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► **To cite this version:**

Mathieu Pinelli, Salomé Cojean. A working memory reversal effect on design principles? Evidence on pauses in video among children. Education and Information Technologies, 2025, <10.1007/s10639-025-13545-1>. <hal-05023089>

HAL Id: hal-05023089

<https://hal.science/hal-05023089v1>

Submitted on 7 Apr 2025

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A Working Memory reversal effect on design principles?

Evidence on pauses in video among children

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Abstract

In the field of multimedia learning, instructional videos have become a widely used tool to facilitate knowledge acquisition across various educational contexts. However, designing these videos effectively is critical to enhancing learning outcomes and minimizing cognitive overload. To address this challenge, researchers have developed design principles aimed at optimizing how information is presented to learners. However, while the limited capacity of Working Memory (WM) is central to the effectiveness of design principles, learners' Working Memory Capacity (WMC) has only been considered in a few studies. Previous findings in the literature suggest a WM reversal effect, for which the current study aims to provide evidence: recommendations from design principles are only beneficial for low-WMC learners and may even be detrimental for high-WMC learners. A focus is made on the design principle of imposed pauses in videos. Forty-seven children took a WMC test before watching a 7-minute instructional video. They were randomly assigned to one of two conditions: the video either included imposed pauses or did not. As expected, the results showed that the benefits of imposed pauses on learning performance depend on WMC. Children with low WMC had better learning outcomes when pauses were imposed, while the imposed pauses had no effect on high-WMC learners. This study demonstrates the importance of WMC in the effect of imposed pauses on learning among children. Design recommendations regarding pauses in videos should specify that the beneficial effect of imposed pauses depends on learners' WMC. Further research on the WM reversal effect should explore other design principles.

Keywords: Video learning; Design principles; Pauses; Working Memory, Working Memory Capacity

Introduction

The use of instructional videos has expanded significantly with the development of the internet. Teachers, for instance, can now integrate videos into flipped learning (Bergmann & Sams, 2012; Van Alten et al., 2019) or use them directly in the classroom (Fan et al., 2024). Because cognitive capacities are limited, effectively integrating knowledge is a central concern in the design of instructional videos. In this regard, pauses have been studied as a means to manage cognitive load and optimize information processing in working memory (Hasler et al., 2007; Spanjers et al., 2012). Current research suggests that novices often struggle to use pauses efficiently, and that imposing pauses might be a more effective solution to enhance learning performance (Biard et al., 2018). However, the beneficial effect of imposed pauses may depend on individual differences in working memory capacity, as the need for pauses can vary according to learners' cognitive abilities (Lusk et al., 2009; Spanjers et al., 2011). Nevertheless, no study has yet examined the impact of working memory capacity on the relationship between imposed pauses and learning performance in children. The present study aims to examine the effect of imposed pauses compared to free pauses on learning performance during school time and to determine whether this effect depends on children's working memory capacity. The paper is organised as follows: the first part presents the theoretical framework, the research question and the hypotheses. The second part presents the methodology and the third the results. Finally, the fourth part deals with the discussion and conclusion of the study.

1. Theoretical background

Many theoretical models have been developed in an attempt to describe the processes involved in learning. Early models, such as Atkinson and Shiffrin's multi-store model (1968) and schema theory (Anderson et al., 1977) have contributed to shaping the understanding of learning and memory. Atkinson and Shiffrin's model, for example, distinguishes between sensory memory, Short-Term Memory (STM), and Long-Term Memory (LTM), emphasizing processes such as attention, encoding, and rehearsal in transferring information from STM to LTM. In contrast,

Anderson's schema theory model describes cognitive structures known as schemas, organized frameworks of knowledge, and explains how new knowledge is integrated with prior knowledge, shaping comprehension and learning. In addition, other models such as Kintsch's construction-integration model (1988) represents knowledge as an associative network and emphasizes how information is integrated into existing knowledge structures, highlighting the role of comprehension in learning. These models aim to explain how knowledge is organized in memory through the creation of mental models that integrate new information with prior knowledge. Among all the learning models, some are specifically designed to describe learning from multimedia content (i.e., words and pictures; Mayer, 2014b).

1.1. Multimedia learning

In the Cognitive Theory of Multimedia Learning (CTML; Mayer, 2014a), learning is defined as the creation of a mental model by selecting information from sensory memory, organizing selected information in working memory, and integrating the organized information with previous knowledge in LTM. This learning model is based on the assumption that information is actively processed in two separate, capacity-limited channels. This limitation refers to the limited capacity of working memory.

1.1.1. The fundamental role of Working Memory

Working Memory (WM) is one of the three core components of executive functions, alongside cognitive flexibility and inhibition, and is considered one of the most important cognitive functions in daily life (Diamond, 2013; Miyake et al., 2000). Previous meta-analyses have highlighted the central role of WM in learning-related outcomes, such as language comprehension, reading, or mathematics (Daneman & Merikle, 1996; Friso-van Den Bos et al., 2013; Peng et al., 2018; Spiegel et al., 2021). Several models of WM (e.g., Barrouillet et al., 2004; Engle et al., 1999) have been proposed and continue to coexist in the literature. For example, Baddeley's model (2012) describes two channels for processing information (i.e., the phonological loop and visuospatial sketchpad, which are closely related to the channels presented in Mayer's

CTML). On the other hand, the Time-Based Resource-Sharing (TBRS) model (Barrouillet et al., 2004) focuses on the allocation of attentional resources. According to the TBRS model, processing new information and maintaining previous information share the same limited attentional resources in WM, and these two processes must alternate (Barrouillet et al., 2004; Barrouillet & Camos, 2007). The TBRS model's predictions have been supported by studies with adults and children samples (Barrouillet et al., 2007; Portrat et al., 2009). Although the definition of WM varies depending on the theory and research context (Oberauer, 2019), the ability to temporarily hold and manipulate a limited amount of information is a common feature across definitions (Baddeley, 2007). Working Memory Capacity (WMC) is limited and considered stable for a given learner, but there is considerable variability across individuals (Wiley et al., 2014). The load imposed on WM during learning is called cognitive load (Paas & Sweller, 2014), and when the limits of WM are exceeded, cognitive overload occurs (Castro-Alonso et al., 2021).

Three types of cognitive loads are identified in the cognitive load theory (Paas & Sweller, 2014). The first is intrinsic cognitive load, which is caused by the complexity of the content (i.e., elements that must be processed simultaneously to be understood). The second is extraneous cognitive load, which is induced by the instructional design (i.e., elements that are processed but are irrelevant to learning). The third is germane cognitive load, which refers to the resources in WM available to handle intrinsic cognitive load once extraneous cognitive load has been processed. Reducing intrinsic cognitive load for learners without altering the content itself is difficult, as it depends on the learners' prior knowledge. However, extraneous cognitive load can be reduced by improving the instructional design. In this regard, design principles based on the CTML (Mayer, 2014a) and cognitive load theory (Paas & Sweller, 2014) have been tested and are now recommended to reduce extraneous cognitive load in WM, thereby facilitating learning.

1.1.2. Design principles

Several models, from the Baddeley's model of WM (2012) to the CTML (Mayer, 2014a), via Paivio's dual coding theory (1990), distinguish between two independent channels that process

verbal and non-verbal information (Cojean & Martin, 2021). Each channel has a limited capacity, but they can be engaged simultaneously, allowing information to be processed in parallel. This assumption leads to one of the first design principles, directly linked to the definition of multimedia, called the *multimedia effect*: adding pictures to words enhances learning (Butcher, 2014; Levie & Lentz, 1982). Words (e.g., written text, speech) are processed in the verbal channel, while pictures are processed in the non-verbal channel. Engaging both channels helps prevent overloading one channel by distributing information process across available cognitive resources. In the CTML (Mayer, 2014a), a further distinction is made between auditory and visual channels. Similarly, using both channels benefits learning. Studies supporting this hypothesis confirm the design principle known as the *modality effect*: spoken speech is more beneficial for learning than written text when paired with visual images (for a meta-analysis, see Ginns, 2005).

Extraneous cognitive load also increases when irrelevant information is presented, a phenomenon known as the *seductive details effect* (for a meta-analysis, see Sundararajan & Adesope, 2020). The associated recommendation is the *coherence principle* (Mayer & Fiorella, 2014). The list of principles that can be followed to reduce extraneous cognitive load (see Mayer & Fiorella, 2014; Sweller et al., 2019) is not exhaustive but includes as well *signaling* (i.e., using cues to help learners select and organise relevant information), *redundancy* (total redundancy between oral and written speech hinders learning), *spatial and temporal contiguity* to reduce split-attention effect (i.e., corresponding elements need to be presented close to each other and simultaneously), etc. These principles have been tested and established to reduce cognitive load due to individuals' limited WMC. They apply to multimedia documents, but some formats, such as videos, have specific constraints related to WMC and therefore require their own design principles.

1.2. Video learning

The growing use of pedagogical videos is driven by the widespread adoption of Massive Online Open Courses (MOOC), the implementation of flipped classrooms, and the overall increase

in distance learning (Cojean & Jamet, 2021; Cojean & Martin, 2021). Whether in the classroom or at home, presenting educational content through video offers benefits but also comes with constraints.

1.2.1. Benefits and constraints

By presenting both speech and images, video benefit from the multimedia and modality effects (Cojean & Martin, 2021; Mayer, 2021; van der Meij & van der Meij, 2014). Additionally, videos are often designed to feature speech alongside animations rather than static images (Cojean & Martin, 2021; van der Meij & van der Meij, 2014), which has been shown to be advantageous for learning concepts that involve changes over time or space (for a meta-analysis, see Höffler & Leutner, 2007).

However, the video format present two specific constraints. Firstly, the organization of video content is often difficult to discern, making information retrieval more difficult compared to written texts (Cojean & Jamet, 2022; Cojean & Martin, 2021; Zhang et al., 2006). Secondly, and this may be the most significant constraint, information in videos is delivered transiently: it disappears as soon as it is presented, unlike in written documents where information remains available (Leahy & Sweller, 2011). Managing the continuous flow of information can generate a high cognitive load in WM (Yu et al., 2023), potentially hindering learning, because new information must be processed while maintaining previously presented information (Leahy & Sweller, 2011; Merkt & Bodemer, 2024; Wong et al., 2019). According to the TBRS model (Barrouillet et al., 2004), these two processes (i.e., maintain and process information) share the same attentional resources and must alternate. The fixed pace of videos makes switching between these tasks difficult to manage: processing new information is to the detriment of the maintenance of previous information, and vice versa (i.e., maintaining information that is no longer available hinders the processing of newly presented information; Spanjers et al., 2012). Since the aims of design principles are to reduce cognitive load in WM, facilitate information processing, and

thereby enhance learning, the specific constraints of video content shape the elaboration of recommendations for effective video-based learning.

1.2.2. Video design principles

Design principles for videos can focus on the characteristics of the instructor or the way the video content is presented. Research has shown that the *presence of an instructor* makes learners split their attention between the content and the instructor (van Wermeskerken & van Gog, 2017), but it also has a positive impact on social presence and positive affects (Beege et al., 2023). Moreover, instructors' *gestures* serve as more effective signaling cues than pointing arrows displayed on the video (Pi et al., 2019), and a *first person perspective*, where learners view tasks from the instructor's point of view, is better for learning assembly tasks than a third-person, face-to-face perspective (Fiorella et al., 2017). When the instructor is not visible, it is beneficial for learning if the voice delivering speech is *human* (rather than computer-generated; Mayer, 2021; van der Meij & van der Meij, 2013), *enthusiastic* (Guo et al., 2014), and *directly addresses to the learner* in a conversational style (rather than using a formal tone; Mayer, 2021; van der Meij & van der Meij, 2013).

Regarding video presentation, providing a *table of contents* can help learners identify the structure of the video content (Cojean & Jamet, 2022), as can using cues to segment the video into *meaningful units* (Spanjers et al., 2012). Overall, outlining the video with a table of contents and *markers on the timeline* is beneficial for learning (Cojean & Jamet, 2022), particularly for information-seeking purposes (Cojean & Jamet, 2017). Another recommendation is to incorporate *interactive features* that allow learners to control the pace and content being delivered (Schwan & Riempp, 2004; van der Meij & van der Meij, 2013). A particularly important feature is the *pause button*. Pauses interrupt the flow of incoming information and provide additional time for cognitive processing (Lee et al., 2020; Spanjers et al., 2012). According to the TBRs model (Barrouillet et al., 2004), pauses create opportunities to halt the processing of new information and to allocate resources to maintaining previously presented information.

Even though previous studies have shown that pauses positively impact learning performance (e.g., Aalioui et al., 2022; Lee et al., 2020; Schwan & Riempp, 2004; Spanjers et al., 2012), both children and adults learners seldom use this option when it is available (Biard et al., 2018; Cojean & Jamet, 2021; Hasler et al., 2007). It seems that learners underestimate their usefulness, even in ecological situations where they take notes (Pinelli & Cojean, 2024). *Imposed pauses* (i.e., system-determined pauses) have been explored to optimize the effects of pauses and have shown promising results (e.g., Aalioui et al., 2022; Biard et al., 2018). In the study by Biard et al. (2018) three experimental conditions were compared: 1) video learning without pauses, 2) with free pauses (i.e. pause button available), or 3) with imposed pauses. Their results indicated that participants performed better with imposed pauses compared to the other two conditions. However, the benefits of imposed pauses have not been consistently observed in all studies (e.g., Merkt et al., 2018). In the only study conducted with children (Hasler et al., 2007), both free and imposed pauses were beneficial for learning compared to conditions without pauses, but the learning performance in the free and imposed pauses conditions was not statistically different.

The design principles of imposed pauses is also sometimes referred to as the segmentation principle (e.g., Spanjers et al., 2012), particularly in earlier studies where the term *animated presentations* was used instead of *videos* (e.g., Mayer & Chandler, 2001). Imposing pauses, like other design principles, is recommended to limit cognitive load in WM during learning (Aalioui et al., 2022; Merkt et al., 2018; Merkt & Bodemer, 2024). However, individual differences, especially in WMC, have rarely been considered in experiments testing these design principles.

1.3. Current study

Previous results have shown the relevance of design principles depending on prior knowledge (i.e., level of expertise). In a study conducted by Spanjers et al. (2011), the learning performance of participants was assessed in two conditions: 1) segmented (i.e., with imposed pauses) or 2) continuous presentation. Imposed pauses were beneficial for learners with low-prior knowledge, but not for those with high-prior knowledge. This phenomenon is known as the

expertise-reversal effect (Khacharem et al., 2013; Spanjers et al., 2011; Sweller et al., 2003): design principles are particularly useful for novices but may not be beneficial, and can even be detrimental, for experts.

So far in the literature, only a few studies examined the differentiated effects of design principles depending on the WMC. As cognitive overload occurs when demands exceed WMC (Sweller, 2010), individuals with lower WMC are more vulnerable to cognitive overload. Similar to the expertise-reversal effect, high-WMC learners may require fewer instructional techniques to reduce their cognitive load. Sanchez and Wiley (2006) demonstrated that seductive details negatively impacted learning performance as expected, but only for low-WMC learners. No negative effects were found for high-WMC learners. Thus, design principles may be useful in a different way depending on WMC, leading to the hypothesis of a general *WM reversal effect*.

The aim and originality of the current study is to test this WM reversal effect concerning the design principle of pauses among children. Pauses, particularly imposed pauses, are expected to benefit learning because video learning imposes a heavy demand on WM. Pauses provide opportunities to halt the processing of new information and to maintain previously presented information. This beneficial effect is expected especially for low-WMC learners, who may struggle more with transient information. Conversely, pauses for high-WMC learners may be unnecessary and detrimental to learning performance (Wiley et al., 2014). A previous study by Lusk et al. (2009) indicated that segmentation (i.e., imposed pauses) was indeed more beneficial for low-WMC learners, but no comparisons with free pauses were tested.

In the current study, the hypotheses are as follows:

Hypothesis 1. Pauses duration. Previous research has indicated that learners tend to take few pauses and often do not know when to pause (e.g., Biard et al., 2018; Cojean & Jamet, 2021; Hasler et al., 2007). Therefore, it is expected that the total time spent pausing will be longer when pauses are imposed compared to when learners are free to choose when to pause.

Hypothesis 2. Cognitive load. Based on WM and cognitive load theories, a negative correlation between WMC and cognitive load is expected. Furthermore, according to design principle regarding pauses, a lower cognitive load is expected when pauses are imposed compared to when learners are only free to take pauses.

Hypothesis 3. Learning performance. Considering the beneficial effects of imposed pauses on learning and the theoretical framework of WMC, better learning performance is expected when pauses are imposed rather than not imposed, particularly for low-WMC learners. For high-WMC learners, however, unnecessary imposed pauses may have a detrimental effect, leading to better learning performance with free pauses instead of imposed pauses.

2. Method

2.1. Participants

Participants consisted of 47 children recruited from two French schools (mean age = 9.4 years; $SD = 0.55$; 23 girls and 24 boys). All families provided their consent to participate in this study. Five participants had neuropsychological disorders, and one did not follow the instructions. These participants were excluded from the sample. The final sample included 41 participants (20 in the “free pauses” condition, and 21 in the “free and imposed pauses” condition).

2.2. Material

2.2.1. Video

The video covered the life of Napoléon Bonaparte from birth to death. It was divided into nine segments, with a mean duration of 44.2 seconds per segment, each representing a different period in Napoleon's life. The audio contained 1030 words, averaging 138.9 words per minute, and the total duration of the video was 445 seconds. Two versions of the video were created: one with free pauses allowed (FP), and another with both free and imposed pauses (FIP). In the FIP condition, nine pauses were included, one at each segment. During these pauses, no information was visible (i.e., the image was blurred; see Figure 1). The video presentation and the recording of pausing

data (including the number, timing, and duration of pauses) were developed using JavaScript (the script and data are available on OSF¹).

2.2.2. Evaluation of WM

The adaptative composite complex span (ACCES) from Gonthier et al. (2018) was used to evaluate the participants' WMC. The ACCES is a computerized task that measures three dimensions of the WM: reading span, operation span and symmetry span. The task consists of six trials for each dimension, for a total of 18 trials. For each participant, their WMC was assessed using the mean score calculated from the scores of the three dimensions.

2.2.3. Evaluation of cognitive load

A pictural scale was used to evaluate the perceived mental effort during learning. This scale featured seven emoji, ranging from a relaxed blue-colored face to a stressed red-colored face (Ouweland et al., 2021). Since the participants were 9-year-old children, the task was simplified by employing a 7-point scale instead of the 9-point scale used in the measure used by Paas (1992).

2.2.4. Learning questionnaire

The evaluation of learning performance included four multiple-choice questions and two open-ended questions. There were two comprehension questions (1 point each), such as, "What did the republic supported by Napoleon Bonaparte during the revolution consist of?", and four recall questions (1 point each), such as, "Which battle did Napoleon win in 1796?". A total score ranging from 0 to 6 was calculated by summing the points for the six questions.

2.2.5. Control variables

Perceived difficulty (1 item) and perceived motivation (1 item) regarding the video presentation were evaluated using 7-point Likert scales, ranging from 1 ("not at all") to 7 ("completely").

¹ <https://osf.io/qp2an/>

Additionally, one item evaluated the children's habits related to using instructional videos (ranging from 1 = “never” to 7 = “very often”). Questionnaires were administered via Qualtrics©.

2.3. Procedure

The procedure consisted of two sessions in which children participated in pairs. Each child had access to an individual laptop equipped with a mouse and headphones. In the first session, the children completed the WMC task for 30 minutes. Several days later ($M = 13$ days), they watched the instructional video. Participants were randomly assigned to one of the two experimental conditions (FP or FIP). The video began after the participants pressed the play button (Figure 1). In both conditions, participants pause the video at will (i.e., they had control over the video using a pause button, allowing them to stop and resume playback), but they did not have the option to rewind or fast-forward. After watching the video, participants filled out questionnaires regarding cognitive load, learning, control variables and demographic information.

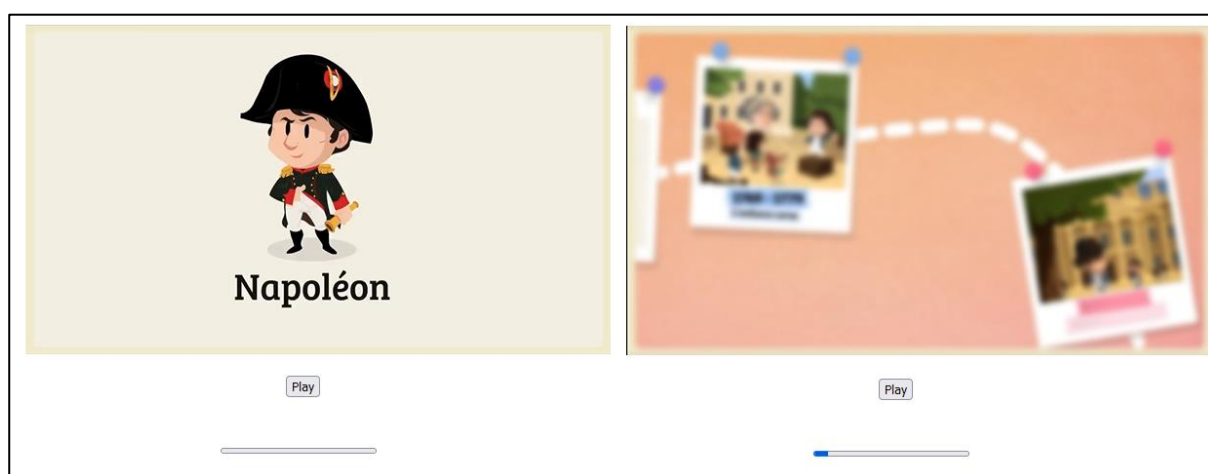


Figure 1. Conditions tested in the study with an example of the FP (left) and FIP (right) conditions. In the FIP condition, the screen was blurred during imposed pauses.

3. Results

3.1. Control variables

There were no significant differences between conditions on perceived difficulty ($F(1, 39) = 2.17, p = .148$), perceived motivation ($F(1, 39) = 0.010, p = .919$), and children' habits related to using instructional videos ($F(1, 39) = 0.002, p = .960$).

3.2. Use of pause button

The results concerning the use of the pause button are presented in Table 1. Overall, children made few free pauses: 21 children made no pauses, 7 children made only 1 pause, and 13 children made more than 1 pause. For the FP condition, the total pause duration consisted solely of free pauses. In the FIP condition, the total pause duration included both free and imposed pauses. The total pause durations were significantly higher in the FIP condition ($M = 38.3$ sec, $SD = 18.3$) than in the FP condition ($M = 12.6$ sec, $SD = 25.2$), $F(1, 39) = 14.01, p < .001, \eta^2p = .27$. Regarding free pause duration, the results showed no significant effect of the pause condition, $F(1, 37) = 2.34, p = .134$, no significant effect of WMC, $F(1, 37) = 0.005, p = .941$, and no interaction between pause conditions and WMC, $F(1, 37) = 0.95, p = .335$.

Table 1. Number of free pauses according to conditions.

| Number of free pauses | Number of learners | |
|-----------------------|--------------------|---------------|
| | FP condition | FIP condition |
| 0 | 10 | 11 |
| 1 | 2 | 5 |
| 2 | 5 | 3 |
| 3 | 0 | 0 |
| 4 | 0 | 0 |
| 5 | 2 | 0 |
| More than 5 | 1 | 2 |

3.3. Data analysis

Analyses of covariance (ANCOVAs) were conducted for each Dependent Variable (DV), namely cognitive load, total learning score, recall score and comprehension score. WMC was

tested as a continuous variable (z-score) and the pause conditions (FP and FIP) were treated as a between-subject factor. Means and standard deviations for the variables are presented in Table 2. Two outliers were detected for the total learning score and two for cognitive load, as identified by Cook's distance. These participants were excluded from the analyses. For each DV, normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated with Levene's test. Tests for normality and homogeneity of variances were not significant for total learning and recall (all $ps > .10$), except for the normality test for the comprehension score ($p < .001$). Bonferroni correction was applied in post hoc comparisons for the total learning score and recall score (i.e., results are presented with correction when the interaction was decomposed by testing simple effects).

Table 2. Means (standard deviations) for WMC, cognitive load and learning scores.

| Condition | N | WMC | Cognitive load | Total learning score | Recall score | Comprehension score |
|------------------|----|-------------|----------------|----------------------|--------------|---------------------|
| Free and imposed | | | | | | |
| pauses (FIP) | 21 | 17.6 (3.23) | 2.62 (1.12) | 2.14 (1.06) | 1.76 (0.83) | 0.38 (0.50) |
| Free pauses (FP) | 20 | 16.3 (4.39) | 2.70 (1.26) | 1.65 (1.14) | 1.20 (0.89) | 0.45 (0.60) |
| Overall | 41 | 16.9 (3.85) | 2.66 (1.17) | 1.90 (1.11) | 1.49 (0.90) | 0.41 (0.55) |

3.3.1. Total learning score

For the total learning score, the results indicated no significant effect of the pause condition, $F(1, 35) = 2.66, p = .112$, nor of WMC, $F(1, 35) = 1.84, p = .184$. However, the interaction between WMC and the pause conditions was significant, $F(1, 35) = 7.08, p = .012, \eta^2p = .17$. Decomposing the interaction revealed a significant difference between the FP and FIP conditions for low-WMC learners (-1 SD), $F(1, 35) = 8.97, p = .010, \eta^2p = .20$. This difference was not significant for high-WMC learners (+ 1 SD), $F(1, 35) = 0.86, p = .360$ (see Figure 2). In other words, imposed pauses

were beneficial only for low-WMC learners. For high-WMC learners, imposed pauses had no significant impact on learning performance.

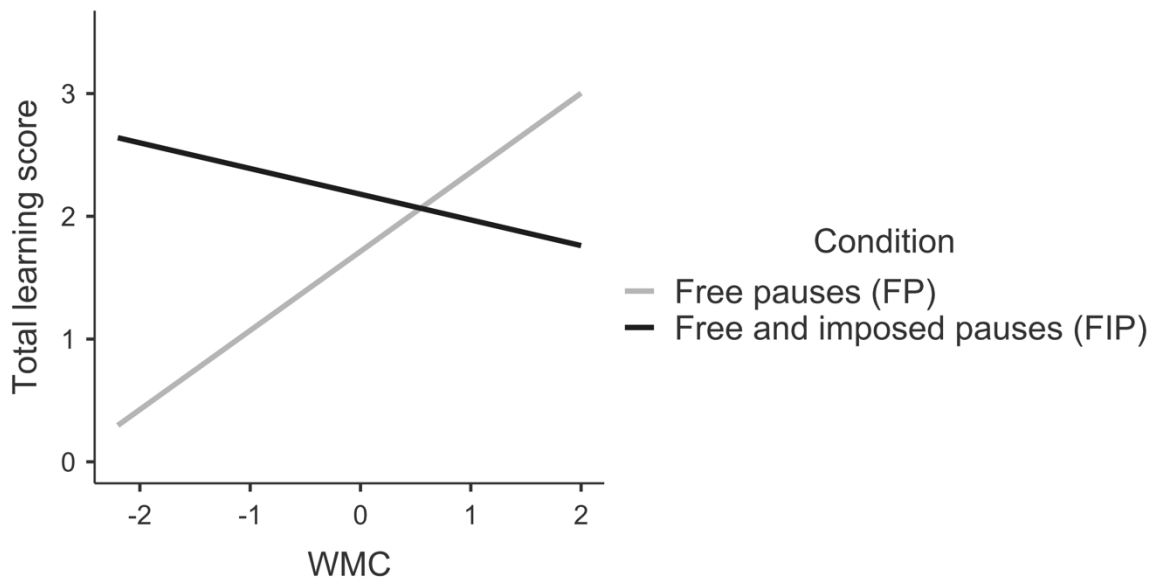


Figure 2. Total learning score according to the pause condition and WMC (z-score).

3.3.2. Recall score

Results for the recall score showed no effect of WMC, $F(1, 37) = 1.11, p = .29$, nor of the pause condition, $F(1, 37) = 3.99, p = .053$. However, the interaction between WMC and the pause condition was significant, $F(1, 37) = 4.78, p = .035, \eta^2 p = .11$. The recall scores were higher in the FIP condition than in the FP condition, particularly for low-WMC learners, $F(1, 37) = 8.39, p = .012, \eta^2 p = .18$. No significant effect was observed for high-WMC learners, $F(1, 37) = 0.04, p = .833$.

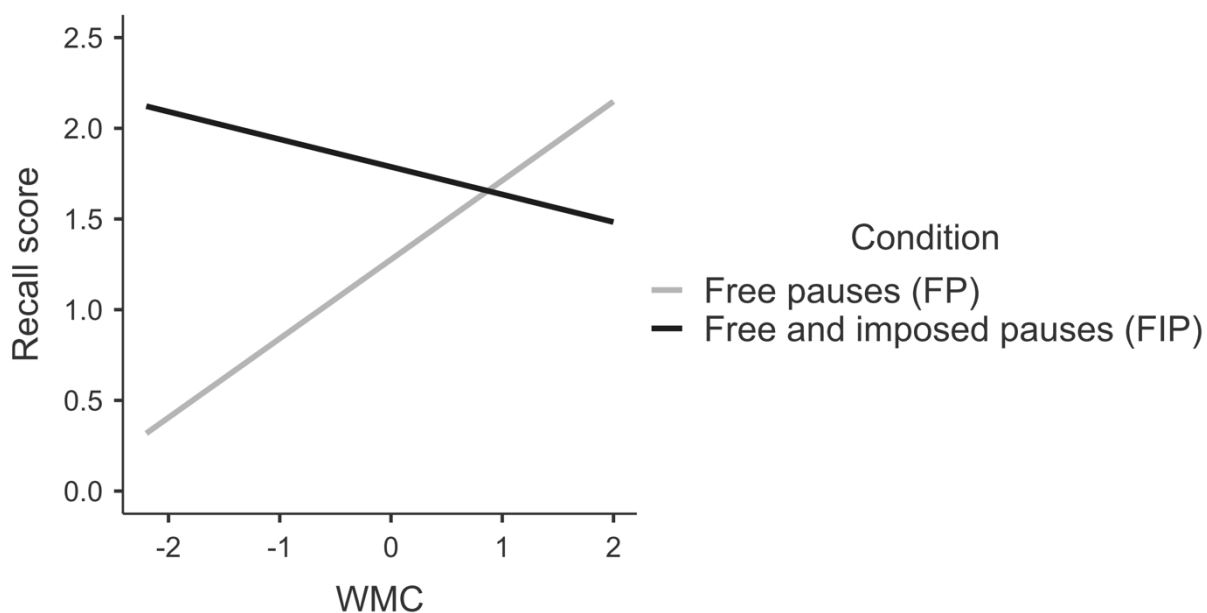


Figure 3. Recall score according to the pause condition and WMC (z-score).

3.3.3. Comprehension score

Regarding comprehension score, no significant effect of the pause condition was found, $F(1, 37) = 0.45, p = .505$, nor was there a significant effect of WMC, $F(1, 37) = 2.09, p = .157$. The interaction between the pause condition and WMC was also not significant, $F(1, 37) = 1.51, p = .227$.

3.3.4. Perceived cognitive load

Results regarding cognitive load indicated no significant effect of the pause condition, $F(1, 35) = 0.11, p = .747$. However, there was a significant positive effect of WMC, $F(1, 35) = 10.30, p = .003, B = 0.48, \eta^2 p = .23$. This suggests that the higher the learners' WMC, the higher their perceived cognitive load (see Figure 4). The interaction between WMC and the pause condition was not significant, $F(1, 35) = 0.26, p = .616$.

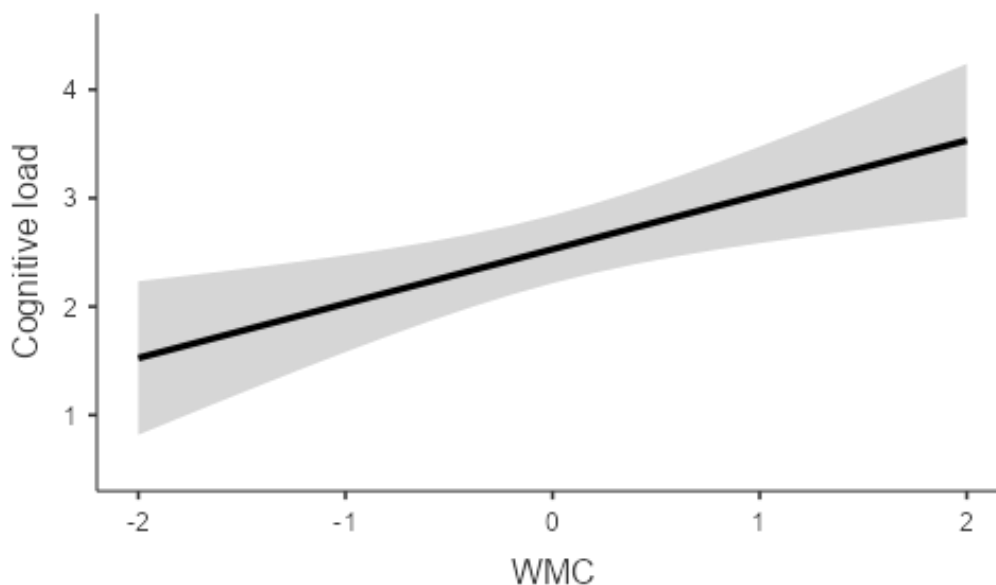


Figure 4. Relationship between cognitive load and WMC (z-score).

4. Discussion

The aim of this study was to investigate the interaction between WMC and the pause condition (i.e., imposed or not) on learning and cognitive load among children. It was predicted that, since learners do not spontaneously utilize the pause option, imposing pauses would increase the total amount of time spent paused. Furthermore, it was expected that the effects of imposed pauses on cognitive load and learning performance would depend on WMC. Specifically, it was expected that imposed pauses would be more beneficial than free pauses for learning and cognitive load for low-WMC learners, while being detrimental for high-WMC learners.

Results confirmed a longer total pause duration in the FIP condition compared to the FP condition, supporting H1. This finding aligns with previous studies that demonstrated increased pause duration during learning when pauses are imposed (e.g., Biard et al., 2018). Additionally, children in the current study made few free pauses (1.49 on average, $M = 7.92$ seconds). This result about the number of free pauses is consistent with previous studies conducted on both adults and children (e.g., Biard et al., 2018; Cojean & Jamet, 2021; Hasler et al., 2007).

No significant effects of the pause condition, nor any interaction between the pause condition and WMC, on cognitive load were observed. However, although the video was not perceived as particularly difficult ($M = 3.80$) or cognitively demanding ($M = 2.66$), results indicated a positive and significant correlation between WMC and cognitive load, which does not support H2. This unexpected result may stem from the ability of children to accurately estimate their WMC. Indeed, some studies on metacognition suggest that lower WMC is associated with less accurate metacognitive judgement and less consciousness about one's WMC (Forsberg et al., 2021). Therefore, in the current study, high-WMC learners may have been more aware of their cognitive load than low-WMC learners, rather than actually experiencing higher cognitive load. These findings could also be attributed to the scale used to evaluate cognitive load, which comprised a single item measuring perceived mental effort (Paas, 1992). While cognitive load is a significant framework in educational research (Klepsch et al., 2017), there are few adequate measures available, and those that exist are validated for adults (e.g., Klepsch et al., 2017; Leppink et al., 2013). Consequently, the use of a single-item scale may fail to capture the complexity of cognitive load, including its intrinsic, extraneous, and germane dimensions, which could explain the absence of interaction between WMC and cognitive load. Future studies are needed to develop appropriate scales for evaluating cognitive load in children.

Importantly, the effect of imposed pauses on learning performance was dependent on WMC, validating H3. As expected, children had better learning performance in the FIP condition, compared to the FP condition, particularly among low-WMC learners. However, contrary to the hypothesis, no effect of pauses (imposed or not) was observed for high-WMC learners. Interestingly, this interaction was observed for both the total learning score and the recall score, but not for the comprehension score. A possible explanation for this could be a floor effect, as children performed poorly on the comprehension score (with an average of 0.41 on a scale of two). Future research should replicate these results with a larger sample size.

Nevertheless, these results provide evidence that supports and extends cognitive load theory, the CTML, and the TBRS model (e.g., Barrouillet et al., 2004; Mayer, 2014a; Paas & Sweller, 2014) by demonstrating a significant effect of WMC on the relationship between pauses and learning performance. Limited WMC is central to the framework of cognitive load and multimedia learning, and it is often referenced to explain observed results. However, the actual measurement of learners' WMC has been proposed in only a few studies. The results of this study show that not only are imposed pauses beneficial for children, but also that individual differences in WMC lead to differentiated effects on learning performance. Indeed, according to the TBRS model (Barrouillet et al., 2004), maintaining and processing information should be more challenging for low-WMC learners. Consequently, video learning may be more cognitively demanding for them (i.e., may lead to cognitive overload more quickly). Given that children made few free pauses, imposed pauses provide more time and opportunities for switching between information maintenance and processing. Interestingly, unnecessary imposed pauses were expected to be detrimental for learning for high-WMC learners, but no reversal effect was found.

The beneficial effects of imposed pauses observed in the current study among children can be explained because pauses allow for more efficient processing of transient information (Hasler et al., 2007). Another explanation relates to the segmentation principle, where pauses help structure learning content into meaningful units (Merkt et al., 2018; Spanjers et al., 2012). While previous studies have struggled to disentangle these two mechanisms (Merkt et al., 2018), future research should aim to investigate these distinct explanations among children, taking individual differences such as WMC into account (e.g., Lawson & Mayer, 2024).

One limitation of the current study pertains to the availability of free pauses in both conditions. This option was included because prior studies on the effects of pauses have shown that learners typically take few pauses (e.g., Biard et al., 2018; Cojean & Jamet, 2021). Although no significant differences were observed between the two conditions regarding the number or duration of free pauses, it remains uncertain whether these pauses influenced the effects of pause

condition and WMC on learning outcomes. Future research should replicate these findings by incorporating a control condition featuring a continuous video without pauses, along with a larger sample size. Think-aloud protocols or interviews could also be conducted to gain deeper insight into the strategies used by learners (Wolcott & Lobczowski, 2021).

Another limitation relates to the differences between free and imposed pauses: when pauses were imposed, the image displayed in the video was blurred, whereas it remained visible during free pauses. However, essential information in the video was mainly presented orally, and no text was presented. Therefore, unlike some previous studies where the last screen remained displayed during pauses (e.g., Spanjers et al., 2012), the results of the current study cannot be attributed to additional information that children may have been exposed to (see also Merkt et al., 2018).

From a practical perspective, instructional videos are playing an increasingly role in educational contexts. Previous research has highlighted the positive impacts of technology, including videos, on learning performance (Brame, 2016; Fyfield et al., 2022; Schmid et al., 2014). Today, instructional videos are commonly integrated into both online and offline courses, serving as effective tools for education (Brame, 2016). This study demonstrates the importance of imposed pauses for children's learning, particularly for those who typically face difficulties (i.e., low-WMC learners). However, implementing the necessary technology poses challenges, as it requires technical skills to code the imposed pauses. Moreover, the results are currently limited to the specific video used in this study, restricting the generalizability of the results to other video content. Future research should explore the development of a platform that facilitates the automatic integration of imposed pauses, thereby simplifying the process for teachers and researchers to implement pauses and test various videos.

Imposed pauses positively have a positive impact on learning performance, and this effect depends on individual differences in WMC. While previous studies have demonstrated the beneficial effect of imposed pauses on learning performance among pre-teens, this study highlights the significant role of WMC in the relationship between pauses and learning in a school context.

Results of this study underscore the importance of considering WMC in research on instructional videos and emphasize the necessity of integrating imposed pauses, rather than relying solely on free pauses, in instructional videos designed for children.

5. Conclusion

Previous research has highlighted the benefits of imposed pauses for learning. The present study provides a significant contribution by demonstrating the central role of Working Memory Capacity (WMC) in determining effectiveness of pauses, particularly in a school context. The results reveal that imposed pauses are specifically beneficial for children with low WMC, while no effect was observed for high-WMC learners. These findings emphasize the necessity of considering individual differences, such as WMC, when designing instructional materials. Nevertheless, several limitations should be considered, such as implementation of system-determined pauses in instructional videos during school hours, which may present challenges or the generalizability of results to other types of videos. Moreover, future studies should replicate these findings by including a condition with continuous video and explore other design principles aimed at reducing cognitive overload, taking into account learners' WMC. Consequently, recommendations that apply to all learners may need to be adjusted based on these individual differences.

Acknowledgements

This work has been supported by MIAI@Grenoble Alpes, (ANR-19-P3IA-0003), within the Technologies Used in Pedagogy with Artificial Intelligence Adaptations (TUPAIA) chair.

Access to the facility of the MSH-Alpes SCREEN platform for conducting the research is gratefully acknowledged. We would like to thank the 4 students in Education sciences (master's degree) who got involved in this research project.

Conflict of Interest

The authors declare that they have no conflict of interest.

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