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Cognitive arousal assessment from central to peripheral nervous functions in school-age children

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Abstract

Cognitive skills are a set of higher-order thinking processes that allow children to learn successfully. By developing cognitive skills, the brain is connected to Rapidly complete the information processes. The aim of this study was to examine the cognitive process development, decision making and eventually cognitive performance in school-age children evaluated by the galvanic skin conductance response (SCR) method. Peripheral SCR signals during cognitive loading were recorded in children in grades 1 to 3 of a representative school in Southern Thailand. Eriksen flanker and dexterity tests were conducted to evaluate the development of its association with cognitive skill. Regression-based analyses showed reduced reaction time on Eriksen flanker (both congruent trials with regression coefficient = -0.02924, $p < 0.001$ and incongruent trials with regression coefficient = -0.04231, $p < 0.001$) and time spent to achieve dexterity tests (regression coefficient = -0.32206379, $p < 0.05$) from students' grades 1 to 3. In SCR modulation, analysis of variance revealed highest peak SCR magnitudes in students grade 3, compared to students in grade 2 ($p < 0.001$) and grade 1 ($p = 0.046$). On the other hands, numbers of peaks were highest in students grade 1 when they were in the calm stage ($p < 0.001$), and highest in student grade 3 ($p = 0.002$) when they were in the focus mind state. These findings support the association of the psychophysiological index of changes in brain and cognitive development among age related experience to focus attention improving under the task.

Introduction

Cognitive control, which contributes toward goal-directed behaviours, has been associated positive academic performances among children (Diamond, Barnett, Thomas, & Munro, 2007; Howie & Pate, 2012; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Conceptual and clinical findings revealed the correlation between brain cognitive status and performance outcomes (Hammond & Summers, 1972). According to the results from several studies, the attention levels of school students can be enhanced. These results were derived from experiments to assess the performance of children with regard to physical activity (Aslan, Aksoy, &

İmamoğlu, 2020; Canli & Koçak, 2018; Gür, Çoban, & Gür, 2018; Ibis & Aktug, 2018), and to assess the capacity of children with mild intellectual disabilities to learn as normal (Alnajjar, Cappuccio, Renawi, Mubin, & Loo, 2021; Top, 2021). However, it was revealed that disturbance of attention span in the adult ADHD brain stems from the shifting of focus with regards to the successful completion of the task, which consequently leads to loss of demand (Salmi et al., 2018). Intelligence involves the ability to think, solve problems, analyze situations, and understand social values, customs, and norms. Intelligence testing or IQ test is the popular estimation of a student's current intellectual functioning. A child with a low score on an IQ test would need different instruction than one with a high score due to the clear-cut standardized scores contained in the tests. All labels are harmful to children - and can have a drastic impact on their future behavior. There have been continued to debate their usefulness and current relevance, as it requires them to perform various tasks designed to assess different types of reasoning. (Cross & Cross, 2017). Children's strengths, weaknesses, environment, and culture should all be considered. Rather than just focusing on quantitative scores, scholars focus on qualitative learning and general potential as a means of overcoming the many issues surrounding IQ testing for children.

To date, three major brain anatomical pathways for constructing electrical skin activity have been mentioned. (Measures et al., 2012). Firstly, limbic structures direct ipsilateral responses. For instance, the hippocampus interacts with the inhibitory processes during behavioural control and inhibition. However, the excitatory neurotransmitter facilitates a defensive behavioural response. These are the main influencers of emotion and attention. Secondly, the basal ganglia and premotor regions direct contralateral responses. A significant response is associated with the preparation motor actions. And lastly, the reticular modulating system comes with situations that necessitate increased general arousal. A highly aroused sympathetic branch (SNS) of the autonomic nervous system is associated with increased sweat gland activity, which in turn increases skin conductance, and vice versa. As a prospective physiological indicator of cognitive load and emotions, galvanic skin response (GSR) has recently attracted researchers' attention (Nourbakhsh, Wang, Chen, & Calvo, 2012). Investigations on the psychological issues included research on judgement and the decision-making process (Frith & Allen, 1983; Sakai et al., 2017; Van Zonneveld, Platje, Sonneville, Van Goozen, & Swaab, 2017). This included neuro-marketing studies (Bercea, 2012; Gakhal & Senior, 2008) to identify consumer preference and judement. In terms of sweat glands and the brain, one of the key players in this area is the amygdala, which generates skin conductance response (SCR) regardless of the source of arousal (Davis & Whalen, 2001; Orem et al., 2019). The hypothalamus plays a critical role by maintaining internal balance and facilitating sympathetic responses (Caruelle, Gustafsson, Shams, & Lervik-Olsen, 2019). SCR as the index of sympathetic activity, established significant correlation in the limbic brain system: the amygdala, the hypothalamus and hippocampus. The electrical stimulation confirmed that the cortical regions and prefrontal areas - especially the ventromedial prefrontal cortex (VMPFC) – are connected to SCR, decision making and emotion (Critchley, Elliott, Mathias, & Dolan, 2000). The decision-making task (i.e., the Iowa Gambling Task) can promote SCR in the mind stage, in anticipation of a risky choice. In contrast, there was no response from the VMPFC lesion in the SCR index, and it also came with low decision altitudes (Nicholson, 2018). Given the methodology of the SCR, we here seek to introduce SCR encouraging to be a practical starting point for students' cognitive processes evaluation in predicting school achievement, educational and occupational performance.

Material and methods

Participants

The participants involved in this study comprised children between the ages of 6 and 8 (N = 40; 22 girls and 18 boys), from a primary school located in Songkla, Thailand. They were separated into educational levels of grades 1, 2 and 3. All participants were verified healthy and with normal vision. This study was performed under the principles

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of the Declaration of Helsinki, and approved by the Prince of Songkla University ethics committee (HSc-HREC-63-043-1-1).

Design and procedure

The participants were required to carry out three assignments: the flanker test, the dexterity test and the hunting game, with short breaks in between assignments. The Eriksen flanker task was conducted on a laptop, in accordance with the site http://cognitivefun.net/test/6. Participants were instructed to press the key (left or right) matching the arrow in the center presented on the screen. Surrounding arrows (designated flankers) need to be ignored. Participants were allowed 12 practice trials, the results for which were not taken into consideration. Two flanker tests were conducted, and the percentage for correct, and time to accomplish congruent (similar flankers' direction to target arrows) as well as incongruent (dissimilar flankers' direction to target arrows) stimuli were evaluated (Servant & Logan, 2019). For the dexterity test, the participants were required to pick up pins with the dominant hand, and deliver them to a pegboard one after another. Two sequences were performed for this task, and the time involved was averaged. The findings from this exercise successfully assessed the fine hand performance and sensory-motor brain connectivity in children (Arnould, Penta, & Thonnard, 2008). Mindfield esense skin response measures epidermal conductance, between two electrodes attached to the index and middle fingers, of the subject's non - dominant hand. The records were set to 5 Hz, and a threshold level of 1 μS. The eSense App was used to collect skin conductance data, which was subsequently processed to precisely determine the mental workload, stress levels and other human sympathetic nervous responses (Mitose, Harvey, Peper, Rogers, & Liu, 2014; Ng, Lai, Tan, Sulaiman, & Zainal, 2016; Widyanti, Muslim, & Sutalaksana, 2017). Participants were required to shut their eyes for a minute, before proceeding to search for 7 different spots, from two figures. This was followed by an analysis of rise duration, SCR peak magnitude and peak number.

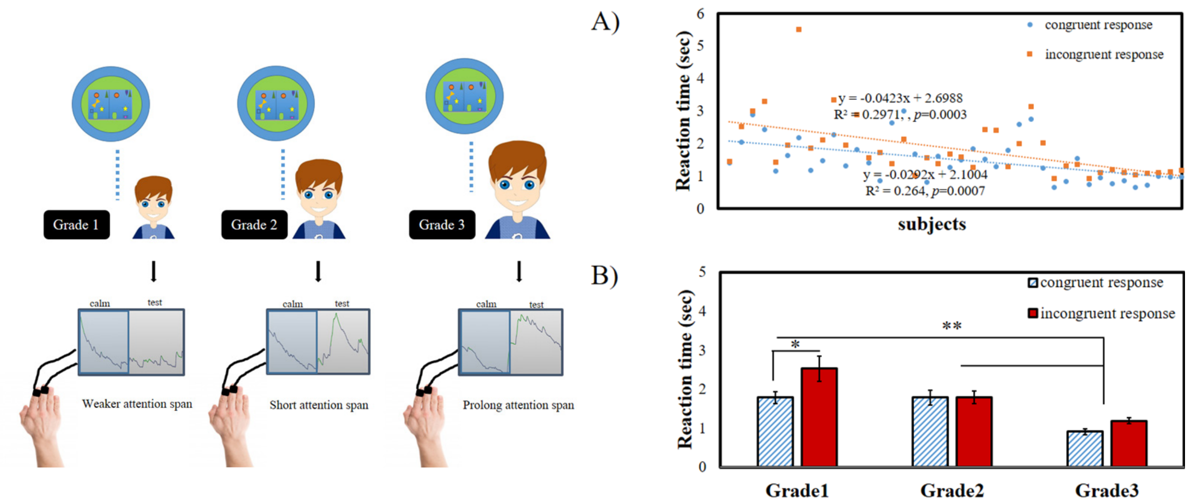

Figure 1: Reaction time for congruent and incongruent response for flanker task. A) Scatter plot shows student scores in two condition responses. B) The graph shows reaction time scores for responses in each educational stages to achieve the task. Results are represented as mean ± SEM and significance was Two-way repeated measure ANOVA followed by Tukey's post hoc test (*P < 0.05, **P < 0.01; n1 = 13, n2 = 14, n3 = 13).

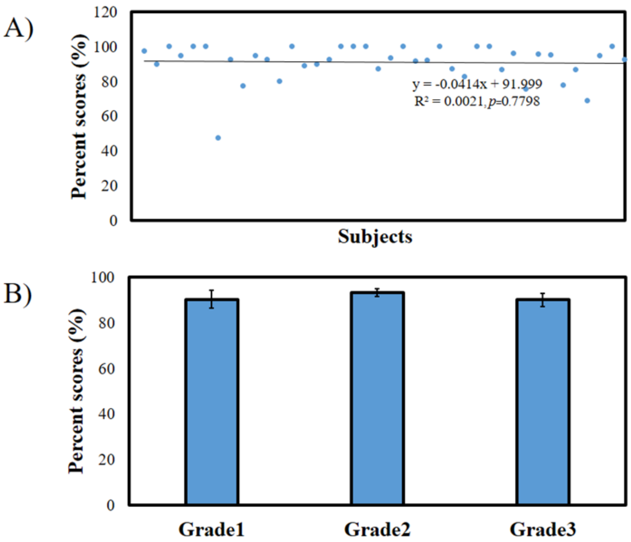

Figure 2: Percent correct scores for flanker task. A) Scatter plot shows individual's percent correct scores for the task. B) The graph shows percent correct scores for the flanker task on educational groups. Results are represented as mean ± SEM.

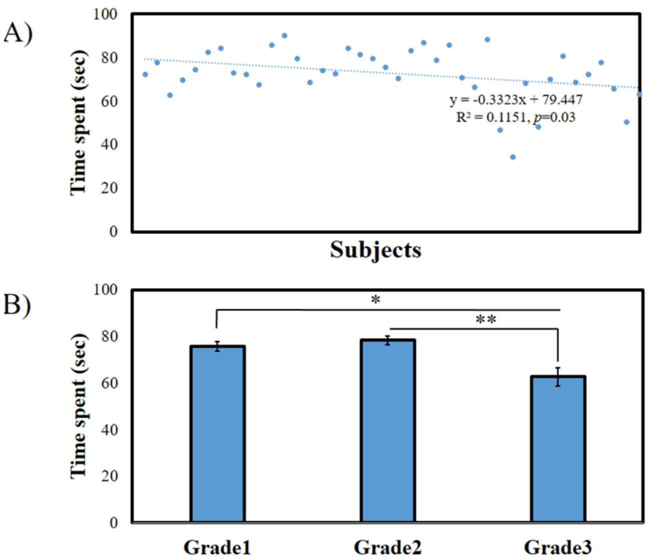

Figure 3: Time spent for dexterity test over 3 educational levels. A) Scatter plot shows individual's time score for the test. B) The graph shows time spent for dexterity test over educational level groups. Results were shown as mean ± S.E.M and significance was One-way ANOVA followed by Tukey's post hoc test (*P < 0.05, **P < 0.01; n1 = 13, n2 = 14, n3 = 13).

Results

In cognitive psychology, the basic structure of the flanker task has to do with the response to target stimuli (congruent flankers) flanked by irrelevant stimuli, or the opposite response (incongruent flankers) which can interface with the response. In a comparison of data based on age, a simple linear regression analysis revealed a significant inverse relationship between reaction time to flanker test response, both of congruent ($p=0.0007$) and incongruent ($p=0.0003$) response and age (Figure 1A). A two-way repeated measure ANOVA model was applied to the data, under distinct stimuli (congruent and incongruent stimuli), for grades 1 to 3 educational levels. The time spent on the test was significantly influenced by the educational level ($F= 20.677$, $p <0.001$). Multiple comparison indicated

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that the average reaction time for the flanker task, is lowest for students from grade 3, and significantly different in comparison to students from grades 1 and 2 ($p < 0.001$) (Figure 1B). Additionally, grade 1 students were observed to be profoundly affected by the disturbance from flankers. With these students, the response time for irrelevant stimuli is greater, when compared to the response time for congruent stimuli ($p = 0.003$). No significant differences were detected among students in grades 2 and 3. With regards to accuracy, the regression model and statistical analysis showed no significant differences between the percentage of correct scores and educational levels (Figures 2A-B). The scatter plot revealed a minor negative relationship between response time to the task, and age (Figure 3A). A significant difference in time spent to complete the task, was observed among the educational level groups ($F = 9.734$, $p < 0.001$). It was verified that the least time spent for the task is attributed to the children from grade 3, in comparison to children from grades 1 ($p = 0.004$) and 2 ($p < 0.001$) (Figure 3B). Indexes comprising the rise time, peak magnitude and a number of peaks, were examined in accordance with the skin conductance response (SCR) data (Figure 4A). One-way analysis of variance revealed the significant influence of skin conductance, during the search for points in the task, with regards to the educational level groups ($F = 8.403$, $p < 0.001$). The Tukey test confirmed the significantly high SCR peak magnitude for grade 3 students, compared to students in grade 2 ($p < 0.001$) and grade 1 ($p = 0.046$) (Figure 4C). Two-way ANOVA revealed the impact of the number of SCR peaks, on the different educational groups ($F = 11.163$, $p < 0.001$). Multiple comparison procedures verified that the SCR peak numbers, recorded by grade 3 students during focus, were higher than the numbers recorded for the eyes-closed exercise ($F = 8.403$, $p = 0.002$). The significant findings between different mind stages also revealed that for grade 1 students, the peak numbers during focus, were higher than the numbers recorded for the eyes-closed exercise ($p = 0.003$). Also, the highest SCR peak numbers during the calm stage, were delivered by students from grade 1 ($p < 0.001$) (Figure 4D). There were no differences in the rise duration of SCR monitoring, among the educational levels (Figure 4B). The SCRs for 60 seconds, during the performance of the task, were normalized with the eyes-closed period. The results revealed a significant increase for grade 3 participants after 40 seconds spent searching for spots ($p < 0.001$), in comparison to the grade 1 and 2 participants (Figure 5A). No significant gender effects were detected, with regards to skin conductance response, during the performance of the task (Figure 5B).

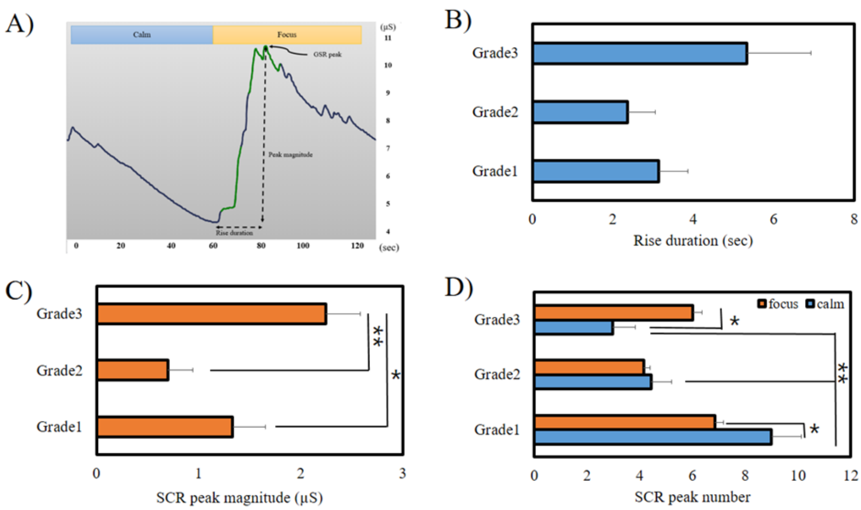

Figure 4: Skin conductance response (SCR) during focus on the task. A) Schematic to monitor attention when students stay calm and focusing on the task. B) The graph shows rise duration for SCR when students focusing on the task. C) The graph shows SCR peak amplitude between calm and attention stages of children from grade 1-3. D) The graph shows number of SCR peak between calm and attention stages of children from grade 1-3. Results were shown as mean ± S.E.M and significance was One-way and Two-way repeated measure ANOVA followed by Tukey's post hoc test (*P < 0.05, **P < 0.01 compared among grades, #P < 0.05 compared among mind stages; n1 = 13, n2 = 14, n3 = 13).

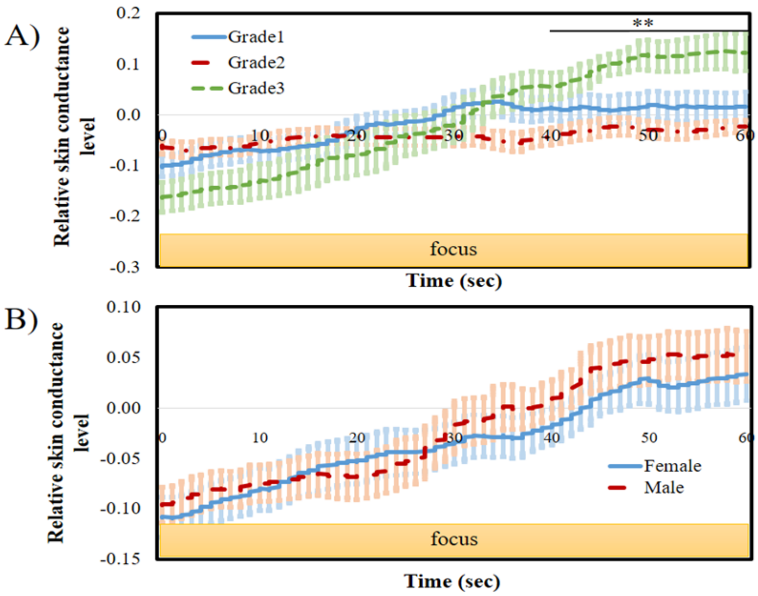

Figure 5: SCR during performing a minute of the task normalized to eye closed state. A) The graph shows relative SCR for grade levels. B) The graph shows relative SCR for gender, female and male participants. Results were shown as mean ± S.E.M and significance was One-way ANOVA followed by Tukey's post hoc test (**P < 0.001; n1 = 13, n2 = 14, n3 = 13).

Discussion

The Eriksen flanker and manual dexterity tests, clearly verified that cognitive performance during childhood is impacted by age. A clear flanker effect, identified in grade 1 students, which speeds up the response to high conflict trials (incongruent stimuli), is not effective when it comes to the response to targets with congruent stimuli. The effect vanished when the test was performed for grade 2 and 3 students. The difficulties, speed in response to a target surrounded by flankers, and the time-consuming factor in the response to the target stimuli, are covered in the standard Eriksen flanker task (Eriksen & Eriksen, 1974; Eriksen & Spencer, 1969; Estes & Wessel, 1966). The information comes to feature detectors from a local region in the visual field, which matches target and non-target flankers. The brain mechanisms are perceptible to parallel activities between visual information processing, and response competition among targets with flankers. The data reveals that grade 3 students are the most stable, with an exceptional level of attention during evaluation. The active mechanism for suppressing visual distractors develops with experience. The suppression of visual distractors facilitates the child's correct response.

The different times spent completing the Erikson and manual dexterity tests, is an indication that cognitive ability and motor performance, varies according to age. As mentioned previously, motor skill performance associated with executive functions (including working memory capacity, planning and problem solving as well as inhibitory control), was enhanced in 5 to 6 year old students (Stöckel & Hughes, 2016). Also, fine movement is related to many parts of the brain, including the motor cortical regions, the spinal cord, and the motor units (Schear & Sato, 1989). During childhood, as anatomical changes progress, the cortical size, and number of layers, increase in size or fold with age (Li, Legault, & Litcofsky, 2014; Lyall et al., 2015). The relay of sensory information from the thalamus to the cortex, and the total cerebral volume,is also an indication of the high correlation with the intelligence quotient (IQ) score in children (Reiss, Abrams, Singer, Ross, & Denckla, 1996; Sherman, 2005). Therefore, in this study, the improvement in speed, for completing the task, is an indication of the relationship between brain development and age. The skin conductance changes, associated the brain arousal system, were observed to obstruct cognitive enhancement when the subject is faced with a visual searching task. The neurological

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basis, associated with the autonomic nervous system, in response to selective attention, is attributed to the anterior cingulate cortex (ACC), which is noted for the monitoring of conflicts (Davelaar, 2013; Tranel & Damasio, 1994). A lower SCR reflects a relaxation control or a calm state of mind and provides a convincing indication of interaction between the central and autonomic nervous systems (Tang et al., 2009). The dorsal amygdala in the fMRI scan confirmed the experience of arousal via skin conductance (Xia, Touroutoglou, Quigley, Feldman Barrett, & Dickerson, 2017). A functional imaging study on the presence of SCR revealed cerebral activity at the orbitofrontal and medial prefrontal cortex, the anterior insula and extrastriate visual cortices, the parietal lobe, and the cerebellum (Critchley et al., 2000). The presence of high peak magnitude during extent attention, and highest peak numbers during the attention stage, compared to the calm stage in grade 3 students, were expressed to characterize component measures of skin conductance to attention levels. Generally, the onset times to specific SCRs generated by the stimulus fall within 1 to 3 seconds (Dawson, Schell, & Courtney, 2011; Venables, Gartshore, & O'riordan, 1980). Upon an examination of the data, it was observed that the amplitude that changes from the onset of stimulus till the peak in the SCR, displays the same pattern with the rise time, or the time from the onset to the maximum amplitude of the SCR, and numbers of the SCR peak. From the data, it can be gathered that peak magnitude and numbers of peaks, can be considered among the stronger indexes for measuring attention. Additionally, the highest SCR peak numbers, during the closed-eyes exercise for grade 1 students emphasize the fact, that the young have a relatively short attention span. The relationship between maturation and the learning process has to do with attention and human behavioral control (Posner, Rothbart, Sheese, & Voelker, 2014). A major study conducted on the attention span of infants, uncovered developments in the prefrontal cortex and the anterior cingulate (Reynolds & Richards, 2005). The primary goal of attention is to achieve the alert state, adapt to sensory inputs, and resolve the conflict among competing responses (Petersen & Posner, 2012; Posner & Petersen, 1990).

Conclusion

The alterations in SCR measures from the attention state, confirms the cognitive aspects of the sympathetic skin conductance response in grade 3 students, between 40 to 60 seconds following the closed-eyes relaxation exercise, to focus on the task. In conclusion, increased skin conductance, levels and peaks were considered, to monitor mind attention and chill. Skin conductance monitoring is one of the most promising methods for objectively evaluating attention. The involvement of educational groups in this study served to reveal that the contribution of the cognitive process towards improved performance, has to do with the development of attention systems during childhood.

Recommendations

Skin conductance method is noninvasive tool. These measures can be readily used in infants and children. It can be useful for researchers and educators to assess student learning skill and development by using skin conductance technique in order to design a suitable course of instruction for each student in group of learners. The technique can assess the intention of focusing, cognitive skills during the tests and the subject's relaxation. In this way, this technique can also reflect brain abilities and how they relate to emotional states. The limitation, however, is the use of which an expert is required to assess signal characteristics (Is the signal quality? and how is the interpretation). Recommendation for further studies, another study can be a longitudinal study. Not only that but also the larger sample from the survey can be used for generalization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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