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# Effects of Attention Cueing on Learning Speech Organ Operation through Mobile Phones

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**ABSTRACT**

The studies regarding using a cross sectional view of speech organs enriched with attention cueing and written text to probe learners' learning efficiency and behavior through mobile phones is scant. The purpose of this study was to examine whether the presence of attention cueing can benefit learners with different amounts of prior knowledge in learning operational functions of the speech organs. Additionally, this study investigated the interactive effects of the experimental treatment and the learners' prior knowledge on their test performance and cognitive load. A self-regulatory, mobile-phone-based text with accompanying pictures depicting places and manner of articulation comprised the instrumentation. The participants were comprised of 101 English as a foreign language (EFL) learners from four sections of a phonetics course. First, their level of prior knowledge was assessed. Next, they were randomly assigned to one of four modules—picture-only, picture-plus-signal, picture-plus-text, or picture-plus-text-plus-signal. Immediately, after the treatment period, the participants were administered retention and transfer tests as well as cognitive load measurement. The results indicated that the enriched visualization somewhat reduced the participants' cognitive load and enhanced their learning efficiency. However, presenting too much visual information impaired learning. The results of the study implied that enriched visualization compacted on the small screen might cause interference.

**Keywords**

Cognitive load, Mobile learning, Signaling principle, Working memory

## Introduction

The prevalence of mobile phones enables users to obtain information anytime and anywhere due to their potential to make learning spontaneous, authentic, informal, situational, and personalized (Kukulska-Hulme, 2009). Today's advanced digital functions in mobile phones along with wireless technology provide users with rich opportunities to access the real world, while allowing educators to extend learning beyond the traditional classroom (Thornton & Houser, 2005). Mobile phones have been employed as a language learning device to support the development of vocabulary (Chen, Hsieh, & Kinshuk, 2008), listening (Hsu, Hwang, Chang, & Chang, 2013b), speaking (Ahn & Lee, 2016), and reading (Hsu, Hwang, & Chang, 2013a) skills. However, due to mobile phones' small screen sizes, incorporating mobile technology with alternative visualization options deserves further exploration (Chen et al., 2008; Kim & Kim, 2012).

According to the cognitive view of multimedia learning, the simultaneous presence of text and graphics will overburden a learner' visual channel, whereby written text and images compete for the learners' limited cognitive resources in processing the input and categorizing it in visual working memory. Simultaneously presenting text and images thus increases learners' cognitive load and impairs learning. On the other hand, Baddeley's (1986) working memory model claims that visual information is processed in the visuospatial sketchpad while verbal input is processed in the phonological loop. According to this view, presenting text and images simultaneously does not overload learners but rather helps them build up referential connections between text and images and achieve greater learning efficiency—the same concept that is behind dual coding theory (Paivio, 1986). Therefore, the explanation of Baddeley's working memory model appears to be inconsistent with that of the cognitive view of multimedia learning.

Learners who visually search information using instructional visualizations may miss the focus. Providing visuospatial cueing on instructional visualization is expected to draw learners' attention toward essential information, reduce visual search processes, foster selection of relevant information, and integrate information into a coherent mental representation (de Koning et al., 2009). However, whether the presence of enriched visualization (e.g., attention cueing and additional verbal information) can induce greater learning outcomes still remains controversial (de Koning et al., 2010b; de Koning et al., 2011a; Imhof et al., 2013).

EFL learners in China/Taiwan might be interfered by their mother tongue, use mother tongue to produce English sounds, and result in incorrect pronunciation. Besides, EFL learners cannot observe the operational mechanism of speech organs whenever they produce sounds, to figure out the operation of speech organs appears to be too abstract for them. Therefore, presenting EFL learners with a cross sectional view of speech organs by showing the operation of tongue, velum and vocal folds will help them understand the mechanism of sound production. Besides, the addition of motion-indicating arrows to indicate the movement of speech organs will help learners understand an abstract concept and build up a mental model (Hegarty, Kriz, & Cate, 2003).

While incorporating learning theories and instructional visualization with mobile phone technology in examining learners' learning outcomes, individual learner characteristics should also be considered (Chen et al., 2008). This study explores the effects of different forms of visualization and learners' expertise level on construction of mental models (Hegarty et al., 2003) and cognitive load in learning the operation of human speech organs through mobile phones.

## Literature review

### Mobile assisted language learning

Previous studies have investigated the use of handheld devices in supporting foreign language learners' development of vocabulary (e.g., Chen et al., 2008; Kim & Kim, 2012; Sandberg et al., 2014; Thornton & Houser, 2005), listening (e.g., Hsu et al., 2013b), speaking (e.g., Ahn & Lee, 2016; Liu & Chu, 2010), and reading (e.g., Hsu et al., 2013a).

Chen et al. (2008) presented four different annotations to probe vocabulary acquisition among EFL learners with different visuospatial aptitudes, and found that they learned better when the annotation type suited their visuospatial aptitudes. Sandberg et al. (2014) designed a gaming context and intelligent adaptation mode for ESL children to learn animal-related vocabulary, and noted the positive impacts of using adventure games in children's vocabulary acquisition. Thornton and Houser (2005) conducted a study in which they sent English vocabulary and idioms via email to Japanese university students' mobile phones, and observed that doing so prompted learners to review the contents more and also resulted in better learning outcomes compared with students who learn the vocabulary and idioms through web- and paper-based materials.

Hsu et al. (2013b) presented EFL learners with three types of movie captions through handheld devices and supported the potential of mobile devices for vocabulary acquisition and listening skill development. Liu and Chu (2010) constructed a ubiquitous game-based learning environment to help EFL learners develop listening and speaking skills through Personal Digital Assistant (PDA) device, in which gaming users showed more favorable learning outcomes and enhanced motivation compared with non-gaming users. Ahn and Lee (2016) employed speech recognition technology to assist EFL learners in practicing speaking. The learners gave positive comments, suggesting that mobile phones have potential to support the development of speaking skills in EFL contexts.

Hsu et al. (2013a) designed a recommendation-based system that involved recommend reading materials tailored for individual EFL learners based on their English proficiency and reading preferences. The system required learners to take notes in either individual- or shared-annotation mode, which they felt comfortable and satisfied with. This system also helped improve learners' reading comprehension.

Empirical studies concerning mobile learning have highlighted the potential of mobile devices on language skill development. However, learning the operation of speech organs to understand the pronunciation of IPA symbols through mobile phones was not probed in the past. Because small screens might be challenging for learners to perceive visualization (Stockwell, 2008; Stockwell, 2012; Thornton & Houser, 2005) and result in perceptual errors (Kim & Kim, 2012); presenting attention cueing in mobile-phone-based visualization might reduce learners' cognitive load and enhance learning efficiency (Liu, Lin, & Paas, 2013).

### Signaling principle

In terms of perceptual processing, the addition to the visualizations that contrasts explicitly with corresponding features of its neighbors can preferentially attract learners' attention and ameliorate the processing cost associated with complex visualizations (Lowe & Boucheix, 2011).

Crooks et al. (2012) and Ari et al. (2014) examined the effects of cueing and modality on a computer-based diagram depicting places of articulation in human speech. They found that the presence of cueing yielded no significant differences between learners in terms of their test results and cognitive load ratings. A study conducted by Lin and Atkinson (2011) also indicated that learners' test performance and cognitive load were similar regardless of whether or not visual cues were provided. However, visual arrow cueing reduced learners' study time on the instructional visualizations. Boucheix and his colleagues (2013) conducted studies concerning learning the operation of a piano mechanism and found the localized coordinate and progressive path cueing yielded a better idea about the operation of a piano mechanism compared with entity cueing and non-cueing. The spreading-color cueing presented the learners with specific and continuous spatio-temporal direction of attention by establishing pathway of causal chains; however, arrow cueing failed to establish continuous pathway of spatial and temporal linkage for each entity and resulted in unfavorable mental model development (e.g., Boucheix & Lowe, 2010). While another similar study observed no promising effects of visuospatial cueing (e.g., Lowe & Boucheix, 2011).

Imhof et al. (2013) investigated the effects of multiple vs. single visualizations with the presence/absence of arrow cueing on learning fish locomotion patterns. The experimental results indicated that enriched visualizations with attention cueing caused interference, wherein simultaneous highlighting of multiple elements without specificity caused confusion (Moreno, 2007). Kriz and Hegarty (2007) speculated that attention cueing aims to capture learners' attention and directs it toward specific or essential elements in visualizations but without conveying any new information or guaranteeing that conceptual understanding and construction of mental models have taken place.

de Koning and his colleagues (2011b) conducted several studies in which they decreased the luminance of uncued subsystems to show a visual contrast between them and cued subsystems in an animated cardiovascular system. The learners exhibited similar test performances regardless of cueing conditions and display speeds. Besides, studies addressing self- or instructional explanations accompanied with attention cueing (de Koning et al., 2010b; de Koning et al., 2011b) had yielded inconsistent results. A study by Kalyuga, Chandler, and Sweller (1999) demonstrated that the presence of enriched color cueing captured learners' attention and yielded better efficiency when they had to split their attention to process text and diagrams.

In sum, studies investigating the promising effects of attention cueing on multimedia learning efficiency have yielded mixed results. The use of attention cueing has been shown to facilitate learning efficiency and reduce learners' cognitive load (e.g., Boucheix & Lowe, 2010; Boucheix, et al., 2013; de Koning et al., 2010b; de Koning et al., 2011b; Imhof et al., 2013; Kalyuga et al., 1999). Other studies have shown that attention cueing may facilitate learning efficiency but without reducing cognitive load (de Koning et al., 2010b). Still other studies have found attention cueing to be ineffective and even causes interference (e.g., Crooks et al., 2012; de Koning et al., 2010a; de Koning et al., 2011a; Imhof et al., 2013; Kriz & Hegarty, 2007; Lin & Atkinson, 2011; Lowe & Boucheix, 2011; Moreno, 2007).

**Statement of the problem**

Some empirical researches concerning mobile learning did not incorporate a control group (Sandberg et al., 2014). Moreover, whether providing attention cueing can encourage learners to extract and process visual information and thereby build up mental models have shown inconsistent results. Research suggests that visual cueing will be more effective in static visualizations than in animation (Boucheix et al., 2013; de Koning et al., 2009). The quality of mental model construction through static visualizations can be improved by enriching the static visualizations with motion-indicating arrows (Heiser & Tversky, 2002) or written information (Hegarty & Just, 1993; Hegarty et al., 2003). Verbal text accompanying diagrams may vividly illustrate abstract concepts which may especially benefit novices (Kriz & Hegarty, 2007). The present research will investigate whether integrating both written information and attention cueing can augment learning results more than using only a single approach (e.g., Crooks et al., 2012). Besides, prior knowledge of how speech organs function through the use of mobile-phone-based visualization as a moderating factor was ignored in the past (e.g., Ari et al., 2014; Crooks et al., 2012). Learners' study time and number of clicks have also not been probed in the past (Crooks et al., 2012). To address the unresolved issues, the research questions in the present study are as follows:

- Do learners perform better when given attention cueing compared to not having attention cueing when learning about the operation of the speech organs?
- Do learners who are given attention cueing experience a lower cognitive load when learning about the operation of the speech organs compared to learners who are not given attention cueing?
- Do learners study for different lengths of time and have a differing number of clicks under different presentation modes?

## Methodology

### Participants

A total of 101 EFL learners (male = 23, female = 78) with an age of 19 (*M* = 19.29, *SD* = 0.91) volunteered to participate in the experiment. They were recruited from four classes of introduction to phonetics course at a technology university in southeastern China. The participants had not had previous experience with the instrument used in the present study. According to the prior knowledge test score, the top 30% were classified into high-knowledge and the bottom 30% were low-knowledge learners. Each group was comprised of both high- and low-knowledge learners. A one-way ANOVA revealed no significant difference among the four groups with respect to their prior knowledge, $F(3,97) = 0.648$, $p = .586$.

### Research design

The present study examined four conditions with the purpose of determining the potential benefit of enriched information contained in static visualizations by investigating whether motion-indicating arrows and written text in static visualizations were more beneficial than the same visualizations without arrows or written text. Presentation mode and prior knowledge were the independent variables. Retention and transfer test results, cognitive load ratings, study time, and number of clicks were the dependent variables (Figure 1).

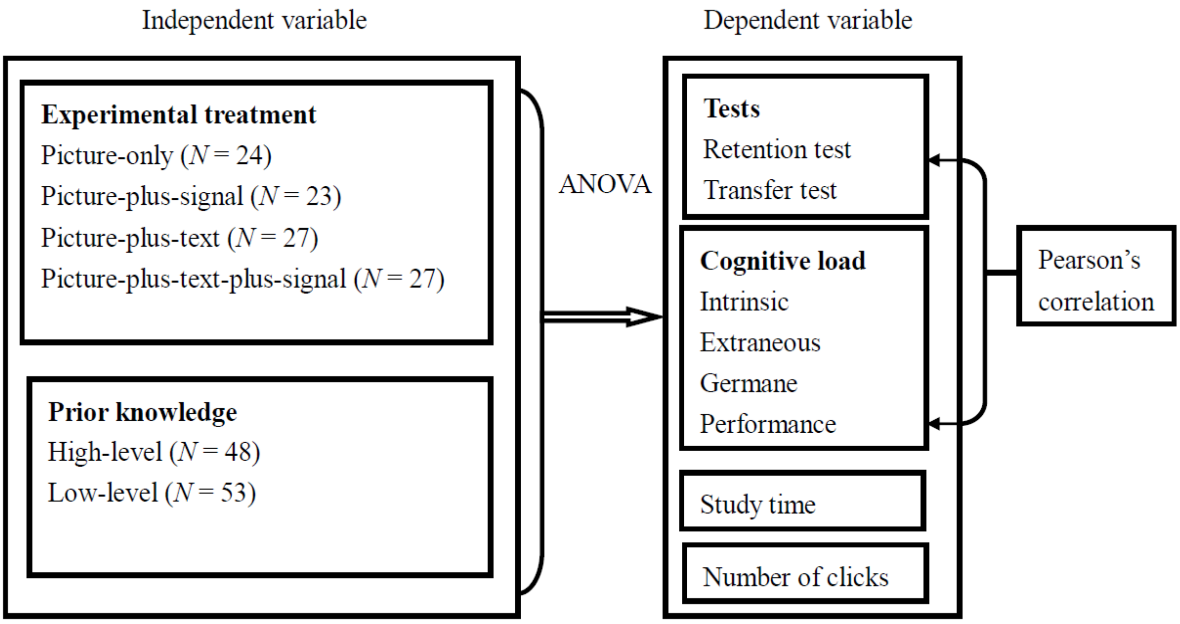


*Figure 1*. Research design

### Independent variables

*Experimental treatment*

The instrumentation (Figure 2) was developed by the researcher and administered to the students in the formal experiment. The picture was at the bottom, while each IPA (International Phonetic Alphabet) symbol was at the top of the picture. When a student clicked on an IPA symbol, a corresponding picture popped up, depicting the place and manner of articulation. A total of twenty-nine IPA symbols (i.e., p, b, m, t, d, ɖ, n, k, g, ŋ, f, v, θ, ð, s, z, ʃ, ʒ, ç, q, h, x, ɕ, ʑ, ɸ, β, ɱ, sʷ, and ɟ) used to represent how the speech organs operate. A recorder was installed in the system to record how many times the students clicked on each IPA symbol and how much time they spent learning how the speech organs operate.

In the experiment, four presentation modes were designed respectively: picture-only, picture-plus-signal, picture-plus-text, and picture-plus-text-plus-signal. For the picture-only group (PG), the learners were given the IPA symbols and corresponding static visualizations only. When the students clicked on each IPA symbol, one static picture appeared on the screen showing static status of the lips shape, tongue, velum, and vocal folds when that

IPA symbol was vocalized (Figure 2a). For the picture-plus-signal group (PSG), the learners received the IPA symbols and corresponding static visualizations enriched with attention cueing. When the learners clicked each IPA symbol, one static picture embedded with attention cueing popped up showing the static positions of the lips shape, tongue, velum, and vocal folds. The picture was enriched with attention cueing when the speech organs had one of following features: (1) different shapes of lips when producing bilabials, bilabial fricatives, labiodental-fricatives, or stops; (2) nasalization; (3) voiced sounds; and (4) the tongue in dental, alveolar, post-alveolar, palatal, velar, or uvular positions. For example, in the picture corresponding to [n], one motion-indicating arrow alerted the learners of the movement of the tongue; another motion-indicating arrow indicated the downward movement of the velum; and a wavy line demonstrated how the vocal folds vibrated (Figure 2b). On the other hand, the picture was not enriched with attention cues when the speech organs had one of following features: (1) spread lips; (2) oral sound; (3) voiceless sounds; and (4) the tongue in a resting status. For the picture-plus-text group (PTG), the learners were given the IPA symbols, corresponding static visualization and the verbal text. When the students clicked on each IPA symbol, one static picture appeared depicting the static positions of the speech organs enriched with verbal texts annotating places of articulation, lips shape, and status of velum and vocal folds (Figure 2c). In the picture-plus-text-plus-signal group (PTSG), the learners were given the same visualizations as those in the PTG but enriched with the same attention cueing as those in the PSG (Figure 2d).

| Without text | | With text | |
|---|---|---|---|
| Without signal | With signal | Without signal | With signal |


(a) PG (b) PSG (c) PTG (d) PTSG

*Figure 2*. Sample screenshots of the four conditions

*Prior knowledge test*

This was comprised of a table of 24 IPA symbols (i.e., p, b, t, d, k, g, f, v, s, z, ʃ, ʒ ,tʃ, dʒ ,m, n, w, l, r, h, θ, j, ŋ , and ð). The students chose the correct symbol from a drop-down menu (i.e., [p] should be selected from the menu under the column "voiceless, bilabial, stop"). Each correct answer gained one point (Figure 3).

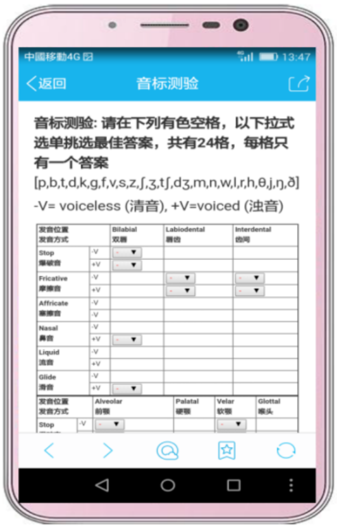
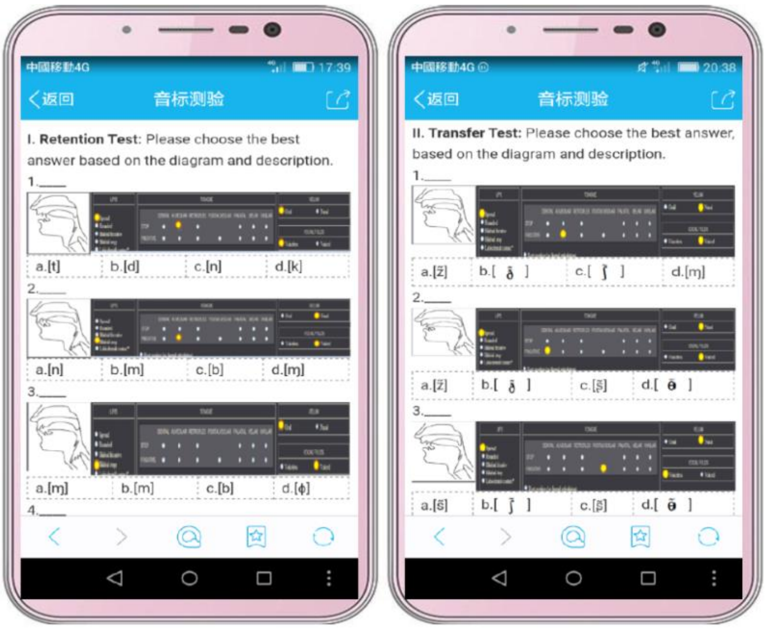



*Figure 3.* Sample screenshot of the prior knowledge test

## Dependent variables

### *Retention test*

The purpose of the test was to assess the learners' understanding and retention of the instructional visualizations. The test consisted of 20 multiple-choice questions regarding the phonetic symbols (i.e., b, t, m, d, n, x, ʒ, sʷ, h, v, θ, ð, s, z, ʃ, ɕ, ɸ, β and ɱ). The learners made inferences from the diagrams and verbal texts, and chose an IPA symbol (Figure 4a). Each correct answer gained one point.




(a) Retention test (b) Transfer test

*Figure 4.* Sample screenshots of the tests

### *Transfer test*

The students' application ability was assessed by 20 multiple-choice questions containing: (1) IPA symbols that are used in some languages (i.e., tʷ, ʃʷ, t̪, gʷ, hʷ, t̪ʷ, kʷ, d̪ʷ, n̪, n̪, and n̪ʷ); and (2) IPA symbols that are not regularly used in any languages (i.e., s̃, z̃, θ̃, ð̃, J̃, ɸ͡θ, v͡ð, and s̃ʷ). These IPA symbols never appeared in the instrumentation, and the students had never encountered them in their daily life. The questions were to assess how much learners could apply what they had learned from the instructional visualization, make inferences from the diagrams and verbal texts, and think about a possible IPA symbol (Figure 4b). Dr. Daniel Currie Hall was consulted about the usage of these IPA symbols in the world's languages. Each correct answer gained one point.

*Cognitive load*

A subjective cognitive load measurement with a scale ranging from 1 to 9 (Kalyuga et al., 1999; Paas, 1992) measured the learners' cognitive load, with 1 representing the lowest level and 9 representing the highest level. Item 1 dealt with intrinsic load; item 2 dealt with extraneous load; item 3 probed germane load; item 4 examined perceived difficulties in answering the retention test; and item 5 queried perceived difficulties in answering the transfer test.

*Study time and number of clicks*

A recorder installed in the system recorded the total amount of seconds the learners spent learning the operation of the speech organs, and the total number of clicks they clicked on each symbol.

**Data collection instrumentation**

A pilot study involving 63 undergraduates in the College of Humanities was conducted before the experiment. Point-biserial correlation was conducted to eliminate the less reliable test items (Wu & Tu, 2006). The reliability of each measurement is detailed below:

*Prior knowledge test, retention test, and transfer test*

After item analysis, all of the items on the prior knowledge test (Cronbach's alpha = 0.909) were retained. Three questions on the retention test (Cronbach's alpha = 0.764) and five questions on the transfer test (Cronbach's alpha = 0.740) were eliminated. All thirty-two test items in the retention and transfer tests were preserved since they demonstrated good internal consistency (Cronbach's alpha = 0.811).

*Cognitive load measurement*

A Pearson correlation analysis revealed a significant result on the critical ratio and item-total correlation. The Cronbach's alpha was 0.859. Bartlett's test of sphericity was significant and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) was 0.832. The eigenvalue was greater than 1 and the total explained variance was 86.962%.

**Experimental procedures**

The students were seated in a language laboratory and were required to use the 5-inch 4G mobile phones provided. Each mobile phone had a resolution of 720 x 1280. All instructional visualizations were conveyed through the mobile phones. The presentation mode comprised a self-regulatory model to allow the students to spend as much time as they wanted to learn the lessons and answer all the questions. If any of the students missed answering any question before moving on to next step, they would be reminded by the system to complete the missing information. The experimental procedures consisted of five stages:

First, the students were required to enter their name, age, gender, and student ID to log into the designated web page. Then they took a prior knowledge test concerning English phonetics.

Secondly, they moved on to read the explanations of the interface and experimental procedures on mobile phones silently by themselves before the start of the formal experiment.

Thirdly, in the formal experiment, when the students were learning about the operation of the speech organs, they were allowed to click each IPA symbol as many times as they wanted to learn the positions of lips shape, tongue, velum, and vocal folds. Afterwards, they answered three cognitive load questions concerning the difficulty level of the instrumentation.

Fourthly, the students were given 2 minutes to read a brief introduction about interface features of the retention and transfer tests. Some terminology and particular IPA symbols were explained to reduce the learners' anxiety regarding the tests. After 2 minutes, the system automatically initiated the retention test. The students took the retention test and submitted their answers. Then, they answered one cognitive load question concerning the retention test.

Finally, they took the transfer test and submitted their answers after completing 20 multiple-choice. Then, they answered one cognitive load question regarding the transfer test.

After answering all of the questions and submitting all answers into the system, the students logged out. The server logs recorded the students' learning activities, study time, and test results. The overall experimental procedure took approximately 1.5 hours. The data from the four conditions were collected during separate class periods.

## Results

**Research question one: Do learners perform better when given attention cueing compared to not having attention cueing when learning about the operation of the speech organs?**

A Pearson correlation revealed a statistically significant negative correlation between the learners' test scores and overall cognitive loads, $r = -0.204$, $p = 0.041$. As the learners' cognitive load decreased, their test performance increased, and vice versa.

A two-way ANOVA was conducted to examine the interactive effects between the experimental conditions and prior knowledge on the test results. In Table 2, the ANOVA source of variation results indicated no significant interaction effects on the retention test, $F(3,93) = 0.837$, $p = .477$, partial $\eta^2 = 0.026$. However, the main effect of the experimental condition was statistically significant, $F(3,93) = 5.146$, $p = .002$, partial $\eta^2 = 0.142$. The PG ($M = 11.50$, $SD = 3.934$) significantly outperformed the PTSG ($M = 8.48$, $SD = 2.517$), $p = .09$. The PSG ($M = 11.70$, $SD = 2.914$) significantly outperformed the PTSG ($M = 8.48$, $SD = 2.517$), $p = .005$. The main effect of prior knowledge was statistically significant, $F(1,93) = 4.556$, $p = .035$, partial $\eta^2 = 0.047$. The learners with high prior-knowledge ($M = 11.23$, $SD = 3.598$) significantly outperformed those with low prior-knowledge ($M = 9.83$, $SD = 3.418$) (see Table 1).

There were no interaction effects in the transfer test, $F(3,93) = 0.774$, $p = .511$, partial $\eta^2 = 0.024$. However, the main effect of the experimental condition was statistically significant, $F(3,93) = 2.808$, $p = .044$, partial $\eta^2 = 0.083$. The PSG ($M = 8.13$, $SD = 2.242$) significantly outperformed the PG ($M = 5.67$, $SD = 2.839$), $p = 0.016$. The main effect of prior knowledge was not statistically significant, $F(1,93) = 3.907$, $p = .051$, partial $\eta^2 = 0.040$.

*Table 1*. Test results of four groups

| Group | Retention test | | Transfer test | | Total | |
|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| PG (*N* = 24) | 11.50 | 3.934 | 5.67 | 2.839 | 17.17 | 5.592 |
| PSG (*N* = 23) | 11.70 | 2.914 | 8.13 | 2.242 | 19.83 | 4.428 |
| PTG (*N* = 27) | 10.59 | 3.876 | 7.48 | 3.298 | 18.07 | 6.101 |
| PTSG (*N* = 27) | 8.48 | 2.517 | 6.78 | 2.636 | 15.26 | 4.528 |
| High (*N* = 48) | 11.23 | 3.598 | 7.65 | 2.993 | 18.88 | 5.541 |
| Low (*N* = 53) | 9.83 | 3.418 | 6.43 | 2.707 | 16.26 | 5.016 |

There were no interaction effects in total score $F(3,93) = 0.841$, $p = .475$, partial $\eta^2 = 0.026$. However, the main effect of the experimental treatment was statistically significant, $F(3,93) = 3.159$, $p = .028$, partial $\eta^2 = 0.092$. The PSG ($M = 19.83$, $SD = 4.428$) significantly outperformed the PTSG ($M = 15.26$, $SD = 4.528$), $p = .012$. The main effect of prior knowledge was also statistically significant, $F(1,93) = 6.013$, $p = .016$, partial $\eta^2 = 0.061$. The high prior-knowledge learners ($M = 18.88$, $SD = 5.541$) significantly outperformed the low prior-knowledge learners ($M = 16.26$, $SD = 5.016$) (see Table 1).

*Table 2*. Results of two-way ANOVA on tests

| Source | Test | Type III Sum of Squares | *df* | *MS* | *F* | *Sig.* | $\eta^2_p$ |
|---|---|---|---|---|---|---|---|
| Group | Retention | 170.206 | 3 | 56.735 | 5.146 | .002** | .142 |
| | Transfer | 64.575 | 3 | 21.525 | 2.808 | .044* | .083 |
| | Total | 248.658 | 3 | 82.886 | 3.159 | .028* | .092 |
| Prior knowledge | Retention | 50.227 | 1 | 50.227 | 4.556 | .035* | .047 |
| | Transfer | 29.958 | 1 | 29.958 | 3.907 | .051 | .040 |
| | Total | 157.765 | 1 | 157.765 | 6.013 | .016* | .061 |
| Group * knowledge | Retention | 27.697 | 3 | 9.232 | 0.837 | .477 | .026 |
| | Transfer | 17.801 | 3 | 5.934 | .774 | .511 | .024 |
| | Total | 66.192 | 3 | 22.064 | .841 | .475 | .026 |
| Error | Retention | | 93 | 11.025 | | | |
| | Transfer | | 93 | 7.667 | | | |
| | Total | | 93 | 26.237 | | | |

*Note*. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

**Research question two: Do learners who are given attention cueing experience a lower cognitive load when learning about the operation of the speech organs compared to learners who are not given attention cueing?**

A two-way ANOVA was conducted to examine the interactive effects between the experimental conditions and prior knowledge on cognitive load. In Table 4, the ANOVA source of variation results indicated no significant interaction effects on intrinsic load, $F(3,93) = 1.167$ $p = .327$, partial $\eta^2 = 0.036$. The main effect of group treatment was not statistically significant, $F(3,93) = 2.216$, $p = .091$, partial $\eta^2 = 0.067$. The main effect of prior knowledge was statistically significant, $F(1,93) = 5.221$, $p = .025$, partial $\eta^2 = 0.053$. The low-knowledge learners (*M* = 5.79, *SD* = 1.691) had higher intrinsic load than the high-knowledge learners (*M* =5.02, *SD* = 1.564) (see Table 3).

*Table 3*. Cognitive load ratings under different conditions

| Group | Intrinsic | | Extraneous | | Germane | | Retention | | Transfer | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| PG (*N* = 24) | 5.79 | 1.503 | 5.67 | 1.971 | 6.04 | 1.899 | 7.83 | 1.465 | 8.29 | 1.301 | 33.63 | 6.371 |
| PSG (*N* = 23) | 5.26 | 2.072 | 4.96 | 1.581 | 4.96 | 1.551 | 5.83 | 1.922 | 6.39 | 2.231 | 27.39 | 7.421 |
| PTG (*N* = 27) | 4.81 | 1.178 | 4.85 | 1.350 | 5.41 | 1.217 | 5.67 | .784 | 6.93 | 1.299 | 27.67 | 4.867 |
| PTSG (*N* = 27) | 5.85 | 1.725 | 5.81 | 1.733 | 6.22 | 1.577 | 6.37 | 1.735 | 7.15 | 1.379 | 31.41 | 6.091 |
| High (*N* = 48) | 5.02 | 1.564 | 5.02 | 1.564 | 5.33 | 1.562 | 6.27 | 1.830 | 7.08 | 1.889 | 28.73 | 6.603 |
| Low (*N* = 53) | 5.79 | 1.691 | 5.60 | 1.780 | 5.98 | 1.635 | 6.53 | 1.624 | 7.28 | 1.511 | 31.19 | 6.499 |

There were no interaction effects in regard to extraneous load, $F(3,93) = 0.595$, $p = .620$, partial $\eta^2 = 0.019$. Neither the main effect of group treatment, $F(3,93) = 2.051$, $p = .112$, partial $\eta^2 = 0.062$, nor the main effect of prior knowledge was significant, $F(1,93) = 2.509$, $p = .117$, partial $\eta^2 = 0.026$.

There were not interaction effects in regard to germane load, $F(3,93) = 0.499$, $p = .684$, partial $\eta^2 = 0.016$. However, the main effect of group treatment was statistically significant, $F(3,93) = 3.114$, $p = .030$, partial $\eta^2 = 0.091$. The PTSG (*M* = 6.22, *SD* = 1.577) had a significantly higher germane load than did the PSG (*M* = 4.96, *SD* = 1.551), $p = 0.027$ (see Table 3). The main effect of prior knowledge was not statistically significant, $F(1,93) = 3.620$, $p = .060$, partial $\eta^2 = 0.037$.

There were no interaction effects in regard to retention load, $F(3,93) = 0.350$, $p = .790$, partial $\eta^2 = 0.011$. The main effect of the group treatment was statistically significant, $F(3,93) = 9.451$, $p = .000$, partial $\eta^2 = 0.234$. The PG (*M* = 7.83, *SD* = 1.465) had a higher retention load than did those in the PSG (*M* = 5.83, *SD* = 1.922), $p = .000$ as well as those in the PTG (*M* = 5.67, *SD* = 0.784), $p = .000$ and in the PTSG (*M* = 6.37, *SD* = 1.735), $p = .006$ (see Table 3). The main effect of prior knowledge was not statistically significant, $F(1,93) = 0.216$, $p = .643$, partial $\eta^2 = 0.002$.

There were no interaction effects in regard to transfer load, $F(3,93) = 1.360$, $p = .260$, partial $\eta^2 = 0.042$. However, the main effect of group treatment was statistically significant, $F(3,93) = 6.095$, $p = .001$, partial $\eta^2 = 0.164$. The PG (*M* = 8.29, *SD* = 1.301) had a higher transfer load than the PSG (*M* = 6.39, *SD* = 2.231), $p = .000$

as well as the PTG (*M* = 6.93, *SD* = 1.299), *p* = .014 (see Table 3). The main effect of prior knowledge was not statistically significant, *F*(1,93) = 0.122, *p* = .728, partial $\eta^2$ = 0.001.

*Table 4*. Results of two-way ANOVA on cognitive load

| Source | Load | Type III Sum of Squares | *df* | *MS* | *F* | *Sig.* | $\eta^2_p$ |
|---|---|---|---|---|---|---|---|
| Group | Intrinsic | 17.044 | 3 | 5.681 | 2.216 | .091 | .067 |
| | Extraneous | 17.080 | 3 | 5.693 | 2.051 | .112 | .062 |
| | Germane | 22.834 | 3 | 7.611 | 3.114 | .030* | .091 |
| | Retention | 67.698 | 3 | 22.566 | 9.451 | .000** | .234 |
| | Transfer | 45.479 | 3 | 15.160 | 6.095 | .001* | .164 |
| | Total | 626.667 | 3 | 208.889 | 5.520 | .002* | .151 |
| Prior knowledge | Intrinsic | 13.383 | 1 | 13.383 | 5.221 | .025* | .053 |
| | Extraneous | 6.966 | 1 | 6.966 | 2.509 | .117 | .026 |
| | Germane | 8.847 | 1 | 8.847 | 3.620 | .060 | .037 |
| | Retention | .517 | 1 | .517 | .216 | .643 | .002 |
| | Transfer | .303 | 1 | .303 | .122 | .728 | .001 |
| | Total | 111.117 | 1 | 111.117 | 2.936 | .090 | .031 |
| Group * knowledge | Intrinsic | 8.971 | 3 | 2.990 | 1.167 | .327 | .036 |
| | Extraneous | 4.956 | 3 | 1.652 | .595 | .620 | .019 |
| | Germane | 3.661 | 3 | 1.220 | .499 | .684 | .016 |
| | Retention | 2.504 | 3 | .835 | .350 | .790 | .011 |
| | Transfer | 10.151 | 3 | 3.384 | 1.360 | .260 | .042 |
| | Total | 105.360 | 3 | 35.120 | .928 | .430 | .029 |
| Error | Intrinsic | | 93 | 2.563 | | | |
| | Extraneous | | 93 | 2.776 | | | |
| | Germane | | 93 | 2.444 | | | |
| | Retention | | 93 | 2.388 | | | |
| | Transfer | | 93 | 2.487 | | | |
| | Total | | 93 | 37.844 | | | |

*Note*. *$p < .05$, **$p < .01$, ***$p < .001$.

There were no interaction effects in regard to overall cognitive load, *F*(3,93) = 0.928, *p* = .430, partial $\eta^2$ = 0.029. The main effect of group treatment was statistically significant, *F*(3,93) = 5.520, *p* = .002, partial $\eta^2$ = 0.151. The PG (*M* = 33.63, *SD* = 6.371) had a higher overall cognitive load than the PSG (*M* = 27.39, *SD* = 7.421), *p* = 0.004 as well as the PTG (*M* = 27.67, *SD* = 4.867), *p* = .005 (see Table 3). There was a significant trend in prior knowledge, *F*(1,93) = 2.936, *p* = .090, partial $\eta^2$ = 0.031.

**Research question three: Do learners study for different lengths of time and have a differing number of clicks under different presentation modes?**

A two-way ANOVA was conducted to examine the interactive effects between the experimental conditions and prior knowledge on study patterns. In Table 6, the ANOVA source of variation results indicated no significant interaction effects on study time *F*(3,93) = 1.814, *p* = .150, partial $\eta^2$ = 0.055. The main effect of group treatment was statistically significant, *F*(3,93) = 4.934, *p* = .003, partial $\eta^2$ = 0.137. Learners in the PTG (*M* = 408.37, *SD* = 411.297) spent more time than did those in the PSG (*M* = 176.13, *SD* = 134.290), *p* = .013 as well as those in the PTSG (*M* = 168.30, *SD* = 143.531), *p* = .006 (see Table 5). The main effect of prior knowledge was not statistically significant, *F*(1,93) = 0.043, *p* = .836, partial $\eta^2$ = 0.000.

*Table 5*. Results of study pattern

| Group | Study time | | Number of clicks | |
|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* |
| PG (*N* = 24) | 255.75 | 256.848 | 81.67 | 69.717 |
| PSG (*N* = 23) | 176.13 | 134.290 | 22.78 | 26.831 |
| PTG (*N* = 27) | 408.37 | 411.297 | 71.11 | 62.635 |
| PTSG (*N* = 27) | 168.30 | 143.531 | 70.22 | 48.875 |
| High-knowledge (*N* = 48) | 259.69 | 235.180 | 62.00 | 59.258 |
| Low-knowledge (*N* = 53) | 250.83 | 317.067 | 62.72 | 58.077 |

There were no interaction effects in regard to number of clicks, $F(3,93) = 0.868$, $p = .461$, partial $\eta^2 = 0.027$. The main effect of group treatment was statistically significant, $F(3,93) = 5.510$, $p = .002$, partial $\eta^2 = 0.151$. The PG ($M = 81.67$, $SD = 69.717$) significantly had more number of clicks than the PSG ($M = 22.78$, $SD = 26.831$), $p = .002$. The PTG ($M = 71.11$, $SD = 62.635$) significantly had more number of clicks than the PSG ($M = 22.78$, $SD = 26.831$), $p = .014$. The PTSG ($M = 70.22$, $SD = 48.875$) significantly had more number of clicks than the PSG ($M = 22.78$, $SD = 26.831$), $p = .017$ (see Table 5). The main effect of prior knowledge was not statistically significant, $F(1,93) = 0.051$, $p = .822$, partial $\eta^2 = 0.001$.

*Table 6*. Results of two-way ANOVA on study pattern

| Source | Test | Type III Sum of Squares | *df* | *MS* | *F* | *Sig.* | $\eta^2_p$ |
|---|---|---|---|---|---|---|---|
| Group | Study time | 1029604.844 | 3 | 343201.615 | 4.934 | .003* | .137 |
| | Clicks | 50422.072 | 3 | 16807.357 | 5.510 | .002* | .151 |
| Prior knowledge | Study time | 3014.436 | 1 | 3014.436 | .043 | .836 | .000 |
| | Clicks | 155.996 | 1 | 155.996 | .051 | .822 | .001 |
| Group * knowledge | Study time | 378566.907 | 3 | 126188.969 | 1.814 | .150 | .055 |
| | Clicks | 7939.852 | 3 | 2646.617 | .868 | .461 | .027 |
| Error | Study time | | 93 | 69562.421 | | | |
| | Clicks | | 93 | 3050.597 | | | |

*Note*. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

## Discussion

### Research question 1

The presence of either cueing or verbal text was beneficial to help the learners develop greater conceptual understanding, construct mental models, and result in deep learning (Hegarty & Just, 1993; Heiser & Tversky, 2002). The results in the experiment (see Table 7) were partially consistent with the results of previous studies (e.g., Boucheix & Lowe, 2010; Boucheix, et al., 2013; de Koning et al., 2010b; de Koning et al., 2011b; Imhof et al., 2013; Kalyuga et al., 1999) in which attention cueing helped learners organize and integrate information in their working memory.

*Table 7*. The mean value comparisons of the four conditions

| Group | PG | PSG | PTG | PTSG | High | Low | Post hoc tests |
|---|---|---|---|---|---|---|---|
| Retention score | 11.5 | 11.7 | 10.59 | 8.48 | 11.23 | 9.83 | PG > PTSG<br>PSG > PTSG<br>High > Low |
| Transfer score | 5.67 | 8.13 | 7.48 | 6.78 | 7.65 | 6.43 | PSG > PG |
| Total score | 17.17 | 19.83 | 18.07 | 15.26 | 18.88 | 16.26 | PSG > PTSG<br>High > Low |
| Intrinsic load | 5.79 | 5.26 | 4.81 | 5.85 | 5.02 | 5.79 | Low > High |
| Extraneous load | 5.67 | 4.96 | 4.85 | 5.81 | 5.02 | 5.6 | |
| Germane load | 6.04 | 4.96 | 5.41 | 6.22 | 5.33 | 5.98 | PTSG > PSG |
| Retention load | 7.83 | 5.83 | 5.67 | 6.37 | 6.27 | 6.53 | PG > PSG<br>PG > PTG<br>PG > PTSG |
| Transfer load | 8.29 | 6.39 | 6.93 | 7.15 | 7.08 | 7.28 | PG > PSG<br>PG > PTG |
| Total load | 33.63 | 27.39 | 27.67 | 31.41 | 28.73 | 31.19 | PG > PSG<br>PSG > PTG |
| Study time | 255.75 | 176.13 | 408.37 | 168.3 | 259.69 | 250.83 | PTG > PSG<br>PTG > PTSG |
| Clicks | 81.67 | 22.78 | 71.11 | 70.22 | 62 | 62.72 | PG > PSG<br>PTG > PSG<br>PTSG > PSG |

However, simultaneous presence of both cueing and verbal text caused interference was possibly because simultaneously presenting multi-faceted information in the visualizations without specificity distracted the learners from the focus (Imhof et al., 2013; Moreno, 2007). Perhaps the learners' attention was captured more by either salient cueing or verbal text than by surrounding information thereby preventing them from effectively gaining a conceptual understanding and mental model constructions (Kriz & Hegarty, 2007). Secondly, probably the presence of cueing that contrasted conspicuously with surrounding information preferentially attracted the learners' attention; however, the verbal text that did not compete with the cueing for the learners' attention but subservient to it (Boucheix et al., 2013), in which conceptual understanding was impaired. Thirdly, probably the cueing was detected but failed to continuously direct the learners' attention across extended viewing of the visualization; therefore, the effects of cueing was compromised (Lowe & Boucheix, 2011). Finally, small screen size may have been another obstacle (Kim & Kim, 2012), since the text, pictures, and cueing were densely compacted on the small screens. Visual scanning to locate information on small screens could have likely proven to be too challenging for the students to perceive and comprehend the visualizations (Kim & Kim, 2012). Scanning information on the small screens made the students feel uncomfortable (Stockwell, 2012; Thornton & Houser, 2005), because it could easily affect their thinking processes and reasoning skills, while imposing a cognitive load on them (Kim & Kim, 2012). In addition, personal factors, such as the learners' visuospatial ability (Boucheix & Lowe, 2010; Hegarty et al., 2003), cue habituation (Lowe & Boucheix, 2011), motivation, or metacognitive strategies (Kriz & Hegarty, 2007) could also diminish the impact of visuospatial cueing.

**Research question 2**

Those who received no visual cueing to reduce their visual search processes consumed their cognitive resources on processing non-essential information in the visualization. The cost of failing to extract highly relevant information from the visualization was that the quality of mental model construction would be compromised (Boucheix et al., 2013), thereby deep learning did not take place and yielded a high cognitive load. The presence of visual cueing that captured the learners' attention might reduce the learners' attention demands in selection of relevant information. With the reduction of attention demands, more cognitive resources would be released for essential information processing involved in the organization or integration of information (Jamet et al., 2008) and reduced the learners' cognitive load. The presence of verbal text also helped the learners make referential connections between text and images and reduced their cognitive load. However, simultaneous presence of both cueing and verbal text yielded similar cognitive load as those who received nothing was probably the learners applied cognitive resources to process either the conspicuous cueing or verbal text and missed the essential information. If that was the case, it did not help them organize information into a coherent structure, fail to optimize conceptual understanding and impose a heavier cognitive load on them. The findings were partially in line with the study of Kalyuga et al. (1999) but were inconsistent with those of previous studies (e.g., Crooks et al., 2012; de Koning et al., 2010a; de Koning et al., 2011a; Lin & Atkinson, 2011) in which the presence of attention cueing yielded similar cognitive load.

**Research question 3**

Those who received attention cueing generally spent less time learning the lesson than their counterparts. This result only partially echoed the findings in Lin and Atkinson's (2011) study but was inconsistent with the findings in Boucheix and Lowe's (2010) study. Cue engagement may not guarantee cue obedience (Boucheix et al., 2013), and cue obedience may not guarantee cue consequence (Lowe & Boucheix, 2011). More cue loyalty and fast cue engagement may not guarantee better comprehension (Boucheix et al., 2013). Although visual cueing was successful in perceptually directing learners' attention, the higher-order cognitive processes may not occur (Boucheix et al., 2013). Those in the PG received no visual cueing to reduce their visual search process, they were elicited to click more often and had longer viewing duration than their counterparts. Or perhaps the terminology in the instructional visualizations was too difficult, prompting those in the PTG to click more and had longer viewing duration than their counterparts. Those in the PTSG had short viewing duration when each time they clicked on the visualization was probably because the conspicuous cueing preferentially attracted their attention and triggered them to click frequently; however, the neighboring but highly-relevant information failed to compete equally with conspicuous cues for their attention (Boucheix et al., 2013), in which conceptual understanding was impaired. Besides, short viewing duration and high frequency of clicks implied more exploratory processing, such as visual searching and scanning (Lowe & Boucheix, 2016). Consuming cognitive resources on unnecessary visual searching was helpless for deep processing, whereas long viewing duration and low frequency of clicks might involve deep learning. Another possible explanation was that simultaneously presenting multiple-information on a small screen was more cognitively demanding to cause eyestrain (Kim & Kim, 2012; Stockwell, 2008), and prompting them to finish the task quickly or even give up without spending sufficient time carefully studying the visualizations. Besides, a lack of motivation (Liu & Chu, 2010) or other personal factors might also prevent the learners from completing the activities on mobile phones (Stockwell, 2008) thereby compromising the effects of visual cues.

## Conclusion

The experimental results indicated that the presence of either visual cueing or verbal text was beneficial for learners to develop greater conceptual understanding. However, if cueing failed to continuously attract learners' attention across extended viewing of the visualization, the effects of cueing would be diminished. Whether the presence of progressive path cueing (Boucheix et al., 2013) or spreading-color cueing (Boucheix & Lowe, 2010) can provide learners with continuous attraction of attention by establishing pathway of causal chains and result in favorable mental model development is suggested to be probed in the future. Secondly, whether the verbal text presented in salient color initially and then switched to its original color can compete equally with conspicuous arrow cueing for learners' attention is also suggested to be explored. Thirdly, relation cueing or anti-cueing (Lowe & Boucheix, 2011) is also suggested to be provided. With the diminishing of cue obedience after initial cue engagement, learners should shift their attention to neighboring but relevant areas in order to build a coherent, organized, and high-quality mental model (Boucheix et al., 2013). Finally, visual cueing that initially captures learners' attention might wane over time due to learners' cueing habituation or metacognitive strategies (Lowe & Boucheix, 2011), and these personal factors deserve further exploration.

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