Time-Compressed Audio on Attention, Meditation, Cognitive Load, and Learning

Xiaozhe Yang[1], Lin Lin[2*], Yi Wen[1], Pei-Yu Cheng[3], Xue Yang[2] and Yunjo An[2]
[1]Institute of Curriculum and Instruction, East China Normal University, China // [2]Department of Learning Technologies, University of North Texas, USA // [3]Department of Engineering Science, National Cheng Kung University, Taiwan // worldetyang@gmail.com // Lin.Lin@unt.edu // wenyiyimy@163.com // peiyu.cheng.tw@gmail.com // sketchmichelle@gmail.com // Yunjo.An@unt.edu
[*]Corresponding author

(Submitted May 9, 2020; Revised June 24, 2020; Accepted July 16, 2020)

ABSTRACT: This study examined how three auditory lectures delivered at different speeds – normal (1.0x), fast (1.5x) and very fast (3.0x) speeds – affected the graduate students' attention, cognitive load, and learning that were assessed by pre- and post-comprehension tests, cognitive-load questionnaire, and Electroencephalography (EEG) device. The results showed that there was no significant difference in the students' attention, cognitive load, and learning performance between the normal (1.0x) and 1.5x speed. However, when the auditory lecture speed reached three times of its original speed (3.0x), the students' comprehension scores were significantly lower both in the immediate and (one-week) delayed recall tests, than those in the other two speed conditions. When listening to the lecture at the 3.0x speed, the learners had a higher level of attention and cognitive load. The study provided insights for teaching, instructional design, and learning.

Keywords: Time-compression, Audible, Attention, Cognitive Load, Electroencephalography (EEG)

1. Introduction

New multimedia technologies have made auditory and visual learning more popular than ever (Wang, Wu, & Wang, 2009). An increasing number of young people prefer to listen to or watch videos rather than to read books when seeking information or learning new things (Evans, 2008). Audible.com, one of the world's largest producers of downloadable audiobooks, sells digital audiobooks, radio and TV programs, and audio versions of magazines and newspapers of all kinds. Audiobooks are valuable alternatives to music and podcasts. With the rising popularity of Audible and other audiobook providers, it is easier than ever to stimulate one's mind listening to news and stories while doing other things. The ubiquitous online learning has also facilitated auditory and visual learning opportunities with audio-video lectures in formal and online learning environments (Kress & Selander, 2012).

However, auditory narratives present certain constraints. For instance, it may take longer for a learner to listen to or watch someone present information than to read the texts for the same information (Barron & Kysilka, 1993; Koroghlanian & Sullivan, 2000). Studies have shown that adults in most English-speaking countries can read 280 words per minute, while the normal speed of speaking is only 120-180 words per minute (Pastore, 2012). The native Chinese speakers can usually read at an average speed of 295±51 words per minute (Wang et al., 2018), while a survey of broadcasters showed that each word spoken in Mandarin Chinese would take about 0.224s (Lee & Chan, 2003). That is, the average speech rate of the Mandarin speakers is only 260-300 words per minute. In addition, reading allows a reader to adjust the speed him or herself, while the speed of the auditory narratives is highly dependent on the timing of the auditor (Orr, Friedman, & Graae, 1969). This inflexibility may be in conflicts with the desire of self-directed learners to increase learning efficiency and effectiveness (Broadbent, 2017). In fact, different teaching approaches and learning strategies are constantly adapted to increase learning effectiveness and efficiencies (i.e., achieving the best learning with the least amount of time).

Time compression is a technique to increase the speed of auditory lectures without distorting the tones, intonations, or the output quality of the spoken lectures (Barabasz, 1968; Goldhaber, 1970). Researchers have begun to examine the impact of time compression techniques on cognition and learning. When the time is compressed by 50% or 1.5x speed, it means that the learning task can be completed in half of the time, which is very appealing to the learners. Some researchers found that time compression was directly proportional to the degree of hearing difficulties, and as the compression rate increased, cognitive difficulties began to increase (King & Behnke, 1989). Yet, some other studies showed that there was no difference in the understanding by learners after the speed of auditory lecture increased (Orr et al., 1969; Pastore, 2010; Ritzhaupt, Pastore, & Davis, 2015; Thompson & Silverman, 1977). In fact, in some studies, the level of satisfaction of the participants increased when the auditory speed was increased (Ritzhaupt et al., 2008b). There is not a consensus on the impact of the auditory speed of learning lectures on students' learning. Previous studies did not delve into the impact of time compression on the learning processes.

By far, researchers have examined the relationships between time compressed auditory materials and learning using academic comprehension tests (King & Behnke, 1989; Thompson & Silverman, 1977; Zemlin et al., 1968), cognitive load tests (Pastore, 2012; Pastore, 2010), and satisfaction tests (Ritzhaupt et al., 2008a; Ritzhaupt et al., 2015). However, they used more subjective methods, and collected little objective data such as physiological data. Further, previous studies focused on immediate recalls after listening to auditory learning materials (King & Behnke, 1989) or on training students over time to see if they could adapt to time-compressed speech (Banai & Lavner, 2012; Gabay, Karni, & Banai, 2017). Little research has examined students' delayed memory or recalls of auditory information, which would better reflect the students learning.

In this study, we examined the effects of time-compressed lectures on the individual students' attention, cognitive load, and comprehension of the lectures. In addition to using pre- and post-tests to assess the students' comprehension and the established cognitive load questionnaire to assess the students' perceived loads, we used an electroencephalography (EEG) device to capture the students' brainwave data and understand their attention and meditation (relaxation) values when they were listening to the auditory lectures at different speeds. The following research questions guided the study: (1) Are there any differences in students' attention as detected by the EEG device among the three different auditory speed conditions? (2) Are there any differences in students' cognitive load among the three different auditory speed conditions? and (3) Are there any differences in students' comprehension and memory among the different auditory speed conditions?

2. Literature review and related work

2.1. Auditory learning

Auditory learning has become increasingly popular with the increasing demands for mobile, online, and multimedia learning (Cheon, Lee, Crooks, & Song, 2012; Moreno & Mayer, 2002). The use of auditory playback software, such as podcasts, as a teaching tool has increased dramatically (Pastore, 2010). Students have shown a positive attitude towards integrating these tools into classroom instructions (Evans, 2008).

As for auditory learning, listening comprehension has been a main focus for researchers (King & Behnke, 1989). Comprehending a language being spoken is a complex skill, involving many processes that have become the focus of classroom-oriented research (Call, 1985). Comprehensive listening is typically conceptualized as understanding and remembering a message that is usually associated with long-term memory (Bostrom & Waldhart, 1980). Some researchers defined comprehension as the ability to repeat facts contained in an auditory record, and they developed comprehension tests based on this framework (King & Behnke, 1989).

For comprehension tests, researchers often use both immediate recalls and delayed recalls (Folkard, Monk, Bradbury, & Rosenthall, 1977; Lawson & Hogben, 1998). The immediate recall comprehension tests are usually given immediately after the learners have completed the auditory or reading materials. The delayed recall comprehension tests are usually given some time (usually a week) after the learners have completed the materials. Previous studies showed that the results of immediate recalls and delayed recalls often differed (Folkard et al., 1977), as the learning material would not always remain in short-term memory long enough to be encoded or organized. Yet, as the ultimate goal of education is to pursue long-term memory and learning benefits (Lawson & Hogben, 1998), the delayed recalls should not be ignored in the research of comprehensive tests. Therefore, this study incorporated delayed recall tests.

2.2. Time-compressed instructions or lectures for learning

Research using time-compressed speech dates back to the 1950s (Fairbanks, Guttman, & Miron, 1957). When researchers began experimenting with compressed sounds, they changed the pitch and rhythm. As a result, they changed the sound quality, often making the auditory sound like a fast-paced chipmunk voice, which was distracting to students (Pastore, 2010). As algorithms have been improved, researchers have found ways to artificially shorten the duration of the auditory signal without effecting the fundamental frequency of the signal (Golomb, Peelle, & Wingfield, 2007). The time compression used in this study increased the auditory rate without changing the auditory quality.

Many researchers reported that auditory lectures that were sped up a little bit did not have a significant negative impact on learning. Orr et al. (1969) found that the auditory material with spoken speed accelerated for 1.5x times had no significant difference on the listeners' quiz choices and understanding of the learning material as compared to the material in its original speed. Ritzhaupt et al. (2008b) investigated the effects of different auditory speeds on learners' performance and satisfaction. The authors set the compression speed to 1.0x, 1.4x, and 1.8x of the original multimedia presentation and found that there was no significant difference in performance among the different conditions. However, there were significant differences in the learner' satisfaction levels. The results showed that the learners in the 1.4x condition had the highest satisfaction scores.

Some studies have shown that an increase in compression rate led to an increase in learning difficulties and an adverse effect on learning. Zemlin et al. (1968) had 40 college students assess the difficulty levels of the auditory materials at different compression speeds (1.2x, 1.3x, 1.6x, and 2x). The results showed that starting from 1.2x times, the students' perceived difficulty levels of the materials increased. When the time was compressed at 50% (i.e., doubling the speed of the original spoken materials), the students' perceived difficulty level of the material reached at about 5 times of the difficulty level of the original material. Ritzhaupt and Barron (2008a) found that the scores of learners' content recognition was significantly reduced at very fast speed (2.5 times). Ritzhaupt et al. (2015) found that increased speed (up. To. 1.5x) did not affect learners' comprehension of the listening materials, but the learners' satisfaction declined.

Existing research shows that multimedia auditory lectures can be compressed to a certain extent, and such processing may not cause much loss of information, and sometimes may facilitate the learning of auditory materials. Yet, when the compression ratio rises to a certain level, the compressed auditory will have a significant negative impact on the students (King & Behnke, 1989). There have been studies on time-compressed speech, mainly focusing on the learner's learning performance (Adank & Janse, 2009), satisfaction level (Ritzhaupt & Barron, 2008a), and cognitive load (Pastore, 2012; Pastore, 2010), but there is a lack of research on the effects of time compression on attention, cognitive load, and long-term memory.

2.3. Cognitive load, attention, and auditory learning

In the learning process, if learners do not know the limitations of their working memory or do not adopt complex problem-solving strategies, they may be subject to learning interference and suffer from cognitive overload (Sun & Yu, 2019). There are three types of cognitive load: intrinsic, extraneous, and germane loads (Sun & Yu, 2019; Sweller, 1988). Intrinsic cognitive load is the load placed on working memory from task-inherent complexity of the materials to be learned (Ayres, 2006). Extraneous load refers to the cognitive load caused by the way information is presented and the requirements of teaching activities (Künsting, Wirth, & Paas, 2011). The germane load refers to the mental resources required for acquiring and automating schemata in long-term memory, which contributes to students' learning (Debue & Van De Leemput, 2014).

Cognitive load theory suggests that in complex cognitive tasks, learners who are overwhelmed by a large number of interactive information elements would not be conducive to meaningful learning (Van Gog, Paas, & Sweller, 2010). To this end, cognitive load theory focuses on the concentration and use of cognitive resources in learning and problem solving (Chandler & Sweller, 1991) to keep working memory in the right amount without overloading it. In two studies, Pastore explored the association between time compression techniques and learners' cognitive load levels (Pastore, 2012; Pastore, 2010). One study investigated the impact of a measurement chart and time-compression teaching on learners' perceived cognitive load (Pastore, 2010). The other study measured the impacts of time compression teaching and redundancy (with text) on learning and learners' perceived cognitive load (Pastore, 2012). Both studies showed that the cognitive load of learners did not increase with a little increase of the speed compression (25%). However, the participants had a higher level of cognitive load and lower level of learning performance when the speed compression rate reached at 50%.

Cognitive load theory focuses on the fact that learning materials occupy the learners' working memory (Sun & Yu, 2019). Studies have shown that cognitive load does not increase significantly in time compression that is not increased too much (Pastore, 2012). Yet, so far, insufficient attention has been paid to the impacts of time compression in the multimedia environment. At present, there is very limited research on the brain states of learners when they listen to the time-compressed auditory lectures. Some researchers used functional magnetic resonance imaging (fMRI) techniques to investigate the responses of spoken and written sentences in the brain. The results showed that the activation rate and amplitude of the cortical region were significantly different (Vagharchakian, Dehaene-Lambertz, Pallier, & Dehaene, 2012). This study explores the changes in learners' cognitive load at higher speeds and adds more physiological evidence to explain this important issue.

Brainwave detection technologies such as the Electroencephalography (EEG) are usually used to detect abnormalities in people's brain waves or electrical activities. In research, EEG has been used to study cognitive development and activities such as studies of time-compressed auditory learning. Attention and meditation values are two important indicators of brain wave measurements. Smith, Colunga, and Yoshida (2010) pointed out that learning depends on attention, and attention plays an important role in aggregating, acquiring, and applying knowledge in daily lives. Learners need to stay in a highly concentrated state, but excessive concentration may also have a negative effect. Concentration can benefit from meditation or relaxation, both of which can help people calm down and recharge their attention and energy (Hsu, 2017). NeuroSky, which is a popular mobile brainwave EEG sensor, has been shown to be effective in the measuring attention and meditation values (Lin, Su, Chao, Hsieh, & Tsai, 2016; Liu, Chiang, & Chu, 2013; Sun et al., 2018). This study used NeuroSky to explore the effects of auditory speed on the participant's attention and meditation. Through collecting the brainwave data of the students while listening to the auditory lectures at three different speeds, we attempt to gain a deeper understanding of the effect of time-compressed auditory lectures on learning.

3. Method

This study aims to examine how time compression influences individual students' attention, cognitive load, understanding and memory of the lectures. We used pre- and post-tests and questionnaires to assess students' learning and cognitive load. We used the EEG device to capture the students' brainwave data and understand their attention and meditation/relaxation values while they were listening to the auditory lectures at different speeds. The study explored whether there were any differences in students' attention, cognitive load, comprehension, and memory among the three different auditory speed groups.

3.1. Participants and auditory lectures/materials

The participants included 25 graduate students in China. Fifteen students (60%) of the participants were female, and the average age of the participants was 24.8 years old. A total of three auditory lectures, equivalent in content and difficulty levels, were selected for the experiment. Each lecture included about 2900-3000 written Chinese characters. All lectures were narrated with the same male voice. The article came from three popular books. The pronunciation, intonation, and depth of interpretations were also consistent. The lengths of the three auditory lectures were about 10 minutes at the normal (1.0x) speed. For the study, we modified two of the lectures in the way that they would be at faster speeds, i.e., 1.5x and 3.0x speeds. As a result, we had one auditory lecture, entitled "Mastering the skills of practice" spoken at the normal speed (1.0x); one lecture entitled "Office designs for creativity" spoken at the fast speed (1.5x); and one lecture entitled "Peek performance" spoken at the very fast speed (3.0x). As such, the three different voice speeds turned the auditory lectures into three different auditory durations or lengths. The presentation time lengths and approximate Words per Minute (WPM) for the three lecture conditions are provided in Table 1.

Table 1. Auditory speeds, presentation lengths, and the approximate words per minute (WPMs) of the three auditory lectures

Auditory lecture speed conditions	Presentation lengths (minutes: seconds)	Approximate WPMs (in Mandarin Chinese)
Normal (1.0x times)	10:00	298
Fast (1.5x times)	6:40	442
Very fast (3 times)	3:20	894

3.2. Participants and auditory lectures/materials

Before listening to the auditory lectures, the participants completed a demographic survey and a pre-test measuring their prior knowledge of the lecture content. Each participant came to the researcher's lab and participated in the experiment individually at a time. They were asked to listen to all three lectures with different speeds. While they were listening to the auditory lectures, the participants wore the EEG brainwave equipment, which recorded their attention and meditation values. After completing each auditory lecture, the participant took a quiz (post-test) of the lecture and a cognitive load survey. These processes were repeated for the 2nd and the 3rd lecture and assessments. A week after the experiment, each participant was tested of their knowledge of the lectures again. Figure 1 below shows the experimental procedure.

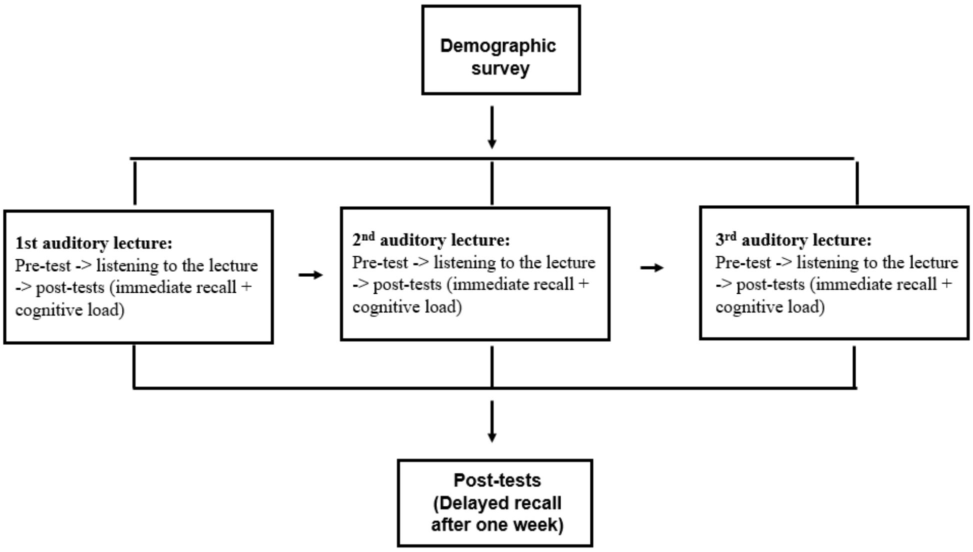

Figure 1. Experimental procedure

The three auditory lectures were purposefully sequenced in the way that when the first participant came in and followed in the sequence of "normal > fast > very fast" speed, the second participant would listen to the lectures in the sequence of "fast > very fast > normal" speeds, and the third participant would listen to the lectures in the sequence of "very fast > normal > fast" speeds. Consequently, there were six different sequences randomly assigned to the students coming to the lab to participate in the study. The total time each participant spent to complete the study (listening to the lectures and completing tests and questionnaires) was about 40 minutes.

3.3. Instruments

3.3.1. EEG brainwave detection system

NeuroSky headset recorded electroencephalogram (EEG) data through a single touch sensor on the forehead of the learner. The eSense is a NeuroSky's proprietary algorithm for representing mental states. To calculate eSense, the NeuroSky Think Gear technology intensifies the raw brainwave signal and removes the ambient noise and muscle movement. The eSense algorithm is then applied to the remaining signal, resulting in explicated eSense meter values. Based on real-time EEG data, the headset could output two values, namely attention and meditation (i.e., relaxation). Both the attention value and the meditation value were between 0 and 100. Previous research has shown that NeuroSky headsets provide sufficient, effective and reliable data for studies of this nature (Hardy, Drescher, Sarkar, Kellett, & Scanlon, 2011; Chen & Huang, 2014). The analysis results showed that the attention value and meditation value measured by NeuroSky headsets had satisfactory validity and reliability.

3.3.2. Learner cognitive load questionnaire

The cognitive load scale, developed by Paas (1992) and Sweller, Merrienboer, and Paas (1998) was adopted to assess the participants' cognitive loads while listening to the three auditory lectures at different speeds. The scale consisted of eight items, including five items for "mental load" and three items for "mental effort." A seven-point Likert scale was used. The Cronbach's alpha values of the two dimensions were .86 and .85, respectively, demonstrating the high reliability of the scale.

3.3.3. Learning performance tests

Three listening comprehension tests were designed based on the three auditory lectures to assess the students' learning performance. As mentioned earlier, the three lectures were "Mastering the skills of practice" spoken at the normal (1.0x) speed; "Office designs for creativity" spoken at the fast (1.5x) speed; and "Peek performance" spoken at the very fast (3.0x) speed. Ten multiple-choice questions were developed for each auditory lecture, based on Bloom's Taxonomy (Bloom, 1956). Five out of 10 questions were basic-level questions (related to knowledge recall and understanding); three out of 10 were intermediate-level questions (related to knowledge application and analysis); and two were in-depth level questions (related to knowledge evaluation and creation).

The highest score a participant could receive was 10 points (with 1 point for each correct answer). Basic level questions sought information or facts that would be easily recalled from the auditory lecture. Intermediate-level comprehension questions required the participants to summarize the key concepts (or to discard untrue statements). In-depth questions required the participants to assess and synthesize what's said and create new meanings. Responses to these questions allowed us to see the depth of comprehension by the participants, and to examine the impact of the auditory lectures at different speeds on the participants.

The participants received one point for each question answered correctly in the quiz, with a total score of 10 for one lecture. Based on the statistical analysis of a pilot study, we confirmed that the difficulty levels between the three tests were comparable. The three tests had high reliability in assessing academic performance. The three tests were each used three times during the experiment. First, each test was used as a pre-test to assess the participants' prior knowledge of the lecture to be listened. Then the test was used immediately after the participant listened to the lecture to assess immediate recall of the lecture. Finally, after a week, the tests were used to assess the participants delayed recalls of the lectures. In order to ensure the reliability and effectiveness of the return visit after one week, the participants was not informed at the beginning that they would be tested again a week later.

4. Results

4.1. Analysis of individual attention and meditation from EEG data

ANOVA was used to answer the first research question, "Are there any differences in students' attention as detected by the EEG device among the three different auditory speed conditions?" The results of the individual attention and meditation of the three conditions are shown in Table 2.

Table 2. ANOVA results of attention for the three auditory lectures

Auditory lecture speed conditions	*N*	Mean	*SD*	*F*	Post hoc tests
Normal (1.0x times) (a)	25	46.39	8.63	6.263^{**}	(c) > (a)
Fast (1.5x times) (b)	25	45.32	6.00		(c) > (b)
Very fast (3 times) (c)	25	52.76	9.13		

Note. $^{**}p < .01$.

According to the ANOVA result for attention ($F = 6.263$, $p < .001$), the students had a significant higher attention in the very fast speed condition than when they were in the normal speed ($p < .05$) and the fast speed ($p < .05$) conditions. There was no significant difference in the attention value between the normal speed and the fast speed conditions ($p > .05$). When it comes to meditation, the students in the very fast speed condition had a significantly lower meditation than when they were in the other two conditions ($p < .05$) (see Table 3).

Table 3. ANOVA results of meditation (relaxation) of the three auditory lectures

Auditory lecture speed conditions	*N*	Mean	*SD*	*F*	Post hoc tests
Normal (1.0x times) (a)	25	55.09	9.26	4.383^{*}	(c) < (a)
Fast (1.5x times) (b)	25	54.07	6.41		(c) < (b)
Very fast (3 times) (c)	25	48.80	8.20		

Note. $^{*}p < .05$.

4.2. Analysis of individual cognitive load

ANOVA was also used to answer the second research question, "Are there any differences in students' cognitive load among the three different auditory speed conditions?" The ANOVA results regarding the cognitive load of the three conditions are shown in Table 4.

There were significant differences in cognitive loads between the three conditions ($F = 35.11$; $p < .001$). As shown in Table 4, the students reported a significantly higher cognitive load in the very fast speed condition than in the normal speed condition ($p < .05$) and the fast speed condition ($p < .05$).

Table 4. ANOVA results of the reported cognitive loads of the three auditory lectures

Auditory lecture speed conditions	*N*	Mean	*SD*	*F*	Post hoc tests
Normal (1.0x times) (a)	25	2.27	1.54	35.11^{***}	(c) > (a)
Fast (1.5x times) (b)	25	2.34	1.22		(c) > (b)
Very fast (3 times) (c)	25	5.24	1.50		

Note. $^{***}p < .001$.

4.3. Analysis of the learning performance

By using the paired-sample *t* test, we examined whether the three lectures generated good learning performance based on pretest and posttest scores. In addition, we examined whether the learning performance differed significantly among the three auditory conditions. The analytical results indicated that the students did significantly better in their immediately recall post-tests than in the pre-tests in all the three lectures (see Table 5).

Table 5. Paired-sample *t* test results of pre-tests and immediate recall post-tests with three different time-compressed lectures

Auditory lecture speed conditions	Learning of the lectures	*N*	Mean	*SD*	*t*
Normal (1.0x times) (a)	Pretest	25	3.36	1.08	16.65^{***}
	Posttest	25	9.40	1.15	
Fast (1.5x times) (b)	Pretest	25	3.68	1.18	19.77^{***}
	Posttest	25	9.00	1.00	
Very fast (3 times) (c)	Pretest	25	3.80	1.22	8.414^{***}
	Posttest	25	6.56	1.26	

Note. $^{***}p < .001$.

Before analyzing the learning performance of the three conditions, we did a baseline analysis of the participants' the pretest scores to answer the third research question, "Are there any differences in students' comprehension and memory among the different auditory speed conditions?" The ANCOVA results regarding the learning performance in the three conditions are shown in Table 6.

Table 6. ANCOVA results of immediate recall post-test comparisons between the three auditory lectures

Group		Pre-test		Post-test		ANCOVA	
	N	Mean	*SD*	Mean	*SD*	*F*	Pairwise comparison
Normal (1.0x times) (a)	25	3.36	1.08	9.41	1.15	38.9254^{***}	(a) > (c)
Fast (1.5x times) (b)	25	3.68	1.18	9.00	1.00		(b) > (c)
Very fast (3x times) (c)	25	3.80	1.22	6.55	1.26		

Note. $^{***}p < .001$.

According to the ANCOVA results of learning performance ($F = 38.9254$, $p < .001$), the average scores of the immediate recall post tests were 9.41, 9.00, and 6.55 for the conditions at the normal speed (1.0x), with fast speed (1.5x), and with very fast speed (3.0x), respectively. Students in the very fast speed condition (3x times) group had significantly lower listening comprehension scores (6.55) after the post-hoc test ($p < .001$) than the fast group (9.00) and the normal group (9.41). There were no differences between the fast and the normal groups ($p > .05$).

Table 7. ANCOVA results of the delayed recall (after one-week) post-test comparisons between the auditory lectures

		Pretest		Delayed recall		ANCOVA	
Group	*N*	Mean	*SD*	Mean	*SD*	*F*	Pairwise comparison
Normal (1.0x times) (a)	25	3.36	1.08	8.09	1.36	19.50^{***}	(a)>(c)
Fast (1.5x times) (b)	25	3.68	1.18	8.02	1.54		(b)>(c)
Very fast (3x times) (c)	25	3.80	1.22	5.45	1.87		

Note. $^{***}p < .001$.

Table 7 shows the ANCOVA results of learning performance (after one-week) ($F = 19.50$, $p < .001$). The mean values of the delayed-recall (after one week) post-test scores were 8.09 for the normal speed, 8.02 for the fast speed, and 5.45 for the very fast speed. The students in the very fast speed condition (3x times) had significantly lower listening comprehension scores (5.45) after one week ($p < .001$) than the fast group (8.02) and the normal group (8.09). There was no significant difference between the fast speed and the normal speed conditions ($p > .05$).

5. Discussions, limitations, and conclusion

The study has several significant implications for educational theory and practices. First, we found that there was no significant difference in students' attention, cognitive load, comprehension, and memory between the normal speed (1.0x) and the fast speed (1.5x) conditions. The findings on learning performance are consistent with previous studies that examined the impact of time compression on learning outcomes (Adank & Janse, 2009; Thompson & Silverman, 1977). In addition to immediate recalls, we added delayed recalls of the lectures. The results showed no significant difference in the students' delayed recall scores between the normal (1.0x) speed and the fast (1.5x) speed. This dimension added weight to the claim that increasing speed of the auditory lectures to a degree may not affect their learning negatively. Further, we used the EEG brainwave device and captured the students' attention during their learning processes, and we asked the students to report their cognitive load for each lecture they listened. The results showed that the students exhibited similar levels of attention, meditation / relaxation, and cognitive load in the normal (1.0x) speed and the fast (1.5x) speed conditions. Based on all these findings, we can safely suggest that increasing the auditory lecture speed up to 1.5x times might not negatively affect students' learning, attention or cognitive load. This is an important finding because it shows that learners can increase their learning efficiency by speeding up their auditory lecture to a certain degree. At the same time, educators can potentially adopt this strategy in teaching.

Second, the results of this study showed that when the speed was increased three times (3.0x), the students' learning performance suffered greatly. Further, the lecture at the 3.0x speed significantly increased the students' cognitive load. These are consistent with prior studies as well (Ayres, 2006; Künsting et al., 2011). The participants' brainwaves detected by EEG device also showed that the participants' attention was three times more intensive, and that their meditation values were significantly lower than when they were in the other two conditions (the normal and the fast speed conditions). That is, when the participants were listening to the auditory lecture at the very fast (3.0x) speed, they were very intense and not-relaxed, although they were at a very high level of attention. This research finding can be used to further explain the combined effects of the fast (3.0x) speed on the learning process. In a more stressful state, even if the attention is more concentrated, the cognitive load is more likely to increase, and the learning outcome is worse. This finding provides more evidence for understanding the speeds to which to compress the instructional videos without sacrificing the learning (Ritzhaupt et al., 2015). Therefore, instructional designers and learners should not simply pursue faster speed and obtaining information in a shorter period of time, but instead, they should choose an appropriate time compression ratio, to ensure that meaningful learning can take place (Mayer, 2003).

The study has some limitations. First, although we assessed the participants' prior knowledge of the auditory lectures, we did not focus on the individual differences pertaining to attention, cognitive load, past experiences of time-compression lectures, or memory capacities. Future studies could look more in-depth into individual differences. In addition, the use of the EEG device limited the amount of time for experiments. The total time each participant spent to complete the study was about 40 minutes. The short lectures and the extended time to complete the study could all affect the results of the study. Last but not the least, although we purposely sequenced the three different speed lectures in the way that they would take turns to be the 1st, 2nd, or the 3rd lectures to be listened and completed by different participants, the sequence might still have affected the participants' attention, cognitive load, comprehension, and memory.

Despite these limitations, this study addressed several research gaps. We collected physiological data of brain waves to better understand the students' learning processes of auditory lectures at different time-compression speeds (Banai & Lavner, 2012; Gabay et al., 2017; Pastore, 2012). Compared to prior studies, this study used EEG data and added the delayed recall assessments to examine to what extent the students were able to retain the information after one week. The results of the study help researchers, educators, and learners further understand the effects and underlying mechanisms of time-compressed auditory learning. This study further confirms that a certain degree of time compression may be acceptable and may not affect learners' attention and meditation values, cognitive load, or learning outcomes negatively. As digitally recorded auditory learning such as podcasts is widely integrated into multimedia learning environments (Evans, 2008; Moreno & Mayer, 2002), educators and learners can choose appropriate time compression ratios to increase learning efficiency (Littlejohn, Hood, Milligan, & Mustain, 2016). Once the time compression ratio is found to be too high and the learner perceives tension, educators can reduce the time compression ratio. The widespread use of time compression for auditory lectures highlights the value of this research. Time compression is becoming a new habit for more and more learners to obtain information on multimedia, mobile and online learning environments (Pastore, 2012; Pastore, 2010). Major media and learning platforms can be optimized in terms of time compression ratio settings, providing learners with better time compression options (Gillani & Eynon, 2014). Future researchers should continue to explore areas where the theory and practices are closely integrated.

References

Adank, P., & Janse, E. (2009). Perceptual learning of time-compressed and natural fast speech. *The Journal of the Acoustical Society of America, 126*(5), 2649-2659.

Ayres, P. (2006). Impact of reducing intrinsic cognitive load on learning in a mathematical domain. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition, 20*(3), 287-298.

Banai, K., & Lavner, Y. (2012). Perceptual learning of time-compressed speech: More than rapid adaptation. *PloS one, 7*(10), e47099.

Barabasz, A. F. (1968). A Study of recall and retention of accelerated lecture presentation. *Journal of Communication, 18*(3), 283-287.

Barron, A. E., & Kysilka, M. L. (1993). The Effectiveness of digital audio in computer-based training. *Journal of Research on Computing in Education, 25*(3), 277-289.

Bloom, B. S. (1956). *Taxonomy of educational objectives. Vol. 1: Cognitive domain*. New York, NY: McKay.

Bostrom, R. N., & Waldhart, E. S. (1980). Components in listening behavior: The Eole of short-term memory. Human Communication Research, 6(3), 221-227.

Broadbent, J. (2017). Comparing online and blended learner's self-regulated learning strategies and academic performance. *The Internet and Higher Education, 33*, 24-32.

Call, M. E. (1985). Auditory short-term memory, listening comprehension, and the input hypothesis. *Tesol Quarterly, 19*(4), 765-781.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and instruction, 8*(4), 293-332.

Chen, C. M., & Huang, S. H. (2014). Web-based reading annotation system with an attention-based self-regulated learning mechanism for promoting reading performance. *British Journal of Educational Technology, 45*(5), 959-980.

Cheon, J., Lee, S., Crooks, S. M., & Song, J. (2012). An Investigation of mobile learning readiness in higher education based on the theory of planned behavior. *Computers & Education, 59*(3), 1054-1064.

Debue, N., & Van De Leemput, C. (2014). What does germane load mean? An Empirical contribution to the cognitive load theory. *Frontiers in psychology, 5*, 1099-1111.

Evans, C. (2008). The effectiveness of m-learning in the form of podcast revision lectures in higher education. *Computers & Education, 50*(2), 491-498.

Fairbanks, G., Guttman, N., & Miron, M. S. (1957). Auditory comprehension of repeated high-speed messages. *Journal of Speech and Hearing Disorders, 22*(1), 20-22.

Folkard, S., Monk, T. H., Bradbury, R., & Rosenthall, J. (1977). Time of day effects in school children's immediate and delayed recall of meaningful material. *British Journal of Psychology, 68*(1), 45-50.

Gabay, Y., Karni, A., & Banai, K. (2017). The Perceptual learning of time-compressed speech: A Comparison of training protocols with different levels of difficulty. *PloS one, 12*(5), e0176488.

Gillani, N., & Eynon, R. (2014). Communication patterns in massively open online courses. *The Internet and Higher Education, 23*, 18-26.

Goldhaber, G. M. (1970). Listener comprehension of compressed speech as a function of the academic grade level of the subjects. *Journal of Communication, 20*(2), 167-173.

Golomb, J. D., Peelle, J. E., & Wingfield, A. (2007). Effects of stimulus variability and adult aging on adaptation to time-compressed speech. *The Journal of the Acoustical Society of America, 121*(3), 1701-1708.

Hardy, J. L., Drescher, D., Sarkar, K., Kellett, G., & Scanlon, M. (2011). Enhancing visual attention and working memory with a web-based cognitive training program. *Mensa Research Journal, 42*(2), 13-20.

Hsu, W. Y. (2017). A Wireless brainwave-driven system for daily-life analyses and applications. *Telematics and Informatics, 34*(8), 1793-1801.

King, P. E., & Behnke, R. R. (1989). The Effect of time-compressed speech on comprehensive, interpretive, and short-term listening. *Human Communication Research, 15*(3), 428-443.

Koroghlanian, C. M., & Sullivan, H. J. (2000). Audio and text density in computer-based instruction. *Journal of Educational Computing Research, 22*(2), 217-230.

Kress, G., & Selander, S. (2012). Multimodal design, learning and cultures of recognition. *The Internet and Higher Education, 15*(4), 265-268.

Künsting, J., Wirth, J., & Paas, F. (2011). The Goal specificity effect on strategy use and instructional efficiency during computer-based scientific discovery learning. *Computers & Education, 56*(3), 668-679.

Lawson, M., & Hogben, D. (1998). Learning and recall of foreign-language vocabulary: Effects of a keyword strategy for immediate and delayed recall. *Learning and Instruction, 8*(2), 179-194.

Lee, P. S., & Chan, A. H. (2003). Chinese speaking times. *International Journal of Industrial Ergonomics, 31*(5), 313-321.

Lin, H. C. K., Su, S. H., Chao, C.-J., Hsieh, C. Y., & Tsai, S. C. (2016). Construction of multi-mode affective learning system: Taking affective design as an example. *Educational Technology & Society, 19*(2), 132-147.

Littlejohn, A., Hood, N., Milligan, C., & Mustain, P. (2016). Learning in MOOCs: Motivations and self-regulated learning in MOOCs. *The Internet and Higher Education, 29*, 40-48.

Liu, N. H., Chiang, C. Y., & Chu, H. C. (2013). Recognizing the degree of human attention using EEG signals from mobile sensors. *Sensors, 13*(8), 10273-10286.

Mayer, R. E. (2003). Elements of a science of e-learning. *Journal of Educational Computing Research, 29*(3), 297-313.

Moreno, R., & Mayer, R. E. (2002). Verbal redundancy in multimedia learning: When reading helps listening. *Journal of Educational Psychology, 94*(1), 156-163.

Orr, D. B., Friedman, H. L., & Graae, C. N. (1969). Self-pacing behavior in the use of time-compressed speech. *Journal of Educational Psychology, 60*(1), 28-31.

Paas, F. G. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A Cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429-434.

Pastore, R. (2012). The Effects of time-compressed instruction and redundancy on learning and learners' perceptions of cognitive load. *Computers & Education, 58*(1), 641-651.

Pastore, R. S. (2010). The Effects of diagrams and time-compressed instruction on learning and learners' perceptions of cognitive load. *Educational Technology Research and Development, 58*(5), 485-505.

Ritzhaupt, A. D., & Barron, A. (2008a). Effects of time-compressed narration and representational adjunct images on cued-recall, content recognition, and learner satisfaction. *Journal of Educational Computing Research, 39*(2), 161-184.

Ritzhaupt, A. D., Gomes, N. D., & Barron, A. E. (2008b). The Effects of time-compressed audio and verbal redundancy on learner performance and satisfaction. *Computers in Human Behavior, 24*(5), 2434-2445.

Ritzhaupt, A. D., Pastore, R., & Davis, R. (2015). Effects of captions and time-compressed video on learner performance and satisfaction. *Computers in Human Behavior, 45*, 222-227.

Smith, L. B., Colunga, E., & Yoshida, H. (2010). Knowledge as process: contextually cued attention and early word learning. *Cognitive Science, 34*(7), 1287-1314.

Sun, J. C. Y., Hwang, G.-J., Lin, Y. Y., Yu, S. J., Pan, L. C., & Chen, A. Y. Z. (2018). A Votable concept mapping approach to promoting students' attentional behavior: An Analysis of sequential behavioral patterns and brainwave data. *Educational Technology & Society, 21*(2), 177-191.

Sun, J. C. Y., & Yu, S. J. (2019). Personalized wearable guides or audio guides: An evaluation of personalized museum guides for improving learning achievement and cognitive load. *International Journal of Human–Computer Interaction, 35*(4-5), 404-414.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive science, 12*(2), 257-285.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Thompson, A. J., & Silverman, E.M. (1977). Children's comprehension of time-compressed speech: Effect of speaker's familiarity. *Perceptual and Motor Skills, 45*(3_suppl), 1253-1254.

Vagharchakian, L., Dehaene-Lambertz, G., Pallier, C., & Dehaene, S. (2012). A Temporal bottleneck in the language comprehension network. *Journal of Neuroscience, 32*(26), 9089-9102.

Van Gog, T., Paas, F., & Sweller, J. (2010). Cognitive load theory: Advances in research on worked examples, animations, and cognitive load measurement. *Educational Psychology Review, 22*(4), 375-378.

Wang, Q., Ren, X., Hu, J., Li, Q., Cui, S., & Zou, Y. (2018). Preliminary study on reading speed test with IReST for normally-sighted young Chinese readers. [Zhonghua yan ke za zhi] *Chinese Journal of Ophthalmology, 54*(2), 120-124.

Wang, Y. S., Wu, M. C., & Wang, H. Y. (2009). Investigating the determinants and age and gender differences in the acceptance of mobile learning. *British Journal of Educational Technology, 40*(1), 92-118.

Zemlin, W. R., Daniloff, R. G., & Shriner, T. H. (1968). The Difficulty of listening to time-compressed speech. *Journal of Speech and Hearing Research, 11*(4), 875-881.