Visual event-related potential studies supporting the validity of VARK learning styles’ visual and read/write learners

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Submitted 17 June 2015; accepted in final form 11 February 2016

Thepsatiporn S., Pichitpornchai C. Visual event-related potential studies supporting the validity of VARK learning styles’ visual and read/write learners. Adv Physiol Educ 40: 206–212, 2016; doi:10.1152/advan.00081.2015.—The validity of learning styles needs supports of additional objective evidence. The identification of learning styles using subjective evidence from VARK questionnaires (where V is visual, A is auditory, R is read/write, and K is kinesthetic) combined with objective evidence from visual event-related potential (vERP) studies has never been investigated. It is questionable whether picture superiority effects exist in V learners and R learners. Thus, the present study aimed to investigate whether vERP could show the relationship between vERP components and VARK learning styles and to identify the existence of picture superiority effects in V learners and R learners. Thirty medical students (15 V learners and 15 R learners) performed recognition tasks with vERP and an intermediate-term memory (ITM) test. The results of within-group comparisons showed that pictures elicited larger P200 amplitudes than words at the occipital 2 site ($P < 0.05$) in V learners and at the occipital 1 and 2 sites ($P < 0.05$) in R learners. The between-groups comparison showed that P200 amplitudes elicited by pictures in V learners were larger than those of R learners at the parietal 4 site ($P < 0.05$). The ITM test result showed that a picture set showed distinctly more correct responses than that of a word set for both V learners ($P < 0.001$) and R learners ($P < 0.01$). In conclusion, the result indicated that the P200 amplitude at the parietal 4 site could be used to objectively distinguish V learners from R learners. A lateralization existed to the right brain (occipital 2 site) in V learners. The ITM test demonstrated the existence of picture superiority effects in both learners. The results revealed the first objective electrophysiological evidence partially supporting the validity of the subjective psychological VARK questionnaire study.

Learning is one of the processes that can change human behavior and way of thinking. Generally, humans can learn from various sensory inputs, such as seeing, hearing, smelling, tasting, and somatic sensations (17). Learning, as a fundamental element of the educational process, is necessary for existence. Therefore, studies of the factors that affect learning are important for educational development. Examples of these factors include learning styles, learning materials, and teaching styles, just to name a few. At present, student-centered learning or the learner-centered education concept has been used for several decades. Student-centered learning is a shift of learning methods on which learners play a more independent and active role to construct knowledge through gathering, integrating, and synthesizing information and knowledge (1). Learners need to acquire many learning skills, such as inquiry skills through their learning styles, critical thinking, problem-solving skills, and others. Therefore, the role of learning styles on overall learning is worthy of consideration.

Learning styles are characteristic of individual learners, with a preference for certain sensory modes or particular conditions for perceiving and processing the input information (22). However, its validity is questionable. It is possible that people may learn better if their learning is based on the matching of their learning styles or methods and the learning tools provided. Generally, the learning style for each individual varies (28, 29, 36). Identifying learning styles is valuable for understanding the differences in individuals, which may be useful for teachers to design appropriate learning tools, useful for learners to enhance their strengths using their preferred learning methods, and useful for developing other nonpreferred learning methods. There are at least two approaches to study the effect of learning styles on learning: subjective and objective studies. The “subjective study,” or “perception study,” is a study where data or information are offered by participants’ communication (verbal or written data/information) or gathered by observers based on the participants’ or observers’ beliefs, attitudes, and perceptions. The gathered data/information is not always precisely measurable, such as participants’ feelings, which leads to doubt in its validity. The “objective study,” or “scientific study,” is a study where data or information are collected using various kinds of scientific instruments whose data/information can be measured precisely. This results in more reliable validity, such as the temperature taken by using a thermometer compared with feeling warm. In general, subjective evidence from a questionnaire given to participants is used to identify learning styles of individuals, such as the VARK learning style questionnaire (where V is visual, A is auditory, R is read/write, and K is kinesthetic) (10) and Felder learning style inventory (9).

The VARK questionnaire is a kind of subjective study tool and learning style survey used to classify individuals into four major groups comprising V, A, R, and K learners. It claims to classify the steps of information processing (V, A, and R are input steps, whereas K is an output step). The questionnaire can be accessed and downloaded from the internet (10) and has been used in many studies (22, 35). In Thailand, medical students are regarded as some of the most outstanding undergraduate students of higher education. It would be interesting to obtain more information and learn about their preferred learning styles in order for medical schools to develop more effective learning materials. However, a VARK questionnaire only provides psychological and subjective evidence. It is questionable whether any objective evidence exists to support the validity of the VARK questionnaire. To fulfill the aim of
the present study, objective study tools for event-related potential (ERP; electrophysiological data recorded from human brains while they are performing recognition tasks) and an intermediate-term memory (ITM) test were used to substantiate the validity of learning styles.

The recognition task is a method for studying memory. Recognition is a process for the judgment of stimulus previously experienced by matching a process between stimulus content and prior memory content (30). Generally, in a recognition task, subjects are told to memorize stimuli shown on a computer screen during the study phase. Subsequently, they discriminate the targeted stimuli (or the previous stimuli shown during the study phase) from the nontargeted stimuli (or the new stimuli) in the test phase by pressing a button.

ERP averages the electrophysiological voltage changes recorded by using electroencephalography (EEG) to indicate the processes of the brain in response to a particular event (19). Generally, P200 or P2 is considered the most important component in the recognition process. P200 is an early positive component (~200 ms from the stimulus onset) associated with basic sensory processes, such as searching complex visual stimuli and detecting target stimuli. P200 amplitude is sometimes influenced by high-level cognitive operations (7). P200 also occurs when a subject recognizes words shown on a computer screen, known as recognition potential (25). This may reflect the process of comparing visual input with stored knowledge or generated expectations. A previous study (8) revealed that P200 amplitude elicited from words was significantly larger at right frontal electrode sites. On the other hand, the P200 repetitive effect elicited from a picture recognition task was found at the parietooccipital regions. It has also been demonstrated that pictures exhibit larger P200 amplitudes than words (12). However, these findings were investigated in subjects without identifying individual preferences for sensory perception or learning style. It is debatable whether P200 elicited from word tasks and picture tasks is dependent on individual learning styles, such as the VARK learning style. However, picture recognition is partly influenced by the picture superiority effect.

The picture superiority effect is the concept that pictures are easier to recognize than words (14). Previous studies have demonstrated that subjects could remember pictures better when performing picture and word recognition tasks (3, 5, 15). However, these studies were designed to recognize stimuli displayed in the short term. It was hypothesized that the picture superiority effect would exist in ITM as well.

ITM is memory that can retain a large amount of information for ~2–3 h (13, 23). Previous studies have found that ITM is different in individuals depending on age, sex, and education, among other factors (2, 20, 24, 37). However, there have not been any studies regarding the effects of learning styles on ITM. Therefore, the ITM test was used in the present study to demonstrate the effect of learning styles on ITM as well to investigate the existence of the picture superiority effect in learners.

Although the VARK learning style questionnaire has been used extensively over the last 20 yr, its validity has yet to be confirmed (21). This drawback is attributable to a lack of evidence from objective studies, such as electrophysiological or neuroanatomic studies. The findings of objective evidence between learners’ learning styles and their performances in recognition tasks would be valuable for improved classification and validity for the VARK questionnaire. The present study was designed to reveal the association of medical students’ learning styles (especially V learners and R learners classified using VARK questionnaires) with recognition tasks evaluated using visual ERP (vERP; an electrophysiological study) and ITM test (neurobehavioral study). Whether there is any difference in P200 (recognition potential) at parietooccipital electrode sites (picture and word recognition region) between V learners and R learners is open to discussion. The present study aimed to investigate whether vERP could support some aspects of the validity of VARK learning styles and identify the existence of the picture superiority effect in V learners and R learners.

MATERIALS AND METHODS

In this experiment, subjects were asked to perform recognition tasks evaluated using vERP. One hour after the recognition tasks, subjects performed the ITM test.

Subjects. Thirty subjects participated in the experiment, consisting of 15 V learners and 15 R learners from 240 medical students classified using the VARK questionnaire1 (Fig. 1). The subjects included 13 male subjects and 17 female subjects. Subjects ranged in age from 19 to 22 yr, with an average age of 20.17 ± 0.57 (SD) yr. The subjects included in the study were right-handed dominant, identified using the Thai Edinburgh Handedness Inventory, Thai native speakers, and had normal or corrected to normal vision. All subjects had adequate rest before testing and displayed no neurological or psychiatric problems. Subjects were excluded if they had any psychiatric illnesses, neurological disorders, head injuries, hand injuries, were under medication, or lacked a sufficient amount of rest. All subjects signed informed consents, essentially stating that they would be able to withdraw from the experiment at any time and that the experiment would result in no harm to the subjects. The consent was approved by the Human Research Ethics Committee of the Faculty of Medicine Siriraj Hospital.

Stimuli preparation. Neutral valence words and pictures were used as stimuli in the study. Four hundred words were selected from the Thai Dictionary of The Royal Institute B.E. 2542 (32a). They were Thai monosyllable nouns frequently used in daily life (such as: "nok": a cat, "khar": a table, "pue": a bed, etc.) by an average of 10.22 ± 0.33. The words were divided into two groups, neutral valence words and pictures used as stimuli in the study. Four hundred words were selected from Thai Dictionary of The Royal Institute B.E. 2542 (32a). They were Thai monosyllable nouns frequently used in daily life (such as: "nok": a cat, "khar": a table, "pue": a bed, etc.) by an average of 10.22 ± 0.33. Neutral valence words and pictures were used as stimuli in the study. Four hundred words were selected from Thai Dictionary of The Royal Institute B.E. 2542 (32a). They were Thai monosyllable nouns frequently used in daily life (such as: "nok": a cat, "khar": a table, "pue": a bed, etc.) by an average of 10.22 ± 0.33. Four hundred words were selected from Thai Dictionary of The Royal Institute B.E. 2542 (32a). They were Thai monosyllable nouns frequently used in daily life (such as: "nok": a cat, "khar": a table, "pue": a bed, etc.) by an average of 10.22 ± 0.33.

1 Two hundred and forty third-year medical students from the Faculty of Medicine Siriraj Hospital, Mahidol University, participated in this study. The subjects were composed of 119 female subjects and 121 male subjects within an age range of 19–22 yr and a mean age of 19.79 ± 0.54 (SD) yr. Subjects were asked to answer a modified Thai VARK learning style questionnaire, composed of 16 questions, by choosing only the most preferable choice for each question. For analysis, the learning styles of medical students were classified according to their answers as V, A, R, K, and multimodal learners (preferring more than one learning style). The findings showed various learning styles existent in the 240 medical students (Fig. 1). There were 39.17% unimodal learners (those who preferred one mode of learning styles), consisting of 5.42% V learners, 12.08% A learners, 7.50% R learners, and 14.17% K learners. There were 60.83% multimodal learners, consisting of 2.92% VA learners, 1.25% VR learners, 7.08% VK learners, 5.83% AR learners, 10.42% AK learners, 3.75% RK learners, 3.33% VAR learners, 10.00% VAK learners, 3.75% VRK learners, 9.17% ARK learners, and 3.33% VARK learners. There were only 5.42% V learners and 7.50% R learners. Thus, only six single V learners (one multimodal learner comprising high V and low R scores in the V learner group and eight single R learners and seven multimodal learners (comprising high R and low V scores) in the R learner group were used for this experiment.
in this study. These objects were shown on a white background. The stimuli consisting of neutral words and pictures were classified using an event-related potential (vERP) and an intermediate-term memory (ITM) test.

Subjects performed two recognition tasks each consisting of a picture recognition task and a word recognition task. Each task consisted of a block of 10 trials and lasted ~10 min. Subjects were allowed to take a break for ~5 min at the end of the first block. Thus, the picture and word recognition tasks lasted ~25 min.

**EEG recording.** EEG signals were recorded using a Nihon Kohden EP set. Eight Ag/AgCl electrodes of 10–20 international systems included F3, F4, C3, C4, P3, P4, O1, and O2. The reference was the nasal tip, with the ground reference being the right earlobe. In the EEG setting, the EEG amplifier band pass filter was 0.1–100 Hz. The 50-Hz noise was removed using a notch filter. Electrode impedances were <5 kΩ. EEG recording was set from ~100 to 1,000 ms. The total time was ~30–40 min for EEG electrode attachment and EEG setting.

For analysis, computer software automatically deleted any tracing that contained artifacts. The baseline was measured as an average of the signals from ~100 to 0 ms. The amplitude was measured in microvolts from the baseline to the peak. The waveforms of interest in the study were P200 elicited by target stimuli at ~150–275 ms.

**ITM test.** A behavioral study of the ITM test was used in this study. After performing the recognition tasks, subjects were confined in the laboratory for 1 h to prevent external experience contamination. After 1 h, they were requested to perform the ITM test. There were two sets of stimuli composed of a word set and a picture set. Each set consisted of 10 old stimuli seen in the recognition tasks mixed with 10 new previously unseen stimuli. A pseudorandomized subset of five stimuli composed of two or three old stimuli mixed with three or two new stimuli, respectively, were shown on a computer screen for the subject to identify the old stimuli by clicking with a mouse. The program tallied the total number of correct responses. A total of four screens with five word or picture stimuli were done within 4–5 min. Thus, the two sets of word and picture stimuli were finished in 8–10 min. The total number of correct responses was calculated as a percentage.

**Statistical analysis.** The analysis of descriptive statistics is presented as means ± SD. A paired t-test was used to compare two population means within groups of subjects. An independent t-test was used to compare two population means between groups of subjects. Statistical significance was expressed at \( P < 0.05 \), \( P < 0.01 \), and \( P < 0.001 \).

**RESULTS**

For the vERP experiment, P200 amplitudes of picture and word tasks in V learners and R learners were compared within groups and between groups (Table 1). The results of within-group comparison (Fig. 2A) showed that pictures (compared with words) elicited larger P200 amplitudes at the occipital 2 site \([t(14) = 2.93, P < 0.05]\) and at the occipital 1 site \([t(14) = 2.42, P < 0.05]\) and occipital 2 site \([t(14) = 2.47, P < 0.05]\) in V learners and R learners, respectively. The between-group comparison (Fig. 2B) showed that P200 amplitudes elicited by pictures in V learners was larger than those of R learners at the parietal 4 site \([t(28) = 2.36, P < 0.05]\).

In the ITM test, percentages of correct responses of the picture and word set in V learners \((n = 15)\) and R learners \((n = 15)\) were compared within groups (Table 2). The results showed that, for V learners, the picture set exhibited a distinct-
tively higher percentage of correct responses (78.00 ± 16.99%) than that of the word set [52.00 ± 23.66%, t(14) = 7.17, P < 0.001]. This was also found in the same manner as R learners (66.67 ± 17.59% correct responses for the picture set and 46.67 ± 14.96% correct responses for the word set), with a higher P value [t(14) = 4.02, P < 0.01]. Between-group comparisons for percentages of correct responses of both the picture set and word set between V learner and R learner groups were not significantly different from a statistical standpoint.

### Table 1. Comparisons of P200 amplitudes for picture and word tasks in V learners and R learners

<table>
<thead>
<tr>
<th>Within Groups</th>
<th>Electrode Site</th>
<th>Picture Task, μV</th>
<th>Word Task, μV</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V learners</td>
<td>O2</td>
<td>10.22 ± 5.92*</td>
<td>6.23 ± 5.54</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>R learners</td>
<td>O1</td>
<td>7.77 ± 5.06*</td>
<td>4.78 ± 2.37</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>8.59 ± 5.05*</td>
<td>5.29 ± 2.99</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Between Groups</th>
<th>Electrode Site</th>
<th>V Learners, μV</th>
<th>R Learners, μV</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture task</td>
<td>P4</td>
<td>9.36 ± 3.85*</td>
<td>6.55 ± 2.58</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Values are means ± SD; n = 15 visual (V) learners and 15 read/write (R) learners. *P < 0.05.

### Table 2. For the intermediate-term memory test, within-group comparisons of percent correct responses for the picture set and word set in V learners and R learners

<table>
<thead>
<tr>
<th>Within Groups</th>
<th>Picture Set, %</th>
<th>Word Set, %</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V learners</td>
<td>78.00 ± 16.99†</td>
<td>52.00 ± 23.66</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R learners</td>
<td>66.67 ± 17.59*</td>
<td>46.67 ± 14.96</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Values are means ± SD; n = 15 V learners and 15 R learners. *P < 0.01; †P < 0.001.

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**Fig. 2.** Examples of vERP presenting P200 waveforms and topographic maps of the top view of electrode sites of the ERP study. The P200 amplitudes, indicated with arrows, were measured in microvolts from the baseline to the peak. **A:** within-group comparisons of P200 amplitudes comparing between picture tasks (left) and word tasks (right) of V learners and those of R learners. Within V learners, the thick circle indicated that P200 amplitudes at the occipital (O)2 site elicited by picture tasks were larger than those elicited by word tasks. Within R learners, the thick circles indicated that P200 amplitudes at the O1 and O2 sites elicited by picture tasks were larger than those elicited by word tasks. **B:** comparison between P200 amplitudes of V learners and R learners elicited by picture tasks. The thick square indicated that P200 amplitudes at the parietal (P)4 site elicited by picture tasks of V learners were larger than those of R learners. *P < 0.05.
DISCUSSION

The present study is the first to show objective evidence of the effects of learning styles on recognition tasks evaluated using vERP. It focused on the recognition abilities of V learners and R learners because most information was perceived by vision (seeing and reading). There have been other studies on learning differences in normal subjects using visual memory performance to compare memory abilities between groups (6, 18, 27). The confounding factors of subjects were best matched and the paradigms were counterbalanced in the experiments. The factors included the same number of V learners and R learners, with average ages being about the same, about the same numbers of subjects of each sex, and about average or above average intelligence assumed by the ability to pass the entrance examination to the Faculty of Medicine Siriraj Hospital. From the aforementioned factors, the experimental design in this study could be regarded as reliable.

The validity of the VARK questionnaire used to classify learning styles has not been resolved because it uses subjective evidence acquired by answering a 16-item questionnaire. To demonstrate objective evidence of brain electrical activity and behavioral study, 15 V learners and 15 R learners were selected to perform recognition tasks using vERP and ITM tests. In this regard, subjects might show superior learning and memory through their preferred sensory and representational modality (4). The examination of the relationship between learning styles and recognition tasks with different instructional modalities was as follows: first, a VARK questionnaire was used to identify the learning styles of subjects. Second, recognition tasks were conducted using vERP. Normally, psychometric tests are used in the psychology field to provide behavioral evidence. However, such perception or subjective studies are unable to provide objective evidence of brain functions. In this study, vERP methodology was used to provide objective evidence. The benefits and strengths of this study included 1) vERP is the brain signal evoked soon after a stimulus or event appears, resulting in high temporal resolution, and 2) the vERP technique is simple, noninvasive, and inexpensive for repeated studies.

Evidence of pictures eliciting larger P200 amplitudes than words at parietooccipital sites in normal subjects (12) was supported by the present study results of within-group comparisons, where larger P200 amplitudes were found at the occipital 2 site in V learners [t(14) = 2.93, P < 0.05] and at the occipital 1 site [t(14) = 2.42, P < 0.05] and occipital 2 site [t(14) = 2.47, P < 0.05] in R learners. The results of larger P200 amplitudes at the occipital 1 and 2 sites representing the visual cortical areas might partly contribute to the picture superiority effect. A difference between the study of Greenham et al. (12) and the present study was that the former study did not classify learning styles, whereas the latter study design compared within-groups (V learners and R learners) and between groups. Furthermore, there have been a number of studies showing the picture superiority effect in other ERP components, such as the N450 amplitude (11) and the parietal old/new late positive component of ERP (elicited at 500–800 ms) (5). In the present study, the picture superiority effect evidenced by vERP was found in V learners, who are normally capable of processing pictures. Surprisingly, it was found in R learners, who are normally capable of processing words. However, it was noticed that a lateralization (activity devoted to one side of the body or brain) existed to the right brain (occipital 2 site) in V learners, whereas there was no lateralization in R learners (occipital 1 and 2 sites). This could possibly be the result of more neural activities recruited on the right brain of V learners. In addition, the t score of within-group comparison between picture tasks and word tasks for V learners (2.93) tended to be higher than that for R learners (2.42 and 2.47), which might reflect the picture task effect being observed more obviously in V learners than in R learners.

Between-group comparisons of picture tasks revealed that V learners exhibited larger P200 amplitudes at the parietal 4 site than R learners. P200, representing recognition potential (25), was more prominent in V learners than in R learners. It is possible that the recruitment of neural activities in attention mechanism is higher in V learners, as demonstrated by the larger P200 amplitudes elicited by pictures at the right parietal cortical region. Moreover, functional MRI evidence has shown that the parietal lobe is associated with retrieval success, resulting from attentive requirements of the retrieval process (32). The results demonstrated two important points. First, this is the first objective evidence revealing the differences of P200 amplitude elicited by picture tasks performed in V learners and R learners. Second, it showed right hemisphere lateralization of picture processing, which has been found in numerous previous studies (26, 33, 34).

In addition, the ITM test demonstrated the existence of picture superiority effects in both V learners and R learners. The results showed that the picture superiority effect was more obvious in V learners (P < 0.001) than in R learners (P < 0.01). This study was the first evidence demonstrating the picture superiority effect in both V learners and R learners. Previous studies have found picture superiority effects in normal subjects without classifying their learning styles (3, 15, 31). In this study, ITM tests were performed 1 h after the recognition tasks. Furthermore, none of the subjects knew in advance that they had to perform the ITM test. Thus, the results genuinely demonstrated that picture superiority effect existed in both V learners and R learners 1 h after the recognition tasks. Further studies of ITM tests after longer periods (such as 2 or 3 h or a few days or longer) should be examined.

The ITM test demonstrated the existence of the picture superiority effect in both learner groups. The percentages of correct responses of the picture set for V learners and R learners were 78.00% and 66.67%, respectively. The percentages of correct responses of the word set for V learners and R learners were 52.00% and 46.67%, respectively, which was equal to an ~50% chance for correctness from guessing. Although the between-group comparison for the percentage of correct responses between V learners (78.00%) and R learners (66.67%) was not statistically different, there was a tendency for a higher percentage of correct responses in V learners than in R learners. In addition, the P value of the picture set and word set of V learners (P < 0.001) was statistically and significantly different at a lower P value than that of R learners (P < 0.01). This could imply that the picture superiority effect was more prominent in V learners than in R learners.

It seemed surprising that the result did not show a statistical difference of P200 amplitude elicited from word tasks nor ITM...
tests between R learners and V learners. This could be partly a result of the picture superiority effect described above, and further investigations are needed.

The result revealed the differences of the P200 component of vERP elicited by picture tasks performed in V learners and R learners. This objective evidence could be used to support distinguishing V learners from R learners. If learners know their personal learning styles with accuracy, it would help them to plan learning strategically. In addition, different kinds of learning materials could be designed and created for learners with different learning styles to learn more effectively. However, further studies should be carried out to investigate A learners and K learners to obtain more objective evidence and to help validate as well as substantiate the VARK learning style questionnaire.

In conclusion, the vERP results showed that V learners exhibited larger P200 amplitudes at the parietal 4 site elicited by pictures than R learners. The implication is that V learners could be distinguished from R learners by P200 effects. This first objective evidence could be used as a marker for identifying different neural activities in V learners and R learners. It also partially supported the validity of the VARK questionnaire.

In summary, the scientific evidence found in the present study revealed that different neural activities were existent in the brains of V learners and R learners. It also partially supported the validity of the VARK questionnaire.

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and C.P. interpreted results of experiments; S.T. prepared figures; S.T. and Education Commission, Thailand.

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In conclusion, the vERP results showed that V learners exhibited larger P200 amplitudes at the parietal 4 site elicited by pictures than R learners. The implication is that V learners could be distinguished from R learners by P200 effects. This first objective evidence could be used as a marker for identifying individual differences in visual learning style as well as to partially resolve the questionable validity of the VARK questionnaire. From the within-group comparison of vERP, it was noticed that a lateralization existed to the right brain (occipital 2 site) in V learners, whereas there was no lateralization in R learners (occipital 1 and 2 sites). In addition, the ITM test demonstrated the existence of picture superiority effects in both V learners and R learners. In summary, the scientific evidence found in the present study revealed that different neural activities were existent in the brains of V learners and R learners. It also partially supported the validity of the VARK questionnaire.

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This work was supported by Siriraj Graduate Thesis Scholarship and Strategic Scholarships Fellowship Frontiers Research Networks, the Higher Education Commission, Thailand.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: S.T. performed experiments; S.T. analyzed data; S.T. and C.P. interpreted results of experiments; S.T. prepared figures; S.T. and C.P. drafted manuscript; S.T. and C.P. edited and revised manuscript; C.P. conception and design of research; C.P. approved final version of manuscript.

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