Emotional Mechanisms in Supervisor-Student Relationship: Evidence from Machine Learning and Investigation

Jingyi Hu, Yaxuan Liu, Qijian Zheng, and Feng Liu*

Abstract: How to cultivate innovative talents has become an important educational issue nowadays. In China's long-term mentorship education environment, supervisor-student relationship often affects students' creativity. From the perspective of students' psychology, we explore the influence mechanism of supervisor-student relationship on creativity by machine learning and questionnaire survey. In Study 1, based on video interviews with 16 postgraduate students, we use the machine learning method to analyze the emotional states exhibited by the postgraduate students in the videos when associating them with the supervisor-student interaction scenario, finding that students have negative emotions in bad supervisor-student relationship. Subsequently, we further explore the impact of supervisor-student relationship on postgraduate students' development in supervisor-student interaction scenarios at the affective level. In Study 2, a questionnaire survey is conducted to explore the relationship between relevant variables, finding that a good supervisor-student relationship can significantly reduce power stereotype threat, decrease emotional labor surface behaviors, and promote creativity expression. The above results theoretically reveal the internal psychological processes by which supervisor-student relationship affects creativity, and have important implications for reducing emotional labor and enhancing creativity expression of postgraduate students.

Key words: supervisor-student relationship; power stereotype threat; emotional labor; machine learning; computable perception

1 Introduction

Creativity is the interaction of contextual and individual factors in exploratory tasks that produce novel, original, useful, and correct results[1], which is

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the inexhaustible force for a nation to flourish[2]. In a highly competitive contemporary society, enhancing students' creativity is considered a priority goal of higher education[3]. As an important part of higher education, postgraduate education is one of the main ways to cultivate high-level innovative talents[4]. Fostering creativity in postgraduate students can contribute to economic and social development[5]. Research has shown that postgraduate students' creativity helps solve scientific problems[6] and enhances the production of research results or papers[7]. However, relevant studies and research show a lack of innovation awareness, low participation in innovative activities, and low innovative output in Chinese postgraduate education[8, 9]. How to enhance the creativity of the postgraduate students is a pressing issue in Chinese postgraduate education at present.

Chinese postgraduate education implements the supervisor system, so supervisors play an important

role in the cultivation of postgraduate students' creativity[10]. In addition to daily classroom learning, the instruction of supervisors is an important way for postgraduate students to grow and develop. Through psychological empowerment and other positive psychological processes, postgraduate students who have closer communication and interaction with their supervisors will have higher levels of creativity[11, 12]. However, it has also been argued that supervisor-student communication can inhibit postgraduate students' creativity[13, 14]. Different supervisors' mentoring styles can have different effects on postgraduate students' creativity[7, 15, 16]. The impact of supervisor-student relationship on postgraduate students' creativity has not been clearly established.

Most previous studies on supervisor-student relationship have adopted qualitative research methods, focusing on the generation and attribution of supervisor-student relationship and staying at the level of explanatory constructs[17, 18]. In supervisor-student interaction context, less attention has been paid to the interaction and changes in the emotional level and its impact on creativity. We examine the relationship between supervisor-student relationship and creativity from the perspective of emotions in supervisor-student interactions. The supervisor-student relationship affects postgraduate students' emotional feelings and expressions in their interactions with their supervisor[19], and influences the allocation of cognitive resources and thus their creativity[20–22].

We designed two studies to explore the emotional mechanisms in supervisor-student relationship. In Study 1, machine learning methods were employed to identify facial emotions and analyze the emotional types and changes of postgraduate students during supervisor-student interactions. Study 2 involved administering a questionnaire to evaluate the effect of supervisor-student relationship on postgraduate students' creativity, providing a quantitative basis for the development of creativity in postgraduate students.

2 Study 1: Emotions in Bad Supervisor-Student Relationship

2.1 Experiment design

Study 1 is based on an in-depth interview experiment about the supervisor-student relationship. In total, we collected data from 74 subjects (postgraduates) in East China Normal University. To find the emotional features of the postgraduates who have difficulties in supervisor-student relationship, we select 16 participants (8 males, 8 females, and average age = 23.5 years) according to their questionnaires' data.

The whole experiment includes two stages, as shown in Fig. 1. In the first stage, the subject conducts an interview conversation under three topics (self-introduction topic, supervisor topic, and campus life topic). When the interview experiment is finished, the subject is asked to finish a questionnaire related to the supervisor-student effect evaluation in the second stage, and the questionnaire's data are obtained for the model construction in Study 2.

During the interview conversation experiment, subjects are asked open questions and allowed to express themselves without limitation. The questions are about how they get along with their supervisors and their campus life. In the begin of experiment, to allay subjects' worries about being known by their supervisors, we promise them that the content of the conversation will be kept confidential. To better detect
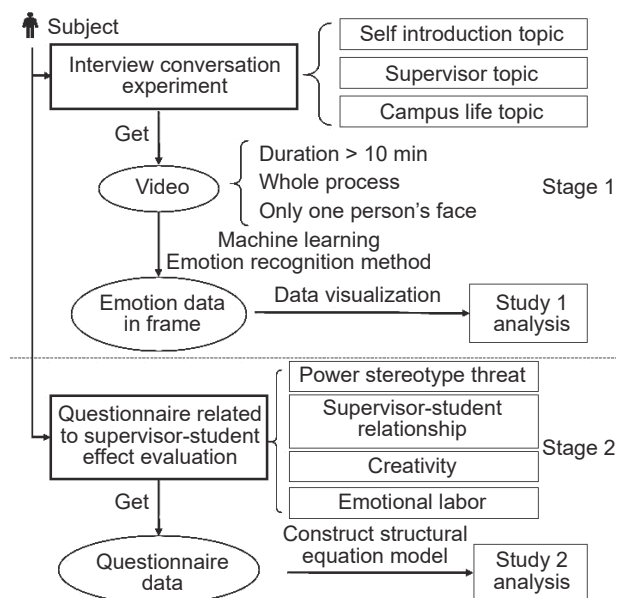

Fig. 1 Schematic of the experimental process and the following data disposals. The experiment can be divided into two stages. In Stage 1, the subject takes an interview conversation experiment and the procedure is recorded by the camera for the following disposals. And in Stage 2, the subject completes a questionnaire related to the supervisor-student effect evaluation. The questionnaire data are added to construct a structural equation model for Study 2 analysis.

subjects' emotional performance, the facial emotion features are captured by our camera equipment for AI analysis.

2.2 Measures and methods

In the previous studies, the emotions of subjects are generally detected through questionnaires. Due to the influence of the Hawthorne effect and the idea of catering to social expectations, measurement errors would inevitably occur. Therefore, we use the facial emotion detection method based on deep learning to directly identify the emotions of the subjects in the experiment, providing more objectivity and accuracy of emotion detection[23]. We refer to and apply the machine learning method for Facial Expression Recognition (FER)[24]. The process of recognition can be summarized and described in detail below.

(1) Select multiple video frames from the target video and pass them into the model. The Multi-Task Convolutional Neural Network (MTCNN) in the model conducts target detection on the face and obtains the position, height, width, confidence, and other information of the face in the image.

(2) According to the height, width, confidence, and other information of the obtained face image, the video frames that meet the emotional detection standards are retained, to prevent the non-facial objects in the image from impeding the emotional judgment of the face.

(3) Crop the original image to obtain a complete face image, then feed the cropped face image into VGG19[25] neural network to generate the emotional information of the subject. The final result is calculated by the emotional proportion.

Through this deep learning method based on computational affection[24], we obtain the emotional distribution of each subject in each frame during the interview. This distribution shows the probability ratio of the seven basic emotions of anger, fear, happiness, neutral, surprise, sad, and disgust of subject in the specific frame. To compare the subject's emotional expressions in supervisor topic with different scenarios, we divide the video into three parts according to their content: self-introduction topic, supervisor topic, and campus life topic. The i-th frame of a certain stage is denoted as F_i^{stage}, and the emotion ratio is represented as a vector denoted by E_i^{stage}.

$$E_i^{\text{stage}} = \left\{ P_{\text{anger}}^i,\ P_{\text{fear}}^i,\ P_{\text{happy}}^i,\ P_{\text{neutral}}^i,\ P_{\text{surprise}}^i,\ P_{\text{sad}}^i, \right.$$
$$\left. P_{\text{disgust}}^i \right\} \tag{1}$$

The P_{emotion}^i means the predicted probability of the emotion recognized by our algorithm. It shows the emotional performance of the subject in the frame, and the emotional distribution of a stage can be represented by the sum of the emotional performance of each frame. The stage emotion vector can be represented as

$$E^{\text{stage}} = \sum_{F_i^{\text{stage}}=F_{\text{start}}^{\text{stage}}}^{F_{\text{end}}^{\text{stage}}} E_i^{\text{stage}} =$$
$$\left\{ P_{\text{anger}},\ P_{\text{fear}},\ P_{\text{happy}},\ P_{\text{neutral}},\ P_{\text{surprise}},\ P_{\text{sad}},\ P_{\text{disgust}} \right\} \tag{2}$$

The three stages' vectors are defined as E^{self}, $E^{\text{supervisor}}$, and E^{campus}.

2.3 Analysis

To compare the negative emotional performance of the subjects in different stages, we transform the emotional distribution of each stage into the ratio of negative emotions to positive emotions: $B^{\text{stage}} = \frac{P_{\text{negative}}}{P_{\text{happy}}+P_{\text{surprise}}}$. It shows subject's negative emotional level through the comparing value of negative and positive emotions. And the emotion ratioes of our three-stage are B^{self}, $B^{\text{supervisor}}$, and B^{campus}. Then we compare the emotional ratio of the supervisor stage with those of other stages and get $C_{\text{self-supervisor}} = \frac{B_{\text{supervisor}}}{B_{\text{self}}}$ and $C_{\text{campus-supervisor}} = \frac{B_{\text{supervisor}}}{B_{\text{campus}}}$. This value reflects the difference between the ratio of positive and negative emotions of students in the stage of supervisor topics and other stages. If this value is larger than 1, it indicates that the supervisor stage exhibits a more significant negative emotional performance compared to the other stages. The larger value means more obvious negative emotional performance of the students in the supervisor topic stage, as shown in Fig. 2.

According to Fig. 2, $C_{\text{campus-supervisor}}$ of most subjects are greater than 1, which means that the negative emotion performance of the subjects in the supervisor topic stage is significantly higher than those in the other two stages. This difference is more obvious in comparison with the self-introduction stage. We attribute the difference in emotional performance between the self-introduction topic stage and the
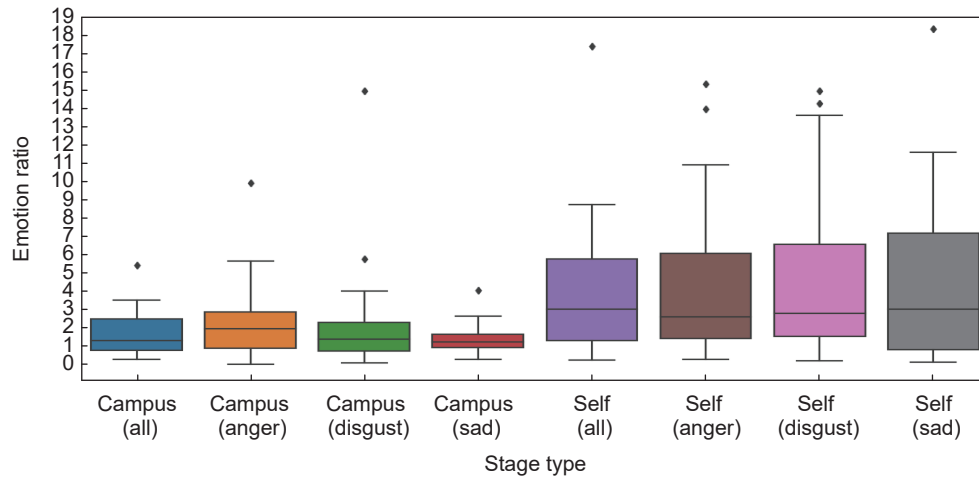
Fig. 2 Box plot of the 16 subjects' negative emotion ratios of supervisor topic compared to those of the other two topics. Figure 2 shows 16 subjects' $C_{\text{campus-supervisor}}$ and $C_{\text{self-supervisor}}$. The value of $C_{\text{campus-supervisor}}$ or $C_{\text{self-supervisor}}$ is calculated by the ratio of each subject's emotional performance between the supervisor topic and the other topics (self-introduction topic and campus topic). Emotional performance of each subject is defined by the ratio between the proportion of negative emotions and the proportion of positive emotions. Campus (all) and self (all) consider all negative emotions (anger, fear, sad, and disgust). Campus (anger), campus (sad), campus (disgust), self (anger), self (disgust), and self (sad) only consider one negative emotion. Due to the minimal proportion (<1%) of fear emotions displayed by the participants in the emotion recognition on video, we omit the fear emotion from the emotion ratio analysis. The diamond markers in the figure represent some outliers, with each marker representing an individual participant whose negative emotional expression exceeds the range of the group.

campus life topic stage to their chat contents. In terms of conversation content, students are usually polite self-statements under the topic of self-introduction and natural descriptions under the topic of campus life. Students' emotions in these two types of topics are usually in a stable state, and therefore it is suitable as a comparison group to reflect students' emotional changes in supervisor topic. By comparing the emotion changes in the supervisor topic and the campus topic, we find that anger is the most obvious emotion among the negative emotions, while disgust and sadness are relatively low. It reflects students' emotional tendency under the supervisor topic. According to the content of the video, these negative emotions are mainly due to students' doubts about the supervisors' work arrangement and tension in the face of the supervisors' authority. Therefore, compared with daily life, students are more prone to have anger emotion when faced with the pressure of the supervisor, which results in a higher emotional energy state instead of low energy state. This kind of state can enhance their creativity to a certain extent, but it also affects the accuracy of their work[26].

After realizing the subjects' emotional characteristics in different stages. To further investigate the emotional responses of individuals within an unfavorable

supervisor-student relationship, we specifically choose a participant whose questionnaire data indicate a negative supervisor-student relationship, thereby impacting the participant's creativity. The end frame of the self-introduction topic is referred to as $F_{\text{end}}^{\text{self}}$, while the start frame of supervisor topic is referred to as $F_{\text{start}}^{\text{supervisor}}$. During the time between these two key frames, the subject's emotional change can be exposed to us, therefore, we take the median of these two frames as the dividing line,

$$F_{\text{mid}} = \frac{F_{\text{end}}^{\text{self}} + F_{\text{start}}^{\text{supervisor}}}{2} \tag{3}$$

Then we take 300 frames (30 s) before and after the F_{mid} for analysis. The proportion of negative emotions in each frame is used as a reference value y_{negative},

$$y_{\text{negative}} = P_{\text{anger}} + P_{\text{fear}} + P_{\text{sad}} + P_{\text{disgust}} \tag{4}$$

Figure 3 shows the intensity of subject's negative emotions during the self-introduction stage (before the 300th frame) and supervisor topic stage (after the 300th frame). When the number of scatter points with a high y_{negative} value increases, subjects show a detectable stress response, corresponding to the 100th, 300th, 500th, and 550th frames on Fig. 3. Especially at the topic changing moment (the 300th frame), there is an obvious negative mood swing, and we consider it as a
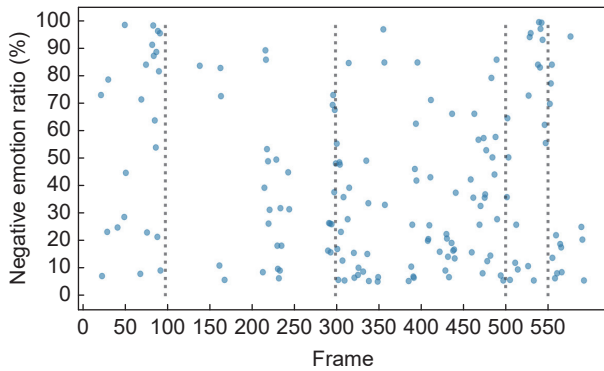
Fig. 3 Scatter plot of a subject's negative emotion during the interview topics changing from self-introduction to supervisor. Each dot represents the subject's negative emotion percent at that frame. To analyze subject's negative performance, we discard insignificant points with a percentage below 5%. We add four auxiliary lines at the 100th, 300th, 500th, and 550th frames, at which the subject's negative emotion performance is more significant.

signal when the subject's mental state changes. The frequency of the subject's negative emotion performance after this emotional signal increases significantly according to the video content. The scatter points with higher negative emotion percent (>40%) become denser, as shown in Fig. 3, which shows that students are in a more serious and nervous state when facing the supervisor's topic.

3 Study 2: Emotional Mechanism of Supervisor-Student Relationship Affecting Creativity

3.1 Related work

(1) Supervisor-student relationship

The supervisor-student relationship mainly refers to the connection between teacher and student. Since the 1990s, discussions on supervisor-student relationships have gradually emerged. It is now generally accepted that the supervisor-student relationship is a multidimensional relational structure in which the teaching relationship, the interpersonal relationship, or both are intertwined. The supervisor-student relationship is one of the specific manifestations of the supervisor-student relationship, which mainly occurs in the educational activities of supervisors and postgraduate students. The supervisor-student relationship is a stable social relationship formed between the supervisors and the postgraduate students in the activities of teaching, research guidance, and

daily interaction, which is the result of the interaction between the supervisors and the postgraduate students[27]. The supervisor-student relationship is a composite relationship, including the institutional relationship stipulated by the system, and the non-institutional relationship arising from the actual identity-role construction between the supervisor and the student[28]. The supervisor-student relationship also presents different characteristics in different cultural traditions and contexts[29]. Current research on supervisor-student relationship mainly focuses on the characteristics[30], typology[31], and predictors[32]. The research methodology is mainly based on qualitative research methods and insufficient quantitative research.

(2) Creativity

Numerous scholars believe that creativity is closely related to divergent thinking[33], and creativity is the production of original, valuable, novel, and useful products and things[34]. Creative people usually approach problems in novel ways[35]. Hocevar[36] summarized the measures of creativity by grouping them into ten categories, which are divergent thinking, attitude and interest inventories, personality inventories, biographical inventories, teacher nominations, peer nominations, supervisor ratings, judgments of products, eminence, and self-reported creative activities and achievements[36].

(3) Power stereotype threat

Stereotype is cognitive structure and specific socio-cognitive schemata consisting of relatively fixed ideas or expectations about members of a group[37, 38]. The Stereotype Content Model (SCM) proposes that enthusiasm and competence are two fundamental dimensions of social cognition. In stereotyped groups, the perceived levels of competence and enthusiasm tend to show opposite trends in direction[39, 40]. Power is the ability to control and influence others and resources[41]. People in high-power positions are often perceived as high in competence and low in enthusiasm, while people in low-power and social positions are often perceived as low in competence and high in enthusiasm[42–44]. Threat is not-yet-occurring but foreseeable harms or losses, and includes two main categories: physical and social threat[45]. Stereotype threat is one of the specific manifestations of threat. Stereotype threat, where individuals fear that they will validate negative stereotypes of the group they belong to, is a psychosocial dilemma[46]. Our study defines the

power stereotype threat as a crisis of negative power stereotyping that confirms one's lack of competence in the context of supervisor-student interactions faced by postgraduate students. A growing number of studies have demonstrated the detrimental and widespread effects that stereotype threat can have on many different populations, including intelligence[46], memory[47, 48], well-being[49], mathematics tests[50–52], mental rotation[53], driving[54, 55], negotiation performance[56], etc. Stereotype threat has negative effects primarily through affective, subjective, cognitive and motivational mechanisms[57].

(4) Emotional labor

Emotional labor is a third type of labor that is distinct from mental and physical labor[58]. The process of regulating emotion and expression for organizational goals in psychology is known as emotional labor[59]. Emotional labor is a core component of occupations that requires interpersonal interaction[60], and therefore can also be applied to a wide range of scenarios that require interpersonal contact and emotional interaction. People often afford emotional labor because they are influenced by the emotional rules required by their organization, performance, job role, or specific cultural traditions. Based on general emotion theory, Hochschild[61] proposed two strategies for managing emotions, i.e., surface acting and deep acting. Surface acting is an emotional state in which an individual's outward expression differs from his or her true inner emotions, and the internal psychological state does not change. Surface acting is a form of emotional masking, which manifests itself in the form of amplifying, faking, or suppressing emotions[62, 63]. Deep acting, on the other hand, is necessary to internalize the emotion to be expressed, so that the emotion expressed is consistent with the emotion felt. Surface acting strategies tend to have a negative impact, while deep acting strategies tend to have a positive impact[64, 65]. Diefendorff et al.[66] integrated the strategies of emotional labor and developed the emotional labor scale, which is widely used in the measurement of emotional labor.

3.2 Theoretical background and hypotheses development

(1) Supervisor-student relationship and power stereotype threat

The sociology of emotion, which has emerged in recent years, argues that emotion is an important driver of human cognition and behavior, as well as of various aspects of social organization. It is important and necessary to focus on specific emotions and their consequences in socio-cultural context[67]. Interaction ritual chain theory suggests that people form and maintain relationships through interaction rituals in everyday communication. Interaction Ritual (IR) is the most basic interaction, and the Emotional Energy (EE) generated in the interaction field is an important driving force in the interaction process. In the micro-context of university supervisor-student interaction, the interaction between postgraduate students and their supervisors is not only limited to the exchange and interaction of academic knowledge, but also the emotional interaction. Successful interactive rituals are reflected in the multidimensional interaction between supervisor and student, with a shared focus on promoting mutual development through the creation of meaningful dialogue. This leads to a deepening of the emotional energy that is built together and ultimately to the formation of symbols that represent a specific group[68].

Emotion is an important factor influencing the willingness of postgraduate students to initiate communication in the context of supervisor-student interaction. When supervisors care about the feelings of postgraduate students and encourage them to express their views and ideas boldly, they give students a psychologically safe environment to approach and interact[69]. Postgraduate students are likely to demonstrate greater trust in their supervisors[70] and seek academic help directly from their supervisors, which includes useful feedback, advice, practical help, and resources[19]. Postgraduate students express their emotions, attitudes, and ideas directly in supervisor-student interaction situations and, feel less threatened by power stereotype threat. In contrast, if the relationship between supervisors and postgraduate students is indifferent, postgraduate students are rarely inclined to express their needs and demand support from their supervisors. Therefore, when supervisors do not signal communication and create an inclusive atmosphere, postgraduate students who lack the psychological perception of safety often feel threatened by higher power stereotype threat[69]. Based on this, our study proposes the following research hypothesis.

Hypothesis 1 (H1): Supervisor-student relationship is negatively related to power stereotype threat.

(2) Power stereotype threat and emotional labor

Power differentials lead to different tendencies to act. Higher power tends to be more active while the lower power side tends towards behavioral restraint[71]. In supervisor-student interaction, supervisors have a higher status and more emotional privilege, and therefore tend to express themselves more directly, while postgraduate students do the opposite[72]. Postgraduate students often face a crisis of negative power stereotype threat, that confirms their lack of competence when interacting with their supervisors, as they often have the stereotype that they are limited and their supervisors are more professional. Culture shapes and constrains the expression of human emotions. China has a cultural tradition of the dignity of the teacher. The tutor system for postgraduate students in China dictates that the supervisor holds the "power of life and death" over students' graduation and promotion. Under the pressure of the system and culture, postgraduate students tend to be submissive and pandering in their interactions, disguising their true emotions and expressions, and putting in more emotional labor. Based on this, our study proposes the following research hypothesis.

Hypothesis 2 (H2): Power stereotype threat is positively related to emotional labor; power stereotype threat is positively related to surface acting (H2a); and power stereotype threat is positively related to deep acting (H2b).

(3) Emotional labor as a mediating mechanism between power stereotype threat and creativity

Creativity is the production of original, valuable, novel, and useful products and things[34], and the promotion of creativity involves adequate cognitive resources[73]. The danger-rigidity theory suggests that individuals tend to become rigid and limited in their thinking when faced with threatening stimuli[74], and that creativity decreases. Numerous empirical studies have also confirmed this idea, such as the ability of threat to slow down individuals' cognition[75], induce anxiety, and limit the generation of novel ideas[76]. In addition, there are various theories that can support this view. Threatening stimulus vigilance and fixation suggest that both physically and socially threatening stimuli may attract and fixate individuals' attention[77], taking up a large amount of cognitive resources[78] and making it harder for individuals to generate creative

ideas. However, it has also been argued that threat promotes creativity. Motivation focus theory suggests that stimuli such as stress and threat can trigger the allocation of cognitive resources necessary for creativity[79]. Power stereotype threat is a specific form of threat[80]. In supervisor-student interaction situations, postgraduate students face a crisis of negative power stereotype threat that confirms their lack of competence when confronted with a supervisor in a higher position of power. This can lead to different emotional processing behaviors by postgraduate students.

When looking at emotional labor from a cognitive perspective, both surface and deep actings adjust to the emotions displayed, but the cognitive processes involved are different, and they consume different cognitive resources[21, 22]. Surface acting refers to postgraduate students disguising external expressions of emotion without changing their true emotions in the context of supervisor-student interaction. In this process postgraduate students need to constantly monitor and correct the outward emotional expressions, consuming a significant amount of cognitive resources that could be used to generate creative ideas[20]. It is beneficial for the postgraduate students to pre-associate positive memories and events in order to alter their perception of a given situation and regulate their external emotional expression. Through pre-cognitive regulation, postgraduate students do not have to expend cognitive resources to manage external emotional expressions at all time[81, 82]. Based on this, our study proposes the following research hypothesis.

Hypothesis 3 (H3): Emotional labor is significantly related to postgraduate creativity; surface acting is negatively related to postgraduate creativity (H3a); and deep acting is positively related to postgraduate creativity (H3b).

3.3   Data anlysis

(1) Methodology

Structural Equation Model (SEM) is employed to analyze the data. SPSS 23 and AMOS 29 are employed to conduct analyses for SEM. For measurement, we adapt the supervisor-student relationship scale[19, 83], the creativity scale[84], and the emotional labor scale[66, 85]. Based on previous experience in developing stereotype threat scales, we use commonly reported scenarios in supervisor-student interactions as

cues to measure power stereotype threat, including three dimensions of situational threatening information perception, talker power stereotypes, and power meta-stereotype activation. The scales are all scored on a 9-point Likert scale. All items are placed in the Appendix.

(2) Data collection

Based on the above scales, we design the overall questionnaire, including variables such as supervisor-student relationship, power stereotype threat, surface acting, deep acting, creativity, age, gender, education, mental health status, and physical health status. We distribute questionnaires to postgraduate students from all over the country through online questionnaire platform Wenjuan Xing, paid 3 yuan for each participant. After two weeks, a total of 1714 questionnaires were collected. After eliminating abnormal questionnaire data through screening questions, 592 effective questionnaires were finally collected, with an effective rate of 34.54% (53.7% male and 46.3% female, ranging from 21 to 29 years old).

(3) Reliability and validity analysis

In this study, a validated factorial model with five latent variables is constructed. As shown in Table 1, the model has a good fit (χ^2 (340) = 784.299, χ^2/df = 2.307, p<0.000; GFI = 0.913, CFI = 0.940, NNFI = 0.934, RMSEA = 0.047, RMR = 0.198, and NFI = 0.900). Both values of the combined reliability CR and Cronbach's α are greater than 0.70. The standardized factor loading values for each measure are greater than 0.50, which have reached the significance level. This indicates that the scale has good convergent validity. Table 2 shows that the square root of the AVE for each latent variable is greater than the correlation coefficient between that variable and other variables, implying good discriminant validity. These indicators indicate

that the measurement scale used in this study has good reliability and validity.

(4) Structural equation model

The relationship between the variables is tested by SEM and the results of the data analysis are presented in Table 3. There is a significant negative effect of supervisor-student relationship on power stereotype threat ($\beta = -0.255$ and $p < 0.001$), supporting Hypothesis 1. This indicates that the closer the relationship between the postgraduate student and the supervisor, the less power stereotype threat the postgraduate student felt in the supervisor-student interaction situation.

Also, there is a significant positive effect of power stereotype threat on both dimensions of emotional labor surface acting ($\beta = 1.203$ and $p < 0.001$) and deep acting ($\beta = 0.571$ and $p < 0.001$), so H2a and H2b are supported. This indicates that the greater the threat of power stereotype in the supervisor-student interaction situation, the more the graduate student tends to manage emotions faced with supervisor. Postgraduate students will reduce their true emotional expression and engage in more emotional labor. The surface acting dimension of emotional labor is significantly negatively associated with creativity ($\beta = -0.22$ and $p < 0.001$), so H3a is supported. This indicates that the surface acting dimension of the emotional labor has a negative effect on graduate students' expression of creativity. However, the deep acting dimension of the emotional labor is positively significant associated with creativity ($\beta = 0.416$ and $p < 0.001$), so H3b is supported, indicating that the deep acting dimension of emotional labor has a positive effect on postgraduate students' expression of creativity. All of the influence paths are shown in Fig. 4.

Table 1　Result of the discriminant validity analysis.

	Supervisor-student relationship	Power stereotype threat	Surface acting	Deep acting	Creativity
Supervisor-student relationship	**0.641**	—	—	—	—
Power stereotype threat	−0.224***	**0.668**	—	—	—
Surface acting	−0.163**	0.719***	**0.694**	—	—
Deep acting	0.237***	0.358***	0.499***	**0.678**	—
Creativity	0.564***	−0.089	−0.044	0.316***	**0.812**
Mean	2.366	0.620	1.011	1.550	1.587
Standard deviation	1.134	1.608	1.522	1.454	1.507

Note: ** denotes $p < 0.01$ and *** denotes $p < 0.001$. The values on the diagonal line in bold are AVE values.

Table 2   Reliability and validity of measurement model.

Variable	Measurement	Standardized path coefficient	*T*-value	Cronbach's α	AVE	CR
Supervisor-student relationship	(1) My supervisor will monitor my academic and research progress.	0.699	10.241	0.725	0.411	0.727
	(2) My supervisor will be able to provide timely evaluation and feedback on my studies.	0.809	10.584			
	(3) My supervisor will respect my research interests and ideas.	0.509	8.696			
	(4) I respect my supervisor's academic and research abilities.	0.490	—			
Power stereotype threat	(1) I prefer to sit at least 1.5 meters away from my supervisor.	0.535	9.264	0.862	0.447	0.863
	(2) I have an expectation that the debriefing will take place. I always believe that supervisor thinks we students don't have enough knowledge and understanding of the issue, and I am worried that such a stereotype will have negative impacts on the debriefing.	0.707	10.642			
	(3) When my supervisor arrives in the room, I stand up and introduce myself to the supervisor. When he greets me with a nod, I feel nervous and uneasy.	0.746	10.877			
	(4) When the debriefing session begins, I have the opinions and ideas of the whole project team in hand, but I am hesitant to speak up and present our views to my supervisor.	0.791	11.122			
	(5) I feel that my supervisor will be serious and intimidating during the debriefing process.	0.467	—			
	(6) I would not want to have a debriefing exchange in front of my supervisor at all if I had a choice.	0.730	10.786			
	(7) I feel that I will play a submissive and dependent role in the debrief.	0.625	10.058			
	(8) I think it will be difficult for me to sway my supervisor as a student.	0.680	10.464			
Surface acting	(1) I put on an act in order to deal with my supervisor in an appropriate way.	0.749	—	0.865	0.482	0.865
	(2) I fake a good mood when interacting with my supervisor.	0.673	15.979			
	(3) I put on a "show" or "performance" when interacting with my supervisor.	0.718	17.107			
	(4) I just pretend to have the emotions I need to display when facing my supervisor.	0.637	15.059			
	(5) I put on a "mask" in order to display the emotions needed to interact with my supervisor.	0.519	12.142			
	(6) I show feelings to my supervisor that are different from what I feel inside.	0.754	18.025			
	(7) I fake the emotions I show when dealing with my supervisor.	0.774	18.521			

(To be continued)

Table 2   Reliability and validity of measurement model.   (Continued)

Variable	Measurement	Standardized path coefficient	T-value	Cronbach's α	AVE	CR
Deep acting	(1) I work hard to feel the emotions that I need to show to supervisor.	0.775	—	0.712	0.460	0.715
	(2) I try to actually experience the emotions that I must show to my supervisor.	0.566	11.335			
	(3) I make an effort to actually feel the emotions that I need to display to my supervisor.	0.677	12.755			
Creativity	(1) During the interaction with my supervisor, I often come up with creative solutions to problems.	0.795	—	0.927	0.659	0.921
	(2) During the interaction with my supervisor, I am good at providing a fresh approach to problems.	0.822	22.323			
	(3) During the interaction with my supervisor, I often come up with new and practical ideas.	0.808	21.824			
	(4) During the interaction with my supervisor, I often have new and innovative ideas.	0.819	22.205			
	(5) During the interaction with my supervisor, I am good at generating creative ideas.	0.859	23.645			
	(6) During the interaction with my supervisor, I often promote and champion ideas to others.	0.764	20.273			

Note: Fitting index of the validated factorial model is as follows: $\chi^2(340) = 784.299$, $\chi^2/\mathrm{df} = 2.307$, $p < 0.000$; GFI = 0.913, CFI = 0.940, NNFI = 0.934, RMSEA = 0.047, RMR = 0.198, and NFI = 0.900.

Table 3   Path coefficients of basic model.

Impact pathway	Path coefficient	Standard error	CR	p
Supervisor-student relationship→Power stereotype threat	−0.255	0.065	−3.940	***
Power stereotype threat→Surface acting	1.203	0.121	9.925	***
Power stereotype threat→Deep acting	0.571	0.089	6.389	***
Deep acting→Creativity	0.416	0.057	7.364	***
Surface acting→Creativity	−0.220	0.044	−4.974	***

Note: Fitting index: $\chi^2 = 994.51$, $\chi^2/\mathrm{df} = 2.883$, $p < 0.000$; GFI = 0.894, CFI = 0.913, NFI = 0.873, RMSEA = 0.056, RMR = 0.311. *** denotes $p < 0.001$.

4   Managerial Implication

This study has important practical implications for the construction of good supervisor-student relationship and the enhancement of postgraduate students' expressions of creativity in the context of Chinese institutional culture. Our study emphasizes the impact of the supervisor-student relationship on postgraduate students creativity and the mediating role played by power stereotype threat, surface acting, and deep acting. Supervisors should pay attention to the emotional mechanisms of power stereotype threat, surface acting, and deep acting, and use them to enhance the creativity of postgraduate students. Our research has shown that supervisor-student relationship can mitigate the negative effects of the power stereotype threat. Therefore, attention needs to be paid to the development of good supervisor-student relationship. A harmonious supervisor-student relationship is a basis for knowledge transfer and innovation, as well as emotional exchange and interaction between supervisors and students[86]. The relationship between postgraduate students and their supervisors is shaped by daily interactions and is primarily based on the development of talent and scientific research[87]. So building a good supervisor-student relationship requires attention in daily interactions.
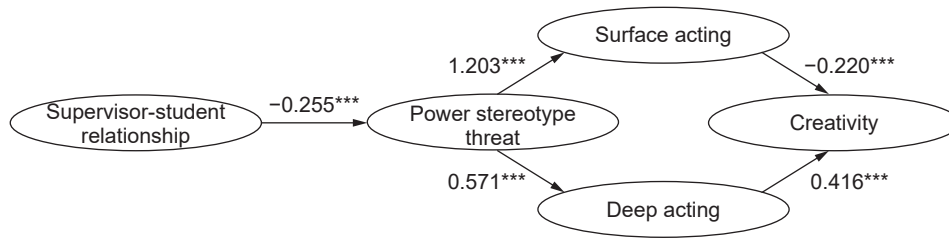
Fig. 4   Standardized path coefficients and significance of model (***denotes $p < 0.001$).

As for institution, on the one hand, there is a need to strengthen the training and assessment of postgraduate supervisors, improve the supervisory management system, and pay attention to the assessment and cultivation of postgraduate supervisors' academic and supervisory abilities[18]. It is also important to guide supervisors to identify the needs and growth potential of postgraduate students, and improve the quality of their interactions with students[88]. Institutions need to support the development of postgraduate supervisors who combine academic competence, mentoring skills, and emotional care. On the other hand, universities need to establish and improve mechanisms for postgraduate student complaints, coordination, and redress. In the Chinese institutional and cultural context, supervisors have natural advantages in many aspects, such as role status and resource possession, and supervisor-student interaction has a high power differential[86]. Postgraduate students are often in vulnerable and subordinate position. Therefore, there is a need to further improve the mechanism for protecting the rights of postgraduate students. As for supervisors, they need to actively encourage postgraduate students to express their ideas and opinions. When postgraduate students have innovative research ideas and need academic resources, supervisors should provide timely feedback and support. In the course of their research work and study, supervisors should discuss and communicate with postgraduate students on an equal footing, encourage them to ask questions, think hard, and give them the opportunity to express their ideas. At the same time, supervisors should consider their suggestions and opinions carefully. As for students, they need to be clear about their role as autonomous and independent learners who take the initiative to think and solve problems[83]. In the interaction between supervisors and students, postgraduate students should give full play to their main initiative and become active builders of a good supervisor-student relationship.

Postgraduate students increase their enthusiasm and initiative in interacting with their supervisors. They should take the initiative to express their real thoughts, reflections, and emotions to their supervisors, so as to enhance their emotional connection with them.

5   Conclusion

We empirically test the effect of the supervisor-student relationship on postgraduate students' creativity. Specifically, power stereotype threat and emotional labor play a mediating role betwewn them. In detail, the worse the supervisor-student relationship, the higher the postgraduate student's perceived threat of power stereotypes, leading to higher emotional labor (surface acting/deep acting). Surface acting has an inhibitory effect on postgraduate students' creativity. Deep acting has a facilitating effect on postgraduate students' creativity. Through the model, we attempt to explore the influence of supervisor-student relationship on postgraduate students' creativity from contextual and emotional perspectives. Our research is conducive to enriching research in the related field and providing suggestions for building creative supervisor-student relationship.

This study has certain limitations. Firstly, its cross-sectional research design precludes drawing conclusions about the causal relationship between the supervisor-student relationship and postgraduate students' creativity. Future attempts should be made to further verify the findings through follow-up studies or experimental studies. Secondly, the sample size is limited to postgraduate students in China. Further expansion of the sample size is necessary to verify the findings' applicability in different contexts. Thirdly, the emotion measurement in Study 1 may be affected by subjects' personal characteristics. Thus, additional test data and finer division of subjects are required to draw broader conclusions about student-supervisor emotion features. Finally, professional distinctions are

not taken into account in this study.

Future studies should consider relevant factors to gain more accurate results. In addition, this research could further be optimized by the relevant deep learning techniques used in this study, such as updating better DFER[89] and speech emotion recognition techniques[90], to increase the accuracy of recognition from a multi-modal perspective.

Appendix

The variable measurement scales that we used in the questionnaire are shown below.

A Supervisor-student relationship

(1) My supervisor will monitor my academic and research progress.

(2) My supervisor will be able to provide timely evaluation and feedback on my studies.

(3) My supervisor will respect my research interests and ideas.

(4) I respect my supervisor's academic and research abilities.

B Power stereotype threat

(1) I prefer to sit at least 1.5 meters away from my supervisor.

(2) I have an expectation that the debriefing will take place. I always believe that supervisor thinks we students don't have enough knowledge and understanding of the issue, and I am worried that such a stereotype will have negative impacts on the debriefing.

(3) When my supervisor arrives in the room, I stand up and introduce myself to the supervisor. When he greets me with a nod, I feel nervous and uneasy.

(4) When the debriefing session begins, I have the opinions and ideas of the whole project team in hand, but I am hesitant to speak up and present our views to my supervisor.

(5) I feel that my supervisor will be serious and intimidating during the debriefing process.

(6) I would not want to have a debriefing exchange in front of my supervisor at all if I had a choice.

(7) I feel that I will play a submissive and dependent role in the debrief.

(8) I think it will be difficult for me to sway my supervisor as a student.

C Surface acting

(1) I put on an act in order to deal with my supervisor in an appropriate way.

(2) I fake a good mood when interacting with my supervisor.

(3) I put on a "show" or "performance" when interacting with my supervisor.

(4) I just pretend to have the emotions I need to display when facing my supervisor.

(5) I put on a "mask" in order to display the emotions needed to interact with my supervisor.

(6) I show feelings to my supervisor that are different from what I feel inside.

(7) I fake the emotions I show when dealing with my supervisor.

D Deep acting

(1) I try to actually experience the emotions that I must show to my supervisor.

(2) I make an effort to actually feel the emotions that I need to display toward my supervisor.

(3) I work hard to feel the emotions that I need to show to my supervisor.

E Creativity

(1) During the interaction with my supervisor, I often come up with creative solutions to problems.

(2) During the interaction with my supervisor, I am good at providing a fresh approach to problems.

(3) During the interaction with my supervisor, I often come up with new and practical ideas.

(4) During the interaction with my supervisor, I often have new and innovative ideas.

(5) During the interaction with my supervisor, I am good at generating creative ideas.

(6) During the interaction with my supervisor, I often promote and champion ideas to others.

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