	.208**	.030	.084	.083	-.001	.231**	.201**	
10		Visual Working Memory	.028	-.010	.012	.056	.067	-.083	-.004	.145*	.197**

Note. * $p < .05$, ** $p < .01$

Retention Scores

Auditory working memory. The GLM Repeated Measures analysis of retention scores with auditory working memory and word reading ability as covariates (see Table 3) showed a significant main effect of auditory working memory, indicating that retention scores were different for different levels of auditory working memory. A Bonferroni confidence interval revealed a positive effect of auditory working memory on retention scores (for T1: $CI_{95\%}$ = [-0.11; 1.18], for T2: $CI_{95\%}$ = [0.11; 1.46]). Overall scores were higher as auditory working memory was higher ($r = 0.24$, $p < .001$).

Furthermore, there was a significant interaction effect for mode*pace (see Table 3) which indicates that retention scores across the different paces were different for audiovisual and visual-only conditions. When lessons were learner-paced, the scores tend to get higher in the visual-only condition (reversed modality), while when lessons were system-paced, the scores tend to get higher in the audiovisual condition (modality effect). However, it should be noted that none of the paired comparisons revealed a significant difference.

The analysis also showed a significant interaction effect for time*mode (see Table 3), and a significant three-way interaction for time*mode*auditory working memory (see Table 3), which indicates there was a decline in retention scores from T1 to T2 which was moderated by auditory working memory. A Bonferroni confidence interval revealed that there was a decline for both the audiovisual ($CI_{95\%}$ = [-0.64; 0.01]), and visual-only conditions ($CI_{95\%}$ = [-0.58; 0.07]), and pairwise comparison revealed that this decline was stronger for the audiovisual condition. However, none of the paired comparisons for time*mode revealed a significant difference. In order to understand the moderating role of auditory working memory, the GLM Repeated Measures analysis was split for mode. In the audiovisual mode the interaction of time*auditory working memory was significant ($F(1, 134) = 4.54$, $p = .035$, $\eta_p^2 = .033$). In the visual-only mode the interaction of time*auditory working memory was not significant ($F(1, 129) = 1.02$, $p = .316$, $\eta_p^2 = .008$). Thus, auditory working memory impacts the decline in retention for audiovisual conditions (the higher the auditory working memory, the more the decline), but not for visual-only conditions. There were no other significant effects (see Table 3).

Visual working memory. The GLM Repeated Measures analysis of retention scores with visual working memory and word reading ability as covariates (see Table 3) showed a significant main effect of word reading ability, which means word reading ability is related to retention scores. A Bonferroni confidence interval revealed a positive effect of word reading ability on retention scores (for T1: $CI_{95\%}$ = [0.00; 0.03], for T2: $CI_{95\%}$ = [0.00; 0.04]). The higher the scores for word reading ability, the higher the retention scores. However, in this follow-up analysis they were no longer significant. There were no other significant effects for the GLM Repeated Measures analysis of retention scores with visual working memory and word reading ability as covariates (see Table 3).

Table 3.

GLM Repeated Measures for Retention with Auditory- and Visual Working Memory as Moderator

	Auditory Working Memory			***Visual Working Memory***		
	F	p	η_p^2	F	p	η_p^2
Mode	0.46	.500	.002	0.00	.965	.000
Pace	1.67	.198	.006	1.27	.260	.005
Mode * Pace	4.25	.040*	.016	0.86	.355	.003
Moderator	12.67	.000*	.046	0.00	.971	.000
Mode * ***Moderator***	0.96	.327	.004	0.03	.868	.000
Pace * ***Moderator***	0.89	.347	.003	0.43	.514	.002
Mode * Pace * ***Moderator***	2.72	.100	.010	0.18	.670	.001
Word Reading Ability	3.81	.052+	.014	8.50	.004*	.001
Mode * Word Reading Ability	0.46	.498	.002	0.36	.549	.001
Pace * Word Reading Ability	0.51	.474	.002	1.82	.178	.007
Mode * Pace * Word Reading Ability	0.99	.322	.004	2.03	.156	.008
Time	0.00	.949	.000	0.00	.967	.000
Time * Mode	4.51	.035*	.017	1.63	.204	.006
Time * Pace	0.44	.510	.002	0.08	.784	.000
Time * Mode * Pace	0.11	.746	.000	0.06	.832	.000
Time * ***Moderator***	0.86	.355	.003	0.48	.489	.002
Time * Mode * ***Moderator***	5.13	.024*	.019	1.63	.203	.006
Time * Pace * ***Moderator***	0.37	.542	.001	0.03	.862	.000
Time * Mode * Pace * ***Moderator***	0.12	.732	.000	0.04	.840	.000
Time * Word Reading Ability	0.92	.338	.003	0.69	.409	.003
Time * Mode * Word Reading Ability	0.02	.887	.000	0.14	.706	.001
Time * Pace * Word Reading Ability	0.31	.577	.001	0.50	.482	.002
Time * Mode * Pace * Word Reading Ability	0.04	.833	.000	0.09	.764	.000

Note. * p < .05, ** p < .01, + p < .10

Transfer Scores

Auditory working memory. The GLM Repeated Measures analysis of transfer scores with auditory working memory and word reading ability as covariates (see Table 4) showed no significant main effects or interaction effects.

Visual working memory. The GLM Repeated Measures analysis of transfer scores with visual working memory and word reading ability as covariates (see Table 4) showed no significant main effects or interaction effects.

Table 4.

GLM Repeated Measures for Transfer with Auditory- and Visual Working Memory as Moderator

	Auditory Working Memory			***Visual Working Memory***		
	F	p	η_p^2	F	p	η_p^2
Mode	1.71	.193	.006	0.80	.373	.003
Pace	1.32	.252	.005	0.89	.347	.003
Mode * Pace	1.40	.237	.005	0.31	.580	.001
Moderator	1.29	.258	.005	0.58	.447	.002
Mode * ***Moderator***	1.21	.273	.005	0.40	.530	.002
Pace * ***Moderator***	2.28	.132	.009	0.71	.402	.003
Mode * Pace * ***Moderator***	0.35	.555	.001	1.44	.231	.005
Word Reading Ability	0.36	.548	.001	0.71	.400	.003
Mode * Word Reading Ability	0.01	.935	.000	0.15	.700	.001
Pace * Word Reading Ability	0.06	.815	.000	0.00	.993	.000
Mode * Pace * Word Reading Ability	2.36	.126	.009	2.49	.116	.009
Time	0.83	.362	.003	0.69	.406	.003
Time * Mode	0.21	.644	.001	2.10	.148	.008
Time * Pace	3.49	$.063^{+}$	.013	0.07	.794	.000
Time * Mode * Pace	1.50	.222	.006	0.01	.946	.000
Time * ***Moderator***	0.28	.597	.001	0.18	.674	.001
Time * Mode * ***Moderator***	0.32	.570	.001	2.90	$.090^{+}$	.011
Time * Pace * ***Moderator***	1.70	.193	.006	0.31	.579	.001
Time * Mode * Pace * ***Moderator***	1.70	.193	.006	0.00	.974	.000
Time * Word Reading Ability	0.02	.882	.000	0.03	.857	.000
Time * Mode * Word Reading Ability	0.01	.916	.000	0.10	.750	.000
Time * Pace * Word Reading Ability	1.72	.191	.006	3.86	$.051^{+}$	.014
Time * Mode * Pace * Word Reading Ability	0.04	.848	.000	0.05	.827	.000

Note: * $p < .05$, ** $p < .01$, $^{+}$ $p < .10$

Discussion

The aim of the present study was to investigate the modality effect with children on short-term and long-term, in learner-paced and system-paced conditions, while examining the interaction between individual working memory and this modality effect. It was expected that there would be a modality effect for system-paced conditions on short-term and long-term, a reversed modality effect for learner-paced conditions on short-term and long-term, and that working memory would be a moderator for the modality effect and reversed modality effect. Results showed an interaction between pace and mode, suggesting a modality effect on retention when lessons were system-paced and a reversed modality effect on retention when lessons were learner-paced. However, while the interaction was significant, the two pace-conditions did not differ in any mode. Furthermore, over time, children with higher auditory working memory forgot more in the audiovisual condition, but not in the visual-only condition.

Short-Term vs. Long-Term effects in System-Paced and Learner-Paced Lessons

The first hypothesis was that there would be a modality effect for system-paced conditions on short-term and long-term. Even though results pointed to the fact that in system-paced conditions audiovisual is to be preferred over visual-only, the lack of any significant differences between the two modes indicate that there was no modality effect. Indeed, previous research has shown that the modality effect is more often found in system-paced than in learner-paced conditions (Ginns, 2005). Not finding the modality effect is in line with the study by Izmirli and Kurt (2016) who also studied the modality effect for different modes (audiovisual vs. visual-only) and different paces (learner-paced vs. system-paced) and found no modality effect. However, they only tested for retention and transfer immediately after the lesson and not on the long-term. Van den Broek et al. (2014) and Oberfoell and Correia (2016) as well found no performance differences immediately after the lesson. Witteman and Segers (2010) who tested for the modality effect with children, even found a reversed modality effect for retention immediately after the lesson. Their learning- and testing material was the same as the material used in the present study. The only difference was that Witteman and Segers only had learner-paced conditions and the present study had learner-paced conditions and system-paced conditions. Retention scores for audiovisual conditions were similar in their study and the present study. However, retention scores for visual-only conditions were higher in the study by Witteman and Segers than in the present study. Thus, no advantage of visual-only lessons over audiovisual lessons was found in the present study. It could be that children in the present study did not use additional time in learner-paced conditions to study the material, while children in the study by Witteman and Segers did.

The meta-analysis by Ginns (2005) already showed that the modality effect is weaker for studies with children than for studies with university students or adults. An explanation for a weaker modality effect with children could be that children grow up in a media rich environment, in which they listen to music while completing other tasks. It could be that young people are half-reading, half-listening to content and therefore do not perceive both fully. It could be that they do not pay attention to spoken language as much as older people do. However, this is a tentative argument and it requires additional research. A second explanation for a weaker modality effect in studies with children could be that the instructional material is less suited for children than for university students or adults. An explanation for the fact that Segers et al. (2008) found a modality effect in a study with children, while the present study found no modality effect in a study with children could therefore be that the learning material in the first mentioned study was more suitable for the age group. In fact, although the multimedia lessons of the present studies are no videos, they could be seen as instructional videos, and as instructional videos they fail to meet important requirements (Van der Meij & Van der Meij, 2013). For instance, the text of the multimedia lessons regularly describes a phenomenon or event that can be seen in the picture. However, the attention of the participant is not drawn to that specific phenomenon or event. Therefore, the participant first has to identify where to look in the picture, which likely makes it harder to understand the picture and the text. Furthermore, some common conceptions (warm corresponds to the color red, cold corresponds to the color blue) are reversed in the translated lessons. Cold air is marked red and warm air is marked blue, while the temperature gauge for cold temperature is blue and the temperature gauge for warm temperature is red, which is inconsistent. According to Van der Meij and Van der Meij (2013): “Graphics are better understood and remembered when there is a natural cognitive correspondence between the real thing and the graphical representation.” (p.210). There exists a possibility that university students and adults are more capable of ignoring poor design of the material. However, this is tentative and additional research is necessary to investigate it.

The second hypothesis was that there would be a reversed modality effect for learner-paced conditions on short-term and long-term. Even though results pointed to the fact that in learner-paced conditions visual-only is to be preferred over audiovisual, the lack of any significant differences between the two modes indicate that there was no reversed modality effect. Previous research has shown that in earlier research into the modality effect, classic modality effects were found, while in subsequent research the modality effect reversed. This reversed modality effect was often found for learner-paced multimedia lessons, both for adults (Van den Broek et al., 2014; Inan et al., 2015; She & Chen, 2009; Stiller et al., 2009; Tabbers et al., 2004), and children (Segers et al., 2008; Witteman & Segers, 2010). An explanation for reversed modality effects in learner-paced conditions is that written text can be reread, whereas spoken text must be maintained in working memory in order to be integrated with subsequent information. Furthermore, learners can decide how much time they spend on studying the material in learner-paced conditions and therefore they can use beneficial strategies for processing written text. For spoken text this is more difficult. An explanation for the fact that no reversed modality effect was found in the present study, could be that participants did not use extra available time in learner-paced conditions. However, additional research including log-data is needed to shed light on this argument.

Moderation Effect of Auditory Working Memory

The third hypothesis, that working memory was a moderator for the modality effect, could partly be confirmed. Results first of all showed a decline of retention scores over time moderated by auditory working memory. Although this was visible for children who watched an audiovisual and for children who watched a visual-only lesson, the decline was larger for children who watched an audiovisual lesson. So even though there was no modality effect on retention, the role of auditory working memory showed a reversed modality effect over time. The larger decline for audiovisual conditions is in line with Witteman and Segers (2010). However, they found a general effect for auditory- and visual working memory on retention scores, but no moderation effect for working memory.

The finding that the moderation of auditory working memory on retention scores was stronger for audiovisual conditions than for visual-only conditions corresponds to the assumption that in audiovisual multimedia lessons, more information is processed in auditory working memory than in visual-only conditions. It is mostly in line with the assumption that written text is initially processed in visual working memory (Mayer, 2014). However, it is not in line with the assumption that written text is processed in auditory working memory (Baddeley, 2000). Therefore, it seems that based on these results Mayer's theory of working memory should be adopted over Baddeley's theory of working memory. However, due to the small effect size, results should be interpreted with caution. Furthermore, the finding that children with higher auditory working memory forgot more in the audiovisual condition than children with lower auditory working memory is striking. It was expected that children with higher working memory would forget less than children with lower auditory working memory. Why this is not the case is difficult to explain.

Although a moderation of auditory working memory was found, results showed no effect of visual working memory, which indicates that differences in visual working memory do not influence scores on retention and transfer. A possible explanation for the fact that no effect of visual working memory was found, could be that the retention and transfer questions were verbal and not pictorial. When retention and transfer questions would be pictorial there could be more demand for visual working memory. A pictorial assessment for retention could for instance show the static graphic from the lesson with an arrow pointing towards a specific event and ask the learners to name or describe the specific event indicated by the arrow. However, pictorial assessment is applicable for retention assessment, but less applicable for transfer assessment. It would be interesting to replicate the research and add pictorial assessment to check whether visual working memory would moderate the effect of mode and pace on retention and transfer scores.

Finally, the abovementioned moderating role of auditory working memory was only found for retention and not for transfer. For transfer, integration of different information is more demanding than for retention, since retention usually only requires information to be remembered and transfer requires information to be connected to other information in order to be applied to new situations (Sweller, van Merriënboer, & Paas, 1998). Therefore, it would make sense if for transfer a stronger moderation of working memory would be visible. However, transfer scores in the present study were low for all four conditions (lower than in the study by Witteman and Segers (2010)), which could indicate that the transfer questions were rather difficult and demanding and as a result did not differentiate for different levels of working memory.

Limitations and Future Research

Some limitations of the present research should be taken into account. First, similar to most research into the modality effect, the present study focused on the phonological loop and the visuo-spatial sketchpad. However, another important part of working memory is the central executive (Baddeley, 2000). The central executive could be important in multimedia learning, due to the fact that the presentation of two information sources requires monitoring and coordination of the subsystems and an attentional-controlling system, which is the central executive. Due to its importance in multimedia learning, future research could shed light on the role of the central executive.

Second, the present study did not use eye-tracking measures or process data. However, eye-tracking measures or log-files could provide insight in the actions or study behavior of participants. A remarkable finding in a study by Segers et al. (2008), is that children use their learning time differently than adults. The authors found that children do not use extra available time in learner-paced conditions. Since they do not use extra available time, whereas adults do, there would be less difference between learner-paced and system-paced conditions for children than for adults. Moreover, the study by Segers et al. (2008) showed that children spent more time studying information in audiovisual conditions than in visual-only conditions. It was expected that children in visual-only conditions would spend more time studying the material, since these children can reread the material. In order to determine whether differences in study behavior by adults and children affect the modality effect, eye-tracking measures or log-files are recommended for future research.

Finally, in order to investigate the effect of working memory on the modality effect, the present study used working memory capacity tests. However, a dual-task approach is preferred, since it assesses which processes are interfered with in specific subsystems. By that manner, decrease in performance can be traced back to interference in specific subsystems of working memory. Moreover, a dual-task approach is more sensitive to the task, whereas capacity tests are considered a relatively stable construct and therefore not related to the task (Schüler et al., 2011).

Conclusion

To conclude, the present study aimed to investigate the interaction between working memory and the modality effect with children on short-term and long-term, in learner-paced and system-paced conditions. Results showed an interaction between mode and pace, suggesting a modality effect on retention when lessons were system-paced, and a reversed modality effect on retention when lessons were learner-paced. However, when further analyses were tailored to the specific role of pacing in audiovisual and visual-only conditions, the effects disappeared. Furthermore, there was a decline of retention scores over time moderated by auditory working memory. Although this was visible for both the audiovisual and the visual-only condition, the decline was larger for children in the audiovisual condition. Thus, the role of auditory working memory showed a reversed modality effect over time. A remarkable finding is that children with higher auditory working memory showed a greater decline from the immediate test to the test a day after the lesson than children with lower auditory working memory.

The present results demonstrate that besides pacing, working memory should be taken into account in research into the modality effect. For children, the effect of modality is not very strong. Therefore, it is not required to adjust all learning material to a specific mode.

However, these results in combination with previous results in studies into the modality effect with children show that children benefit more from visual-only lessons than from audiovisual lessons especially in learner-paced lessons. Thus, children will most likely benefit from reading information (written text) rather than from hearing (spoken text). With written text children forget less information over time.

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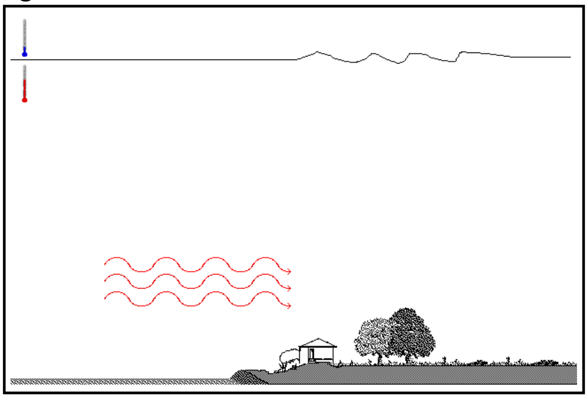
Appendix

Appendix A – Multimedia Lesson

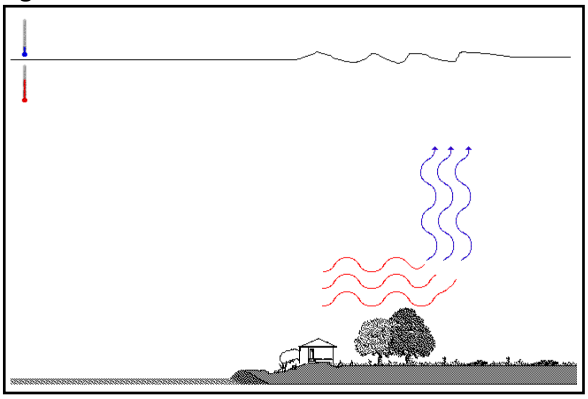
For audiovisual lessons the text was a narration. For visual-only lessons the text was place under the picture.

Pagina 1



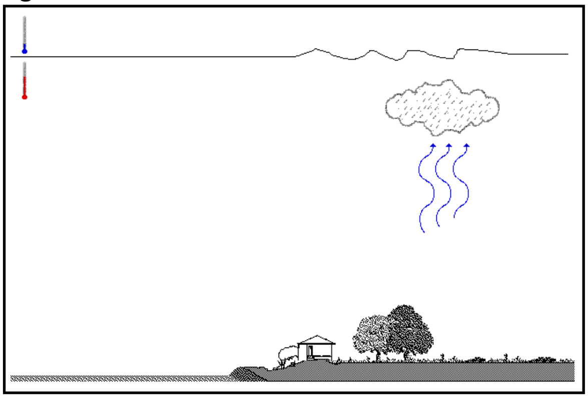
Koele, vochtige lucht beweegt boven warme grond en wordt verwarmd.

Pagina 2



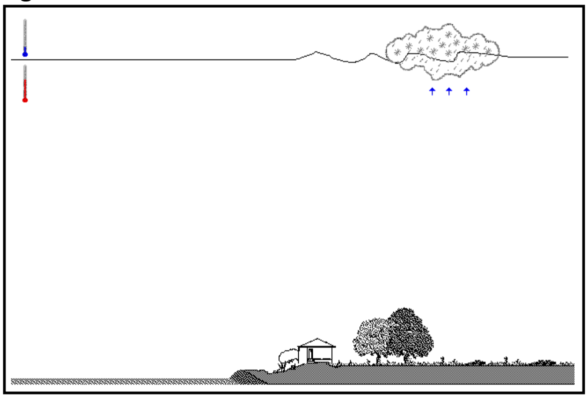
De opgewarmde lucht stijgt snel op.

Pagina 3



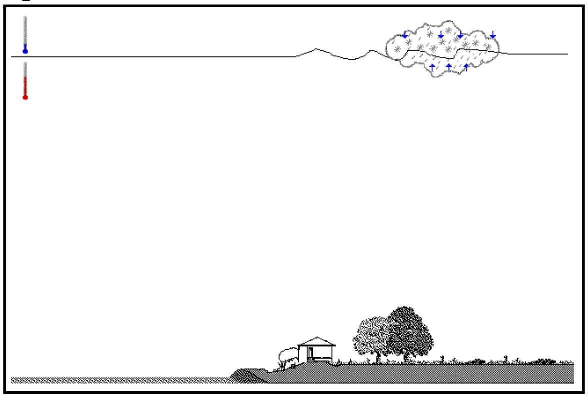
Als de vochtige lucht weer afkoelt, vormen waterdruppeltjes een wolk

Pagina 4



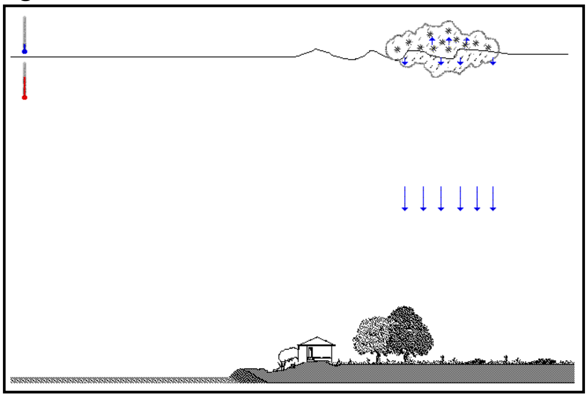
Het bovenste deel van de wolk zit in het koudste gebied en daar ontstaan kleine ijskristallen

Pagina 5



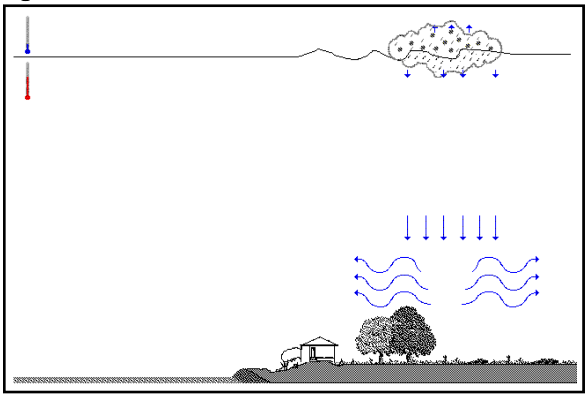
Uiteindelijk worden de waterdruppels en ijskristallen te zwaar en de wolk wordt niet meer naar boven geduwd

Pagina 6



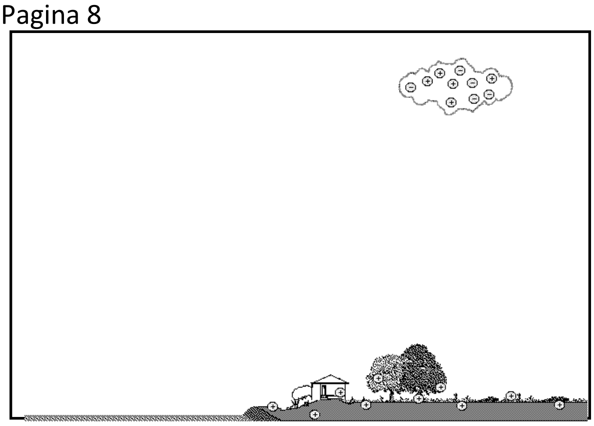
Als de regendruppels en ijskristallen naar beneden drukken, wordt er ook koude lucht naar beneden gedrukt.

Pagina 7



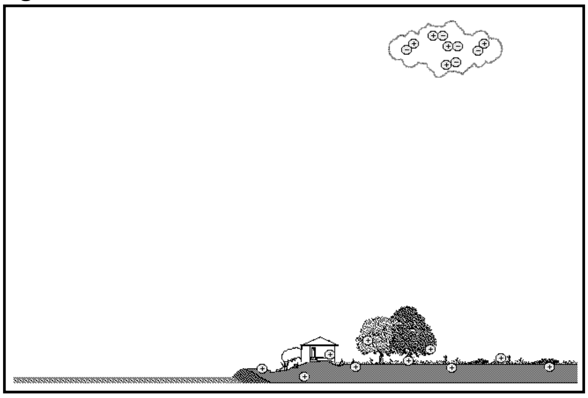
Als de koude lucht naar beneden drukt, ontstaan er koele windvlagen, deze voel je vaak voordat het hard gaat regenen.

Pagina 8



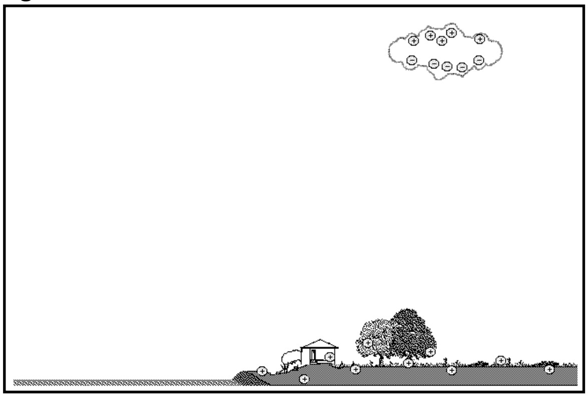
In de wolk ontstaat er elektriciteit door de wrijving van koude en warme lucht.

Pagina 9



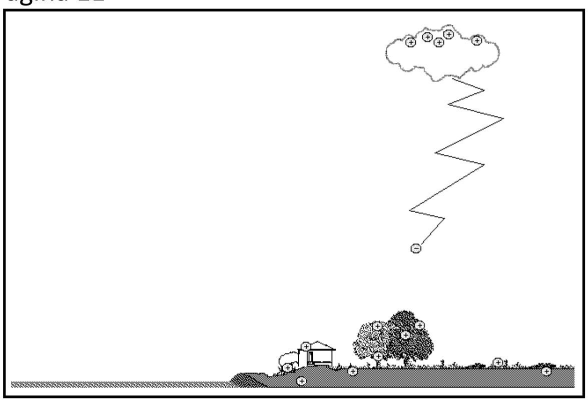
De elektriciteit maakt negatieve en positieve deeltjes in de wolk.

Pagina 10



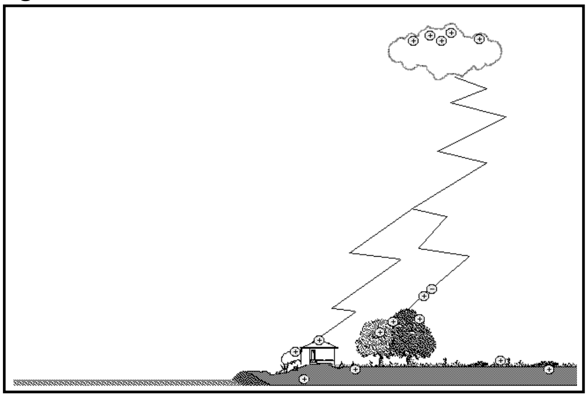
De negatieve zijn het zwaarst en hangen onderin de wolk.

Pagina 11



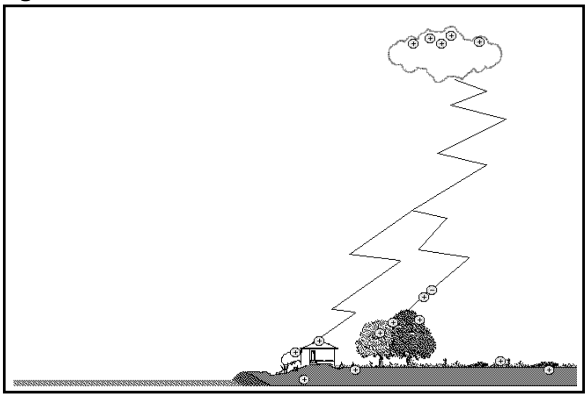
De zwaarste negatieve deeltjes maken een val naar de grond.

Pagina 12



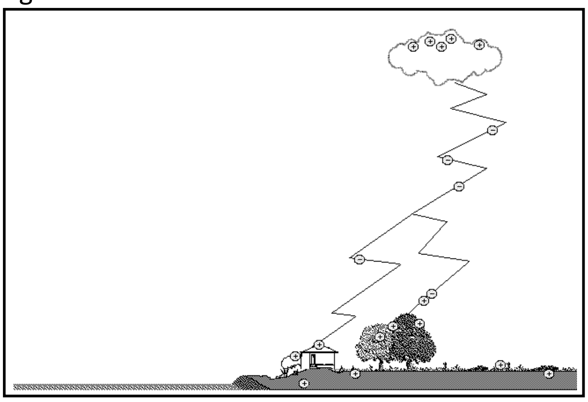
Positieve deeltjes uit de grond worden aangetrokken door deze negatieve deeltjes en klimmen omhoog via huizen en bomen.

Pagina 13



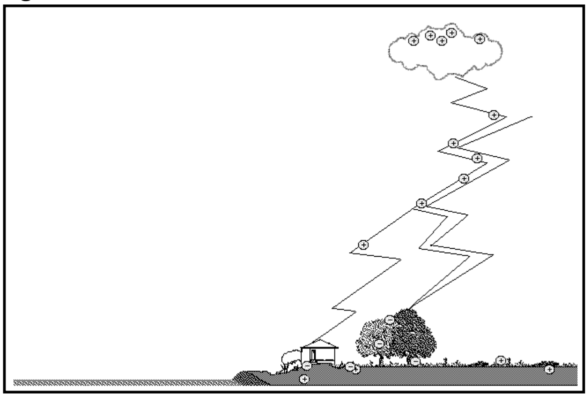
De positieve en negatieve deeltjes ontmoeten elkaar ongeveer vijftig meter boven de grond.

Pagina 14



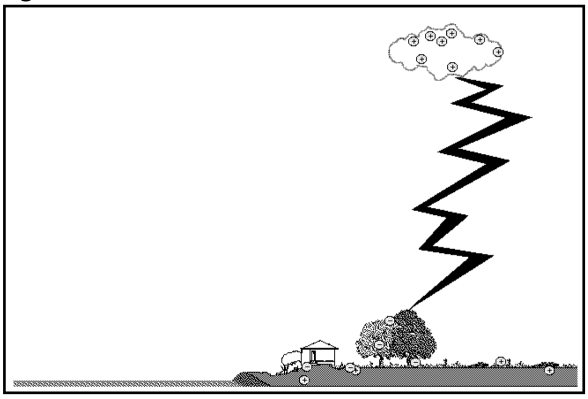
De negatieve deeltjes vallen heel snel naar de grond, dit is niet zo goed te zien.

Pagina 15



Als de negatieve deeltjes de grond raken, komen daar weer heel veel positieve deeltjes op af, die heel snel omhoog willen, naar de vele negatieve deeltjes in de wolk.

Pagina 16



Deze route omhoog produceert de lichtflits die mensen zien als bliksemschicht.

Appendix B – Scoring Form

DEEL A TESTMOMENT 1

Vraag 1 - *Schrijf hieronder alles op wat je nog weet van hoe bliksem werkt.*

- 1 punt per begrip:
- warme/ koude lucht
- ijs(kristallen)
- windvlagen/harde wind/hard waaien
- elektriciteit/ energie/elektrisch
- wrijving
- negatieve deeltjes (0.5 punt voor slechte *(deeltjes)*)
- positieve deeltjes (0.5 punt voor goede *(deeltjes)*)
- 50 meter boven de grond
- Route omhoog
- bliksemschicht/bliksemflits/bliksem/flits

Extra punt voor beschrijvingen zoals:

- De warme lucht die opstijgt koelt weer af, dat vormt een wolk (met regendruppeltjes)
- Door wrijving ontstaat elektriciteit
- Negatieve en positieve deeltjes trekken elkaar aan/ontmoeten elkaar/komen bij elkaar
- De warme lucht/de wolk stijgt op
- De wolk (wordt zwaarder door de ijsdeeltjes en) gaat naar beneden/negatieve deeltjes naar beneden

Vraag 2 - *Wat zou je kunnen doen om de kracht van bliksem te verminderen?*

2 punten: positieve deeltjes van het aardoppervlak halen of positieve deeltjes bij de wolk plaatsen, bliksemafleider plaatsen (beschrijving bliksemafleider is ook goed)

1 punt: minder positieve deeltjes

0 punten: rubber dragen, je klein maken, al het andere

Vraag 3 - *Hoe ontstaan wolken?*

2 punten: opgewarmde lucht die afkoelt, waterdruppeltjes, water dat verdampt en afkoelt

1 punt: koude en warme lucht, damp, dauwdruppels, regendruppels

0 punten: al het andere (ook alleen regen, zonder druppels)

Vraag 4 - *Hoe heeft de temperatuur van de lucht iets te maken met bliksem?*

2 punten: het moet koud genoeg zijn om ijskristallen in de wolk te laten vormen

1 punt: de negatieve deeltjes zitten in het koude gedeelte en positieve in het warme gedeelte van de wolk, door koude temperatuur ontstaan er wolken en die veroorzaken bliksem, warme en koele lucht maken de deeltjes

0 punten: al het andere

<u>DEEL B TESTMOMENT 2</u>

Vraag 1 - *Schrijf hieronder alles op wat je nog weet van hoe bliksem werkt.*

- 1 punt per begrip:
- warme/ koude lucht
- ijs(kristallen)
- windvlagen/harde wind/hard waaien
- elektriciteit/ energie/elektrisch
- wrijving
- negatieve deeltjes (0.5 punt voor slechte *(deeltjes)*)
- positieve deeltjes (0.5 punt voor goede *(deeltjes)*)
- 50 meter boven de grond
- bliksemschicht/bliksemflits/bliksem/flits

Extra punt voor beschrijvingen zoals:

- De warme lucht die opstijgt koelt weer af, dat vormt een wolk (met regendruppeltjes)
- Door wrijving ontstaat elektriciteit
- Negatieve en positieve deeltjes trekken elkaar aan/ontmoeten elkaar/komen bij elkaar
- De wolk (wordt zwaarder door de ijsdeeltjes en) gaat naar beneden/negatieve deeltjes naar beneden
- Route omhoog/ terug omhoog (van positieve deeltjes)

Vraag 2 - Stel je voor dat je wolken ziet, maar geen bliksem. Hoe komt dat?

2 punten: doordat de wolk een bepaalde (lage) temperatuur nodig heeft om ijskristallen te vormen

1 punt: niet alle wolken hebben positieve en negatieve deeltjes/elektriciteit

0 punten: al het andere

Vraag 3 - Waarom slaat bliksem vaak in op het hoogste punt?

2 punten: omdat de afstand tussen de wolk en het hoogste punt het kleinst is, omdat de positieve deeltjes dan sneller bij de negatieve deeltjes zijn

1 punt: het is het dichtstbij, makkelijkst te bereiken, komt de bliksem het snelst bij, komt de bliksem het eerst bij, kortste weg

0 punten: al het andere

Vraag 4 - Hoe ontstaat bliksem?

2 punten: negatieve deeltjes uit de wolk ontmoeten positieve deeltjes op de grond 50 meter boven de grond en de weg terug omhoog veroorzaakt bliksem, de negatieve deeltjes en positieve ontmoeten elkaar en de weg terug omhoog veroorzaakt bliksem

1 punt: positieve en negatieve deeltjes ontmoeten elkaar

0 punten: al het andere

Appendix C – Informed Consent

Beste ouder(s)/verzorger(s),

In de maand november gaat er in de klas van uw kind een onderzoek uitgevoerd worden. Dit onderzoek is een onderdeel van een afstudeeropdracht en zal gaan over begrijpend lezen. Het onderzoek gaat uitgevoerd worden door Adiëlle Niebeek, student aan de Universiteit Twente onder toeziend oog van Prof. dr. Eliane Segers. Via deze brief ontvangt u informatie over het onderzoek en het afwijzingsformulier.

Met vriendelijke groet,

Adiëlle Niebeek

Het onderzoek

We gaan onderzoeken wat kinderen leren in lessen waarbij verschillende media tegelijk wordt gebruikt (bijvoorbeeld beeld en geluid). Het is belangrijk om daar meer over te weten te komen, omdat in deze moderne tijden steeds meer leermateriaal vol multimedia zit.
Wat houdt het meedoen aan het onderzoek concreet in voor uw zoon of dochter?
Op de eerste dag wordt hij/zij uit de klas gehaald om het werkgeheugen te laten meten en om op de computer een multimedia les te doen. Daarna wordt gemeten wat hij/zij nog onthouden heeft. Dit zal samen niet meer dan 20 minuten duren.
Op de tweede dag wordt het kind nog een keer kort uit de les gehaald om te meten wat hij/zij nog onthouden heeft. Dit zal bij elkaar niet meer dan 10 minuten duren. Klassikaal nemen we nog gedurende 5 minuten een technisch leestoets af.
Verder vragen we aan de school nog om de scores op technisch lezen, woordenschat en begrijpend lezen vanuit het leerlingvolgsysteem juni 2017.

Ethiek

Het is belangrijk te vermelden dat we voor dit onderzoek toestemming hebben verkregen van de ethische commissie van onze universiteit. Dit houdt mede in dat we de gegevens die we van uw kind verzamelen op uiterst zorgvuldige manier zullen behandelen. Dat betekent dat er een dataset zal komen die volledig anoniem is, en waar de gegevens niet zijn terug te leiden naar uw kind. Zie de bijlage voor een uitgebreidere uitleg.

Informatie over de toestemmingverklaring

Meedoen aan de studie is vrijwillig. Wilt u niet dat uw kind meedoet? Onderteken dan onderstaand afwijzingsformulier en lever dit formulier vrijdag in op school. Ook als uw kind meedoet, kunt u uw kind alsnog te allen tijde terugtrekken van het onderzoek. Gegevens van kinderen die vroegtijdig stoppen worden direct verwijderd. De toestemmingverklaring (geldt wanneer u niks inlevert) is geldig tot en met februari 2018.

Voor eventuele vragen en/of opmerkingen kunt u gerust contact opnemen via onderstaande gegevens.

Adiëlle Niebeek.
Mail: m.g.a.niebeek@student.utwente.nl

Prof. dr. Eliane Segers.
Mail: p.c.j.segers@utwente.nl

Ondertekend formulier onderzoeker.

Titel onderzoek: Het modaliteitseffect in een systeem-gestuurde en leerling-gestuurde multimedia les voor kinderen.
Verantwoordelijke onderzoeker: Adiëlle Niebeek

In te vullen door de uitvoerende onderzoeker
Ik heb een mondelinge (aan de kinderen) en schriftelijke toelichting (aan de ouders/verzorgers) gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker: Adiëlle Niebeek Datum: 26 – 09 – 2017

Handtekening onderzoeker:

Afwijzingsformulier.

In te vullen door de ouder/verzorger van de deelnemer bij <u>afwijzen deelname.</u>
Ik verklaar hierbij dat mijn kind **niet** deelneemt aan dit onderzoek.

Naam ouder(s)/verzorger(s): ………………………………………………………………… Datum: ………………………………………….

Handtekening ouder(s)/verzorger(s):…..……………………………………………………

Bijlage: verdere uitleg ethische aspecten

Ethisch:
De ethische toestemming houdt in dat de leerlingen veilig mee kunnen doen aan het onderzoek. Het onderzoek zal spelenderwijs worden uitgevoerd, waardoor er geen druk wordt gelegd op het kind. Er zijn geen risico's verbonden aan het meedoen aan dit onderzoek. De prestaties van uw kind zullen alleen gebruikt worden om vast te stellen welke methodevorm voor instructie het best is en niet om uitspraken te doen over de competenties/capaciteiten van uw kind. Tenslotte is dit onderzoek niet in strijd met de Christelijke identiteit van de school. De voordelen van meedoen aan dit onderzoek is dat uw kind een bijdrage levert aan wetenschappelijk onderzoek voor onderwijs en dat op een leuke manier het auditief- en visueel werkgeheugen getest wordt.

Informatie over verwerking:
Elke leerling krijgt een persoonlijk deelnemersnummer. Alle scores worden per leerling gekoppeld aan het deelnemersnummer. Op deze manier wordt alles anoniem behandeld. De deelnemersnummers zijn alleen bij de onderzoeker gekoppeld aan een naam. Daarom is het alleen voor de onderzoeker te achterhalen welke scores bij welke persoon horen. Dit om de scores van eventuele terugtrekkingen te kunnen verwijderen. Er wordt vertrouwelijk met de gegevens omgegaan en ze worden alleen gebruikt door de onderzoeker. De resultaten worden bekend gemaakt in het eindverslag, maar de gegevens worden niet opnieuw gebruikt. Na afloop van de studie worden deze 60 maanden bewaard (volgens wetenschappelijke standaard, zodat gecontroleerd zou kunnen worden of de data daadwerkelijk is verzameld) waarna ze worden vernietigd. Incidentele bevindingen worden verwijderd en er worden geen opnames gemaakt.