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Impact of video quality in online learning on anxiety and motivation: a randomized controlled trial among medical students

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Abstract

Background The widespread adoption of online education in medical teaching has brought new challenges. Technical issues, such as poor video quality, can intensify student anxiety and diminish learning motivation.

Methods A randomized controlled trial was conducted with 93 medical students. The participants watched videos of varying quality (no interference, moderate interference, or severe interference) to evaluate the impact of video quality on their state anxiety (STAI-S) and learning motivation (MSLQ). Gender and trait anxiety (STAI-T) were included as control variables.

Results Lower video quality was associated with higher levels of state anxiety, and gender had no significant moderating effect. Students with greater trait anxiety demonstrated better short-term adaptability under stress. No significant correlation was found between learning motivation and state anxiety.

Conclusion Video quality significantly affects students' immediate psychological states. Optimizing video quality in online education is essential to reduce students' psychological burden and enhance their learning experience.

Keywords Online education, Video quality, State anxiety, Learning motivation, Medical students

Introduction

Background and objectives

With the rapid development of online education, e-learning has become a significant component of the academic training of medical students. However, this mode of learning introduces psychological challenges, including the management of learning motivation, anxiety, and academic stress. Research suggests that technical factors and the learning experience in online education play crucial roles in students' mental well-being [1]. For medical students, the combination of long-term academic pressure and the unique challenges of online education may further exacerbate their psychological burden.

During the transition to remote learning, medical students often encounter common challenges such as feelings of isolation, a lack of social support, and a decline in learning experience due to technical issues. Zapata-Cuervo et al. (2023) reported that self-efficacy and social support are key to enhancing motivation and engagement in online learning, whereas heightened anxiety undermines students' academic performance [2]. Moreover, studies indicate that students' psychological responses

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to online learning vary across different disciplines, with medical students being particularly sensitive and showing heightened levels of anxiety and emotional fluctuations [3].

The relationship between learning motivation and anxiety in online education is especially complex. Camacho et al. (2021) demonstrated that social support from instructors significantly reduces student anxiety while enhancing learning motivation [4]. Conversely, the absence of adequate support and interaction in online learning environments can lead to feelings of frustration and anxiety, thus reducing students' motivation and academic performance. This phenomenon was particularly evident during the COVID-19 pandemic. Al-Kumaim et al. (2021) reported that the sudden shift to online learning had a substantial impact on students' mental health, with anxiety emerging as a key factor affecting their motivation to learn [5].

Furthermore, cultural background and individual differences play significant roles in the psychological outcomes of online education. Kotera and Ting (2021) highlighted that cultural differences influence students' mental health and learning strategies. Additionally, students with limited social support or challenging family environments are more likely to experience anxiety and stress in online learning contexts [6]. These findings underscore the importance of well-designed instructional elements and educational support in enhancing students' psychological adaptation and learning experience.

In summary, previous research has shown that the impact of online education on students' psychological state and learning motivation is multifaceted. While some studies have explored the effects of social support, self-efficacy, and cultural background on student motivation and anxiety, there is still a lack of systematic research on the influence of specific instructional elements—such as video quality—on the immediate psychological state and learning motivation of medical students. Specifically, the role of technical disruptions (e.g., video stuttering or audio-video desynchronization) in increasing students' anxiety levels and further diminishing their motivation remains an area worth further exploration.

This study aims to fill this research gap by systematically investigating the effects of video disruptions on medical students' state anxiety (State-Trait Anxiety Inventory-State (STAI-S)) and learning motivation (Motivated Strategies for Learning Questionnaire (MSLQ)). Additionally, this study examines the moderating role of gender, exploring whether male and female students exhibit significant differences in their psychological responses to video disruptions. Research will also analyze the predictive role of trait anxiety (State-Trait Anxiety Inventory-Trait (STAI-T)) on students' state anxiety to understand how individual traits interact with external situational factors to affect psychological outcomes.

The significance of this research lies in providing empirical evidence to inform the design of online education. This study will help educational institutions optimize video quality and technical support, reducing unnecessary situational stress that negatively affects students' mental health and learning experience. Improving video quality not only enhances students' e-learning outcomes but also helps alleviate academic anxiety and promotes long-term learning motivation and psychological well-being. Through this study, we aim to offer valuable insights for the future design and improvement of online educational resources.

Research hypotheses

Hypothesis 1 (H1): Video quality has a significant effect on medical students' state anxiety (STAI-S). Compared with high-quality videos (control group), videos with technical disruptions (moderate interference and severe interference groups), such as audio–video asynchrony and video lag, significantly increase students' state anxiety levels.

Hypothesis 2 (H2): Video quality significantly affects medical students' learning motivation (MSLQ). A lower video quality diminishes students' learning motivation, particularly in areas related to learning strategies and self-regulation.

Hypothesis 3 (H3): Gender moderates the relationship between video quality and state anxiety. Male and female students may exhibit different anxiety responses when exposed to video disruptions.

Hypothesis 4 (H4): Students' trait anxiety (STAI-T) significantly predicts changes in their state anxiety (STAI-S). Students with higher trait anxiety are expected to experience elevated state anxiety levels under video disruptions but may also demonstrate better short-term adaptability.

Hypothesis 5 (H5): There is a significant negative correlation between state anxiety (STAI-S) and learning motivation (MSLQ). Students with higher anxiety levels are likely to exhibit lower levels of motivation and reduced use of learning strategies.

Methods

Participants

This study employed a single-center, randomized controlled trial design. The participants were fourth-year undergraduate medical students from Wenzhou Medical University, all of whom had completed core online courses with synchronized progress. The inclusion

criteria were as follows: (1) aged between 16 and 25 years; (2) no major mental health issues, with the ability to understand and complete the study requirements; (3) at least one year of online learning experience; and (4) voluntary participation with informed consent. The exclusion criteria included the following: (1) students who were undergoing treatment for mental disorders; (2) students with severe visual or hearing impairments that could hinder video viewing; and (3) students without access to the required network platforms or electronic devices. Participants who failed to complete all assessments or who voluntarily withdrew during the study were also excluded.

To ensure a balanced gender distribution across the three video quality groups (the control group, moderate interference group, and severe interference group), a block randomization method was employed. Specifically, the research team created gender-specific randomization blocks, each containing six participants (two assigned to the control group, two to the moderate interference group, and two to the severe interference group). For example, male participants were randomly allocated so that each block contained two assigned to the control group, two to the moderate interference group, and two to the severe interference group. The same distribution pattern was applied for the female participants.

The randomization sequence was generated in advance, and both the group assignments and participant IDs were stored in an encrypted file. After screening, participants were assigned to their corresponding groups on the basis of the sex-specific sequence, with each participant given a unique ID to ensure data integrity and traceability.

This study followed a single-blind design, in which participants were unaware of their assigned group. Data and psychological measurements were analyzed under blinded conditions, with the research team remaining unaware of the participants' group and gender during the analysis to minimize bias.

Using GPower 3.1 software for sample size estimation, assuming a medium effect size (Cohen's $d = 0.5$), a significance level ($\alpha = 0.05$), and a statistical power of 80%, repeated-measures ANOVA (RMANOVA) indicated that at least 22 participants per group were needed for the study [7].

Initially, 97 students meeting the inclusion criteria were recruited, including 38 males and 59 females. During the screening process, four participants were excluded because of incomplete assessments or voluntary withdrawal. Ultimately, 93 participants (36 males and 57 females) completed all phases of the study and were included in the final data analysis (see Fig. 1).

Intervention process and measures

Intervention process

This study evaluated the impact of online course video quality on the psychological state and learning motivation of medical students by designing videos with varying levels of interference. The participants were fourth-year undergraduate medical students from Wenzhou Medical University, all of whom followed a synchronized

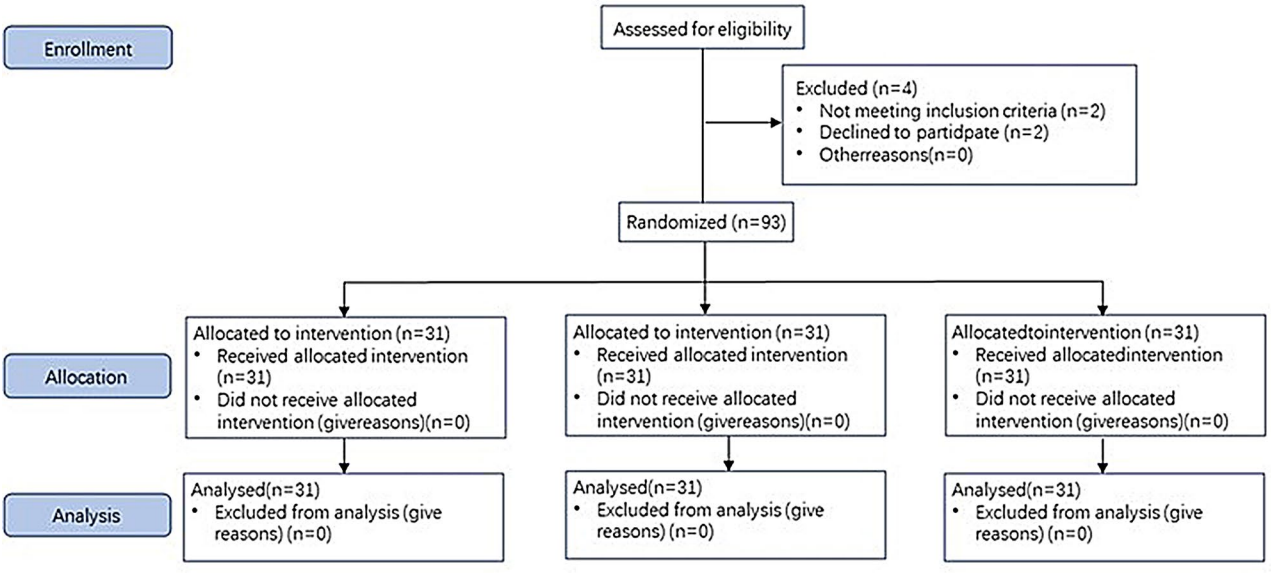

Fig. 1 CONSORT Flow Diagram of Participant Enrollment, Allocation, and Analysis (This flow diagram shows the process of participant enrollment, exclusion, randomization, allocation to intervention groups, and final analysis. A total of 97 participants were assessed for eligibility, with 4 excluded due to unmet inclusion criteria or declining to participate. The remaining 93 participants were randomized into three groups, each with 31 participants. The analysis was conducted on participants who completed the study in their respective groups.)

curriculum. Video quality in online courses is often affected by factors such as network fluctuations, server performance, and streaming platform limitations. This study simulated common negative experiences—audio-video asynchrony and video stuttering—to examine their effects on state anxiety (STAI-S), trait anxiety (STAI-T), and learning motivation (MSLQ) [8].

At the start of the experiment, participants completed the STAI-S pre- and STAI-T questionnaires to establish baseline anxiety levels. The STAI-T was only measured before the experiment, as it reflects a stable psychological trait that is unlikely to change with short-term interventions. Avoiding repeated measurements of the STAI-T also minimized participants' cognitive load and measurement fatigue, ensuring the reliability of the data.

The MSLQ questionnaire was administered only after the intervention. This design balanced the scientific rigor of the study with the participants' overall experience. Although pre- and postassessment could provide more comprehensive data, administering the lengthy MSLQ at the beginning could increase participants' cognitive load and affect their experience, potentially interfering with the experimental results. Moreover, as the MSLQ assesses students' motivation and strategy use in a specific learning context, postintervention measurement was sufficient to capture the overall impact of the intervention.

This simplified measurement protocol optimized the participants' engagement and ensured high-quality data collection while minimizing psychological burden. As such, the STAI-T and STAI-S scores were measured before the experiment to establish baseline levels, and the STAI-S score postintervention and MSLQ score were measured after the intervention to capture changes in psychological state and motivation.

To ensure smooth participation, the experiment began with a brief adaptation phase using a neutral test video. This allowed participants to familiarize themselves with the platform and controls, minimizing emotional interference caused by unfamiliarity. The participants then proceeded to watch a prerecorded internal medicine lecture (duration: 1,822 s, resolution: 1080p, format: MP4). Using Adobe Premiere, the research team added negative interference units to the videos. Each unit consisted of a 10-second segment simulating audio–video asynchrony with a 4-second audio delay, followed by a 10-second segment of video stuttering, with both the audio and video freezing.

The participants were randomly assigned to one of the following three groups:

1. Control group (no interference): The video contained no negative interference units.
2. Moderate interference group (VQ1): The video included three interference units at 300, 800, and 1,500 s.
3. Severe interference group (VQ2): The video contained six interference units at 200, 400, 700, 1,100, 1,400, and 1,800 s (see Fig. 2).

Each participant received the assigned video according to their group allocation and was instructed to download it before the experiment to avoid technical issues. The participants were also required to ensure device compatibility following the playback guidelines to reduce the likelihood of malfunctions.

To maintain standardization, all the participants watched the videos during the same time period. The Tencent Video Player was used as the unified playback platform, with the following minimum device specifications: a screen size of at least 13 inches, a resolution of 1080p or higher, and the use of high-quality external headphones for optimal audio output. The participants were asked to view the videos in their usual learning environments to minimize environmental interference. Most participants opted to watch videos in study rooms equipped with individual booths, ensuring a distraction-free setting. A short break was included during the video to reduce fatigue and ensure data accuracy.

After completing the intervention, the participants were required to fill out the STAI-S postintervention questionnaire to measure their state anxiety. They also completed the MSLQ questionnaire to assess their learning motivation and strategy use. The questionnaire data were automatically recorded and stored, with each participant assigned a unique ID for traceability. To encourage full participation and minimize dropout, small incentives were provided to the participants.

Following the completion of the questionnaires, the participants were given a brief relaxation session featuring a lighthearted video to help alleviate emotional tension. Although this session did not affect the experimental data, it reflected the research team's care for participants' well-being and helped maintain positive research experience.

Measures

This study employed the State-Trait Anxiety Inventory (STAI) and the Chinese version of the Motivated Strategies for Learning Questionnaire (MSLQ-CAL) to assess participants' psychological state and learning motivation.

State-trait anxiety inventory (STAI)

The STAI consists of two subscales: the State Anxiety Inventory (STAI-S) and the Trait Anxiety Inventory (STAI-T). The STAI-S measures participants' immediate anxiety levels during testing or under hypothetical

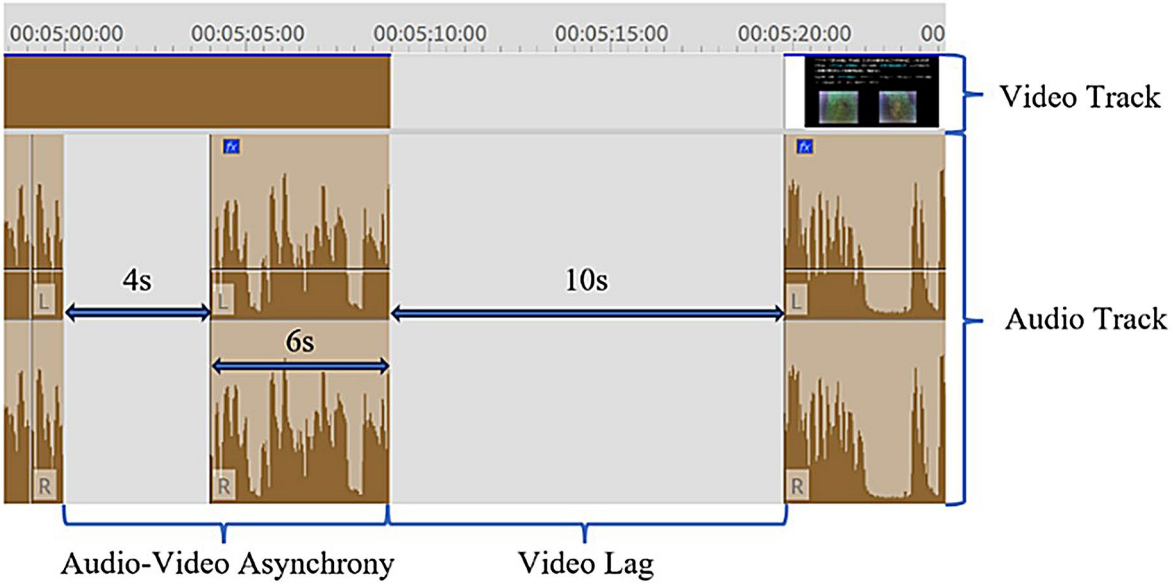

Fig. 2 Video quality control unit (This figure illustrates the structure of the Video Quality Control Unit used in the study. The video and audio tracks were manipulated to introduce simulated disruptions reflecting common online learning issues. Each unit contains two types of interference:1.Audio-Video Asynchrony: The first segment introduces a 4-second delay in the audio stream, resulting in a mismatch between the audio and video tracks. An additional 6-second segment maintains this asynchrony to amplify the disruption's impact on participants' perception;2.Video Lag: Following the asynchrony, a 10-second segment depicts complete video freezing or missing frames, where the audio track continues without corresponding visual content.These units were embedded periodically within the recorded medical lecture video to create controlled disruptions for different experimental conditions. This design ensures consistent exposure to both audio-video desynchronization and video lag, mimicking real-world technical difficulties in online learning environments)

scenarios, whereas the STAI-T assesses individuals' general tendency toward anxiety and long-term anxiety levels.

In this study, the Chinese version of the STAI was used, which has demonstrated high reliability and validity among Chinese college students, particularly medical students [9–11]. Each subscale includes 20 items rated on a 4-point Likert scale (1 = "Not at all" to 4 = "Very much so"). The STAI-S served as the dependent variable to assess changes in participants' immediate anxiety before and after the intervention. The STAI-T was used as a covariate to explore how participants' long-term anxiety traits influenced the effectiveness of the intervention.

Chinese version of the motivated strategies for learning Questionnaire (MSLQ-CAL)

The MSLQ-CAL is an adaptation of the English version of the MSLQ by Pintrich (1991) and is designed to align with the learning characteristics of Chinese college students [12]. It measures students' self-regulation abilities and has undergone exploratory and confirmatory factor analyses to ensure high reliability and validity.

The motivation subscale consists of six latent dimensions, self-efficacy, task value, test anxiety, extrinsic motivation, positive confidence, and negative confidence, comprising a total of 25 observed variables. The model fit indices are CFI = 0.880, SRMR = 0.057, and RMSEA = 0.059, indicating an acceptable model fit.

The learning strategies subscale contains nine latent dimensions, such as rehearsal strategies, elaboration strategies, critical thinking, self-regulation, time management, and learning environment management, with a total of 27 observed variables. The model fit indices are CFI = 0.896, SRMR = 0.044, and RMSEA = 0.046, indicating good reliability and validity.

In this study, participants completed the MSLQ-CAL after watching the intervention videos. The questionnaire was rated on a 7-point Likert scale (1 = "Not at all like me" to 7 = "Very much like me"), which was used to assess the impact of video quality on participants' motivation and learning strategies. The mean scores from the MSLQ-CAL were analyzed to identify differences in learning motivation and strategies across experimental groups and between genders.

Data collection and storage

All questionnaire responses were automatically collected and stored in a deidentified format within electronic spreadsheets. This ensured data integrity and facilitated subsequent statistical analysis and report writing.

Statistical methods

The data were comprehensively analyzed via the Python programming language (version 3.11), along with relevant statistical libraries, including Pandas, Seaborn, Scipy, and Statsmodels. The Shapiro–Wilk normality test was first applied to assess whether the data followed a normal distribution. For continuous variables with a normal distribution, the data are presented as the means ± standard deviations (SDs). Categorical variables are expressed as frequencies and percentages [n (%)]. The homogeneity of groups and genders was assessed via chi-square tests (χ^2) and Welch's t tests, with the significance level set at $\alpha = 0.05$.

A linear mixed-effects model (LMM) was used to evaluate both the main and interaction effects. In the model, the STAI-S score was treated as the dependent variable, while group and gender were included as fixed effects, and their interaction was also examined. Age was included as a covariate to control for potential confounding effects. Parameter estimation was performed via maximum likelihood estimation (MLE), and the Satterthwaite approximation was used to calculate degrees of freedom. The covariance matrix followed a compound symmetry structure, and the iteration limit was set to 100 with a 95% confidence level. The analysis procedure was as follows: First, the group × sex interaction effect was tested. If the interaction was significant, post hoc tests were conducted. If the interaction was not significant, the model was reverted to test for main effects, with Bonferroni correction applied for multiple comparisons.

Additionally, multiple linear regression analysis was performed to examine the predictive value of group, sex, STAI-T score, and STAI-S score before and after surgery. In the regression model, the dependent variable was the postintervention STAI-S score, and the independent variables were the MSLQ score, STAI-T score, and group. The significance level for the regression model was set at $\alpha = 0.05$. The results are reported with regression coefficients (β), standard errors (SE), t values, p values, and 95% confidence intervals (CIs).

To identify potential multicollinearity, variance inflation factors (VIFs) were calculated for each independent variable. A VIF < 5 indicated no severe multicollinearity, whereas a VIF ≥ 10 suggested that multicollinearity might affect the model interpretability. In cases of multicollinearity, variables with high VIFs are either excluded or adjusted via ridge regression.

A Pearson correlation analysis was conducted to assess the relationship between the STAI-S and the MSLQ. If a significant correlation was found, multivariate analysis of variance (MANOVA) was performed to explore the effects of the independent variables on both the STAI-S and the MSLQ. The significance level for MANOVA was set at $\alpha = 0.05$. For significant group differences, post hoc tests were applied, with Bonferroni correction where appropriate.

This study adheres to the Consolidated Standards of Reporting Trials (CONSORT 2010) guidelines, ensuring transparency and reproducibility in both experimental design and statistical analysis.

Results

Baseline characteristics

The baseline characteristics of the participants, including sex, age, baseline state anxiety (STAI-S pre), and trait anxiety (STAI-T), were analyzed to assess the degree of homogeneity among the three groups (control, VQ1, and VQ2). The results indicated no significant differences across the groups for any of the baseline variables. Specifically, there were no significant differences in sex distribution, age, baseline state anxiety, or trait anxiety among the three groups. These findings suggest that the randomization process was successful and that the groups were comparable at baseline, with no significant variability in the general characteristics or study variables (see Table 1).

Impact of video quality and trait anxiety on state anxiety levels

The results show that different video quality groups had a significant effect on participants' postintervention state anxiety (STAI-S postintervention) (see Table 2). Even after controlling for baseline state anxiety (STAI-S pre), trait anxiety (STAI-T), and gender, video quality remained a significant predictor of postintervention state anxiety. The linear mixed-effects model (LMM)

Table 1 Homogeneity test of general characteristics and study variables among the 3 groups

Variable	Total ($N = 93$)	Control ($n = 33$)	VQ1 ($n = 29$)	VQ2 ($n = 31$)	F (df)	χ^2 (df)	P value
Gender							
Female, n (%)	57 (61.3%)	21 (63.6%)	17 (58.6%)	19 (61.3%)		0.163 (2)	0.921
Male, n (%)	36 (38.7%)	12 (36.4%)	12 (41.4%)	12 (38.7%)			
Age (yr), Mean (SD)	19 (0.33)	18.93 (0.33)	19.05 (0.37)	19.02 (0.26)	1.5 (2, 66)		0.227
STAI-S Pre, Mean (SD)		38.76 (2.19)	38.55 (2.77)	40.85 (5.22)	2.87 (2, 90)		0.062
STAI-T, Mean (SD)		41.74 (5.51)	42.25 (5.25)	40.99 (4.46)	0.43 (2, 90)		0.651

Control= control group, VQ1 = Video-quality Group 1 (Moderate video quality issues group), VQ2 = Video-quality 2 (Severe video quality issues group), SD = standard deviation

Table 2 Linear mixed effects model results

Variable	Coefficient (Coef.)	Std. Error (Std.Err.)	z-Statistic (z)	*p*-Value (*P*>|z|)	95% Confidence Interval (CI)
Intercept	44.4	1.13	39.27	< 0.001	[42.18, 46.62]
Group[T.VQ1]	3.1	1.44	2.15	0.032	[0.27, 5.93]
Group[T.VQ2]	5.97	1.41	4.24	< 0.001	[3.21, 8.73]
Gender[T.Male]	1.51	1.6	0.94	0.346	[-1.63, 4.66]
Group[T.VQ1] × Male	-1.05	2.32	-0.45	0.651	[-5.60, 3.50]
Group[T.VQ2] × Male	0.82	2.3	0.36	0.721	[-3.68, 5.33]
STAI_T	-0.068	0.005	-13.98	< 0.001	[-0.078, -0.059]

Table 3 OLS regression results

Variable	Coefficient (Coef.)	Std. Error (Std.Err.)	t-Statistic (t)	*p*-Value (*P*>|t|	95% Confidence Interval (CI)
Intercept (const)	4.204	3.777	1.113	0.269	[-3.304, 11.712]
Group_VQ1	2.8953	0.651	4.45	< 0.001	[1.602, 4.188]
Group_VQ2	4.2969	0.657	6.538	< 0.001	[2.991, 5.603]
Gender_Male	0.4229	0.552	0.766	0.446	[-0.674, 1.520]
STAI_T	-0.0126	0.053	-0.237	0.813	[-0.118, 0.093]
STAI_S_Pre	0.9873	0.075	13.18	< 0.001	[0.838, 1.136]

revealed that participants in the moderate interference group (VQ1) had significantly greater state anxiety than did those in the control group (coefficient = 3.10, $p = 0.032$, 95% CI = [0.27, 5.93]). The participants in the severe interference group (VQ2) showed an even greater increase in state anxiety (coefficient = 5.97, $p < 0.001$, 95% CI = [3.21, 8.73]). These results indicate that declining video quality leads to higher levels of state anxiety, with more severe interference causing greater anxiety increases.

While the state anxiety levels varied significantly across video quality groups, the main effect of gender was not significant (coefficient = 1.51, $p = 0.346$, 95% CI = [-1.63, 4.66]). Similarly, the interaction effect between video quality and gender was not significant. This suggests that video quality influenced anxiety levels similarly for both male and female participants. For example, the interaction effect of VQ1 × Male was not significant (coefficient = -1.05, $p = 0.651$, 95% CI = [-5.60, 3.50]), nor was the interaction effect of VQ2 × Male (coefficient = 0.82, $p = 0.721$, 95% CI = [-3.68, 5.33]). These findings indicate that participants of different genders presented similar patterns of anxiety when exposed to deteriorating video quality.

The analysis also revealed that trait anxiety (STAI-T) significantly predicted state anxiety levels (coefficient = -0.068, $p < 0.001$, 95% CI = [-0.078, -0.059]). Surprisingly, there was a negative correlation between trait anxiety and postintervention state anxiety. This suggests that participants with higher trait anxiety levels exhibited lower state anxiety during the intervention. One possible explanation is that individuals with greater trait anxiety may develop better short-term adaptability under external stress. Another possibility is that their chronic anxiety was not triggered further by the specific situational stressors used in this experiment.

These results highlight that external environmental factors, such as video quality, had a stronger influence on participants' state anxiety than did individual traits. Even participants with higher trait anxiety experienced significant fluctuations in state anxiety depending on the quality of the video.

In conclusion, video quality had a significant effect on state anxiety levels, and this effect was not moderated by gender. Participants with higher trait anxiety (STAI-T) were still influenced by the external environment. These findings underscore the importance of video quality as a short-term external factor affecting immediate anxiety responses.

Baseline state anxiety and trait anxiety as key predictors of postintervention state anxiety

The results from multiple linear regression analysis indicate that baseline state anxiety (STAI-S pre) and trait anxiety (STAI-T) play important roles in predicting postintervention state anxiety (STAI-S post). The regression model revealed that pre-STAI-S score was a significant predictor of post-STAI-S score (coefficient = 0.987, $p < 0.001$, 95% CI = [0.838, 1.136]) (see Table 3). This finding suggests that participants with higher levels of state anxiety before the experiment tended to have higher state anxiety levels after the intervention. As a key individual variable, baseline state anxiety significantly explained differences in postintervention anxiety, highlighting the long-lasting impact of participants' initial emotional state on experimental outcomes.

Although trait anxiety (STAI-T), which reflects long-term anxiety tendencies, was included in the regression model, its predictive effect on postintervention

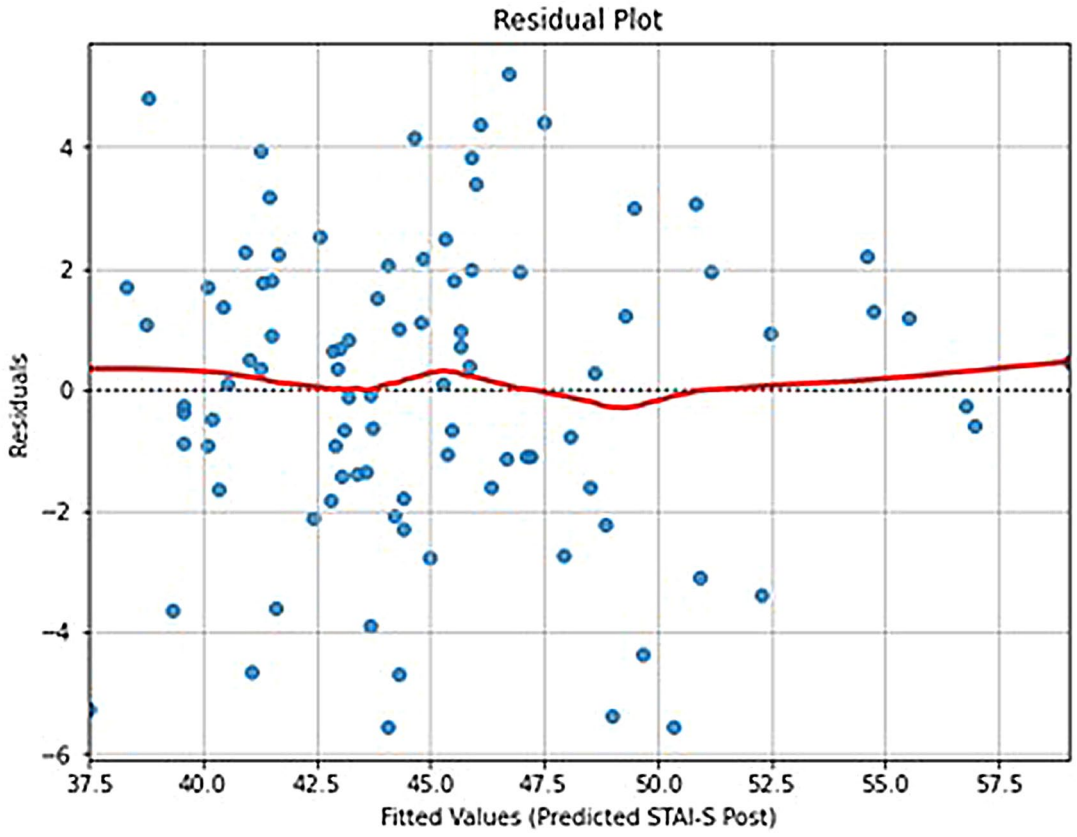

Fig. 3 LMM Residual Plot. (This residual plot assesses the goodness-of-fit of the linear mixed-effects model (LMM) used to predict post-intervention state anxiety (STAI-S) scores. The plot displays the residuals (difference between observed and predicted values) against the fitted values. A relatively random distribution of residuals around the zero line suggests that the model adequately captures the relationship between video quality and state anxiety. As indicated by the LMM results, both VQ1 and VQ2 groups exhibited significantly higher anxiety levels compared to the control group, with coefficients of 2.895 ($p < 0.001$, 95% CI = [1.602, 4.188]) and 4.297 ($p < 0.001$, 95% CI = [2.991, 5.603]), respectively. The increasing anxiety trend aligns with the decrement in video quality, further validating the model's fit)

state anxiety was not significant (coefficient = -0.0126, $p = 0.813$, 95% CI = [-0.118, 0.093]). This result indicates that participants with higher trait anxiety, while generally more prone to state anxiety, did not exhibit significantly higher anxiety levels after the intervention. In the context of changing video quality and experimental settings, the ability of long-term anxiety tendencies to predict postintervention anxiety was limited.

The regression model also revealed that gender was not a significant predictor of postintervention state anxiety (coefficient = 0.423, $p = 0.446$, 95% CI = [-0.674, 1.520]). This finding aligns with the results from the mixed-effects model, confirming that gender was not a major factor influencing state anxiety levels after the intervention.

Further analysis of group effects revealed that participants in both the VQ1 (moderate interference) and VQ2 (severe interference) groups had significantly greater postintervention state anxiety than did those in the control group. The coefficient for VQ1 was 2.895 ($p < 0.001$, 95% CI = [1.602, 4.188]), whereas the coefficient for VQ2 was 4.297 ($p < 0.001$, 95% CI = [2.991, 5.603]). These findings indicate that as video quality deteriorated, participants' state anxiety increased, with the negative impact of poor video quality becoming more pronounced in the VQ2 group than in the VQ1 group.

The R^2 value of the regression model was 0.764, indicating that the model explained 76.4% of the variance in postintervention state anxiety. This suggests that the model has strong explanatory power and reliability in capturing the relationship between the independent variables and the outcome variable. The residual analysis revealed no significant systematic bias in the residual distribution, further supporting the model's validity (see Fig. 3).

In summary, multiple linear regression analysis confirmed the critical role of baseline state anxiety (STAI-S pre) in predicting postintervention state anxiety. This study also highlighted the significant influence of video quality on anxiety levels, with greater interference leading to greater anxiety. These findings are consistent with the results from the mixed-effects model, emphasizing the importance of both initial emotional state and

external environmental factors in shaping participants' state anxiety.

No significant correlation was found between learning motivation (MSLQ) and state anxiety

This study used Pearson correlation analysis to examine the relationship between learning motivation (MSLQ) and postintervention state anxiety (STAI-S post). The analysis yielded a correlation coefficient of $r = 0.0818$ with a p value of 0.4359, indicating that there was no significant linear relationship between the two variables. This result suggests that although different video qualities may influence learning motivation, there was no significant association between participants' learning motivation and their immediate state anxiety following the experiment.

These findings imply that participants' learning motivation after watching the videos was not significantly related to their immediate state anxiety levels. Theoretically, both the MSLQ and the STAI-S may be influenced by different psychological and environmental factors, and their relationships may not follow a simple linear pattern.

Additionally, since the MSLQ score was measured after the experiment, it reflects participants' subjective evaluation of their motivation and learning strategies, whereas the STAI-S score captures participants' immediate anxiety at the time of completing the experiment. The difference in measurement timing could partly explain the lack of significant correlation between the two variables. Owing to this timing difference, the MSLQ was not included in the regression model but was instead analyzed independently via Pearson correlation to explore its relationship with state anxiety.

This finding highlights the need for future research to explore the potential complex relationship between learning motivation and anxiety at different times and in various contexts. For example, future studies could investigate whether anxiety has a delayed effect on long-term learning motivation or whether other mediating variables might influence the relationship between these two factors.

Discussion

Relationship between video quality and state anxiety

This study revealed that video quality significantly influenced participants' state anxiety levels. In particular, under conditions of audio–video asynchrony and video stuttering (VQ2 group), participants experienced a significant increase in state anxiety. This finding aligns with cognitive load theory (CLT), which posits that external disruptions increase learners' cognitive load, thereby increasing emotional stress [13]. Previous studies have similarly shown that technical issues, such as video stuttering and network delays, disrupt students' learning rhythm and heighten frustration, contributing to emotional pressure [14]. These results underscore the importance of maintaining high technical quality in video design and teaching platforms to safeguard learners' positive emotional states and mental well-being.

While the findings align with those of prior research, this study makes a unique contribution by focusing on Chinese undergraduate medical students and refining key variables. First, this study extends research on the impact of video quality by investigating its effects within a specialized academic context. This provides a foundation for future interdisciplinary research to validate how video quality influences students' psychological states. Second, the study simulated two specific disruptions—audio-video asynchrony and video stuttering—and explored both their independent and combined effects. This nuanced approach offers practical guidance for optimizing video design and providing technical support for online learning platforms. Unlike prior studies that typically focus on general technical failures, this research highlights the distinct psychological effects of specific disruptions, offering insights for educational improvements.

The results also reveal a cumulative effect between video quality and state anxiety. As disruptions worsened, participants' state anxiety levels increased. This finding supports existing theoretical frameworks while emphasizing that multiple disruptions can accumulate to amplify psychological distress. Future research could further explore how different types of disruptions accumulate or interact over long-term online learning to affect students' emotions and learning experiences. Additionally, future studies could investigate whether students develop a tolerance mechanism—adapting to some disruptions over time and experiencing reduced psychological impact. Conversely, some types of disruptions may have more lasting psychological effects that intensify with prolonged exposure.

The relationship between gender and state anxiety

Although some studies suggest that women tend to exhibit higher anxiety levels in certain situations [15], this study revealed no significant interaction effect between video quality and gender. This result aligns with the findings of Pereira et al. (2022), who reported that medical students, regardless of gender, develop similar emotional coping mechanisms because of their prolonged exposure to high-pressure learning environments [16]. The findings suggest that emotional responses to video disruptions were not significantly different between male and female participants.

The lack of sex differences may be related to the unique characteristics of medical education. Students in high-pressure academic environments may develop

comparable emotional regulation and adaptive strategies over time, irrespective of gender. This result offers a new avenue for future research—to explore whether gender differences emerge under similar experimental conditions in other academic disciplines or among students in nonmedical fields.

The predictive role of trait anxiety and baseline state anxiety

This study revealed that both trait anxiety (STAI-T) and baseline state anxiety (STAI-S pre) significantly predicted postintervention state anxiety (STAI-S post). Previous studies have also shown that individuals with higher levels of long-term anxiety tend to be more susceptible to external stimuli in the short term [17]. However, this study also revealed that situational pressure—such as video disruptions—had a stronger effect on state anxiety than on long-term trait anxiety. This suggests that even individuals with high trait anxiety experience noticeable immediate anxiety when exposed to external disruptions, such as video quality issues. This result aligns with the findings of Brosschot et al. (2006), who highlighted the triggering effect of external stressors on immediate emotional responses [18].

Interestingly, the findings also revealed that students with greater trait anxiety may demonstrate better psychological adaptability when facing short-term disruptions. This challenges conventional views, suggesting that individuals with greater anxiety may develop more effective coping strategies under specific conditions. This phenomenon could be closely related to the characteristics of medical students. Research has shown that medical students often exhibit greater psychological resilience when facing anxiety and display strong adaptive abilities during posttraumatic growth processes [11].

Future research could explore the dynamic adaptability mechanisms of anxiety, focusing on how individuals with chronic anxiety respond to short-term stress and the potential role of psychological resilience in this process. Understanding these emotional coping patterns could offer new insights into managing anxiety in educational settings and beyond.

Relationships between learning motivation and state anxiety

The study revealed no significant linear correlation between learning motivation (MSLQ) and postintervention state anxiety (STAI-S post). This finding aligns with the research of Schunk and DiBenedetto (2020), who argued that learning motivation is influenced by multiple factors, such as the learning environment and social support, rather than solely by immediate psychological states [19].

Additionally, in this study, learning motivation was measured after the experiment, reflecting participants' self-assessed motivation and learning strategies. In contrast, state anxiety captured participants' immediate emotional state after watching the videos. The difference in the timing of these two measurements may explain the lack of a significant correlation between them.

This finding suggests that future research could adopt a longitudinal design to explore the long-term relationship between learning motivation and anxiety. Researchers could also investigate whether mediating variables play a role in moderating the relationship between these two constructs. Such an approach may provide deeper insights into the complex interplay between motivation and anxiety in educational settings.

Limitations and future directions

This study has several limitations. First, the sample was limited to undergraduate medical students from a single center, which may limit the generalizability of the findings. Future studies should validate these results across different disciplines and regions. Second, although the simulated video disruptions closely resembled real-world conditions, they could not fully capture the complexity of actual online education environments, such as the combined impact of multiple network failures and platform-specific technical issues. Third, the study employed a short-term experimental design, which captured only participants' immediate state anxiety. This study did not explore the potential long-term effects of video quality on students' psychological well-being or academic performance.

The time discrepancy between the measurements of learning motivation and state anxiety may have influenced the accuracy of the correlation analysis. Future research could adopt multiple time-point measurements to better capture the dynamic nature of psychological changes. Furthermore, the study relied on self-report questionnaires to assess psychological states and motivation, which could introduce subjective bias. Future studies could integrate physiological data (e.g., heart rate variability or skin conductance) to increase the reliability and validity of the findings.

The gender analysis was restricted to binary categories (male and female), without considering the influence of gender diversity on psychological responses. Future research could adopt more inclusive gender frameworks to explore how different gender identities shape emotional and motivational responses to video disruptions. Additionally, the study did not account for individual factors such as cultural background or family circumstances, both of which could affect students' emotions and motivation during the learning process. Although efforts have been made to standardize viewing conditions, differences

in learning environments—such as noise levels, lighting, or device quality—may still have influenced the results.

To further refine and expand the conclusions of this study, future research should implement longitudinal designs, conduct replication studies across disciplines, and perform experiments in real-world educational settings. These efforts will enhance the effectiveness of online education and provide empirical evidence for optimizing learning experiences and mental health support for students.

Conclusion

This study demonstrates the significant impact of video quality on the state anxiety of medical students, underscoring the importance of high-quality video technology in online education. While the findings align with those of previous studies, this study provides new empirical insights by examining the specific effects of audio–video asynchrony and video stuttering. These insights offer practical guidance for improving the design and functionality of online teaching platforms.

Additionally, the results regarding trait anxiety suggest that individuals with higher anxiety levels may exhibit better adaptability when facing short-term stressors. The nonsignificant effect of gender on state anxiety indicates that male and female medical students may develop similar coping strategies under stressful academic conditions. This finding encourages future research to explore the interaction between academic disciplines and gender to further understand these dynamics.

In summary, this study confirms the relationship between video quality and state anxiety and expands its application within the context of medical education. Future research could investigate the long-term relationship between learning motivation and anxiety through longitudinal designs, uncovering interaction effects between different variables. These efforts will support educational institutions in optimizing teaching resources, enhancing students' mental health, and improving their learning experience.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-025-06795-7 .

Supplementary Material 1

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Author contributions
Yu Li and Jinyan Shao carried out the studies, collected the data, and drafted the manuscript. Yu Li and Qingqing Fang performed the statistical analysis and participated in its design. Wei Jiang and Ying Chen participated in the acquisition, analysis, or interpretation of the data and drafted the manuscript. All the authors read and approved the final manuscript.

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Data availability
The authors declare that the data supporting the findings of this study are available within the paper. The data are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics Committee of Minhang Hospital, Fudan University (Ethics approval number: 2024-pijian-041-01k) and was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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