sustainability

Article

Problem Solving by Agricultural Extension Students with Various Levels of Creativity through a Neurocognitive Lens

Chaoyun Liang

Department of Bio-Industry Communication and Development, National Taiwan University, Taipei 10617, Taiwan; cliang@ntu.edu.tw

Abstract: The cultivation of agricultural extension talent is key to sustainable agricultural development because it can help create unique economic relationships, add new knowledge and skills to traditional agriculture, identify marketing advantages in emerging markets, and promote the transition to a sustainable society. This study identified the activated brain regions and thought patterns of agricultural extension students when they performed numerical, spatial, and verbal intelligence tasks. The cerebral activity of the student participants was captured through electroencephalography to analyze their activated brain regions and thought patterns during the problemidentification and resolution-reaching phases. A total of 36 participants were recruited and divided into high-creativity (HC) and low-creativity groups to analyze differences in their thought patterns. The results indicated that numeric problem solving activated the frontoparietal network and was associated with a high level of self-generated thought. The function of evaluating creativity was inhibited in the HC group, and the participants engaged in divergent semantic processing during the numeric task. Spatial problem solving activated the frontal regions and was associated with intensive visual search tasks. The HC group exhibited suppressed creativity evaluation and analogical reasoning. Verbal problem solving activated the frontoparietal regions and was associated with verbal memory, semantic-based word processing, and self-generated thought. Creative associations in the verbal task were enhanced in the HC group. This study adopted innovative approaches to address a complex topic that has not been thoroughly investigated but is essential for the theoretical development of both neurocognitive science and agricultural sustainability.

Keywords: agricultural extension students; agricultural sustainability; creativity; electroencephalography; intelligence quotient; neurocognitive approach; problem solving

check for updates

Citation: Liang, C. Problem Solving by Agricultural Extension Students with Various Levels of Creativity through a Neurocognitive Lens. *Sustainability* **2022**, *14*, 16371. https://doi.org/10.3390/su142416371

Academic Editor: Donald H. Saklofske

Received: 8 October 2022
Accepted: 5 December 2022
Published: 7 December 2022

1. Introduction

Agricultural development in the 21st century faces the challenges of climate change and increasingly intense global competition [1]. Because the traditional model based on mass production has negatively affected the natural environment, most countries have adopted new concepts of agricultural operation, such as environmental friendliness, resource integration, technological innovation, marketing communication, and value-added knowledge management and promoted the transition to sustainable agricultural development [1,2]. Taiwan's agriculture is at a critical turning point in its transition from a production orientation to knowledge orientation, and its ability to identify and solve problems is crucial.

The cultivation of agricultural extension talent is key to agricultural education because it can help create unique economic relationships, add new knowledge and skills to traditional agriculture, establish innovative communication networks, foster efficient producer organizations, and identify marketing advantages in emerging markets [3–5]. Despite a lag in the global economy, the potential of rural entrepreneurship and the successful documentation of its implementation have encouraged young people to contribute to rural innovation, which is a prominent trend in the field of agricultural extension [1,5]. Agriculture students with new ideas are ideal candidates for initiating agricultural extension projects, and agricultural practitioners should continue to innovate and reinvent themselves to remain competitive in an ever-changing environment with technological advancement, fluctuating consumer needs, and the necessity for a sustainable society [6].

Agricultural extension is the process of motivating people, organizations, communities, and businesses involved in agricultural resource management to produce cognitive and behavioral changes [7]. Agricultural extension practitioners plan and implement agricultural extension services and act as promoters of creativity and actions related to rural innovation [8]. Consequently, agricultural extension practitioners require strong capabilities in terms of problem identification, social interaction, campaign design, system construction, community building, operation management, and evaluation implementation [9]. Like architectural engineering, for which practitioners must analyze spatial aesthetics and user behavior while applying systems, materials, structure, and cutting-edge technology, agricultural extension is interdisciplinary. The teaching methods and learning strategies for interdisciplinary fields are often complex and have therefore attracted the attention of the global academic community. Among them, Liang and colleagues [10] investigated the neuro activities of students in different majors while they responded to spatial, numeric, and verbal intelligence questions. However, their study did not explore this question in a specific interdisciplinary field. This research gap warrants further inquiry and motivates the planning and implementation of the current study. Determining how experts in agricultural extension solve problems can offer insights to address such complexity. This motivated us to use a novel approach, namely neurocognition tools, to investigate how students of agricultural extension solve problems. This study used intelligence quotient (IQ) test questions to investigate the type of problems they solve. IQ tests commonly use numeric, spatial, and verbal intelligence problems to measure intelligence [11,12]. Most studies have used paper-and-pencil methods to measure IQ, but in the last decade, cognitive scholars have begun to use neuroscience tools to understand the organization and control of human intelligence [13].

Because of the urgency to cultivate agricultural extension talent and develop rural entrepreneurial potential and the challenges in the education of interdisciplinary agricultural extension, this study explored the brain activity exhibited by students of agricultural extension when they responded to various numeric, spatial, and verbal intelligence tasks through electroencephalography (EEG). EEG data were recorded in both problem-identifying and resolution-reaching phases for each participant. A total of 36 participants were recruited, and their level of creativity was determined. The bottom and top third of the participants were categorized as low-creativity (LC) and high-creativity (HC) groups. The objectives were as follows: (1) to determine which brain regions were activated when the participants engaged in numeric, spatial, and verbal IQ tasks; (2) to identify the participants' thought patterns when they engaged in the experimental tasks; and (3) to identify the differences in thought patterns between the HC and LC groups, which is crucial because students in agriculture must be creative [9].

2. Literature Review

2.1. Intelligence Quotient and Related Neuroscientific Studies

Numerical, spatial, and verbal problems each require different cognitive resources and information processes. Thus, IQ tests can effectively predict real-world performance [14]. Neuroscientists have attempted to identify the architecture of human intelligence and have yielded results regarding goal-directed, brain-based biomarkers. However, studies on intelligent behavior have yet to successfully characterize the combined performance of the brain's systems [15,16]. Whether prefrontal networks and distributed cortical regions are operationally necessary for human intelligence remains a central question [17].

2.2. Neuroscientific Studies of Numerical Problem Solving

The development of the frontoparietal network, comprising the intraparietal sulcus and dorsolateral prefrontal cortex of both hemispheres, is essential for the development of numerical intelligence [18]. Numeric processing involves nonabstract representation in the right parietal region and abstract representation in the left parietal region [19]. Liang and associates [10] demonstrated that numeric intelligence tasks activate the frontoparietal network and that engineering students spent less brain resources in the right anterior temporal area than did literature students, indicating that literature students may perceive quantitative information as nonabstract representations (words or images).

Liu and Liang [20] showed the essential role of the anterior cingulate cortex in the problem identification phase and indicated that liberal arts participants concentrated on transferring information from the right temporal area (number recognition) to the left temporal area (calculation ability) less often than engineering participants did and that the liberal arts participants used more resources to transfer information from the left parieto-occipital area (verbal perception) to the right frontal area (emotional thought). Liu and Liang thus inferred that engineering participants straightly focused on calculation, whereas liberal arts participants performed question comprehension in the problem identification phase. During the resolution-reaching phase, the engineering students focused on transferring information from calculation to verbal perception, whereas the liberal arts students focused on transferring information from number recognition to mathematical cognition (the left frontal region), suggesting that the liberal arts participants focused their concentration on logical thinking, whereas the engineering participants quickly shifted their focus to answer selection in this phase.

2.3. Neuroscientific Studies of Spatial Problem Solving

The development of spatial problem-solving ability is closely related to the spatial processing network, comprising the posterior parietal, right superior temporal, and prefrontal cortices [10]. To generate spatial cognition, the hippocampus creates allocentric environmental representations, and the parietal region creates egocentric representations [21]. Scholars have emphasized the crucial role of the prefrontal cortex in the network architecture of cortical processing in visuospatial problem solving [22]. Liang and colleagues [10] supported that engineering students spent less brain resources in the right posterior temporal area than did literature students, indicating that literature students focused on visuospatial recognition during spatial problem solving.

Liu and Liang [20] demonstrated that liberal arts participants used less resources to transfer information from the right frontal region (spatial relation integration) to the left parieto-occipital region (verbal perception) than did engineering participants in the problem identification phase. The engineering participants used less resources to transfer information from the left temporal region (verbal comprehension) to the left frontal region (analogical reasoning) than did liberal arts participants. Therefore, Liu and Liang inferred that liberal arts participants retrieved spatial context memory by understanding the problems, whereas engineering participants solved verbal problems by using spatial relation integration. Liberal arts participants spent more resources to transfer information from the left frontal area (spatial thinking) to the right frontal area (spatial relation integration and emotional thought). In the same phase, engineering participants used more energies for transferring information from the right temporal area (nonverbal communication) to the right parieto-occipital area (visual perception and spatial attention).

Therefore, the engineering students triggered their spatial processing network to recognize spatial configurations and integrate spatial relationships, whereas the liberal arts students shaped spatial relationships using contextual information in the resolution-reaching phase.

2.4. Neuroscientific Studies of Verbal Problem Solving

Verbal problem solving involves the activation of neural circuits distributed across both cerebral hemispheres. The language-processing network is crucial for the development of verbal intelligence [23]. Scholars have indicated that those with strong verbal capabilities have a higher level of intelligence than do others [24]. Liang and colleagues [10] indicated that verbal problem solving activates the language-processing network and that literature students spent less cognitive resources in the left lateral frontal area than did engineering students, indicating that engineering students focus on analogical reasoning and concept formation during verbal reasoning. By contrast, literature students use more resources in the right-biased posterior frontal region than do engineering students, indicating that literature students focus on mnemonic conflict detection during verbal reasoning.

Liu and Liang [20] noted that the anterior cingulate cortex acts as a hub for transferring information and that liberal arts participants used less resources to perform processes circulating between message comprehension and verbal recognition than did engineering participants in the problem identification phase, whereas liberal arts participants used more brain resources in recognizing verbal forms. Liu and Liang thus suggested that the verbal problem-solving capability of engineering students can be improved through verbal message comprehension and text feature identification practice and that liberal arts students can improve this capability through the frequent stimulation of related word families.

3. Methods

3.1. Participants and Experimental Materials

This study recruited 42 Taiwanese students majoring in agricultural extension who had received distinctions of academic excellence to participate in the EEG experiment. The participants had corrected to normal vision and no history of vestibular or cardiovascular disorder or alcohol or drug abuse. Because of signal malfunction or failure to complete experiment, only the EEG data of 36 participants (19 women and 17 men aged 20–27 years) were collected for analysis. Prior to the experiment, the participants completed the creative personality scale (CPS) developed by Gough (1979); higher scores in CPS are interpreted to possess higher creativity. The bottom and top thirds of the participants were designated as the low-creativity (LC) and high-creativity (HC) groups. The brainwaves of the groups were compared to identify differences in their thought patterns.

This study used the IQ test (four items each for numeric, spatial, and verbal intelligence) developed by Liang and colleagues [10], which is slightly revised from the Taiwanese version of the Stanford–Binet Intelligence Scale. The numerical intelligence items comprised figures and thinking, estimations and global judgments, and simple arithmetic (e.g., percentages, powers, and fractions). The spatial intelligence section comprised items related to spatial navigation, visualizing objects from different angles, mental generation of images, and image rotation. The verbal intelligence items focused on analogical relationships, word-building tests, synonyms and antonyms, and practical knowledge of social rules.

3.2. Data Collection

The participants' brain activity was documented using wireless EEG equipment that has a sampling rate of 250 Hz. This inflatable headset is equipped with sensors, making direct contact with the scalp to precisely detect brain activity. On the basis of the international 10–20 system, the scalp markers were placed aligning with cerebral structures [25]. Data collected from the experiment were exported in ASCII (.txt) format, which can be wirelessly transmitted to portable devices through the headset.

The experiment began after the EEG signals from the participants wearing the headsets were consistently obtained. The participants were instructed to watch a presentation on a television screen and minimize their movement. Their brain activity during rest periods was recorded for 30 s to create a baseline for potential correction. During the experiment, the participants were not allowed to ask questions and required to decide which number belonged in the space with the question mark. Their answers to the questions on the IQ test were not recorded because the objective of this study was to investigate brain activity and thought patterns rather than test scores.

The participants could view the questions without a time limit, but a short break was arranged between items as intertrial intervals to prevent overlying brain signers from being recorded. The EEG data for the problem-solving processes were acquired separately for each item. This process was made undetectable for the participants to ensure experimental consistency. On average, each experiment was completed within 30 min, and each participant spent roughly 16 s on each verbal question (*M* = 14.64 s, *SD* = 4.18 s), 30 s on each numerical question (mean [*M*] = 29.40 s, standard deviation [*SD*] = 6.78 s), and 24 s on each spatial question (*M* = 25.36 s, *SD* = 6.12 s).

3.3. Data Analysis

The data were thoroughly analyzed, and noise signals, such as systematic noise, electrical artifacts, muscle movement interference, line noise, and oculomotor activity, were ignored. Irregular signals were revealed using kurtosis in EEGlab by employing five SDs as the threshold and eliminating them manually. The removed channels were replaced with averages from the data. After the noise signals were removed, cleaned EEG signals were divided into two phases, Second 2 to Second 5 (problem identification phase) and the final second (resolution-reaching phase) [20], to identify the participants' activated regions and thought patterns. All numeric, spatial, and verbal data were averaged and decomposed through an independent component (IC) analysis by using EEGlab, through which all components were assembled into clusters on the basis of similarity.

Correlation coefficients between ICs were analyzed to determine the association between two specific brain regions. We used the fast Fourier transform (FFT) function to transform the EEG time-domain data into frequency-domain data. The spectral power of the ICs was computed using FFT. The analysis of thought pattern was performed in accordance with the procedure suggested by Liu and Liang [20]. In accordance with the 10–20 system, estimated dipoles from six brain areas were alienated: the left (pre)frontal (K1), right (pre)frontal (K2), left temporoparietal (K3), right temporoparietal (K4), left parieto-occipital (K5), and right parieto-occipital (K6) regions (Figure 1). ICs corresponding to the partitioned dipoles were averaged for these six regions. In other words, the averaged ICs were used to signify the brain activation for each brain region.

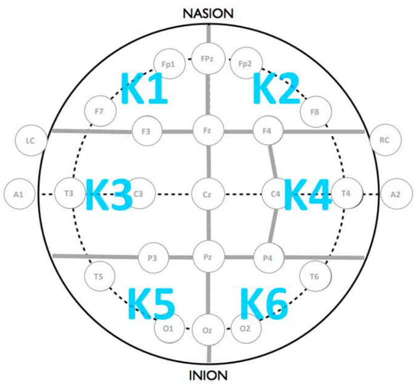


Figure 1. Dipole partitioning.

The multivariate Granger causality toolbox was adopted to implement a multivariate vector autoregressive (MVAR) model to investigate brain activity networks in a time domain [26]. The MVAR model and *p*th-order MVAR are expressed as the equation $\mathbf{x}_t = \sum_{k=1}^{p} \boldsymbol{A}_k \cdot \mathbf{x}_{t-k} + \boldsymbol{\varepsilon}_t$ [20]. A MVAR model is the widely used operational model of Granger causality [27,28]. The Bayesian information criterion was used for order selection. To validate the stationarity, whiteness, and consistency of the fitted models, we also used the ordinary least squares algorithm for parameter estimation [26].

4. Analysis Results and Discussion

4.1. Cerebral Activation during Numerical Problem Solving

Cerebral activation was divided into four components: the left temporoparietal, right-biased frontoparietal, left (pre)frontal, and right (pre)frontal clusters (Figure 2a,d). The scalp map for the root cluster indicated that the left temporoparietal, left (pre)frontal, and right (pre)frontal regions exhibited low brain activation and that the right-biased frontoparietal region exhibited high activation during the numeric task (Figure 2).

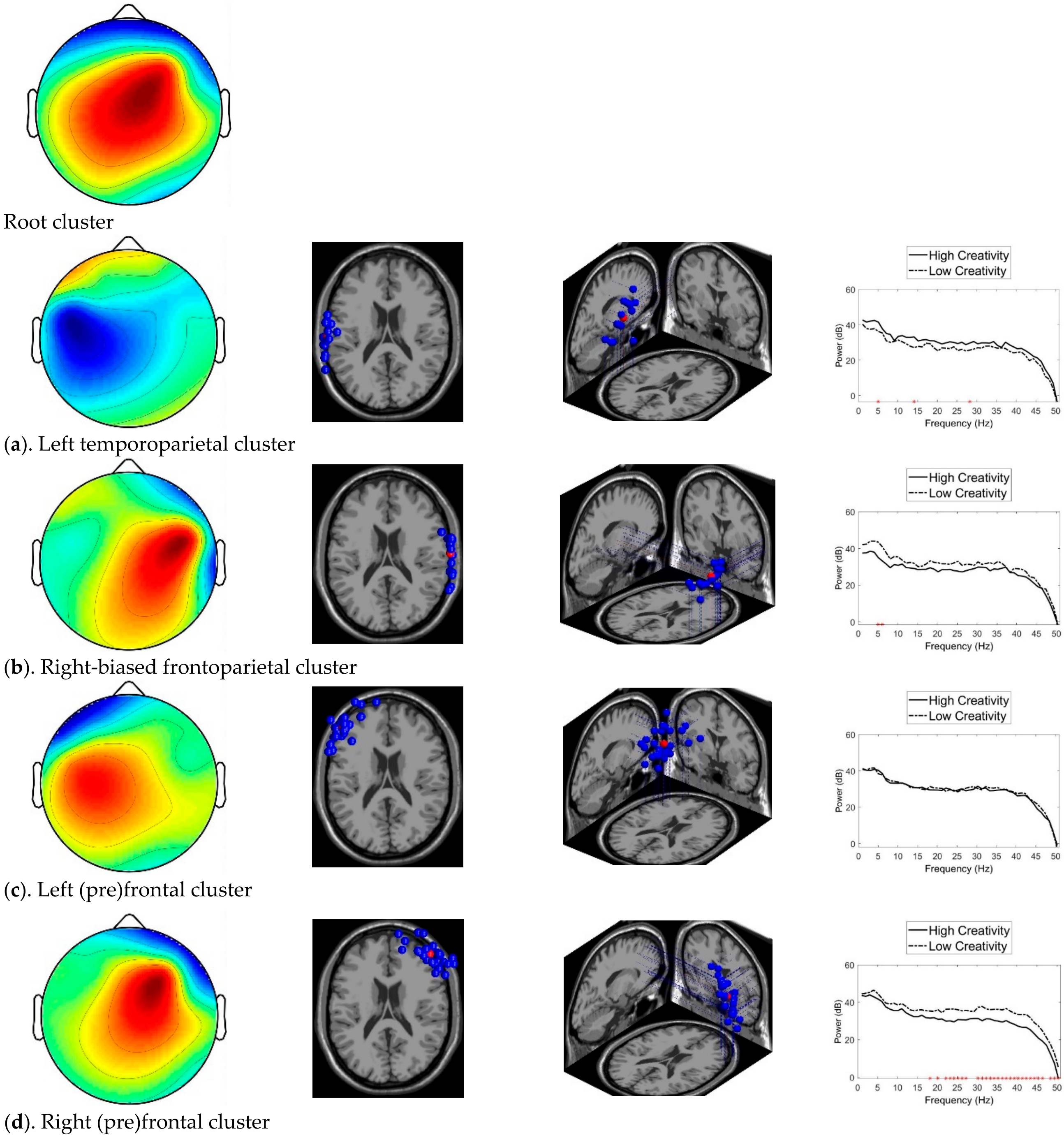


Figure 2. Scalp maps, 3D dipole plots, and Wilcoxon signed-rank test of spectral power for the numeric problem-solving tasks.

Power differences (HC > LC) appeared in the three distributed theta and beta bands in the left temporoparietal cluster (Figure 2a). Only two significant power differences (LC > HC) appeared in both theta bands at 5 and 6 Hz in the right-biased frontoparietal cluster (Figure 2b). No power difference appeared in the left (pre)frontal cluster (Figure 2c). The differences in spectral power (LC > HC) in most beta and gamma bands were also observed in the right (pre)frontal cluster (Figure 2d).

The EEG results indicated that the frontoparietal network was activated during the numeric problem-solving task (the root cluster), which is consistent with the results of other studies [10,18]. The frontoparietal network is associated with the default mode network, which is linked to internally directed cognition [29], indicating that performing numeric problem-solving tasks is related to a high level of self-generated thought for students of agricultural extension.

The left temporoparietal region is involved in assessing creativity; its deactivation may indicate that creativity is facilitated rather than inhibited [30]. In this study, the low brain activation in the left temporoparietal region indicated the differences between two groups (HC > LC). According to Benedek et al. [31], the right-biased frontoparietal region is involved in self-generated thought, and divergent thinking prompts activation of this region. Low brain activation in the frontoparietal region explains the differences (LC > HC) in this region. The right (pre)frontal region is crucial to the divergent semantic processing involved in creativity [32], and low brain activation in this area explains the differences (LC > HC) in Figure 2d.

According to the results, to promote the numeric problem-solving capabilities of students of agricultural extension, particularly for those who have the potential to assume managerial responsibilities, educational strategies, such as linking numeric reasoning to household chores, encouraging students to generate meaningful daily experiences with numeric tasks, and creating vivid mental images through learning by doing [33,34], may need to be implemented and improved.

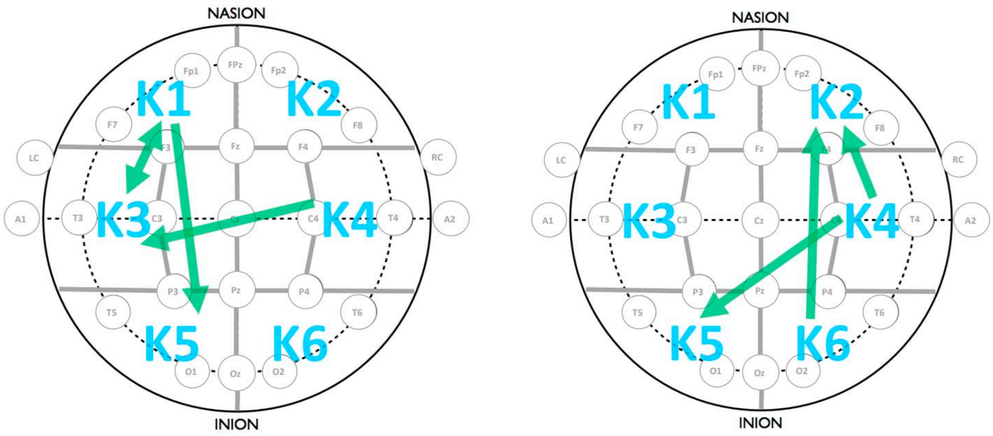
4.2. Thought Patterns during Numerical Problem Solving

The participants' thought patterns were analyzed on the basis of the estimated dipoles separated from the six main brain areas. Table 1 summarizes these brain areas and their associated functions.

Table 1. Six major brain areas, their associated functions, and information sources.

Brain Regions	Associated Functions	References
K1: Left (pre)frontal region	Analogical reasoning, concept formation, concept shifting, mathematical cognition, spatial thinking, visual associations	[20,35–38]
K2: Right (pre)frontal region	Divergent semantic processing, emotion regulation, spatial relation integration	[32,39–41]
K3: Left temporoparietal region	Decoding word/number, encoding word/number, enhancing mood stability, retrieving semantic-based words, verbal processing	[42–48]
K4: Right temporoparietal region	Nonverbal communication, nonverbal memory, spatial attention, word/number recognition	[20,44,49,50]
K5: Left parieto-occipital region	verbal perception	[51]
K6: Right parieto-occipital region	Conceptual decisions on numbers rather than object names, spatial attention, visual perception	[49,52,53]

The results for the problem identification phase of the numerical problem-solving tasks revealed three major thought patterns in the HC group: links with unidirectional information transfer from K1 to K5 and K4 to K3 and the link with bidirectional information transfer between K1 and K3 (Figure 3a). The three major thought patterns in the LC group were the links with unidirectional information transfer from K4 to K2, K4 to K5, and K6 to K2 (Figure 3b).

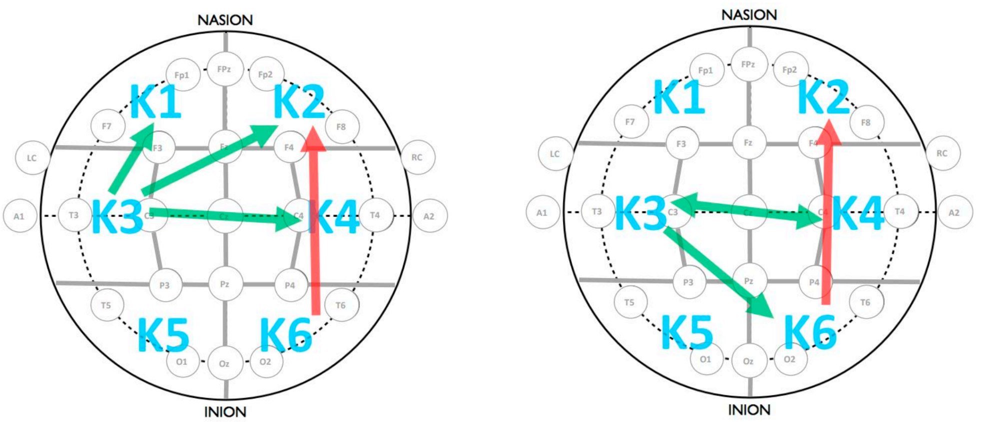


(**a**) (**b**)

Figure 3. Brain connectivity in the problem identification phase of numerical problem-solving tasks. (**a**). Graphical view of high-creativity (HC) group. (**b**). Graphical view of low-creativity (LC) group.

In the problem identification phase, the HC group focused on the transitions from number recognition to number comprehension and from mathematical cognition to verbal perception and the interaction between number comprehension and mathematical cognition (Figure 3a). By contrast, the LC group focused on the transitions from number recognition to divergent semantic processing and verbal perception and from visual perception to divergent semantic processing (Figure 3b). These results indicate that during this phase, the HC group quickly comprehended the questions and directly focused on calculation, whereas the LC group devoted the most effort to question comprehension. Familiarity with and intuitive heuristics toward numerical tasks are crucial for managerial candidates among students of agricultural extension.

In the resolution-reaching phase of the numerical problem-solving tasks, the HC group exhibited four thought patterns: the links with unidirectional information transfer from K3 to K1, K3 to K2, K3 to K4, and K6 to K2 (Figure 4a). The LC group exhibited three thought patterns: the links with unidirectional information transfer from K3 to K6 and K6 to K2 and the link with bidirectional information transfer between K3 and K4 (Figure 4b). Among these flows, the mean *f* value of the link between K6 and K2 was significantly higher in the HC group than in the LC group.



(**a**) (**b**)

Figure 4. Brain connectivity in the resolution-reaching phase of numerical problem-solving tasks. Note: Red arrow: HC > LC; green arrow: general paths. (**a**). Graphical view of HC group. (**b**). Graphical view of LC group.

In the resolution-reaching phase, the HC group was active in the transitions from number comprehension to mathematical cognition, divergent semantic processing, and number recognition and from visual perception to divergent semantic processing (Figure 4a). The LC group focused on the transitions from number recognition to number comprehension, from number comprehension to visual perception, and from visual perception to divergent semantic processing (Figure 4b). These results indicate that during the resolution-reaching phase of the numerical problem-solving tasks, the HC group focused on calculation, answer selection, and semantic processes, whereas the LC group focused less on calculation and instead focused on logical thinking between message perception and comprehension.

This difference in thought pattern from visual perception to divergent semantic processing was statistically significant (HC > LC). This indicates that the HC group made decisions regarding numbers [52] under more emotional control than did the LC group [38]. Therefore, practice and familiarity with numerical tasks and financial management project simulations [54] are imperative if agricultural extension education requires creative management capabilities.

4.3. Cerebral Activation during Spatial Problem Solving

Cerebral activation during spatial problem solving was divided into three main components: the right (pre)frontal, left temporoparietal, and left (pre)frontal clusters (Figure 5a–c). The scalp map for the root cluster indicated that the participants exhibited high brain activation in these three regions when engaging in the spatial problem-solving tasks (Figure 5). No power difference appeared in the right (pre)frontal cluster (Figure 5a). Significant power differences (LC > HC) appeared in several distributed gamma and beta bands in the left temporoparietal cluster (Figure 5b). The differences in spectral power (HC > LC) were also observed in some theta and alpha bands in the left (pre)frontal cluster (Figure 5c).

Our results indicated that the frontal areas were activated during the spatial problem-solving tasks (the root cluster), which is consistent with the results of Shokri-Kojori et al. [22]. In addition, the low brain activation in the parietal area may have accelerated the interaction between frontal and occipital cortices for visuospatial reasoning. A high level of frontal–occipital neuronal interaction has been observed in visual search [55], indicating that the performance of spatial problem solving is associated with intensive visual search tasks for students of agricultural extension.

Although the right (pre)frontal region is critical for divergent semantic processing related to creativity [32], the high levels of brain activation in this area did not reflect the differences between the two groups. The left temporoparietal region is associated with creativity evaluation. The fact that its activation may impede creativity [30] may explain the differences (LC > HC) in this region. Aichelburg et al. [35] indicated that the left (pre)frontal area handles analogical reasoning, which is crucial for making inferences and processing novelty. This may explain the differences (HC > LC) in this region.

According to the results, educational strategies, such as those teaching students to simulate object formation and rotation, visualize objects from a range of perspectives, and imagine objects at various scales [56,57], must be improved to strengthen the spatial problem-solving capabilities of students of agricultural extension, particularly for those who have the potential to oversee rural planning and development.

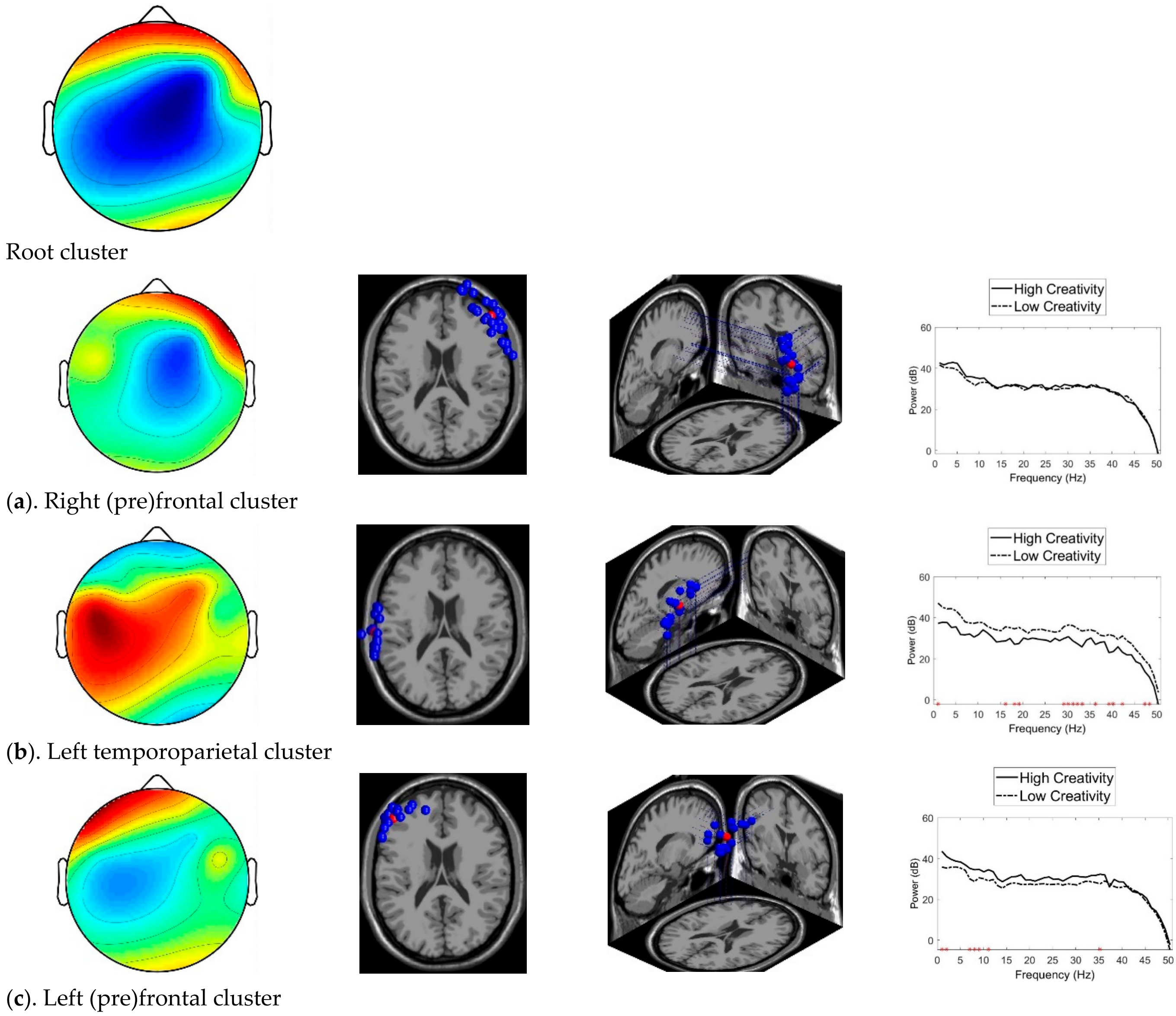
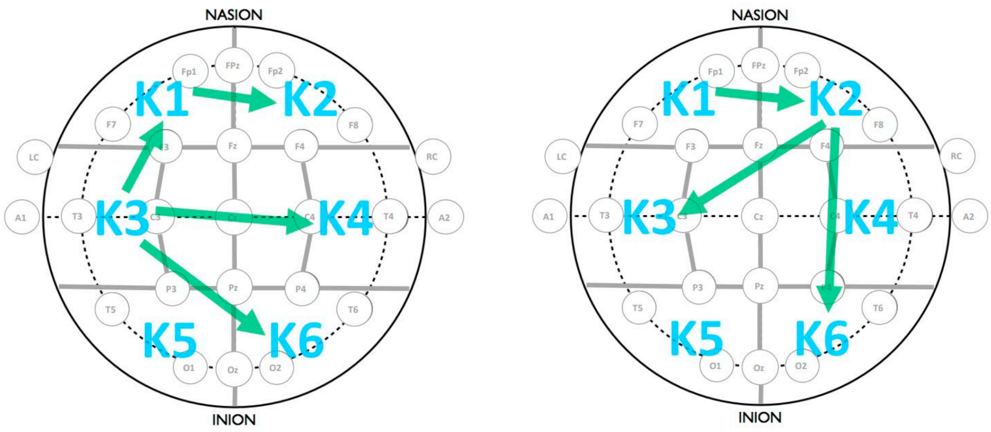


Figure 5. Scalp maps, 3D dipole plots, and Wilcoxon signed-rank test of spectral power for the spatial problem-solving tasks.

4.4. Thought Patterns during Spatial Problem Solving

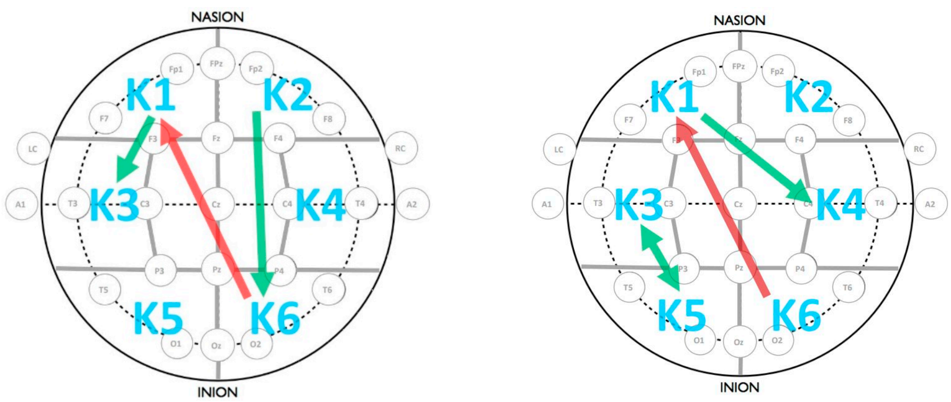
The results for the problem identification phase of the spatial problem-solving tasks indicated four thought patterns in the HC group: the links with unidirectional information transfer from K1 to K2, K3 to K1, K3 to K4, and K3 to K6 (Figure 6a). The LC group exhibited three thought patterns: the links with unidirectional information transfer from K1 to K2, K2 to K3, and K2 to K6 (Figure 6b).



(**a**) (**b**)

Figure 6. Brain connectivity in the problem identification phase of spatial problem-solving tasks. (**a**). Graphical view of HC group. (**b**). Graphical view of LC group.

In the resolution-reaching phase, the HC group focused on the transitions from spatial thinking to mood stability, from spatial relation integration to spatial attention, and from spatial attention to spatial thinking (Figure 7a). The LC group focused on the transitions from spatial thinking to spatial attention and from spatial attention to spatial thinking and the interaction between mood stability and verbal perception (Figure 7b). These results indicate that the HC group focused on spatial attention, spatial thinking, and relation integration, whereas the LC group focused on spatial attention and answer selection during this phase.



(**a**) (**b**)

Figure 7. Brain connectivity in the resolution-reaching phase of the spatial problem-solving tasks. Note: Red arrow: HC > LC; green arrow: general paths. (**a**). Graphical view of HC group. (**b**). Graphical view of LC group.

The difference in thought patterns from spatial attention to spatial thinking was statistically significant between the two groups (HC > LC). This indicates that the HC group's spatial thinking was focused more on analogical reasoning and visual associations [35,37] than that of the LC group. Therefore, agricultural extension educators should incorporate spatially oriented games (e.g., blocks and puzzles) or virtual and augmented reality technology related to spatial intelligence [58,59] as instructional materials. Project-based spatial tasks [60] are crucial for the development of talent, particularly for those who focus on rural planning and development.

4.5. Cerebral Activation during Verbal Problem Solving

Cerebral activation was divided into the left temporal and right prefrontal clusters (Figure 8a–b). The scalp map for the root cluster indicates that the participants showed low reaction in the right prefrontal area and high reaction in the left temporal area when involved in the verbal problem-solving tasks (Figure 8). Significant power differences (HC > LC) in four theta bands were observed in the left temporal cluster (Figure 8a). Significant power differences (LC > HC) appeared in several distributed gamma and beta bands in the right prefrontal cluster (Figure 8b).

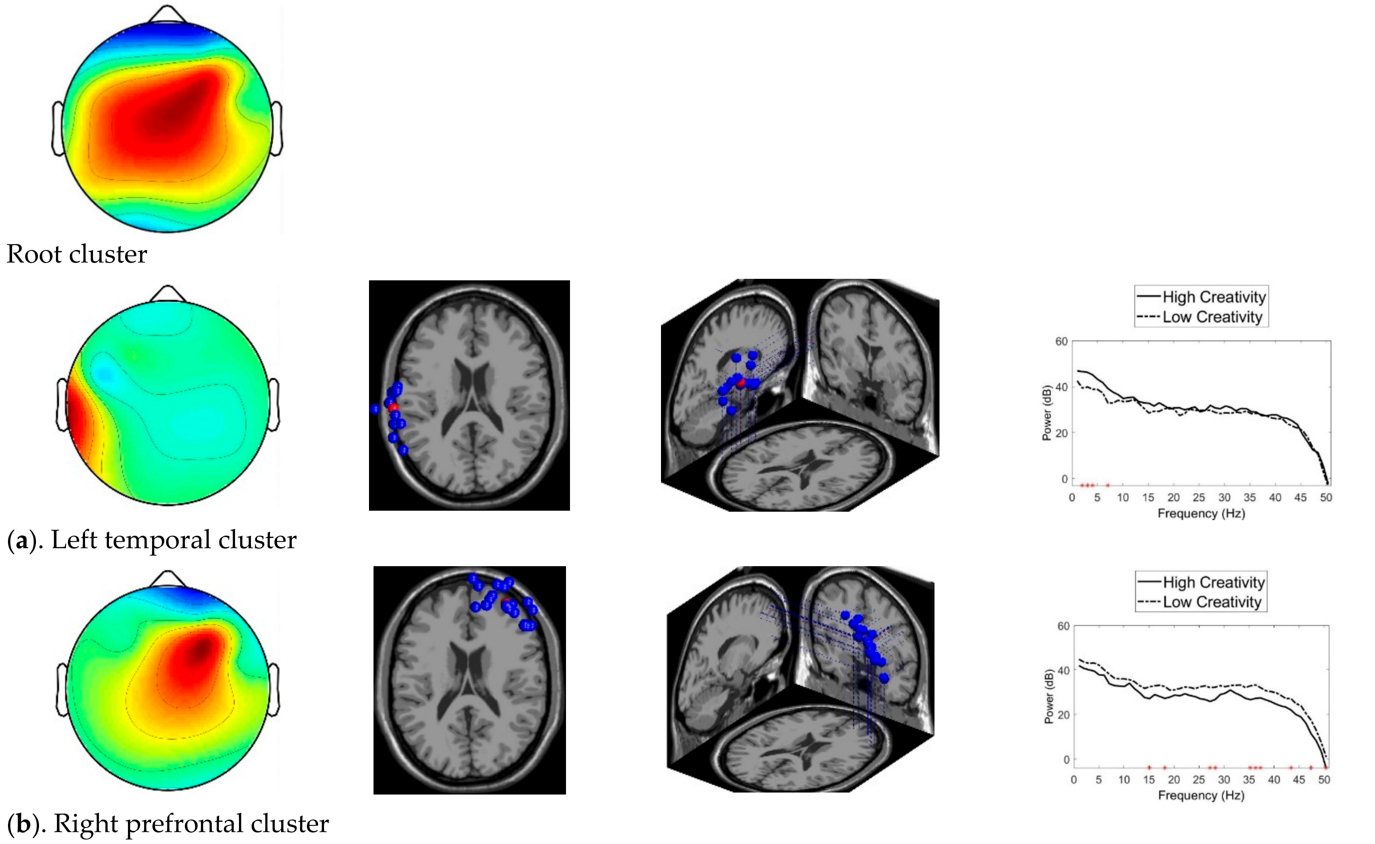


Figure 8. Scalp maps, 3D dipole plots, and Wilcoxon signed-rank test of spectral power for the verbal problem-solving tasks.

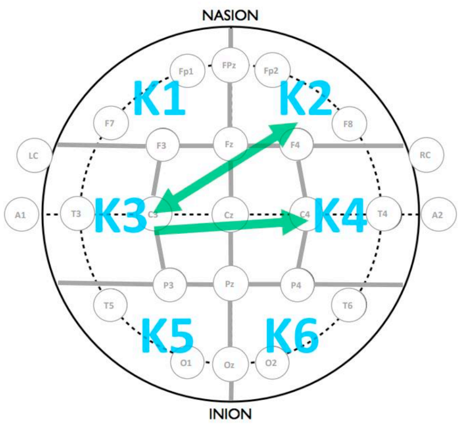
The EEG data indicated activation of the frontoparietal area and deactivation of the prefrontal areas during the verbal task (the root cluster), which is consistent with the results of other studies [23,61]. The left temporal cortex controls verbal memory, and the left temporal cortex mediates semantic-based word retrieval [47]. The right prefrontal region is related to emotional response regulation, and low brain activation in this area indicates a strong response to stressful events [62]. High brain activation in the right-biased frontoparietal area could stimulate internally directed cognition [29]. This may indicate that the participants experienced stress during the tasks and that the verbal problem-solving task was associated with verbal memory, semantic-based word processing, and self-generated thought.

Scholars have demonstrated the contribution of the left temporal pole to creative thinking [63], which explains the differences (HC > LC) in this region. The right prefrontal region can enhance creative association [64], and the low activation in this area explains the differences (LC > HC) in this study.

According to the results, to enhance the verbal problem-solving capabilities of students of agricultural extension, educational strategies, such as the free association among various concepts, extracted keywords and core ideas from long sentences, exercising concept formations, and recalling related word families [65,66], must be offered and improved.

4.6. Thought Patterns during Verbal Problem Solving

The results for the problem identification phase of the verbal problem-solving tasks indicated three thought patterns in the HC group: the links with unidirectional information transfer from K3 to K4 and the links with bidirectional information transfer between K3 and K2 (Figure 9a). The LC group exhibited four thought patterns: the links with unidirectional information transfer from K4 to K2 and K3 to K5 and the link with bidirectional information transfer between K2 and K3 (Figure 9b).



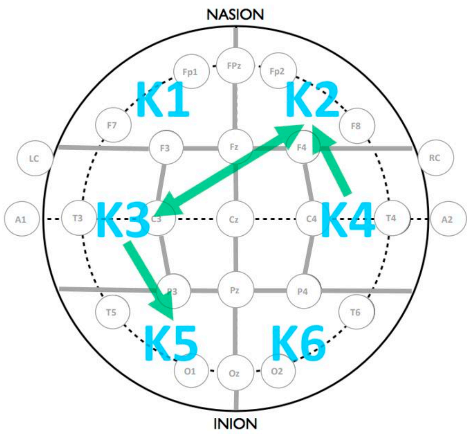


Figure 9. Brain connectivity in problem identification phase of verbal problem-solving tasks. (**a**). Graphical view of HC group. (**b**). Graphical view of LC group.

In the problem identification phase of the verbal problem-solving tasks, the HC group focused on the transition from verbal processing to nonverbal processing and the interaction between verbal processing and divergent semantic processing (Figure 9a). The LC group focused on the interaction between verbal processing and divergent semantic processing and the transfer of information from verbal processing to verbal perception and from nonverbal processing to divergent semantic processing (Figure 9b). These results revealed that during this phase, the HC group focused on comprehending questions, whereas the LC group focused on word recognition and semantic processing of the question. Verbal intelligence is closely associated with various types of communication and is the basis for the practice of agricultural extension. Therefore, agricultural extension educators should incorporate crossword puzzles as teaching materials because semantic processing is associated with the meanings of and relationships between words and nonverbal concepts. Course content should also be linked to students' self-referential memory, particularly episodic memory [67].

The EEG data from the resolution-reaching phase of the verbal problem-solving tasks revealed three thought patterns in the HC group: the links with unidirectional information transfer from K3 to K2, K5 to K2, and K6 to K2 (Figure 10a). The LC group exhibited four patterns: the links with unidirectional information transfer from K2 to K1, K4 to K2, K4 to K6, and K6 to K2 (Figure 10b). No significant differences in thought pattern were observed between the HC and LC groups.

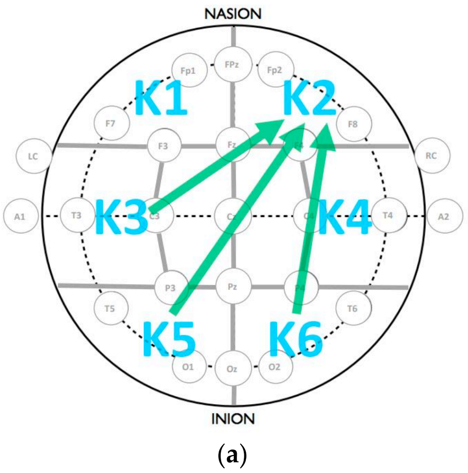


Figure 10. Brain connectivity in resolution-reaching phase of the spatial problem-solving tasks. (**a**). Graphical view of HC group. (**b**). Graphical view of LC group.

In the resolution-reaching phase, the HC group used most cognitive resources for the transfer of information from verbal perception, nonverbal perception, and verbal processing to divergent semantic processing (Figure 10a). The LC group focused on the transitions from nonverbal processing to nonverbal perception and divergent semantic processing, from nonverbal perception to divergent semantic processing, and from divergent semantic processing to concept formation (Figure 10b). These results indicate that during this phase, the HC group focused on transferring thoughts to divergent semantic processing, whereas the LC group focused on visual perception, word recognition, and semantic processing. Therefore, agricultural extension educators should encourage students to practice linking unrelated materials to generate a coherent narrative [32] or rethink assignments.

5. Contributions and Research Limitations

Because of the rural entrepreneurial potential, this study explored the brain activation and thought patterns exhibited by students of agricultural extension when they responded to verbal, numeric, and spatial problem-solving tasks. The following eight results were yielded: (1) the performance of numeric problem solving activates the frontoparietal network and is associated with self-generated thought for agricultural extension students; (2) the HC group enabled the cerebral functions of inhibiting creativity evaluation and engaging in divergent semantic processing in the numeric task; (3) although the two groups differed in thought pattern, only the transition from visual perception to divergent semantic processing in the resolution-reaching phase of the numeric task was significantly different between the groups (HC > LC); (4) spatial problem solving activated the frontal regions and was associated with intensive visual search tasks; (5) the HC group promoted the cerebral functions of inhibiting creativity evaluations and analogical reasoning in the spatial task; (6) only the transition from spatial attention to spatial thinking in the resolution-reaching phase of the spatial task was significantly different between the groups (HC > LC); (7) verbal problem solving activated the frontoparietal regions and was associated with verbal memory, semantic-based word processing, and self-generated thought; (8) the HC group enhanced the cerebral functions of creative associations in the verbal task, and no significant differences between the two groups in the problem identification and resolution-reaching phases were observed.

The use of neuroscientific tools and the experimental design presented several limitations. Most EEG studies have examined simple cognitive processes. Complex problem-solving processes and dynamic interactions among brain regions prevent coherent conclusions. In addition, the low number of participants limited the generalizability of the findings. Furthermore, the questions used in this study may have affected the results; this could be improved by adding supplementary items.

Intelligence is an integrative reasoning process that allows individuals to process information and solve problems effectively. This study contributes to agricultural extension education by identifying the brain networks and information flows involved in numeric, spatial, and verbal problem solving and by suggesting educational strategies to cultivate essential competencies in critical areas of agricultural extension, such as general communication, project management, and rural planning and development. This study adopted innovative approaches to address a complex topic that has not been thoroughly investigated but is essential for the development of agricultural sustainability. This development would highly depend on agricultural extension talents to integrate both benefits of agronomic and ecological management.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was approved by by the Research Ethics Office of National Taiwan University (NTU-REC 202105HM060).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data available upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kilelu, C.W.; van der Lee, J.; Koge, J.; Klerkx, L. Emerging advisory service agri-enterprises: A dual perspective on technical and business performance. *J. Agric. Educ. Ext.* **2021**, *28*, 45–65. [CrossRef]
2. Runhaar, H.; Runhaar, P.; Bouwmans, M.; Vink, S.; Buijs, A.; Kleijn, D. The power of argument: Enhancing citizen's valuation of and attitude towards agricultural biodiversity. *Int. J. Agric. Sustain.* **2019**, *17*, 231–242. [CrossRef]
3. Adamsone-Fiskovica, A.; Grivins, M. Knowledge production and communication in on-farm demonstrations: Putting farmer participatory research and extension into practice. *J. Agric. Educ. Ext.* **2021**, *28*, 479–502. [CrossRef]
4. Stuiver, M.; Leeuwis, C.; van der Ploeg, T.D. The power of experience: Farmers' knowledge and sustainable innovations in agriculture. In *Seeds of Transition*; Wiskerke, J.S.C., van der Ploeg, J.D., Eds.; Van Gorcum: Assen, The Netherlands, 2004; pp. 98–113.
5. Zaremohzzabieh, Z.; Krauss, S.E.; D'Silva, J.L.; Tiraieyari, N.; Ismail, I.A.; Dahalan, D. Towards agriculture as career: Predicting students' participation in the agricultural sector using an extended model of the theory of planned behavior. *J. Agric. Educ. Ext.* **2021**, *28*, 67–92. [CrossRef]
6. Hsu, Y.; Peng, L.-P.; Wang, J.-H.; Liang, C. Revising the imaginative capability and creative capability scales: Testing the relationship between imagination and creativity among agriculture students. *Int. J. Learn. Teach. Educ. Res.* **2014**, *6*, 57–70.
7. State Extension Leaders Network. Enabling Change in Rural and Regional Australia: The Role of Extension in Achieving Sustainable and Productive Futures. 2006. Available online: http://www.seln.org.au (accessed on 15 December 2014).
8. Leeuwis, C. *Communication for Rural Innovation: Rethinking Agricultural Extension*, 3rd ed.; Wiley-Blackwell: Hoboken, NJ, USA, 2004.
9. Liang, C.; Chang, W.-S.; Yao, S.-N.; King, J.-T.; Chen, S.-A. Stimulating the imaginative capacities of agricultural extension students. *J. Agric. Educ. Ext.* **2016**, *22*, 327–344. [CrossRef]
10. Liang, C.; Liu, Y.-C.; Chang, Y.; Liang, C.-T. Differences in numeric, verbal, and spatial reasoning between engineering and literature students through a neurocognitive lens. *Cogn. Syst. Res.* **2020**, *60*, 33–43. [CrossRef]
11. Carter, P.J.; Russell, K.A. *Test and Assess Your IQ: Numeric, Verbal, and Spatial Aptitude Tests*; Kogan Page: London, UK, 2008.
12. Jaarsveld, S.; Lachmann, T. Intelligence and creativity in problem solving: The importance of test features in cognition research. *Front. Psychol.* **2017**, *8*, 134. [CrossRef]
13. Miller, E.K.; Phelps, E.A. Current opinion in neurobiology: Cognitive neuroscience. *Curr. Opin. Neurobiol.* **2010**, *20*, 141–142. [CrossRef]
14. Richardson, K.; Norgate, S. Does IQ really predict job performance? *Appl. Dev. Sci.* **2015**, *19*, 153–169. [CrossRef]
15. Gläscher, J.; Rudrauf, D.; Colom, R.; Paul, L.K.; Tranel, D.; Damasio, H.; Adolphs, R. Distributed neural system for general intelligence revealed by lesion mapping. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 4705–4709. [CrossRef]
16. Paul, E.J.; Larsen, R.J.; Nikolaidis, A.; Ward, N.; Hillman, C.H.; Cohen, N.J.; Kramer, A.F.; Barbey, A.K. Dissociable brain biomarkers of fluid intelligence. *NeuroImage* **2016**, *137*, 201–211. [CrossRef]
17. Deary, I.J.; Penke, L.; Johnson, W. The neuroscience of human intelligence differences. *Nat. Rev. Neurosci.* **2010**, *11*, 201–211. [CrossRef]
18. Cohen Kadoshsend, R.; Soskic, S.; Iuculano, T.; Kanai, R.; Walsh, V. Modulating neuronal activity produces specific and long-lasting changes in numeric competence. *Curr. Biol.* **2010**, *20*, 2016–2020. [CrossRef] [PubMed]

19. Kadosh, R.C.; Kadosh, K.C.; Kaas, A.; Henik, A.; Goebel, R. Notation-dependent and -independent representations of numbers in the parietal lobes. *Neuron* **2007**, *53*, 307–314. [CrossRef] [PubMed]
20. Liu, Y.-C.; Liang, C. Neurocognitive evidence for different problem-solving processes between engineering and liberal arts students. *Int. J. Educ. Psychol.* **2020**, *9*, 104–131. [CrossRef]
21. Burgess, N. Spatial cognition and the brain. *Ann. N. Y. Acad. Sci.* **2008**, *1124*, 77–97. [CrossRef]
22. Shokri-Kojori, E.; Motes, M.A.; Rypma, B.; Krawczyk, D.C. The network architecture of cortical processing in visuospatial reasoning. *Sci. Rep.* **2012**, *2*, 411. [CrossRef] [PubMed]
23. Nishimura, K.; Aoki, T.; Inagawa, M.; Tobinaga, Y.; Iwaki, S. Brain activities of visual thinkers and verbal thinkers: A MEG study. *Neurosci. Lett.* **2015**, *594*, 155–160. [CrossRef] [PubMed]
24. Smedler, A.-C.; Törestad, B. Verbal intelligence: A key to basic skills? *Educ. Stud.* **2006**, *22*, 343–356. [CrossRef]
25. Liu, Y.-C.; Chang, C.-C.; Yang, Y.-H.; Liang, C. Spontaneous analogising caused by text stimuli in design thinking: Differences between higher- and lower-creativity groups. *Cogn. Neurodyn.* **2018**, *12*, 55–71. [CrossRef]
26. Barnett, L.; Seth, A.K. The MVGC multivariate Granger causality toolbox: A new approach to Granger-causal inference. *J. Neurosci. Methods* **2014**, *223*, 50–68. [CrossRef]
27. Friston, K.J.; Bastos, A.M.; Oswal, A.; van Wijk, B.; Richter, C.; Litvak, V. Granger causality revisited. *NeuroImage* **2014**, *101*, 796–808. [CrossRef]
28. Granger, C.W.J. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* **1969**, *37*, 424–438. [CrossRef]
29. Liang, C.; Lin, C.-T.; Yao, S.-N.; Chang, W.-S.; Liu, Y.-C.; Chen, S.-A. Visual attention and association: An electroencephalography study in expert designers. *Des. Stud.* **2017**, *48*, 76–95. [CrossRef]
30. Mayseless, N.; Aharon-Peretz, J.; Shamay-Tsoory, S. Unleashing creativity: The role of left temporoparietal regions in evaluating and inhibiting the generation of creative ideas. *Neuropsychologia* **2014**, *64*, 157–168. [CrossRef] [PubMed]
31. Benedek, M.; Jauk, E.; Fink, A.; Koschutnig, K.; Reishofer, G.; Ebner, F.; Neubauer, A.C. To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage* **2014**, *88*, 125–133. [CrossRef] [PubMed]
32. Howard-Jones, P.A.; Blakemore, S.J.; Samuel, E.; Summers, I.R.; Claxton, G. Semantic divergence and creative story generation: An fMRI investigation. *Cogn. Brain Res.* **2005**, *25*, 240–250. [CrossRef] [PubMed]
33. Abramovich, S.; Grinshpan, A.Z.; Milligan, D.L. Teaching mathematics through concept motivation and action learning. *Educ. Res. Int.* **2019**, *2019*, 3745406. [CrossRef]
34. Yuanita, P.; Zulnaidi, H.; Zakaria, E. The effectiveness of Realistic Mathematics Education approach: The role of mathematical representation as mediator between mathematical belief and problem solving. *PLoS ONE* **2018**, *13*, e0204847. [CrossRef] [PubMed]
35. Aichelburg, C.; Urbanski, M.; de Schotten, M.T.; Humbert, F.; Levy, R.; Volle, E. Morphometry of left frontal and temporal poles predicts analogical reasoning abilities. *Cereb. Cortex* **2016**, *26*, 915–932. [CrossRef] [PubMed]
36. Thompson-Schill, S.L.; Ramscar, M.; Chrysikou, G.E. Cognition without control: When a little frontal lobe goes a long way. *Curr. Dir. Psychol. Sci.* **2009**, *18*, 259–263. [CrossRef]
37. Yao, S.-N.; Lin, C.-T.; King, J.-T.; Liu, Y.-C.; Liang, C. Learning in the visual association of novice and expert designers. *Cogn. Syst. Res.* **2017**, *43*, 76–88. [CrossRef]
38. Dennis, T.A.; Solomon, B. Frontal EEG and emotion regulation: Electrocortical activity in response to emotional film clips is associated with reduced mood Induction and attention interference effects. *Biol. Psychol.* **2010**, *85*, 456–464. [CrossRef] [PubMed]
39. Gallup, G.G.J.; Platek, S.M. Cognitive empathy presupposes self-awareness: Evidence from phylogeny, ontogeny, neuropsychology and mental illness. *Behav. Brain Sci.* **2002**, *25*, 36–37. [CrossRef]
40. Giannouli, V. Creativity and giftedness: A study of attitudes. In *Exploring the Benefits of Creativity in Education, Media, and the Arts*; Silton, N.R., Ed.; IGI Global: New York, NY, USA, 2016; p. 184.
41. Han, J.; Cao, B.; Cao, Y.; Gao, H.; Li, F. The role of right frontal brain regions in integration of spatial relation. *Neuropsychologia* **2016**, *86*, 29–37. [CrossRef]
42. Amen, D.G. *Healing the Hardware of the Soul: How Making the Brain-Soul Connection Can Optimize Your Life, Love, and Spiritual Growth*; Free Press: New York, NY, USA, 2002.
43. Baldo, J.V.; Schwartz, S.; Wilkins, D.; Dronkers, N.F. Role of frontal *versus* temporal cortex in verbal fluency as revealed by voxel-based lesion symptom mapping. *J. Int. Neuropsychol. Soc.* **2006**, *12*, 896–900. [CrossRef] [PubMed]
44. Banich, M.T.; Compton, R.J. *Cognitive Neuroscience*, 4th ed.; Cambridge University Press: Cambridge, UK, 2018.
45. Casasanto, D. Hemispheric specialization in prefrontal cortex: Effects of verbalizability, imageability and meaning. *J. Neurolinguist.* **2003**, *16*, 361–382. [CrossRef]
46. Davis, M.H.; Meunier, F.; Marslen-Wilson, W.D. Neural responses to morphological, syntactic, and semantic properties of single words: An fMRI study. *Brain Lang.* **2004**, *89*, 439–449. [CrossRef]
47. Henry, J.D.; Crawford, J.R. A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology* **2004**, *18*, 284–295. [CrossRef]
48. Perfetti, C.A.; Frishkoff, G.A. The neural bases of text and discourse processing. In *Handbook of the Neuroscience of Language*; Stemmer, B., Whitaker, H.A., Eds.; Elsevier: New York, NY, USA, 2008; pp. 165–174.
49. Corbetta, M.; Shulman, G.L. Control of goal-directed and stimulus driven attention in the brain. *Nat. Rev. Neurosci.* **2002**, *3*, 201–215. [CrossRef] [PubMed]

50. Wisniewski, I.; Wendling, A.S.; Manning, L.; Steinhoff, B.J. Visuospatial memory tests in right temporal lobe epilepsy foci: Clinical validity. *Epilepsy Behav.* **2012**, *23*, 254–260. [CrossRef] [PubMed]
51. Budohoska, W.; Fersten, E.; Szumska, J.; Szymański, L. Cerebral hemispheric differences in visual perception of various types of verbal material. *Acta Neurobiol. Exp.* **1983**, *43*, 201–213.
52. Cappelletti, M.; Lee, H.L.; Freeman, E.D.; Price, C.J. The role of right and left parietal lobes in the conceptual processing of numbers. *J. Cogn. Neurosci.* **2010**, *22*, 331–346. [CrossRef]
53. Malhotra, P.; Coulthard, E.J.; Husain, M. Role of right posterior parietal cortex in maintaining attention to spatial locations over time. *Brain* **2009**, *132*, 645–660. [CrossRef] [PubMed]
54. Fisher, D.; Kusumah, Y.S.; Dahlan, J. Project-based learning in mathematics: A literatur review. *J. Phys. Conf. Ser.* **2020**, *1657*, 012032. [CrossRef]
55. Pantazatos, S.P.; Yanagihara, T.K.; Zhang, X.; Meitzler, T.; Hirsch, J. Frontal-occipital connectivity during visual search. *Brain Connect.* **2012**, *2*, 164–175. [CrossRef]
56. Fujita, T.; Kondo, Y.; Kumakura, H.; Kunimune, S.; Jones, K. Spatial reasoning skills about 2D representations of 3D geometrical shapes in grades 4 to 9. *Math. Educ. Res. J.* **2020**, *32*, 235–255. [CrossRef]
57. Kozhevnikov, M.; Motes, M.; Hegarty, M. Spatial visualization in physics problem solving. *Cogn. Sci.* **2007**, *31*, 549–579. [CrossRef]
58. Jirout, J.J.; Newcombe, N.S. Building blocks for developing spatial skills: Evidence from a large, representative U.S. sample. *Psychol. Sci.* **2015**, *26*, 302–310. [CrossRef] [PubMed]
59. Wong, J.; Yu, K.; Giacaman, N. Scaffolding spatial ability with augmented reality and virtual reality. *Int. J. Mob. Learn. Organ.* **2021**, *15*, 50–70. [CrossRef]
60. Anjarsari, E.; Hobri, H.; Irvan, M.; Sunardi, S. Spatial intelligence on solving three dimensional geometry object through project based learning. *Int. J. Soc. Sci. Humanit. Invent.* **2017**, *4*, 3817–3822. [CrossRef]
61. Jung, R.; Haier, R. The parieto-frontal integration theory (P-FIT) of intelligence: Converging neuroimaging evidence. *Behav. Brain Sci.* **2007**, *30*, 135–154. [CrossRef]
62. Ryan, R.M.; Kuhl, J.; Deci, E.L. Nature and autonomy: An organizational view of social and neurobiological aspects of self-regulation in behavior and development. *Dev. Psychopathol.* **1997**, *9*, 701–728. [CrossRef] [PubMed]
63. Yan, T.; Zhuang, K.; He, L.; Liu, C.; Zeng, R.; Qiu, J. Left temporal pole contributes to creative thinking via an individual semantic network. *Psychophysiology* **2021**, *58*, e13841. [CrossRef] [PubMed]
64. Liu, Y.-C.; Yang, Y.-H.; Liang, C. How do creativity levels and stimulus types matter? A preliminary investigation of designer visual association. *J. Neurol. Neurosci.—Imedpub* **2017**, *8*, 185. [CrossRef]
65. Bloom, P. Précis of how children learn the meanings of words. *Behav. Brain Sci.* **2001**, *24*, 1095–1103. [CrossRef] [PubMed]
66. Dunlosky, J.; Rawson, K.A.; Marsh, E.J.; Nathan, M.J.; Willingham, D.T. Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychol. Sci. Public Interest* **2013**, *14*, 4–58. [CrossRef] [PubMed]
67. Miotto, E.C.; Balardin, J.B.; Martin, M.D.G.M.; Polanczyk, G.V.; Savage, C.R.; Miguel, E.C.; Batistuzzo, M.C. Effects of semantic categorization strategy training on episodic memory in children and adolescents. *PLoS ONE* **2020**, *15*, e0228866. [CrossRef]