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Be Creative to Innovate! EEG Correlates of Group Decision-Making in Managers

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Abstract: Background: Organizational creativity and sustainability-oriented innovation are key factors for leaders and managers. This study explores the neural correlates underlying creative decisions in the managerial field in two distinct conditions: individual and group conditions. **Methods:** A Muse electrophysiological (EEG) headband was applied to a group of managers compared to a group of non-managers during the execution of a realistic complex problem-solving task in an individual and group condition, while EEG frequency bands (delta, theta, alpha, and beta) were collected. **Results**: Both managers and non-managers group showed specific neural activations during the task, elucidating the effect of creative thinking at workplace on the prefrontal cortex (PFC) and the temporal parietal junction (TPJ). Significantly higher delta, theta and beta mean values were detected in the right TPJ in the group condition as well as in the right PFC in the individual condition for managers. Higher alpha band activation was found in the left PFC for managers, regardless of the condition. **Conclusions**: This study suggests the possibility to uncover, through neuroscientific techniques, the more socially sustainable working conditions that foster innovation, organizational creativity, and the fruitful sharing of one's ideas while tackling complex problems within organizations.

Keywords: creativity; problem-solving; EEG; manager; neuromanagement

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1. Introduction

The ability to address sustainability challenges and disruptive innovations to sustainability problems is significantly influenced by the innovation, sustainability vision, and commitment of the owner-manager.

Considering an organizational environment, when creative ideas are implemented, then innovation occurs [1]. The construct of creativity is in fact fundamental for leaders and managers, not only to develop it individually but also to promote it to their subordinates, to future generations of workers [2] and for organizations' long-term survival in a competitive environment.

The term "organizational creativity" refers to the creativity that emerges when people collaborate within a complex social structure, such as an organization, which is influenced by both individual and collective creativity as well as by the organizational environment [3]. Organizational creativity and its relation to sustainability-oriented innovation has been little explored in the literature [4]. Even less explored is the link between organizational creativity and how it promotes positive relationships that foster long-term social sustainability within the organizations.

Within complex real environments such as the organizational field, indeed, several difficult choices arise that often require a novel solution, so that reality constraints are transformed in an adaptive and useful way [5]. To improve organizational decisions,

managers and entrepreneurs are required to share a common goal, a common vision, and coherent strategies (particularly when tackling complex problems as a group), as well as create meaning, propose creative solutions, and enable themselves and the group to discover, evaluate and harvest their creative endeavors [6]. Interestingly, the creative decision-making process was found to be significantly affected by states of cooperation and social interaction [7,8].

But what are the most socially sustainable working conditions that promote creativity in managers' decision-making when faced with complex and challenging problems that require creative solutions?

In the current article, we report the findings of a neuroscientific study that was carried out in the field of organizations with the goal of examining the brain correlates of a group of managers in comparison to a group of non-managers, when facing realistic complex problems requiring creative solutions to be solved. We explored the differences between these two groups when they are performing the realistic complex problem-solving task under two distinct conditions, i.e., individually and in a group.

This article discusses the importance for professionals to be creative and work in group to innovate; moreover, it can suggest to future generations of managers what are the best and more socially sustainable conditions of work from a neural perspective, when managers need to face complex challenges.

To our best knowledge, this is the first time that neuroscience techniques are applied in an organizational setting to investigate the concept of organizational creativity.

2. Literature Review

2.1. Measuring Creativity Components

Along with problem-solving, memory, and decision making, creativity belongs to the family of high order functions, and it has been defined as the capacity to generate novel solutions to problems through effective thinking: the more ways individuals find to combine acquired and new information, the more likely it is that a creative idea will arise [9,10].

Creativity is supported by three key components at the individual level: domain-relevant skills, creativity-relevant processes, and task motivation [11]. The first component refers to knowledge and expertise; the second one to cognitive styles and strategies, along with personality variables; the third one consists of intrinsic goals, emotions, and beliefs about the individual's capability to generate a creative idea [11]. According to this view, creative solutions are generated when existing concepts are searched and collected to be then updated with new concepts created [2].

To analyze these three key components, different self-report measures can be used. For instance, the Short Scale of Creative Self (SSCS; [12]) was selected in this research to assess the perceived expertise and the personal motivation to think in a creative fashion and define one own's self as creative (i.e., the first and second component of Amabile's model). Also, according to Karwowski and colleagues [12], creativity can be conceptualized into two factors: creative self-efficacy and creative personal identity. The first factor corresponds to the individual's ability to manage creative challenges; thus, it refers to the self-perception of one's own potential for creative activity. On the other hand, creative personal identity refers to the personal identity according to which an individual defines themself as creative. Because creative self-efficacy is domain-specific or even task-specific, it can be predictive of creative achievements: it is this factor that may more strongly influence creative personal identity. Moreover, an increase in creative personal identity can occur in organizational settings, leading to a higher creative self-efficacy [13].

In addition, to assess the third component of Amabile's model, the Cognitive Processes Associated with Creativity (CPAC; [14]) scale can be adopted to measure the cognitive styles and strategies to promote creative thinking.

2.2. Creativity in the Managerial Field

In the managerial field, individual characteristics of creativity are part of the creative behavior in the workplace [2]. In fact, the social environment can influence both the individual and group level, as well as the frequency of creative behavior [1]. On the other hand, group characteristics and organizational characteristics are the two categories of work environment to be considered to investigate how creativity arises: team member diversity and openness to confrontation promote a variety of unusual ideas that underlie creative thinking [15]. Workgroups reflect a diversity of skills and are made of individuals who feel free to communicate and challenge their ideas in a constructive and creative manner [16]. In fact, retrieving information from internal and external sources must be encoded in a manner that facilitates creative production [17]. Additionally, team creativity is positively related to task discourse, which is in turn positively related to team performance [18].

Five organizational factors are recognized to enhance creativity in workplaces: organizational climate, leadership style, organizational culture, resources and skills, and the structure of the organization. These factors have an impact both on the individual worker and on the working team [16]. It is in companies' interest to promote creativity among their workers, to remain competitive in the market [16].

With reference to the team dimension, cooperation is a clear example of joint action involving two or more individuals, with the shared purpose of common behavioral effects [19]. Consequently, social support indeed contributes to creative problem solving [20], as socializing and cooperation are at its basis [21]. This is also true in group interaction, because exchanging ideas promotes more and newer viewpoints [22]. Group interactions are effective when people show interest in each other's ideas to promote creativity [23]. As a matter of fact, effective collaboration and communication between team members have proven to be effective for group creativity, promoting their willingness to share and combine each other's points of view [20]. Semantic connection is a key component in creative thinking: when interacting, people form a novel semantic connection that leads to creative solutions [20].

2.3. A Neuroscientific Approach to Measure Group Creativity

Moving on to the methodological level, to address the complexity of individual and group creative processes in the managerial context, it could be useful to consider a multilevel measure of the dynamics of these processes.

Self-report measures imply the subjectivity and social desirability bias, demand effect, and they can only measure the explicit level of the self-assessment. Instead, the integration of a multimethodological neuroscientific approach provides several methodological advances.

First, it complements existing sources of data (self-report data), triangulates across measurement data, and reduces common method bias by not relying on any single measurement method [24]. Secondly, it provides supplement source of information, since it allows the exploration of implicit and unconscious correlates of the process (such as automated or complex cognitive processes, hidden emotions, social dynamics, moral issues), which otherwise would remain below the threshold of awareness [24]. Thirdly, through the continuous real-time measurement collected when a participant is performing a realistic problem-solving task, which induced the participants to identify themselves in a realistic condition, it allows a more comprehensive explanation of the ongoing phenomenon, also considering its neural substrate [25].

In fact, from a neural perspective, previous research adopted electrophysiological (EEG) and neuroimaging techniques to explore the neurophysiological correlates of creative problem-solving [9,26]. Starting from the cerebral localization of the processes of interest, the right temporoparietal junction (rTPJ; [7,27–29]) and prefrontal cortex (PFC; [30–33]) are shown to be key neuroanatomical substrates in social interaction and creativity contexts. In a study focused on lovers' collaboration, Duan and colleagues [20] found that increased activations in PFC and rTPJ support the improvement of creativity through effective

collaboration. From this study, it has been shown that PFC and rTPJ activations are indicators of teamwork and team creativity, but also of social interaction and cooperation. More specifically, PFC activation correlates with originality and indices of cooperation: the frontal cortex supports the maintenance of meta-cognitive representations [34] and the understanding of others' intentions [35]. Moreover, left frontal areas are correlated with group creativity when it occurs in a face-to-face manner. The rTPJ has been shown to support social interactions and verbal information transmission [36].

Moreover, beyond neural activity localization, the neurophysiological basis of creative decision-making in applied contexts can be explored through EEG. EEG, as a non-invasive and with high temporal resolution method, demonstrated its potential in shedding light on complex and transient neurophysiological processes connected to creativity [37–39].

Previous studies exploited the analysis of EEG frequency bands (namely, delta, theta, alpha, and beta waves), and their functional meaning according to the process of interest and their neural localization, to elucidate the role of specific cortical areas supporting the creative process [37,40,41]. For instance, in the context of creativity, an increase in the low frequency band (delta and theta band) in the frontal regions was previously associated with the process of creative insight and integration of new information coupled with an affective orientation towards satisfaction [42]. Fink and Benedek [40] showed that the alpha band is systematically activated during creative tasks: the more a task is creativity-related, such as finding original alternate solutions to a problem, the stronger is the synchronization of alpha activity. Also, alpha waves increased in the frontal lobe of the brain during creative business problem-solving but decreased under stressful conditions, during which beta waves in the brain increased [41].

Thus, the ease of application of the EEG and deepening of the frequency bands could provide information on the neural ongoing dynamics during creative decision-making process, even in organizational context. For example, they can provide insights into professionals' implicit cognitive and affective reactions to specific organizational conditions that may favor or discourage creative decision-making in the firm.

Despite these methodological considerations, advantages, and potential developments of using EEG in managerial contexts, few previous studies adopted neurophysiological (EEG) techniques to explore the neural correlates underlying organizational creativity.

2.4. The Current Study

This exploratory study investigates the EEG correlates underlying creative decisions, both when they are made as a result of individual reasoning (i.e., individual condition) compared to an interpersonal process of sharing creative ideas (i.e., group condition), in a group of managers compared to a group of non-managers. To explore this phenomenon in ecologically valid conditions (that is when the individuals were sharing their creative ideas on how to solve the task in group), a wearable EEG device, which has proven to be informative, reliable, and easy-to-use in ecological contexts, such as the organizational ones, was applied [43,44]. The EEG device was exploited to collect standard EEG frequency waves (delta, theta, beta and alpha) from four main sources located in frontal (AF7 and AF8) and temporoparietal (TP9 and TP10) brain areas while a group of managers compared to a group of non-managers were performing a realistic complex problem-solving task (RCPT; modified version of the NASA Moon Survival problem exercise [45]), in an individual and group condition. Self-report measures were also applied to collect potential differences in individuals' creative self-efficacy and personal identity (through the SCSS; [12]) and cognitive components that underlie the creative process (through the CPAC; [14]) in the group of managers compared to controls.

Given these premises, we suppose to observe the activation of frontal areas (AF7 and AF8) that support creative idea generation and demanding creative tasks [46], but also individual originality and meta-cognitive processes to find solutions [30–33], in the individual condition, while in the group condition, we expect to find the activation of

cerebral portions such as the rTPJ (TP10) promoting team working and team creativity, as well as underlying social interactions and verbal information transmission [7,27–29].

This pattern of cortical activation is supposed to be significantly evident for the managers' group with respect to the non-managers group. In fact, at the individual level, managers are used to relying on their expertise, cognitive strategies, and personal motivation [11] to find creative solutions to everyday problems in their working environments. At the group level, managers produce creative ideas relying on the relationship between collaborators: co-creators must be prepared to share individual creative propositions in a broader system, where goals must be reached [47].

It is also supposed that the group of managers would display a higher creative self-efficacy and idea generation scores (measured with the SSCS and CPAC scale, respectively) compared to the non-managers group. By comparing the group of managers with a group of selected participants without managerial experience, it is expected to observe the significant impact of managerialism versus non managerialism in relation to creative problem solving.

3. Materials and Methods

3.1. Participants

Twenty-seven individuals with an age range from 21 to 54 years old [14 males; Mean (M) age = 36.50; Standard Deviation (SD) age = 14.50] were recruited for the current work. The sample consisted of 15 managers with an age range from 27 to 54 years old (Mage = 46.93; SD age = 6.56), with more than 5 years of experience as project manager, and a convenience group of 12 participants (selected as non-managers) with an age range from 21 to 27 years old (Mage = 22.90; SD age = 1.62) (demographic values are reported in Table 1). Given the preliminary nature of this study, a control group that was as neutral as possible, with no managerial experience, was selected: this was undertaken to better elicit the possible effects of professionalism.

Table 1. Demographic values and self-report scores for the two experimental groups.

	Managers (N = 15)	**Non-Managers (N = 12)**
Gender	4 M/11 F	3 M/9 F
Age	46.93 (6.56)	22.90 (1.62)
SSCS—CSE	22.93 (3.39)	19 (5.41)
SSCS—PI	18.66 (3.59)	15.81 (5.07)
CPAC—IM	18.86 (2.09)	19.27 (2.76)
CPAC—IMA	22.66 (2.38)	21.63 (2.38)
CPAC—F	16.33 (1.88)	15.90 (2.06)
CPAC—M/A	13.93 (1.69)	14.09 (0.99)
CPAC—IG	20.71 (2.81)	20.80 (2.52)
CPAC—INC	8 (1.55)	8.60 (1.80)

Values are reported as Mean and Standard Deviation M (SD).

Because the phenomenon under investigation is relatively new in the field of neuromanagement and there is a lack of systematic, repeated data in the literature, we did not exploit previous literature to estimate the sample. A total sample size (with alpha error probability = 0.05 and power 0.80) of 27 was the minimum for detection of a significant within effect or interaction between factors in a repeated measures Analysis of Variance (ANOVA) (G*Power 3.1 software, Heinrich-Heine, Germany; [48,49]).

Criteria for inclusion were normal, or corrected to normal, visual acuity. Exclusion criteria were the presence of sensory and cognitive deficits, a history of psychiatric or neurological diseases, and the ongoing concurrent therapies based on psychoactive drugs that can alter central nervous system functioning. Within each group (managers versus non-

managers), for the "Group" experimental condition, participants were randomly assigned to groups of three people (triplets) and asked to perform a creative task. The triplets were defined a priori and homogeneously composed of only managers (5 triplets of managers) and only non-managers (4 triplets of non-managers). The participants included in each triplet did not share any formal relationship, and no differences in SSCS or CPAC scores were found between triplets. The participants signed informed consent for taking part in the study and allowing the publication of their data. The research protocol has been implemented under the regulations of the Declaration of Helsinki (2013) [50] and has been approved by the ethical committee of the institution where the work was carried out.

3.2. Procedure

Each participant was introduced into a quiet and dimly lit room and asked to sit comfortably on a chair in front of a round table where the experimental session took place. The participants were fully informed about the study aims and signed the informed consent. The Muse™ headband was applied to each participant, the proper connection with a smartphone via Bluetooth was established and the four electrodes were checked. Before starting the recording and to overcome potential recording difficulties, the participants' skin was cleaned with alcohol wipes, the dry electrodes were moistened to reduce impedance, the connection between the device and the smartphone via Bluetooth were set up sequentially, and the participants were asked to minimize the occurrence of eye blinks and movements. A 120-s EEG resting baseline was collected by asking the participants to close their eyes while their EEG data were recorded by Muse.

The experimental phase was divided into two main different steps and the EEG was recorded continuously through the tasks. Participants were asked to perform the Realistic Complex Problem Task [RCPT; a modified version of the NASA Moon Survival problem exercise [45]], first individually and then in group.

During the first experimental phase, participants had 5 min to individually solve the problem. Specifically, participants were asked to read the RCPT and choose only 3 items among 16 that could be used in an innovative way to solve the complex problem.

In the second phase, the participants were assigned to a small group of three individuals, a triplet, and each group had 10 min to discuss the items chosen individually and start a negotiation process, to make a common decision about the 3 items to keep for solving the complex problem in a creative way as a group. All groups received the same amount of time and were instructed to employ the method of group consensus as it has been described in Hall and Watson [45] and previously carried out in Meslec and Curseu [51].

During the task execution, participants were video recorded, and reaction times were collected for both two phases: individual and group conditions. Finally, two questionnaires were administered to all participants to investigate individual differences of the sample, and a self-report measure of creativity. The entire experimental phase lasted about 30 min (Figure 1A).

3.3. The Realistic Complex Problem Task (RCPT)

For this study, the RCPT task was adopted both in the individual and group condition. The RCPT task consisted of a modified version of the NASA Moon Survival problem exercise [45], a test aimed at assessing the novelty and creativity of the decision made.

To each participant, the following instructions were given:

> "*You will now be presented with a brief situation. We ask you to read it carefully and to answer some questions, identifying yourself with the situation presented and trying to use an unusual but innovative way of thinking*".

Then, the following script, which describes the realistic complex problem, was proposed:

> "*You have been selected to participate in a work-related dinner taking place in a countryside house of your CEO, in which the top management team of your corporation is participating. Unofficially, you have been informed that there is a chance that your team*

will receive more funds and more room for decision. So, you will have to provide a detailed report of the projects realized in the past two years, along with reached goals. You are perfectly on time, though before reaching the destination, the van you are traveling with begins to startle and stops abruptly, due to an engine malfunctioning, without repair. You find yourself on a secondary countryside road with no cars passing and no houses nearby, at 10 km far from the destination. It's 8 pm and the dinnertime is set at 8.30 pm. You then check your phones to see that you are out of service. Searching in the car, you find several objects".

The list with the following 16 objects was then presented to the participant: a laptop with a charger, block notes, pens, a laser pointer, an umbrella, a lighter, a torch, hand sanitizer, a long-sleeve shirt, an empty water bottle, a pair of headphones, a pack of paper tissues, a smartphone with a charger, an emergency warning triangle, a first aid kit, a parking disk.

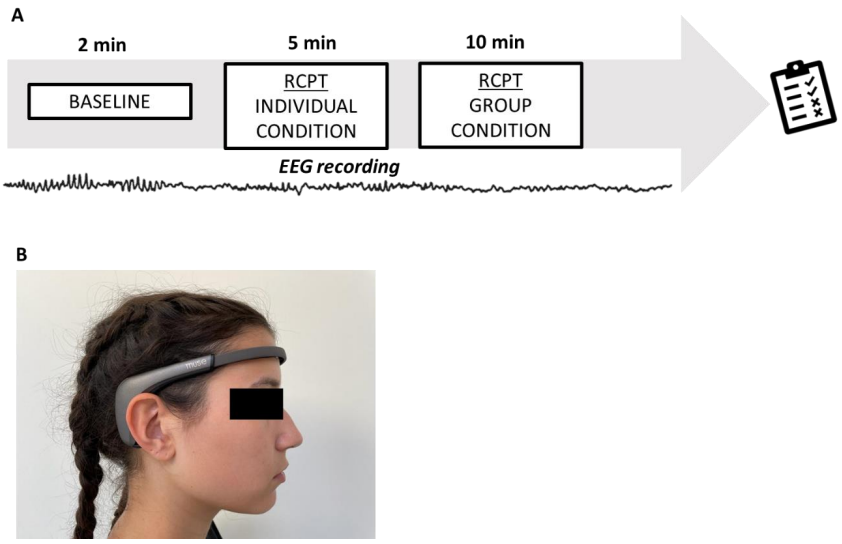


Figure 1. (**A**) Description of the experimental procedure with the execution of the Realistic Complex Problem Task (RCPT) in the individual and group condition. (**B**) The Muse™ Headband version 2 (InteraXon Inc., Toronto, ON, Canada), the wearable EEG device adopted in this study to collect EEG data during the distinct experimental conditions.

After a careful reading of the list, each participant was told they must choose 3 out of the 16 objects made available. For the individual condition, the following instructions were provided:

"*You can bring 3 items with you to help you reach your destination before dinner is over and to take part in the meeting. Attention! Given the limited time available to complete this last part of the journey, you will have only 5 min to decide whether or not to bring each individual object with you and to express the reasons for the choice, preserving a criterion of innovation and trying to contemplate an innovative use of objects. Try to provide a motivation for the choice of each object using a creative, innovative, and unusual way of thinking*".

After the individual phase, for the execution of the task in groups, the following instructions were provided:

"*Now we ask you, comparing with your colleagues, to converge on the choice of three objects that the group will bring with it. For each object you are asked to express the reasons for the choice, preserving a criterion of innovation and trying to contemplate an innovative use of objects. You will have 10 min to choose the three objects and provide an explanation for each of the chosen objects*".

3.4. Short Scale of Creative Self (SSCS)

Lastly, the fifth questionnaire used to investigate creativity during a decision-making task is the Short Scale of Creative Self (SSCS) [12]. This scale is composed of eleven items that are divided into two subscales. The first one is the creative self-efficacy (SSCS-CSE) subscale, composed of six items, and the second one is the creative personal identity (SSCS-CPI) subscale, which is made of five items.

3.5. The Cognitive Processes Associated with Creativity (CPAC)

The Cognitive Processes Associated with Creativity [14] aims at understanding and defining the cognitive components that underlie the creative process. It includes different subscales, which are brainstorming, metaphorical and analogical thinking, perspective-taking, imagery, incubation and flow. The test is composed of 28 items divided in the following way: five items for the idea manipulation subscale (CPAC-IM), six items related to imagery and sensory approach to solutions (CPAC-IMA), four items related to flow of working effort (CPAC-F), four items for metaphorical and analogical thinking (CPAC-M/A), six items for idea generation (CPAC-IG), and three items related to incubation subscale (CPAC-INC) (Table 1).

3.6. EEG Data Collection and Processing

The MuseTM Headband version 2 (InteraXon Inc., Toronto, ON, Canada), a wearable EEG recording system with four gold-plated cup bipolar dry electrodes to detect brain waves in a low-invasive manner, was given to experiment participants (Figure 1B). The electrodes are positioned in accordance with the international EEG placement standard [52]: four are in the temporoparietal (TP9 and TP10, respectively left and right ear) and frontal (AF7 and AF8, in the left and right forehead) regions, and three are utilized as a reference (placed in Fpz). The system has pulse oximetry, a gyroscope, and an accelerometer. With the help of the mobile application Mind Monitor, data are gathered and sent via Bluetooth to the linked smartphone [53]. In addition to applying a 50 Hz notch frequency filter, data are sampled at a constant 256 Hz [54]. Mind Monitor automatically processes the raw data by applying a Fast Fourier Transform to obtain the brain waves at different frequency bands, using the logarithm of the Power Spectral Density (PSD) of the raw EEG data derived from each channel. Delta (1–4 Hz), theta (4–8 Hz), alpha (7.5–13 Hz), beta (13–30 Hz), and gamma (30–44 Hz) were the frequency bands that were extracted from the signal. Every EEG PSD result that Mind Monitor evaluated was typically in the −1: +1 range.

3.7. Statistical Data Analysis

Psychometric, behavioral neurophysiological and data were collected during the tasks. For statistical analyses, a one-way ANOVA using Group (managers vs. non-managers) as a fixed factor was applied to the mean values of the psychometric tests.

Also, a set of repeated measures ANOVA with Group (2: managers and non-managers) as a between-subject factor, and Condition (2: individual and group) and Channel (4: AF7, AF8, TP9 and TP10) as within-subject factors, was computed for each frequency band (delta, theta, alpha and beta band). For significant interactions, pairwise comparisons were utilized to explore simple effects, and repeated comparisons were subjected to Bonferroni correction to reduce potential biases. For each ANOVA test, the degrees of freedom were adjusted using the Greenhouse–Geisser epsilon method where needed. Additionally, to determine if the data distribution was normally distributed, the kurtosis and asymmetry indices were checked and confirmed the normality distribution. The size of statistically significant effects has been evaluated by calculating partial eta squared (η^2) indices.

4. Results

4.1. Psychometric Scale

The statistical significant difference was found for the SSCS-CSE subscale ($F_{[1,27]} = 4.761$, $p = 0.03$, $\eta^2 = 0.166$). Greater mean values were found in the managers confronted with

the non-managers group ($M_{non\text{-}managers}$ = 19.00, $SD_{non\text{-}managers}$ = 5.67; $M_{managers}$ = 22.93, $SD_{managers}$ = 3.51) (Figure 2). No other significant differences were detected for Group (all $p > 0.050$). No significant differences were found for the SSCS-CPI subscale (all $p > 0.050$).

No significant results were observed for the CPAC subscales (all $p > 0.050$).

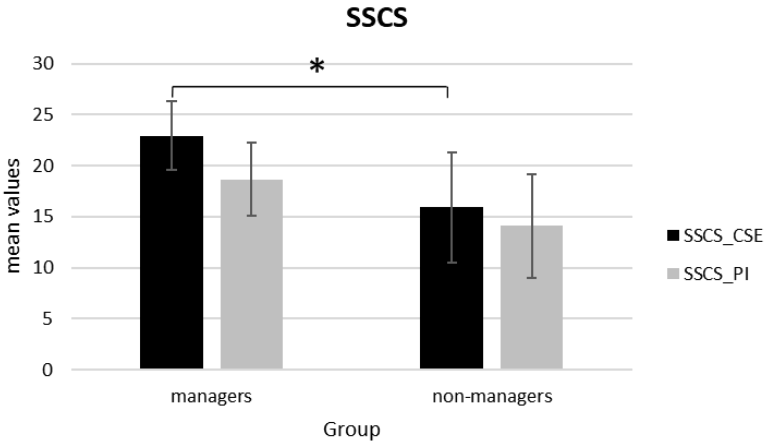


Figure 2. Findings for the SSCS scale. The bar graph shows the significant difference in mean values for the SSCS-CSE subscale observed in the managers compared to the non-managers group. All asterisks denote statistically significant differences with $p < 0.05$, and bars show ±1 Standard Error (SE).

4.2. EEG Data Results

4.2.1. Delta Band

For the delta band, a significant interaction effect Group × Condition × Channel ($F_{[3,26]} = 7.98$, $p = 0.01$, $\eta^2 = 0.378$) was found. Specifically, significant greater mean values were also observed in the managers group in the AF8 channel compared to AF7 during the individual condition ($F_{[1,27]} = 8.90$, $p = 0.01$, $\eta^2 = 0.423$). Also, in the group of managers, higher mean values were found in the TP10 channel compared to TP9 during the group condition ($F_{[1,26]} = 9.09$, $p = 0.01$, $\eta^2 = 0.489$) (Figure 3A,B).

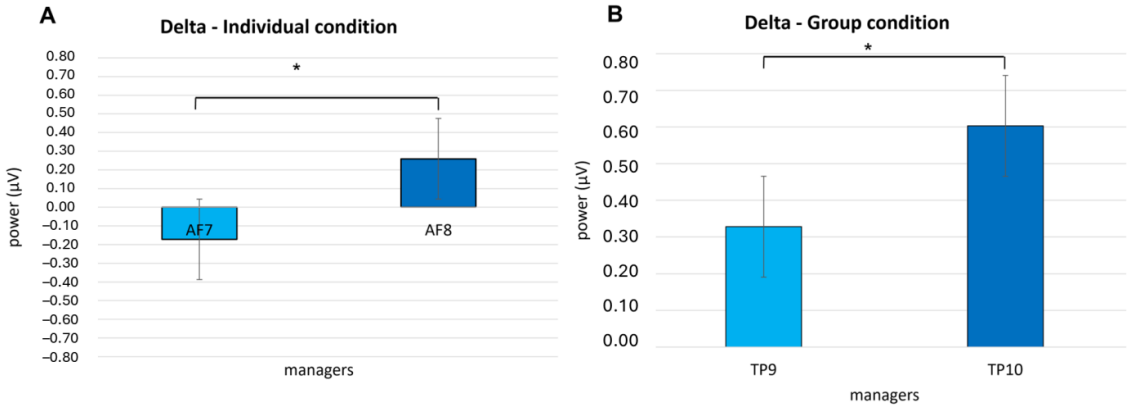


Figure 3. Findings for EEG delta frequency band. (**A**) The bar graph shows the significant difference in delta mean values (power expressed in microvolt) in AF8 compared to AF7 for the managers during the RCPT task performed in the individual condition. (**B**) The bar chart displays the significant difference in delta power in TP10 compared to TP9 for the managers during the RCPT task performed in the group condition. Bars represent the Standard Error (SE) of each chart, while asterisks denote statistically significant differences with $p < 0.05$.

4.2.2. Theta Band

Similarly to the previous results, a significant interaction effect Group × Condition × Channel ($F_{[3,26]} = 9.56$ $p = 0.01$, $\eta^2 = 0.489$) was detected for the theta band. Indeed, higher mean values were also observed in the managers group in the AF8 channel compared to AF7 during the individual condition ($F_{[1,26]} = 8.78$, $p = 0.01$, $\eta^2 = 0.398$). Moreover, pairwise comparisons showed greater mean values in the managers group for the TP10 channel compared to TP9 during the group condition ($F_{[1,26]} = 10.98$, $p = 0.001$, $\eta^2 = 0.567$) (Figure 4A,B).

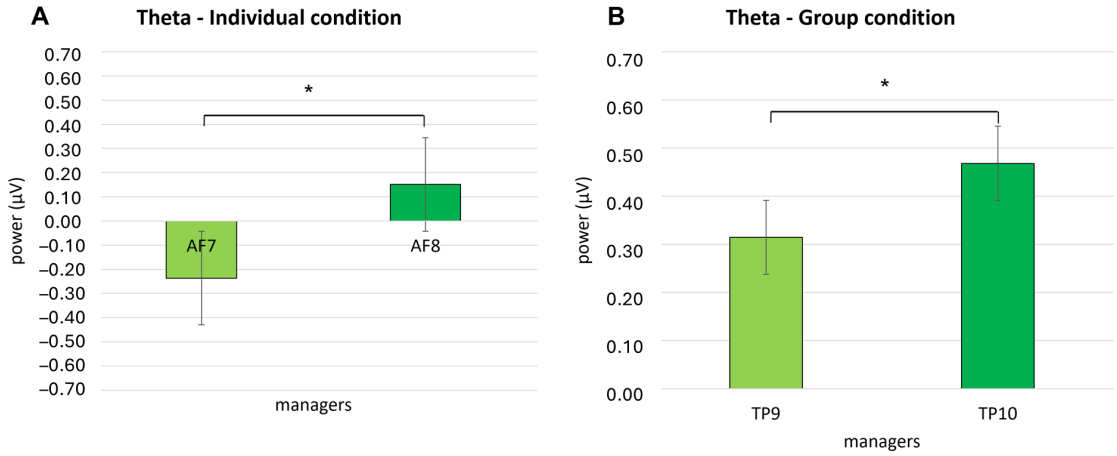


Figure 4. Evidence for EEG theta frequency band. (**A**) The bar graph displays the significant difference in theta power in AF8 compared to AF7 for the managers during the RCPT task performed in the individual condition. (**B**) In the chart is reported the significant difference in theta band activity in TP10 compared to TP9 for the managers during the RCPT task performed in the group condition. For all charts, bars indicate ±1 Standard Error (SE); all asterisks mark statistically significant differences, with $p \leq 0.05$.

4.2.3. Alpha Band

For the alpha band, a significant interaction effect Group × Channel ($F_{[3,26]} = 8.95$, $p = 0.01$, $\eta^2 = 0.366$) was detected. The pairwise comparisons showed greater mean values for the AF7 channel in the manager group confronted with non-manager ($F_{[1,26]} = 7.54$, $p = 0.01$, $\eta^2 = 0.365$) (Figure 5A).

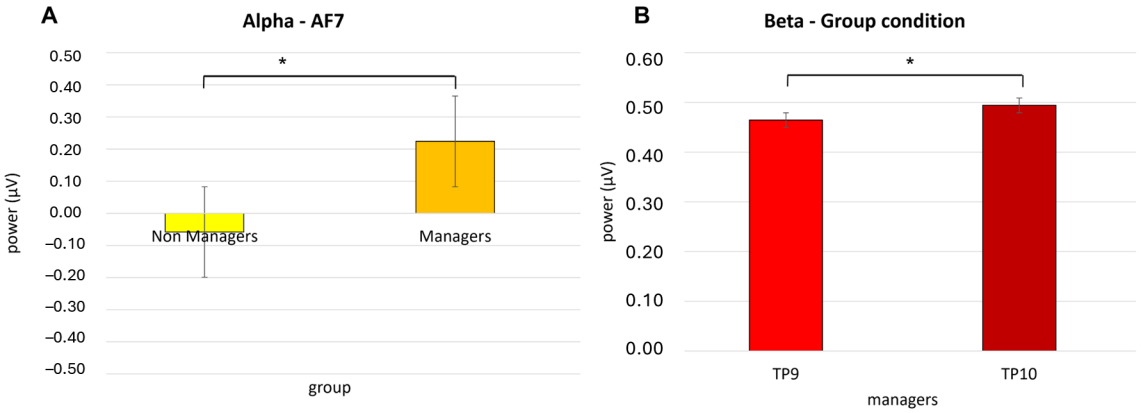


Figure 5. Alpha and beta band activity results. (**A**) The graph displays higher alpha power for the AF7 channel in the managers compared to non-managers. (**B**) In the group of managers, greater mean values of beta band activity were detected in the TP10 channel compared to TP9 during the group condition. Bars represent the Standard Error (SE) of each chart, while asterisks denote statistically significant differences with $p < 0.05$.

4.2.4. Beta Band

Regarding the beta band, a significant interaction effect Group × Condition × Channel ($F_{[3,26]} = 8.97$, $p = 0.001$, $\eta^2 = 0.510$) was observed. In particular, in the group of managers higher mean values were found in the TP10 channel compared to TP9 during the group condition ($F_{[1,26]} = 7.89$, $p = 0.01$, $\eta^2 = 0.387$) (Figure 5B).

5. Discussion

The present exploratory study allowed for the evaluations of the effects of a creative task on the EEG correlates of a group of managers compared to a group of non-managers. Specifically, a Muse EEG headband was applied during the execution of a modified version of the realistic complex problem-solving task (RCPT) in two distinct conditions: in the individual one and in the group one. EEG cortical data were collected from the four available electrodes: AF7, AF8, TP9, and TP10. Interesting findings were found for all the considered frequency bands (delta, theta, alpha, and beta).

In particular, significantly higher delta and theta mean values were found in the right PFC in the managers' group when performing the RCPT in the individual condition. While in the group condition, an increase in delta, theta and beta power was detected in the rTPJ in the managers compared to the non-managers group. Increased alpha-band activity was found in the left PFC in the managers' groups, regardless of the individual or group condition. Also, higher mean values of the creative self-efficacy subscale of the SSCS were found in the managers compared to the non-managers group.

Firstly, an increase in delta and theta power in the right PFC (AF8 electrode position) was observed when the managers performed the RCPT in the individual condition. Before, the activation of the PFC was observed in creative tasks, since this area supports decision-making processes and promotes goal selection [55] along with working memory activity [56], while in terms of the EEG cortical oscillations' functional meaning, the theta band usually reflects the encoding of new information in memory and learning, associated with task difficulty [42]. Related to creativity, the theta band appears to be associated with the integration of new information coupled with an affective orientation towards satisfaction [42]. On the other hand, the delta band is associated with cognitive reasoning related to decision-making processes following a novel or surprising signal [42], which in our case is related to the creativity of the RCPT request. Indeed, an increase in the delta band power in the frontal regions was previously associated with the process of creative insight [42].

Therefore, a possible explanation for this result could be that in the individual condition managers recruited higher cognitive processes, such as goal selection, working memory and learning to complete the RCPT in a creative way. Moreover, they might have developed a higher ability to be cooperative and to utilize group-thinking, rather than self-thinking, which is an "in potentia" skill that they showed to apply in the successive group condition where creative decision-making was required.

Indeed, in the group condition, when the managers were asked to negotiate during the RCPT, a significantly higher delta, theta and beta bands value was found in the rTPJ (TP10 electrode position).

The rTPJ has been consistently found to be activated when empathy and theory of mind processes occur, also involving the ability to simultaneously distinguish between different possible perspectives on the same situation [57]. Along with the PFC activation, this area supports perspective-taking in social conditions [57].

Specifically for EEG frequency bands, findings show that delta band activation can be associated with the subcortical regions responsible for motivation, mood, and reward processing [58]. Furthermore, theta activity in the fronto-parietal network was found to play a significant role in directing attention to the information of motivational significance [59], that in this case is related to the motivational goal of the group to find a common solution. The beta band activity in the parietal regions might be related to attentional processing of visual stimuli [60], such as the written proposals of the task, occurring during the exchange

of information within the group condition. Also, a previous study in the neuromanagerial field related low frequency bands and beta responses to a heightened emotional reaction (theta and delta over frontopolar regions), accompanied by the activation of higher-order brain regions involved in mentalizing and empathy [61]

Thus, it might be argued that in the group condition, social processes prevail for promoting several cognitive processes, such as attention control, memory cues and perspective-taking, contributing to the creative performance [55]. Moreover, previous findings show a rTPJ higher responsiveness when individuals are in a cooperative state [30]. Interestingly, Xue and colleagues [7] recently demonstrated that cooperation can even make two less-creative individuals turn into a highly creative pair. These participants showed higher behavioral cooperation, which is reflected in the activation of rTPJ to support social interaction and cooperation, specifically in the pair condition [29].

So, a possible explanation for this result is that during the group condition, the managers group recruited mainly the right posterior regions to promote social interaction and collaboration, in order to reach a shared goal.

Moreover, regardless of the condition in which the task was performed, an increase in the alpha band was found in the left PFC in the managers, compared to the non-managers group. This result is in line with previous literature. For instance, Fink and Benedek [40] showed that the alpha band is systematically activated during creative tasks: the more a task is creativity-related, such as finding original alternate solutions to a problem, the stronger the synchronization of the alpha activity. Indeed, the alpha band synchronizes specifically during the creative idea generation phase.

The activation of the alpha band only in the managers' group could be explained by the fact that they are used to relying on divergent thinking and creative problem solving in their everyday working life.

This finding could also be interpreted in the light of the questionnaire's evidence, whose results show that the manager group reported higher mean values of creative self-efficacy (CSE) compared to the non-managers group. Before, CSE was shown to mediate the relation between empowering leadership and the innovation of organization [62]. It could be argued that this component of the SSCS scale (SSCS-CSE) might be particularly developed in managers, due to their rooted abilities of leadership and decision making. Nevertheless, to the best of our knowledge, this is the first time such dimension is measured through the SCSS in managers; therefore, further studies are needed to confirm this result. Moreover, in the future, it should be tested if such an individual-related characteristic (CSE) predicts the neurophysiological correlates of creative decision-making under the individual or group condition.

Otherwise, another possible explanation is that the alpha band activation in prefrontal regions could be due to working memory processes [63], particularly occurring within the managers group, given their daily habits of engaging in high-cognitive processes that require attentional support and working memory activation.

Taken together, this EEG evidence is in line with previous results [55], in which the same regions, PFC and rTPJ, were found to be indicators for social interaction and the state of cooperation between members. In fact, authors showed that the PFC and rTPJ play pivotal roles in cognitive processing during creative tasks. Also, other findings support the activation of different EEG frequency bands, such as theta and alpha bands in parietal and prefrontal areas, during creative tasks [37,64]. However, more studies are needed to better clarify these results and the meaning of the frequency bands in relation to the ecological dynamics observed in organizational contexts, to explore the neurophysiological basis of creative problem solving and decision-making processes in managers and correlate the current neurophysiological results with managers individual's characteristics.

Although study findings suggest some first interesting evidence for the neuromanagement field, it is important to acknowledge several limitations. In future research, the relatively small sample size should be enlarged in order to generalize the findings to the entire population of managers or expert professionals.

In future research, individual differences including personality traits or creativity levels should be considered. Indeed, in a study of Xue and colleagues [7], an alternative-uses task was performed to rank individuals' level of creativity and provide a potentially objective measure. In addition, other psychometric measures could be used, such as the Mode Shifting Index (MSI; [65]), which enables the assessment of the ability to shift between associative and analytical thinking within a creative context, or the Types of Intuition Scale (TINTS; [66]), measuring the holistic, inferential, and affective intuition types. The specific age range of the expertise of managers, different professions and roles, and a more balanced control group, could be considered in subsequent research. Future studies are also needed to test if repeating the experimental conditions with the same groups would provide interesting, novel results, perhaps derived from a learning effect, or if they will confirm the current findings.

Moreover, the current study explores only the individual brains of the managers' reactions when performing a creative task under individual and group conditions. Future studies could also adopt more complex paradigms and computation methods, like the hyperscanning paradigm [67,68] that enables the evaluation of the progress of neural/psychophysiological indices of two or more individuals interacting together, considering the neural synchronization that develops between the brains in group (e.g., in the triplets).

The present study also stimulates the development of future studies dedicated to the effort to objectively measure with neuroscientific tools the cognitive and emotional impact of socially sustainable approaches and policies in the company (such as inclusive approaches, which valorize the individual and its development).

Furthermore, as next step on the research agenda, future research could explore the neurophysiological effects of a more inclusive leadership style versus a less inclusive leadership style, during the leader–collaborator or leader–team interaction.

6. Conclusions

To conclude, this study investigated the EEG correlates underlying creative decisions, both when they are made as a result of individual reasoning (i.e., individual condition) compared to an interpersonal process of sharing creative ideas (i.e., group condition), in a sample of managers confronted with non-managers.

It suggests that when faced with the resolution of a complex realistic problem, such as addressing sustainable challenges, in the group of managers, the condition of individual decision seems to activate the EEG correlates that promote the generativity of new ideas, while the group condition appears to be one that activates the neural correlates that support social interaction and collaboration.

This implies the possibility to uncover, through neurotechnological techniques, more socially sustainable working conditions that foster innovation, organizational creativity, decision-making, and the fruitful sharing of one's ideas while tackling complex problems, such as those connected to sustainability.

The cognitive neuroscience perspective appears as a promising opportunity for exploring organizational creativity as a proxy for producing sustainable innovations in managers. A neuroscience interdisciplinary approach—which combines the observation of both the psychological and the neural standpoint—may offer broader interpretations of individuals cognition and emotions, in relation to all dimensions of sustainability [69,70]. Indeed, it must be acknowledged that human cognition is rooted in complex naturalistic environments (like organizations) and is socially situated in nature. The current study presents an effort to bridge the gap between the need for highly controlled hypothesis testing, occurring within artificial laboratory environments, and the need for more realistic evidence on creativity and decision-making in organizational contexts. Indeed, while the former approach can provide high internal validity to the models tested in experimental situations, it often falls short of external validity, failing to produce models of cognitions and behaviors that hold consistent in real-world environments.

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