



# Exploring the complex pathways between somatosensory impairment, physical ability and affective symptoms following stroke: mediation analyses

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**Background:** Based on the theory of postural control and the role of cognitive capacity, this study analyses how physical ability and somatosensory impairment influence affective symptoms in patients with stroke.

**Methods:** The cross-sectional study with a consecutive sampling approach was conducted in 10 different rehabilitation departments in Yunnan Province, China between August 2019 and February 2021. A total of 1,058 patients with stroke were included according to the inclusion criteria and exclusive criteria. Their important functions were evaluated including somatosensory measurement, Brunnstrom recovery stage, manual muscle testing (MMT), Barthel index (BI), mini-balance evaluation systems test (Mini-BEST), Montreal Cognitive Assessment (MoCA), Hamilton Anxiety Scale (HAM-A), and Hamilton Depression Scale (HAM-D). Exploratory Factor Analysis was used to construct the measure models. A path analysis was performed to estimate the role of balance impairment and cognitive capacity as mediators in the relationships between somatosensory impairment, physical ability and affective symptoms.

**Results:** By comparing two models, the final model indicated a good global model fit to the data [ $\chi^2=243.5$ ,  $\chi^2/df=5.181$ , goodness-of-fit index (GFI) =0.977, comparative five index (CFI) =0.944, Tucker-Lewis index (TLI) =0.922, standardized root mean square residual (SRMR) =0.063, and root mean square error of approximation (RMSEA) =0.063, Akaike information criterion (AIC) =303.51, Bayesian information criterion (BIC) =304.26], although Chi-square test was not significant due to the large sample size. In the path analysis, somatosensory impairment significantly negative influenced balance impairment ( $P<0.05$ ,  $\beta=-0.061$ ), and physical ability significantly positively affected balance impairment ( $P<0.001$ ,  $\beta=0.893$ ). A mediation analysis was conducted to show that balance impairment mainly mediated the relationship between physical ability and affective symptoms ( $R^2=0.996$ ), while the relationship between physical ability and affective symptoms was mediated slightly by cognitive capability ( $R^2=0.108$ ).

**Conclusions:** These results suggest that balance impairment mainly mediates the relationship between physical ability and affective symptoms, while cognitive capacity slightly medicates this relationship. Rehabilitation professionals and family caregivers should pay more attention to balance function, which will help to strengthen the physical ability and improve post-stroke mood disorders.

**Keywords:** Mediation analysis; mood; cerebrovascular disease; balance

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## Introduction

Stroke is the third most common cause of disability of disability-adjusted life-years (DALYs) from all-cause after ischemic heart disease, according to the Global Burden of Disease (GBD) 2013 stroke burden report (1-3). Anxiety and depression are the most common issues in post-stroke patients (4-6), and the prevalence of post-stroke depression (PSD) is 31.1%, and post-stroke anxiety (PSA) 20.4% in Germany (7). Furthermore, these features frequently lead to worse activities of daily living (ADL) or quality of life. Li *et al.* found anxiety and depression scores were meaningful predictors for ADL and quality of life (8). Therefore, improving anxiety or depression is critical to improving overall health and quality of life in patients after stroke. In this context, affective symptoms are defined as one's symptoms and disorders of mood (e.g., anxiety, depression).

It has been reported that most patients after stroke suffer from disabilities, such as motor impairment, muscles weakness, and balance disorder (9). Physical disability resulting from the stroke such as poor physical prowess and quality of life can directly affect post-stroke mood disorders (10). A recent study found that limb-extremity motor impairments were also associated with depressive symptoms (11). Boudokhane *et al.* demonstrated that the severity of physical function was a significant factor in predicting health-related quality of life in patients with stroke (12), and in another study, strong correlations were established among depression, balance, and physical performance (13). Similarly, impaired movement may result in poor quality of life, which in turn caused stress, anxiety, vulnerability, and frustration to patients and families. Thus, rehabilitation professionals especially pay attention to muscle strength, the flexibility of a joint, and patients' daily life functioning. Yuan *et al.*, for example, found that improving muscle strength in patients with stroke can be beneficial for the management of patients with mental health disorders (14). Therefore, in the study, we assume that physical activity is negatively associated with affective symptoms.

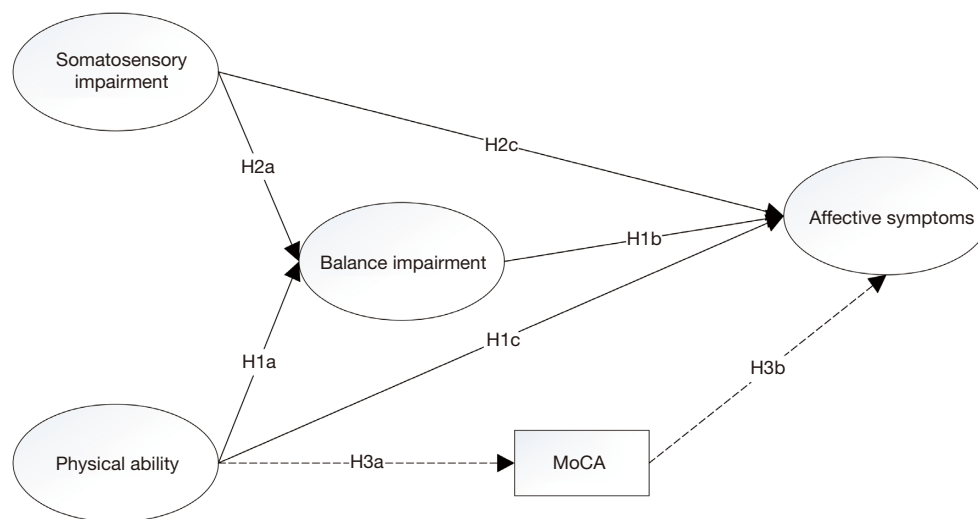
Nevertheless, in terms of somatic sensation, studies focusing on the correlation between somatosensory impairment and depression or anxiety are few concerning

patients with stroke. Impaired sensory function is indirectly associated with mood disorders. For example, neuropathic pain syndromes have the characteristics of unique sensory symptoms, such as hyperalgesia, burning pain, and dysesthesias, which frequently occur in combination with psychiatric disorders (15). Thus, we propose that somatic sensation may negatively influence affective symptoms.

Summing up the above discussion, the first purpose of this study is to elucidate the mechanism through which physical ability and somatosensory impairment influence affective symptoms in patients with stroke.

According to the theory of postural control, it is proposed by Massion in 1992, holding that maintaining equilibrium is base for the postural support for the movement. It also highlights that during a given motor act, the central nervous system has to not only coordinate posture and movement but also coordinate posture and equilibrium (16). The postural control theory has been developed extensively in recent decades. Likewise, core stability is derived from this theory. It is widely accepted that core stability is important for improving athletic function. In 2006, Kibler *et al.* suggests that core stability is pivotal for rehabilitation because it is the base for extremity function (17). It may be concluded that balance is a critical and complex skill integrating many physiological system such as mobility, postural stability, autonomic nervous system (18). Consequently, we assume that balance impairment can mediate the relationship between physical ability and affective symptoms and the relationship between somatosensory impairment and affective symptoms.

At first, we theorize this relationship by drawing on the theory of postural control. The theory discusses that trunk stability is one of the essential components of balance, which plays a vital role in improving sitting and standing balance, gait, and ADL for all people including children, older persons, and post-stroke subjects (19-21). Clinically, the prevalence of balance impairment was 48.1% post-stroke (22). Balance is crucial to maintaining functional activities during sitting and standing. Postural control and sitting balance have been reported to be significant predictors of discharge after stroke (23-28), and balance disorders indicate links between falls and mood disorders (29). For example, poor trunk stability leads to



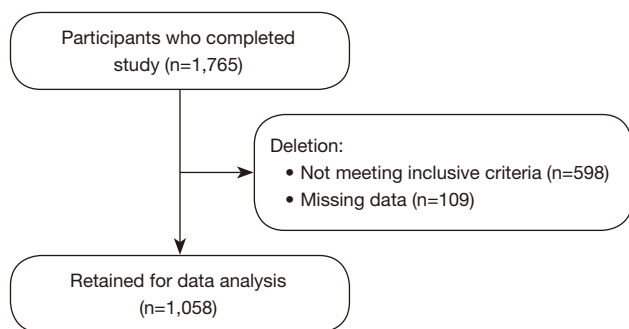
**Figure 1** The competing model. The solid lines represent model 1. Based on the model 1, solid lines combine with dotted lines represent model 2. MoCA, Montreal Cognitive Assessment.

balance disorders as a result of falls, and fall events induce anxiety or depression in patients. Thus, recurrent falls could be directly linked with anxiety or depression (21) and even cause adverse effects on ADL or quality of life (30). Furthermore, Alghwiri *et al.* concluded that better balance ability and physical performance were associated with lower depression scores (13), while French *et al.* found depression symptoms moderate between the relationship physical capability and balance self-efficacy (31). Despite these studies have not directly indicated that balance function mediates the relationship between physical ability and affective symptoms, they do suggest an association between them. Consequently, the second purpose of this study is to elucidate the balance function is a mediator through which physical ability influences affective symptoms in patients with stroke. What's more, one review illustrates that postural stability is associated with autonomic regulation, because they may share neural substrates (18). Considering the autonomic nervous system participating in postural control, we assume that somatic sensation may influence affective symptoms through balance function for patients with stroke.

In addition to the theory of postural control, we especially focus on cognitive ability. This is a fact that cognitive capability has played an important role in the ability to live independently after a stroke (32). A cross-sectional study of older women showed that those who had been inactive physically across the life course may have poorer cognitive performance. This finding also indicated

early-life physical activity may be associated with a lower risk of cognitive impairment in old age (33), which in turn may suggest that physical disability may influence the decrease of cognitive capability. Besides, cognitive impairment has been found to be related to poststroke depression (34). Thus, we propose that physical ability may also affect mood through cognitive capability for stroke patients.

In summary, the aim of this study is threefold. Firstly, we explore the relationship between physical ability, somatosensory impairment and affective symptoms. Secondly, we explore the mediating effect of the balance impairment on the relationship between physical ability and affective symptoms, and the relationship between somatosensory impairment and affective symptoms. Thirdly, we explore the mediating effect of cognitive capability on the relationship between physical ability and affective symptoms. Therefore, we hypothesized that (I) physical ability was negatively associated with affective symptoms (H1c), and somatosensory impairment was positively associated with balance impairment (H2c); (II) balance impairment could mediate the relationship between physical ability and affective symptoms (H1a, H1b) and the relationship between somatosensory impairment and affective symptoms (H2a, H1b); (III) cognitive capacity may mediate the relationship between physical ability and affective symptoms (H3a, H3b) (*Figure 1*). We present the following article in accordance with the STROBE reporting checklist (available at <https://apm.amegroups.com/article/>



**Figure 2** Flowchart of the selection processes.

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## Methods

### Participants

Our study was a multicenter cross-sectional clinical trial and used the consecutive sampling method to recruit participants. A total of 1,765 participants with a diagnosis of stroke were enrolled from 10 different inpatient rehabilitation departments, including the Second People's Hospital of Kunming City, St. John's Rehabilitation Hospital, the People's Hospital of Xiping County, the People's Hospital of Yuxi City, the First People's Hospital of Qujing City, the People's Hospital of Kaiyuan City, Kaiyuan Workers' Hospital, the People's Hospital of Lufeng County, the People's Hospital of Baoshan City, the Second Affiliated Hospital of Kunming Medical University, in various cities across Yunnan Province between August 2019 and February 2021. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) (35). The research was approved by the ethics committee of the Second Affiliated Hospital of Kunming Medical University (No. PJ-2019-04). All participating hospitals were informed and agreed to the study. Informed consent was taken from all the patients. The inclusion criteria were as follows: (I)  $\geq 18$  years old; (II) patients diagnosed with stroke (ischemic or hemorrhagic) confirmed by a neurologist with radiological evidence by either computed tomography (CT) scan and/or magnetic resonance imaging (MRI); (III) stroke of more than one month; (IV) stable non-fluctuating stroke with no acute ongoing neurological development; (V) signed an informed consent. The exclusion criteria were as follows: (I) major depressive or anxiety disorder before stroke; (II) malignancies; (III) severe disease including dementia,

loss of consciousness, or renal, hepatic, or heart disease. Finally, 1,058 eligible participants were included, and their important functions were evaluated on the day of admission and discharge using various validated scales addressing physical activity function, somatosensory function, cognitive capability, and functional balance performance (Figure 2).

### Assessment

Demographic variables, including the age of onset, gender, lesion location, stroke events, disease duration, medical history, and previous episodes of depression, were collected at the baseline.

### Somatosensory measurement

A somatosensory examination was performed by a senior neurologist. The assessment included three subtests; superficial sensation, deep sensation, and complex sensory function. The superficial sensation consisted of three items (light touch sensation, pain, and temperature sensation), the deep sensation had three items (joint position sensation, vibration sensation, and kinesthesia), and the complex sensory functions had four items (two-point discrimination, stereognosis, graphesthesia, and barognosis). One somatosensory assessment was carried out on the affected upper and lower extremities at the time of admission, and was scored as 0 point (normal), 1 point (decreased), and 2 points (absent or hyperalgesia), with higher scores representing poor sensory disturbance.

### Physical ability measurement

Physical ability was measured using the Brunnstrom recovery stage (BRS), manual muscle testing (MMT), and the Barthel index (BI) assessment.

BRS (36) is used to assess the motor recovery stage of paresis after stroke (37), including upper and lower extremities due to its acceptable concurrent and predictive validity (38). The recovery process was classified into six stages from 1 (flaccidity) to 6 (near-to-normal motor control), and the total score equaled the sum of the stages of the arm, hand, and leg on the affected side. For example, if an individual suffered left hemiplegia, their hand stage was 1, the upper limb stage was 3, the lower limb stage was 3, and the left total score was 7. High scores indicate positive recovery.

MMT (39,40) is the most commonly used instrument

for recording impairment in muscle strength, and consists of six scores from 0 (no contraction) to 5 (normal power). According to the standard procedures, as demonstrated by Hislop and Montgomery (41), the proximal and distal muscle strength in both the upper and lower extremities was assessed by a therapist with 5-year experience. The total score was calculated bilaterally as the sum of all measured muscle groups of elbows (extensors/flexors), wrist (extensors/flexors), hip (extensors/flexors), and knees (extensors/flexors), with a maximum total score of 80. The higher the total score, the better the muscle strength.

BI (42) is regarded as a functional independence tool to measure the patient's functional ability without family and social help. The total score equals the sum of each item in a range of 0–100. Most items were allocated to three grades: 0 (inability to perform the task), 5 (any assistance required), 10 (total independence). High scores represent an enhanced ability to live independently.

### ***Balance measurement***

Balance function was measured using the Lindmark motor capacity assessment for balance (LMCA-B) (43,44), and the scores were verified by an experienced therapist. Two subscales selected to evaluate the function of sitting and standing balance consisted of two items that were scored on a 4-point scale from 0 (cannot sit/cannot stand even with support) to 3 (can sit for 5 min without support/can stand with only slight support of one hand). The total score contains both the sitting and the standing balance scores. A high total score represents better balance function.

The mini-balance evaluation systems test (Mini-BEST) (45) is a developed 14-item scale involving dynamic balance. Each item has three levels: 0 (severe), 1 (moderate), and 2 (normal) and the full score of the test is 28 points. The test assesses several postural control systems through the performance of dynamic balance tasks, such as the capability to react to postural perturbations, to stand on an inclined surface, or to walk while performing a cognitive task. A high score suggests good balance function.

Balance confidence: The activities-specific balance confidence (ABC) scale is a 16-item questionnaire that assesses a patient's level of balance confidence. The score of each item is range from 0 (no confidence) to 100 (complete confidence) (46). The mean of the 16 items is an individual's total ABC-score, and a higher score indicates greater balance confidence in daily activities.

### ***Cognitive measurement***

The Montreal Cognitive Assessment (MoCA) is an effective screening tool to detect patients with cognitive impairment, and is a one-page 30-point test administered in 10 minutes (47,48). The MoCA tests the following eight cognitive domains: memory; visuospatial ability; executive function; attention; naming task; language; abstraction; and orientation in time and place and was standardized for Chinese participants. The maximum score is 30 points, with lower scores indicating poorer cognitive ability.

### ***Affective symptoms measurement***

Affective symptoms include anxiety and depression. Anxiety was measured by the Hamilton Anxiety Scale (HAM-A), and depression was assessed by the Hamilton Depression Scale (HAM-D).

The HAM-A is a 14-item questionnaire (49) commonly used in both clinical and research settings. The items include a series of symptoms and measures representing psychic anxiety and somatic anxiety on a scale of 0 (not present) to 4 (very severe), and high scores indicate high severity in anxiety.

The HAM-D is a 17-item survey (50-52) widely used to clinically quantify the severity of depression. Its scores range from 0 (none) to 4 (very much), with high scores indicating a high severity of depression.

### ***Procedure***

The data were collected by four members over 2 years. Firstly, informed consent was obtained, then various neurological assessment instruments, including somatosensory, physical ability, balance impairment, cognitive capability, affective symptoms, and the quality of life, were selected, and data entered into Excel. Subsequently, 10 hospitals were invited to participate in relevant training programs every 3 months, and two trained investigators made irregular visits to different hospitals to collect information and conduct quality control.

### ***Statistical analysis***

Structural equation modeling (SEM) was conducted with IBM SPSS/AMOS version 23.0. Missing data were contained in some variables for some patients (<10%).



Missing data were assumed to be missing at random and were handled by an imputation process of the maximum likelihood estimation (53). Descriptive statistics was conducted to characterize the participants. The competing models were tested using SEM with latent and observed variables. Latent variables included: (I) physical ability: Brunnstrom, muscle strength, and BI; (II) somatosensory impairment: superficial sensation, deep sensation, and complex sensory function; (III) balance impairment: sitting and standing balance, Mini-BEST, and ABC; (IV) affective symptoms: HAM-D and HAM-A. An Exploratory factor analysis (EFA) was conducted first to construct the measure models. Correlation analysis was performed to evaluate the strength of associations between latent variables and observed variables. Then, the significant observed variables were further analyzed with multiple linear regression analysis to independently explain part of the latent variables. The average variance extracted (AVE) and composite reliability (CR) of each observed variable were calculated to test the convergence validity.

The next stage of the statistical analysis was a path analysis. Based on the above results and proposed hypothesis, a path analysis was conducted to test the relationship between the latent variables. SEM is a multivariate statistical analysis technique including two important stages, the measure model and the structural model. A path analysis, a main analysis in the structural model, is considered as a set of multiple linear regression analysis. Additionally, the structural model was used to estimate the direct and indirect effects of the latent variables proposed. A P value of 0.05 or less indicated statistical significance.

To verify cognitive capability and balance impairment may have the mediating effect between physical ability and affective symptoms, we proposed two competing models to better explain our hypothesis. In model 1, we hypothesized that balance impairment would be a mediator which would affect affective symptoms through somatosensory and physical ability. In this model, we did not take account of cognitive capability. In model 2, the assumptions mentioned above holds, and we added the path that the MoCA variable would be another mediator variable. The physical ability variable may impact the affective symptoms variable through the MoCA variable. In other words, we compared these two models to test the significant effect of the hypothesized causal connections between these relationships on model performance.

The asymptotically distribution-free method was

conducted to assess the measurement and structure model (54). To test whether the model fit the data, Hooper *et al.* suggested the following goodness-of-fit indices (55): the  $\chi^2$  value, the ratio of  $\chi^2$  to the degree of freedom ( $\chi^2/df < 2$ ), the goodness-of-fit index (GFI  $> 0.9$ ), the comparative five index (CFI  $> 0.95$ ), the standardized root mean square residual (SRMR  $< 0.08$ ), the Tucker-Lewis index (TLI  $> 0.95$ ), and root mean square error of approximation (RMSEA  $< 0.06$ ). Multiple model fit statistics were evaluated to determine fit and to provide a robust assessment and overcome limitations of individual tests (56). To compare the most parsimonious model, we used the Akaike information criterion (AIC) and Bayesian information criterion (BIC) to indicate which model was better, and smaller values suggested a good fitting, parsimonious model. Finally, the bootstrap procedure of 2,000 samples for bias-corrected confidence intervals (CI) was used to obtain the significance of overall indirect effects from the model (56).

## Results

### Sample characteristics

The characteristics of study participants are listed in *Table 1*, and their mean age was  $60.8 \pm 12.3$  years. The infarction events included 788 (74.5%) ischemic strokes, 266 (25.4%) hemorrhagic strokes, and four (0.4%) undetermined. MoCA scores revealed the below-average levels of cognitive abilities in this sample as  $17.3 \pm 6.7$ . The average baseline level of anxiety score was  $5.7 \pm 6.0$ , and the average baseline level of depression score was  $5.6 \pm 6.4$ .

### Reliability and validity

#### Measurement model analysis

The factor loadings of the observed variables with their latent variables were examined, and *Table 2* lists these and the P value of the constructs. Typically, the factor loadings should be  $> 0.7$ , and the P value should be  $< 0.05$ , which guarantees the convergent validity of the constructs (57).

The assessment of the convergent validity and discriminant validity of the measurement model depends on examining the standardized path coefficient, the AVE, and the CR (57). The CR should be  $> 0.60$ , and the AVE should be  $> 0.50$  (58). As shown in *Table 2*, the CR from all the constructs is  $> 0.60$ , and the AVE is  $> 0.50$ , which is considered acceptable, as was the convergent validity of the measurement model. According to the Fornell-Larcker

**Table 1** Participants' demographic and physical and mental status related characteristics

Characteristics	n (%) / mean $\pm$ SD
Age, years	60.8 $\pm$ 12.3
Male	679 (64.2)
Course of the disease (d)	102.4 $\pm$ 431.5
Stroke events	
Ischemic stroke	788 (74.5)
Hemorrhagic stroke	266 (25.4)
Undetermined	4 (0.4)
Stroke lesion sites	
Left	516 (48.8)
Right	469 (44.3)
Both	73 (6.9)
GCS	14.9 $\pm$ 0.6
Brunnstrom	12.0 $\pm$ 4.7
Muscle strength	63.1 $\pm$ 15.8
BI	77.6 $\pm$ 26.0
Superficial sensation	0.8 $\pm$ 1.0
Deep sensation	1.0 $\pm$ 1.3
Complex sensory function	1.1 $\pm$ 1.5
Sitting balance	2.6 $\pm$ 0.7
Standing balance	2.1 $\pm$ 0.8
Mini-BEST	15.4 $\pm$ 11.3
ABC	50.7 $\pm$ 37.7
Anxiety	5.7 $\pm$ 6.0
Depression	5.6 $\pm$ 6.4
MoCA	17.3 $\pm$ 6.7

GCS, Glasgow coma scale; BI, Barthel index; Mini-BEST, mini-balance evaluation systems test; ABC, activities-specific balance confidence; MoCA, Montreal Cognitive Assessment.

criterion (58), the discriminant validity was evaluated by comparing the square root of each AVE in the diagonal with the correlation coefficients (off-diagonal) for each construct in the relevant rows and columns (*Table 3*).

### Path analysis

Compared two models, the final model (model 2) had adequate model fit indices. In the model 1, the model fit

statistics were ( $\chi^2=733.96$ ,  $\chi^2/df=6.99$ , GFI =0.938, CFI =0.971, TLI =0.97, SRMR =0.035, RMSEA =0.053, AIC =787.96, BIC =788.58) (*Figure 3*). However, as we did not take into account the role of cognitive capability, model 2 was set after adding the observed variable of MoCA. The model fit indices were ( $\chi^2=243.5$ ,  $\chi^2/df=5.181$ , GFI =0.977, CFI =0.944, TLI =0.922, SRMR =0.063, and RMSEA =0.063, AIC =303.51, BIC =304.26) (*Figure 4*). The result of analyzing the difference of the variation of the two models was significant ( $\Delta\chi^2=-490.46$ ,  $\Delta df=-58$ ,  $P<0.05$ ,  $\Delta RMSEA =0.01$ ,  $\Delta SMEA =0.028$ ,  $\Delta AIC=-484.45$ ,  $\Delta BIC =-484.32$ ), although RMSEA and SMEA increased. AIC and BIC decreased in model 2, suggesting this was the more parsimonious model. Compared with these results, model 2 was determined to be the final model in the study.

*Table 4* indicates the standardized path coefficients and significance for the final model. For the direct effects, all paths were significant, except that from somatosensory impairment to affective symptoms ( $\beta=-0.007$ ,  $P=0.895$ ), and that from physical ability to affective symptoms ( $\beta=0.050$ ,  $P=0.750$ ). Additionally, balance impairment was positively affected by physical ability and negatively affected by somatosensory impairment. Furthermore, these variables explained 87.1% of the variance of balance impairment, while affective symptoms were negatively affected by balance impairment and MoCA, which explained 29.9% of the variance in affective symptoms. MoCA was positively affected by physical ability, and the explanatory power of the variable of MoCA was 11.1%.

Bootstrapping tests were used to verify the indirect effects of each path for somatosensory impairment and physical ability on affective symptoms, and the indirect effect of the physical ability path to affective symptoms through balance impairment and MoCA was significant. The effect size of physical ability through balance impairment on affective symptoms was  $-1.037$  to  $-0.225$  at the bias-corrected 95% CI, which did not include 0 in the range of the effect, and  $P<0.001$  and  $R^2=0.996$ , suggesting the indirect effect was significant. Additionally, the effect size of physical ability through MoCA on affective symptoms (95% CI:  $-0.115$  to  $-0.027$ ,  $P=0.001$ ,  $R^2=0.108$ ) was significant, and the total effect was also statistically significant (95% CI:  $-0.771$  to  $-0.448$ ,  $P<0.001$ ). However, the direct effect of the path of physical ability to affective symptoms was not significant, with an effect size of  $-0.351$  to  $0.511$  ( $P=0.782$ ). Therefore, balance and cognitive impairment had mediating effects on the relationship between physical ability and affective symptoms (*Table 5*). On the other hand, the path for

**Table 2** Regression weights and convergent validity for the final model

Latent variable	Observed indicator	Unstd.	$\lambda$	S.E.	<i>t</i>	P	R <sup>2</sup>	CR	AVE
Somatosensory impairment	Superficial sensation	1.000	0.846				0.717	0.918	0.789
	Deep sensation	1.563	0.937	0.028	55.406	<0.001	0.878		
	Complex sensory function	1.695	0.879	0.040	42.205	<0.001	0.773		
Physical ability	Brunnstrom	1.000	0.938			<0.001	0.880	0.935	0.828
	Muscle strength	3.095	0.909	0.064	48.371	<0.001	0.826		
	BI	4.966	0.882	0.124	39.929	<0.001	0.778		
Balance impairment	Standing balance	1.000	0.837			<0.001	0.701	0.943	0.848
	Mini-BEST	15.155	0.973	0.291	52.123	<0.001	0.946		
	ABC	50.550	0.946	0.029	33.416	<0.001	0.895		
Affective symptoms	Depression	1.000	0.933			<0.001	0.871	0.741	0.589
	Anxiety	0.956	0.947	0.029	33.416	<0.001	0.897		

Unstd., unstandardized estimate;  $\lambda$ , standardized estimate; S.E., standard errors; R<sup>2</sup>, square multiple correlation; CR, composition reliability; AVE, average variance extracted; BI, Barthel index; Mini-BEST, mini-balance evaluation systems test; ABC, activities-specific balance confidence.

**Table 3** Latent variable correlations and discriminant validity

Latent variable	AVE	Physical ability	Somatosensory impairment	Balance impairment	Affective symptoms
Physical ability	0.828	0.910*			
Somatosensory impairment	0.789	-0.658	0.888*		
Balance impairment	0.848	0.891	-0.592	0.921*	
Affective symptoms	0.589	-0.422	0.281	-0.464	0.767*

\*, the values of the square root of AVE. These values are greater than the correlations of other constructs, suggesting adequate discriminant validity. AVE, average variance extracted.

somatosensory impairment on affective symptoms through balance impairment was not significant.

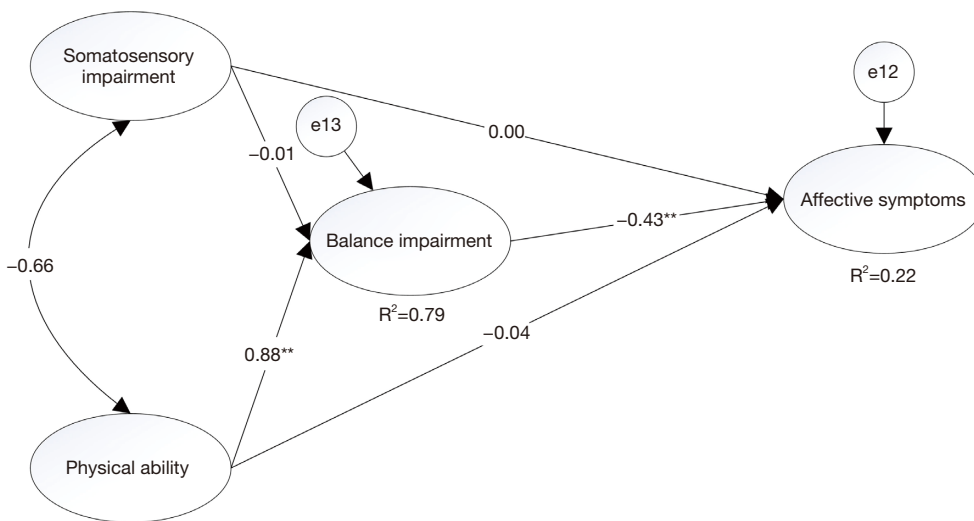
## Discussion

Considering the high prevalence of post-stroke depression/anxiety, this study analyses the factors impacting post-stroke mood disorders and discusses how physical ability influences affective symptoms in patients with stroke. Based on the theory of postural control and the role of cognitive capability, we put forward our research hypotheses. After analyzing the multi-center clinical data using exploratory factor analysis and structural equation model, the results showed that physical ability cannot directly influence post-stroke mood disorders, but can indirectly affect them through two mediating variables: balance impairment and

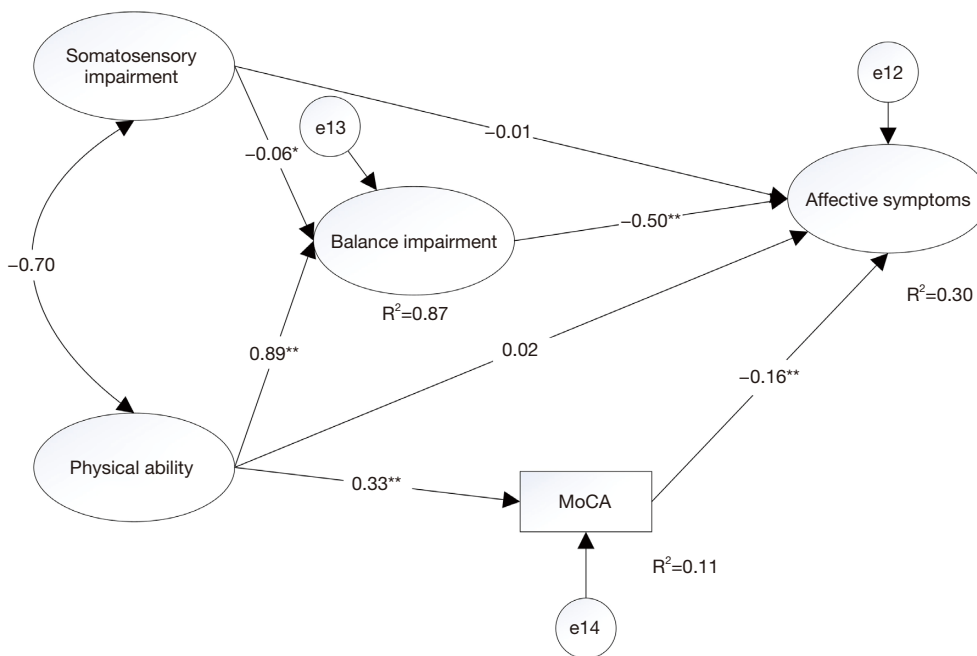
cognitive capability. Nevertheless, balance impairment does not play a mediating role in the relationship between somatosensory impairment and affective symptoms. Additionally, we also found somatosensory impairment significantly negative influenced balance impairment, and physical ability significantly positively affected balance impairment.

Our study provides a new perspective to understand the mediating role of balance function, which has a moderate indirect effect on the latent affective symptoms variable. High balance disturbance is associated with increased mood disorder. This finding is in line with previous evidence linking balance impairment to depression (22,59,60). Similarly, evidence provided by a study on elderly patients suggested that depression problems were associated with postural disturbance (60). Moreover, the finding that





**Figure 3** Theoretical model 1. We hypothesized that balance impairment mediated the relationship between physical ability and affective symptoms and the relationship between somatosensory impairment and affective symptoms. Model fit  $\chi^2=733.96$ ,  $\chi^2/df=6.99$ , GFI =0.938, CFI =0.971, TLI =0.97, SRMR =0.035, RMSEA =0.053, AIC =787.96, BIC =788.58). \*\*, P<0.001. GFI, goodness-of-fit index; CFI, comparative five index; TLI, Tucker-Lewis index; SRMR, standardized root mean square residual; RMSEA, root mean square error of approximation; AIC, Akaike information criterion; BIC, Bayesian information criterion.



**Figure 4** The final model. Based on the model 1, we added the MoCA variable and hypothesized that MoCA mediated the relationship between physical ability and affective symptoms. Model fit:  $\chi^2=243.5$ ,  $\chi^2/df=5.181$ , GFI =0.977, CFI =0.944, TLI =0.922, SRMR =0.063, and RMSEA =0.063, AIC =303.51, BIC =304.26. \*, P<0.05; \*\*, P<0.001. MoCA, Montreal Cognitive Assessment; GFI, goodness-of-fit index; CFI, comparative five index; TLI, Tucker-Lewis index; SRMR, standardized root mean square residual; RMSEA, root mean square error of approximation; AIC, Akaike information criterion; BIC, Bayesian information criterion.

**Table 4** Parameter estimate of the direct paths in the final model

Paths	Unstd.	$\beta$	S.E.	<i>t</i>	P	R <sup>2</sup>
Somatosensory impairment → balance impairment	-0.053	-0.061	0.026	-2.050	<0.05*	
Physical ability → balance impairment	0.140	0.893	0.005	27.623	<0.001**	0.871
Balance impairment → affective symptoms	-4.178	-0.533	1.242	-3.364	<0.001**	0.299
MoCA → affective symptoms	-0.133	-0.157	0.031	-4.245	<0.001**	
Physical ability → MoCA	0.479	0.329	0.044	10.828	<0.001**	0.110
Somatosensory impairment → affective symptoms	-0.049	-0.007	0.370	-0.131	0.895	
Physical ability → affective symptoms	0.061	0.050	0.192	0.318	0.750	

\*, P<0.05; \*\*, P<0.001. Unstd., unstandardized path coefficients;  $\beta$ , standardized path coefficients; S.E., standard errors; R<sup>2</sup>, square multiple correlation; MoCA, Montreal Cognitive Assessment.

**Table 5** Significance of direct and indirect effect of the final model

Effect	Paths	Point estimate	Product of coefficients		Bootstrapping (Bias-corrected 95% CI)		P	R <sup>2</sup>
			S.E.	Z	Lower	Upper		
Total effect	Somatosensory impairment → balance impairment → affective symptoms	0.174	0.429	0.406	-0.729	0.969	0.684	
	Physical ability → balance impairment → affective symptoms	-0.587	0.079	-7.430	-0.771	-0.448	<0.001**	
	Physical ability → MoCA → affective symptoms	-0.587	0.079	-7.430	-0.771	-0.448	<0.001**	
Indirect effect	Somatosensory impairment → affective symptoms	0.223	0.141	1.582	0.015	0.631	0.112	
	Physical ability → affective symptoms	-0.648	0.206	-3.146	-1.112	-0.279	<0.001**	
	Physical ability → balance impairment → affective symptoms	-0.584	0.201	-2.905	-1.037	-0.225	<0.001**	0.996
	Physical ability → MoCA → affective symptoms	-0.063	0.022	-2.864	-0.115	-0.027	0.001*	0.108
Direct effect	Somatosensory impairment → affective symptoms	-0.049	0.432	-0.113	-0.939	0.742	0.910	
	Physical ability → affective symptoms	0.061	0.221	0.276	-0.351	0.511	0.782	

\*, P<0.05; \*\*, P<0.001. S.E., standard errors; R<sup>2</sup>, square multiple correlation; MoCA, Montreal Cognitive Assessment.

balance responds to anxiety is also consistent with the conclusion of the study by Rafsten *et al.* (61), wherein postural balance function had a moderate correlation with anxiety, which was also reported in other studies (62-64). In summary, these findings demonstrated balance impairment might contribute to mood disorders, including anxiety and depression.

The link between balance and anxiety/depression might indicate the problem of underlying falls in mood disorders, and one study indicated falls may result in depression, leading to a fall problem (59). Balance disorders have been reported as the most common cause of falls in the elderly (65), and demonstrated that improved balance reduced the fear of falls (21). Other studies have also

suggested that improving postural control presented a positive trend of decreased fall recurrence significantly (29,66), while in a retrospective study (67), it showed anxiety operated as an outcome of an experienced fall. Moreover, two recent studies demonstrated that fall experience was associated with depression (68,69).

Generally speaking, several putative biological theories may be given to explain the link between it and affective symptoms. Firstly, highly integrated neural networks are responsible for processing emotional information, and balance control and anxiety processing may share similar neural substrates (70). Secondly, attention resources contribute to the postural changes seen in Parkinson's disease or stroke, such that individuals direct their attention

to movements processes, threat-related stimuli, and self-regulatory strategies to compensate for these attentional changes (71). Anxiety feelings are also expressed when threatened (72).

The findings also suggest somatosensory impairment significantly negatively influenced balance impairment ( $P < 0.05$ ,  $\beta = -0.061$ ), and physical ability significantly positively affected balance impairment ( $P < 0.001$ ,  $\beta = 0.893$ ). These results suggest physical ability and somatic sensation are critical factors of balance function, indicating that balance impairment plays a primary role in mood pathology for patients after stroke who have multiple dysfunctions. The current findings could be explained by the theory of core stability, as it was mentioned before. From the perspective of developmental kinesiology, trunk stabilization is a prerequisite for any form of movement and motor performance of the extremities, which is easily observed at the early stages of infant development. For example, in the neonatal stage, a newborn cannot grasp or reach purposefully, and can only appear to have a meaningful limb movement by balancing their head or neck (20). Collectively, this review argues that purposeful movement depends on trunk support. Therefore, core stability is essential for any movement. Multisensory integration is also important for motion. For example, if individuals have insufficient multi-sensory integration, they usually activate too many unnecessary muscles for stabilization and make inefficient movements (73), and it is difficult for such individuals to relax postural muscles, which have negative impacts on postural control. Therefore, understanding a patient's physical ability and somatosensory impairment has important implications for determining the most effective treatment approach in the context of improving affective symptoms.

In terms of physical therapy, corrective stabilization training or balance exercises may be a primary step in the treatment of anxiety or depression symptoms with patients after stroke. Trunk training can also improve postural control or balance disorders, as well as the fear of falling (21,29). However, no study has yet addressed the direct correlation between stabilization training and mood disorders. A recent systematic review indicated depression was significantly associated with post-stroke physical activity (74), and a prospective cohort study put forth both anxiety had a significant non-linear correlation with physical activity and confirmed the indirect effect of physical activity and mood disorder (75). Nonetheless, additional studies are required to examine whether providing balance training to

patients with early stroke as early as possible to complete the target of core stabilization helps reduce anxiety or depression symptoms. Furthermore, these findings demonstrate that various methods are needed to achieve this.

Our findings also showed another indirect path between physical ability and affective symptoms through MoCA was significant. It has previously been shown that motor function is related to global cognition in patients with mild strokes (76), which is in line with our results. Ben Assayag *et al.* (77) found motor performance was a significant predictor of cognitive decline after stroke. Similarly, one review from the psychological and psychosomatic perspective summarized the dynamic relationship between mind and body, and demonstrated the relationship shared the same neural substrates that may help translate thoughts into feelings (78).

### *Practical implications*

The current study provides significant practical implication in designing comprehensive rehabilitation interventions. It is helpful for scholars to target the relevant factors together to improve affective symptoms after stroke. First, given the role of balance function in our study, rehabilitation professionals could pay more attention to the balance function which will help to strengthen physical ability and improve post-stroke mood disorders. Family caregivers should take into account patients' balance impairment to protect their safety in an effective manner. Second, our study also found an important role of cognitive capability. Rehabilitation doctors and therapists should deal with the cognitive capability of patients with stroke to reduce patients' risk post-stroke anxiety or post-stroke depression. In this way, rehabilitation professionals can integrate the various assessment results into treatment plans, resulting in more comprehensive and targeted interventions.

### *Limitations*

The current study utilized an SEM approach to examine the relationship between balance deficits, somatosensory impairment, physical ability, cognitive capability, and mood disorders. Nevertheless, some limitations are present. The data were collected in a cross-sectional design, and Bullock *et al.* suggested longitudinal studies are needed to explore any causal association (79). Although the present research findings cannot directly conclude the causality, scientific assumptions and derivations can provide important

information. Consequently, further studies should be designed to clarify the causal correlation between balance deficits and affective symptoms. Moreover, we did not employ standardized scales to assess the sensory and balance deficits but relied on the clinician's experience to evaluate a specific construct. Also, the latent affective symptoms variable in this study was defined by only two measured variables. Therefore, these variables cannot accurately represent the true construction, and further studies using different indicators are needed to verify the robustness of the current results.

## Conclusions

This cross-sectional study confirmed balance impairment mainly mediated the relationship between physical ability and affective symptoms, while cognitive capability can play a slightly mediating role in the relationship between physical ability and affective symptoms. The findings may help rehabilitation professionals target effective interventions and enhance balance performance to improve mental status.

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## Footnote

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**Ethical Statement:** The authors are accountable for all

aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The research was approved by the ethics committee of the Second Affiliated Hospital of Kunming Medical University (No. PJ-2019-04). Informed consent was taken from all the patients.

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