Niu *et al. BMC Anesthesiology* (2025) 25:95
https://doi.org/10.1186/s12871-025-02968-5

BMC Anesthesiology

RESEARCH

Open Access

Vagal activity mediates the relationship between active housework and delayed neurocognitive recovery in elderly patients: a prospective nested case-control study

Junfang Niu[1,2], Xiang Liu[1,3], Xupeng Wang[1], Fang Gao[1], Peixia Yu[1], Qi Zhou[1] and Qiujun Wang[1*]

Abstract

Background Regular physical activity has been shown to ameliorate cognitive decline associated with aging, and to improve autonomic nervous function. However, the effect of active housework, a form of light to moderate physical activity, on postoperative cognitive function in the elderly remain unknown. The aim of this study is to investigate whether active housework exerts a protective effect against delayed neurocognitive recovery (dNCR), and to explore the role of vagal activity in this relationship.

Methods This is a prospective nested case-control study that enrolled 152 elderly patients scheduled for elective knee replacement surgery. The neuropsychological assessments were conducted to evaluate dNCR both preoperatively and one week postoperatively. Physical activity levels were quantified based on the Physical Activity Scale for the Elderly and categorized into active housework and sedentary behavior groups using hierarchical clustering. High-frequency spectral analysis of heart rate variability was used to assess vagal activity. Multivariable logistic regression analysis was employed to examine the association between active housework, vagal activity, and dNCR. Additionally, mediation analysis was performed to explore the possible mediating effect of vagal activity.

Results dNCR occurred in 33/141 (23.4%) patients. Active housework was associated with 84.7% lower odds of developing dNCR [OR = 0.153, 95% CI (0.042 to 0.550), $p = 0.004$]. There was significant interaction between vagal activity and dNCR [OR = 0.003, 95% CI (0.001 to 0.052), $p < 0.001$]. Vagal activity mediated the association between active housework and dNCR, accounting for 31.92% of the mediation effect.

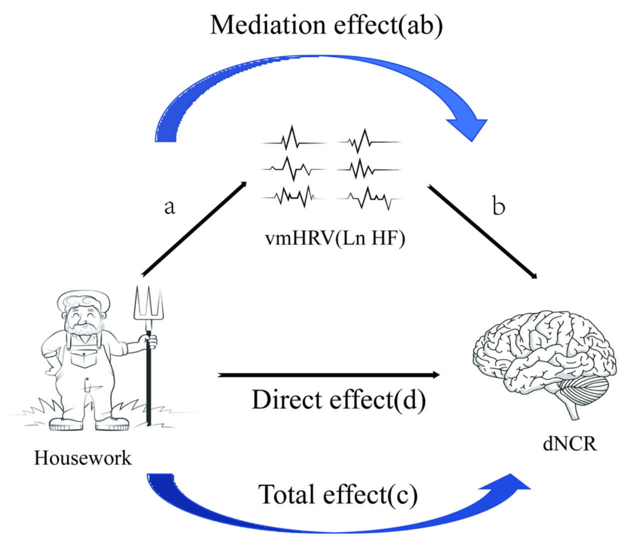
Conclusions Active housework is associated with decreased incidence of dNCR, with vagal activity serving as a mediating factor. This study provides valuable insights for predicting and preventing of perioperative neurocognitive disorders in elderly patients.

Trial Registration Trial registration number: ChiCTR2300070834, date of registration: April 24, 2023.

Keywords Housework, Delayed neurocognitive recovery, Vagus nerve, Elderly, Mediation analysis, Heart rate variability

*Correspondence:
Qiujun Wang
37000628@hebmu.edu.cn
Full list of author information is available at the end of the article

Graphical Abstract



Background

With the growing trend of population aging, the number of elderly patients undergoing surgery has been increasing annually [1]. Perioperative neurocognitive disorders are prevalent complications in elderly patients, with cognitive dysfunction occurring within 30 days postoperatively defined as delayed neurocognitive recovery (dNCR) [2]. Large-scale randomized controlled trials have reported the incidence of neurocognitive disorders in the early postoperative period, within one week after surgery, ranges from 25.8% [3] to 41.4% [4].This condition can profoundly affect patient outcomes and may even elevate the risk of long-term cognitive impairments such as dementia [5]. Advanced age has been identified as a significant risk factor, with other contributing factors potentially involving surgery, anesthesia, patient characteristics, or an interplay of these elements [6]. The pathophysiological mechanisms are multifaceted, encompassing central nervous system inflammation, cholinergic neuronal system dysfunction, neuronal apoptosis, oxidative stress, and genetic factors [7]. Given the absence of a definitive treatment, it is essential to seek effective preventative strategies and to enhance cognitive reserve in patients.

Physical activity is widely recognized as a pivotal strategy for reducing the risk of age-related diseases, notably cognitive dysfunction [8]. Research on the muscle-brain axis has burgeoned in recent years, with substantial evidence suggesting that regular physical activity can delay the onset of Alzheimer's disease (AD) and dementia [9]. Habitual physical activity has been associated with a 14% reduction in the risk of dementia and a 35% reduction in the risk of cognitive decline [10]. Not only does high-intensity structured exercise provide benefits, but even lower levels of physical activity, such as increasing daily steps, can improve cognitive function and reduce the overall risk of mortality [11]. Conversely, a sedentary lifestyle is identified as a risk factor for cognitive impairment [12]. Current clinical and preclinical evidence also indicates that proper exercise can protect against the occurrence of perioperative neurocognitive disorders [13]. Housework is classified as a type of light physical activity. It is not only an important indicator of overall physical activity levels in older adults, reflecting daily energy expenditure, but also closely associated with functional capacity and broader health outcomes. Scholarly research has identified that male elective cancer patients who infrequently engage in housework preoperatively tend to have poorer life outcomes and are at an increased risk of developing postoperative delirium [14]. However, it is currently unclear whether active housework can provide protective effects against dNCR in elderly patients.

The beneficial effects of physical activity may be mediated through various mechanisms, including increasing levels of central neurotrophic factors, modification in autonomic nervous system, promoting neurogenesis in the hippocampus, reducing neuroinflammatory responses, improving mitochondrial function, among other potential pathways [15–17]. Autonomic nervous system function has been correlated with the onset, progression, and prognosis of various brain disorders. Heart rate variability (HRV), an established non-invasive biomarker, reflects the dynamic interplay between central nervous system activity and higher cognitive functions [18]. The neurovisceral integration model regards HRV as a pivotal gauge of an individual's adaptive capacity, underscoring its relevance to cognitive performance [19]. The interconnectedness of the heart and brain via the vagus nerve accentuates the importance of this neural pathway. Empirical evidence suggests that resting vagally mediated heart rate variability (vmHRV) is a robust predictor of cognitive task performance, encapsulating the essence of neurovisceral integration and the body's intrinsic regulatory mechanisms [20]. Preliminary analysis of HRV-related biomarkers may allow for the implementation of autonomously controlled preventive measures to reduce the incidence of perioperative neurocognitive disorders.

Individuals suffering from chronic osteoarthritis often encounter limited physical mobility, with housework frequently representing their main form of physical activity. However, current research lacks sufficient data to ascertain whether active housework can offer protection against early postoperative dNCR when compared to a sedentary lifestyle, as well as the potential role of vagal activity. We hypothesized that active housework before surgery may have been inversely related to the risk of early postoperative dNCR. Furthermore, we examined whether vagal activity acted as a mediating factor in this relationship.

Methods

Study design and ethics

This is a single-center, prospective, observational nested case-control study conducted at the Third Hospital of Hebei Medical University from April 25, 2023, to August 29, 2023. The research received ethical approval from the institutional review board of the Third Hospital of Hebei Medical University (ID: 2023-018-1, dated March 21, 2023). It was also registered with the Chinese Clinical Trial Registry (http://www.chictr.org.cn, ID: ChiCTR2300070834, dated April 24, 2023). The study was carried out in compliance with the Helsinki Declaration and the Research Governance Framework. We ensured strict adherence to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines throughout our study. Informed consent was secured from all participants before surgery.

Study population

Eligible participants for this study were patients undergoing unilateral knee replacement surgery with general anesthesia combined with femoral nerve block who met the following criteria: provision of informed consent; age between 60 and 90 years; American Society of Anesthesiologists (ASA) physical status classification I to III; and body mass index (BMI) ranging from 18 to 30 kg/m^2. Exclusion criteria were as follows: Mini-Mental State Examination (MMSE) score below 24; history of brain disease or presence of neurological or psychiatric disorders as diagnosed by a physician; chronic use of sedatives, psychotropic, or anticholinergic medications; severe hearing or vision impairments; preoperative systolic blood pressure exceeding 190 mmHg, or diastolic blood pressure above 100 mmHg; current atrial or ventricular arrhythmias (including those with a permanent or temporary pacemaker).

Perioperative management

Both surgery and anesthesia were performed by senior surgeons and anesthesiologists. Perioperative care was performed according to standard protocols. Thirty minutes before surgery, an ultrasound-guided femoral nerve block was performed with 20 mL of 0.375% ropivacaine. Patients underwent standard institutional monitoring, including radial artery blood pressure monitoring. General anesthesia was induced with midazolam, sufentanil, propofol, and a depolarizing muscle relaxant, and maintained with remifentanil and propofol, with doses adjusted according to the patient's overall condition and the surgical stimulus. Patient-controlled analgesia, consisting primarily of opioid analgesics and antiemetics, was administered intravenously within 48 h postoperatively. All clinical staff were blinded to the results of dynamic electrocardiograms and cognitive function assessments.

Exposure

In this study, the validated Physical Activity Scale for the Elderly (PASE) is used to assess the type and amount of daily physical activity in elderly patients [21]. The PASE is a simple, easily scored, reliable, and effective tool for assessing physical activity in epidemiologic studies of the elderly population. The assessment was performed according to the guidelines and recommendations provided by the developers of the scale [22]. The types of activities recorded were mainly muscle strength/endurance, strenuous exercise, moderate exercise, light exercise, work involving standing or walking, walking, lawn/garden maintenance, caring for another person, home repairs, heavy housework, light housework, outdoor gardening. After weighting the scores of the different activities, a second-order cluster analysis was performed to classify the participants into two groups: the active housework group and the sedentary behavior group (Supplementary Fig. 1).

Mediator

Three-lead electrocardiographic signals were obtained using LEPU TH12 digital Holter monitors (LEPU Medical Technology, Beijing, China) with a sampling frequency of 1024 Hz. ECG data were analyzed using the LEPU AI-ECG analysis system (version 1.1.12.0, LAPU Care-well, Shenzhen, China). HRV analysis was performed on 5-min segments according to the Task Force guidelines, and serial changes in vagal activity were quantified using the frequency domain of HRV [23]. Frequency domain measurements were obtained by the fast Fourier transform algorithm, which calculated the low-frequency (LF: 0.04–0.15 Hz) and high-frequency (HF: 0.15–0.4 Hz) power spectra. The LF and HF measurements were expressed in normalized units (LF nu and HF nu), where HF nu = HF [ms^2] / (HF [ms^2] + LF [ms^2]) × 100. Given the inverse mathematical relationship between LF nu and HF nu, we focused primarily on HF nu, an index commonly considered to reflect vagal modulation. Due to the skewed distribution of HF nu, a natural logarithmic transformation was applied.

Measurements were scheduled in the morning hours from 9 a.m. to 12 p.m., one to three days before surgery. Participants were instructed to refrain from strenuous physical activity and caffeine intake the day before the assessment. Data collection took place in a quiet room maintained at 24 °C, with patients in the supine position, fasted, and breathing regularly, with an acclimatization period of 20 min before recording commenced.

Outcome

Neurocognitive function was assessed preoperatively and at one week postoperatively, or before discharge. Before the assessment, patients in a delirious state were excluded using the Confusion Assessment Method (CAM) scale. A neuropsychological test battery was administered, including: [1] Rey Auditory Verbal Learning Test (RAVLT) — assessing learning and recall of words, with the number of correctly recalled words recorded; [2] Trail Making Test (TMT) — consisting of Parts A and B, recording completion times; [3] Symbol Digit Substitution Test (SDST) — noting the number of correct substitutions within 90 s; [4] Part C of the Stroop Color-Word Interference Test (SCWT) — recording the time taken to read 20 color-word pairs. Six scores from these tests underwent principal component analysis and oblique rotation factor analysis. Using baseline rotation factor scores, scoring coefficients were determined for all time points to ensure consistency across cognitive domains. Four uncorrelated factors were identified, representing: [1] verbal learning; [2] memory function; [3] executive function; [4] attention. dNCR is defined as a decrease of at least one standard deviation in any cognitive domain score from the baseline.

Covariates

Potential confounders and effect modifiers were identified according to guidelines or consensus documents related to perioperative cognitive function [24, 25]. Demographic data, medical history, lifestyle, laboratory tests, and perioperative conditions were collected through review of the clinical case management system and patient self-report, including: age, gender, BMI, living situation (living alone in the past month: yes/no), education level (completed at least primary school: yes/no), smoking habits (smoked in the past month: yes/no), alcohol consumption (consumed alcohol in the past month: yes/no), comorbidities assessed by the Charlson Comorbidity Index (CCI), ASA classification, total anesthetic dosage (including intraoperative and postoperative analgesia), and additional factors listed in Table 1. Depressive symptoms were measured using the 10-item Center for Epidemiologic Studies Depression Scale (CES-D10) [26]. The Barthel Index was used to assess patients' self-care abilities in Activities of Daily Living (ADL).

Sample size calculation

PASS software (version 11.0.7; NCSS LLC, United States) was used to calculate the sample size required for this study. The study was set at a significance level of 0.05 (α) and a statistical power of 90% (1 - β). Referring to previous studies, the incidence of dNCR within one week after non-cardiac surgery is reported to be between 25.8% and 41.4%. Based on the literature [27], the expected odds ratio (OR) is 0.26, suggesting that regular physical activity is associated with a reduced risk of dNCR, with an exposure ratio in the control group of 0.8. A minimum of 112 patients were required to meet statistical power requirements. In addition, the study accounted for a potential 10% loss to follow-up and assumed a 90% eligibility rate. Therefore, it was estimated that a minimum of 139 patients would be needed to enroll. If the actual withdrawal or ineligibility rate exceeds the pre-specified limits, the sample size may need to be increased to ensure that the study retains sufficient statistical power.

Statistical analyses

SPSS software (version 26.0, IBM Corp., Armonk, NY, USA) was used for data analysis. Normally distributed continuous variables were presented as mean ± standard deviation, with group differences assessed using the independent samples t-test. Non-normally distributed continuous variables were reported as median (interquartile range), and group differences were assessed using the Kruskal Wallis test followed by the Wilcoxon-Mann-Whitney test for post-hoc analysis. Categorical variables were reported as numbers and percentages, with group differences assessed using chi-squared tests or Fisher's exact test, as appropriate.

Potential risk factors for perioperative neurocognitive dysfunction were identified based on relevant literature and guidelines. A Directed Acyclic Graph (DAG) was constructed to identify causal relationships between variables for variable selection and control of confounding factors (Fig. 1). Initially, univariate logistic

Table 1 Baseline characteristics of the participants

Variables	No- dNCR (*n* = 108)	dNCR (*n* = 33)	*p*
Age, years	67(5.75)	71(5)	**< 0.001**
Gender, n (%)			0.618
Female	86(79.60)	28(84.80)	
Male	22(20.40)	5(15.20)	
Body mass index, kg/m2	26.68(4.02)	26.04(4.71)	0.693
Education, n (%)			0.280
Primary school or less	71(65.70)	25(75.80)	
High school or above	37(34.30)	8(24.20)	
Smoking, n (%)			0.243
No	91(84.30)	31(93.90)	
Yes	17(15.70)	2(6.10)	
Drinking, n (%)			0.188
No	95(88.00)	32(97.00)	
Yes	13(12.00)	1(3.00)	
CCI, n (%)			**< 0.001**
0	48(44.40)	3(9.10)	
1	43(39.80)	19(57.60)	
2	12(11.10)	5(15.20)	
3	5(4.60)	3(9.10)	
4	0(0.00)	3(9.10)	
ASA, n (%)			**0.011**
II	104(96.30)	27(81.80)	
III	4(3.70)	6(18.20)	
CES-D 10 score, point	7(2)	9(1)	**< 0.001**
PSQI score, point	8(2.75)	8(2)	0.598
MMSE score, point	27(3)	26(3)	**0.012**
Total anesthesia drugs			
Sufentanil, ug	126.8(5.20)	126.4(4.20)	0.407
Remifentanil, ug	923.63(444.86)	892.5(420.90)	0.477
Propofol, mg	636(120.38)	637.50(104.25)	0.731
Duration of anesthesia, min	150(30)	150(30)	0.442
Duration of surgery, min	90(35.25)	92(30)	0.934
Blood loss, ml	155(100)	150(100)	0.880
VAS, point	2(1)	2(1)	0.561
ADL score, point	100(10)	95(10)	**0.033**
Length of hospital stay, d	8(3)	8(4)	0.383
PASE categorization, point			**< 0.001**
Sedentary behavior	39(36.10)	26(78.80)	
Active housework	69(63.90)	7(21.20)	
vmHRV (Ln HF)	4.10(0.48)	3.14(0.44)	**< 0.001**

Notes Mean ± SD or Median (IQR) for continuous variables; n (%) for categorical variables; The p-values were calculated by t-test, Mann-Whitney U test, chi-squared test, or Fisher's exact test. Boldface values indicate $p < 0.05$

Abbreviations dNCR: delayed neurocognitive recovery; CCI: Charlson Comorbidity Index; ASA: American Society of Anesthesiologists; CES-D 10: the 10-item Center for Epidemiologic Studies Depression Scale; MMSE, Mini Mental State Examination; PASE: physical activity scale for the elderly; PSQI: Pittsburgh Sleep Quality Index; MMSE: Mini-Mental State Examination; VAS: visual analogue scale; ADL: Activities of Daily Living; vmHRV: resting vagally mediated heart rate variability; HF: high-frequency power spectra

regression analyses were performed, and variables with a p-value < 0.05 were considered for inclusion in the multivariate logistic regression analysis. The adjusted logistic regression model examined the association between active housework and dNCR. The model's goodness-of-fit was assessed by the Hosmer-Lemeshow test, and its discriminatory power was determined by the area under the receiver operating characteristic (ROC) curve. All p-values were considered significant if below 0.05 using a two-tailed test.

We performed two sensitivity analyses to further assess the robustness of the study results. First, considering the potential association of housework with age and gender, we repeated the initial analysis after excluding male patients. Second, to further investigate the association between housework and dNCR in older individuals, we excluded patients who were younger than 65 years old.

Mediation analysis was conducted using the SPSS PROCESS Macro, Version 4.2, by Andrew F. Hayes, and available at https://www.processmacro.org. Model 4 within the macro was applied to examine the mediating effects, with the analysis conducted at a 5% significance level (α). The significance of the indirect effect was determined with a 95% bootstrapped confidence interval; if zero is not included in the interval, the coefficient and the indirect effect are deemed significant. The total effect, the mediation effect, the direct effect, and the proportion mediated were all calculated. The total effect, representing the impact of housework on dNCR, is the sum of the direct and mediation effects. The direct effect, a component of the total effect not mediated by the mediator, indicates the influence of housework on dNCR after controlling for confounders, including vmHRV (LnHF). The mediation effect, which is part of the total effect, is mediated by the mediator and is composed of the influence of housework on HRV and the subsequent influence of HRV on dNCR.

Results

Characteristics of the participants

Between April and August 2023, a total of 152 patients met the inclusion criteria and had available electrocardiogram (ECG) data. After excluding 11 cases with insufficient ECG data, we finally analyzed data from 141 participants, whose baseline characteristics were shown in Table 1.

Of the 141 patients, 33 developed dNCR, yielding an incidence of 23.4%. Generally, this was a relatively healthy cohort, with 80.14% having a CCI score of 0 or 1 and 90.78% having an ASA score of 2. The median age of this cohort was 68 years (Q1-Q3: 65–71 years), and 80.85% were female. However, there was no significant difference in the incidence of dNCR between the genders. Significant differences in baseline characteristics, including age, CCI score, ASA score, CES-D10 score, MMSE score, active housework, ADL, and vmHRV (LnHF), were observed between the groups. Patients who developed dNCR were relatively older, with a smaller proportion

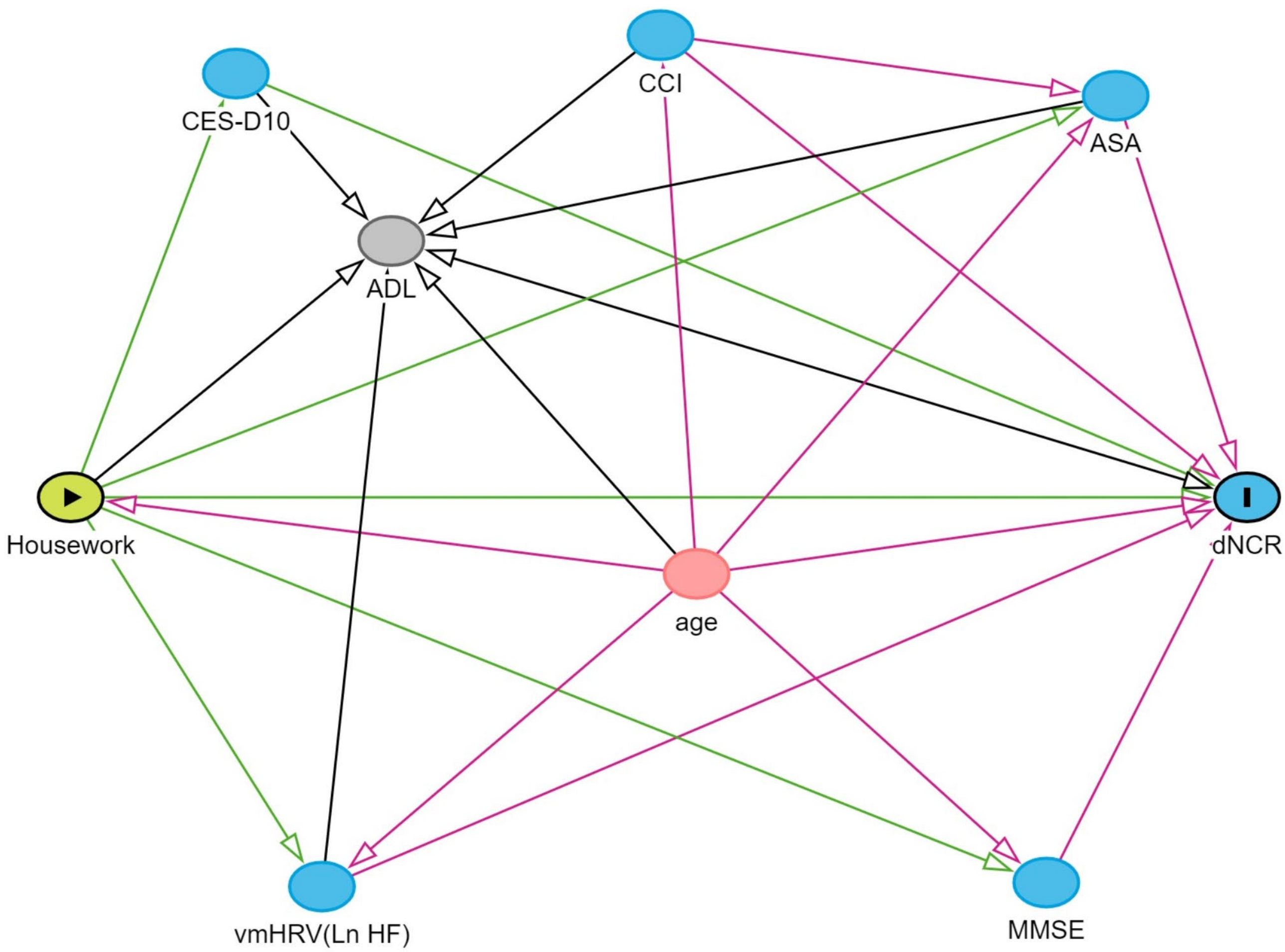


Fig. 1 Directed Acyclic Graph (DAG). Green circles represent exposures, blue circles represent outcomes, red circles represent common ancestors of exposure and outcomes (i.e. confounding factors), light blue circles represent ancestors of the outcome (i.e. causal determinants of the outcome), and brown circles represent other variables. Green lines depict causal pathways from exposure, while red lines indicate biased pathways to the outcome. Variables preceding arrows pointing to exposures or outcomes signify potential influencing factors, and variables linking exposures to outcomes may serve as mediating variables

engaged in active housework, and had lower vmHRV (LnHF) scores, as well as higher scores on the CCI, ASA, CED-10, and MMSE. No significant differences were observed between the two groups in other perioperative outcomes, including anesthetic dose, VAS score, duration of surgical anesthesia, and length of hospital stay.

Associations of active housework with dNCR and vmHRV (LnHF)

Univariate regression analysis revealed a significant correlation between active housework and the occurrence of early postoperative dNCR [OR = 0.152, 95% CI (0.061 to 0.383), $p < 0.001$] (Table 2: Model 1). This significance remained after adjustment for age, CCI, CES-D 10, and ASA. Specifically, active housework was associated with an 84.70% reduction in the incidence of dNCR [OR = 0.153, 95% CI (0.042 to 0.550), $p = 0.004$] (Table 2: Model 2). The predictive accuracy of Model 2 was evaluated by the receiver operating characteristic (ROC) curve analysis, with an area under the curve (AUC) of 0.92 [95% CI (0.88 to 0.97), $p < 0.001$], indicating the high discriminative power of the model (Supplementary Fig. 2). To further ascertain the robustness of our conclusions, we performed two sensitivity analyses. First, after excluding male participants and adjusting for age, CCI, CES-D 10, and ASA, the significant association between active housework and dNCR was maintained. Second, we performed the same statistical analyses by excluding participants under the age of 65, and the results remained significant. These sensitivity analyses further support the protective effect of active housework against dNCR (Supplementary Table 1).

The cross-sectional relationship between active housework and vmHRV (LnHF) was investigated, revealing a significant positive correlation ($r = 0.704$; $p < 0.001$), indicating that higher levels of physical activity were

Table 2 Logistic regression model showing associations between active housework and dNCR

	Model 1		Model 2	
	Crude OR (95% CI)	p	Adjusted OR (95% CI)	p
Age	1.195 (1.081, 1.322)	**0.001**	1.205(1.039, 1.398)	**0.014**
CCI	2.228 (1.452, 3.417)	**< 0.001**	2.156(1.185, 3.924)	**0.012**
CES-D 10	2.557 (1.713, 3.817)	**< 0.001**	2.822 (1.722, 4.624)	**< 0.001**
ASA	5.778 (1.522, 21,936)	**0.01**	3.973 (0.587, 26.904)	0.157
MMSE	0.867 (0.734, 1.024)	0.094	-	-
ADL	0.990 (0.954, 1.027)	0.596	-	-
Active Housework	0.152 (0.061, 0.383)	**< 0.001**	0.153(0.042, 0.550)	**0.004**

Abbreviations dNCR: delayed neurocognitive recovery; CCI: Charlson Comorbidity Index; CES-D 10: the 10-item Center for Epidemiologic Studies Depression Scale; ASA: American Society of Anesthesiologists; MMSE: Mini-Mental State Examination; ADL: Activities of Daily Living; PASE: physical activity scale for the elderly; CI: confidence interval; OR: odds ratio

Model 1: Univariate logistic regression analysis. Boldface values indicate $p < 0.05$

Model 2: Model adjusted for age, CCI, CES-D 10, and ASA

Table 3 Logistic regression model showing associations between vmHRV (ln HF) and dNCR

	Model 3		Model 4	
	Crude OR (95% CI)	p	Adjusted OR (95% CI)	p
Age	1.195 (1.081, 1.322)	**0.001**	1.317(1.021, 1.700)	**0.034**
CCI	2.228 (1.452, 3.417)	**< 0.001**	3.891(1.159, 13.056)	**0.028**
CES-D 10	2.557 (1.713, 3.817)	**< 0.001**	3.905 (1.531, 9.959)	**0.004**
ASA	5.778 (1.522, 21,936)	**0.01**	4.838 (0.189, 123.884)	0.341
Active Housework	0.152 (0.061, 0.383)	**< 0.001**	0.095(0.013, 0.685)	**0.019**
vmHRV(Ln HF)	0.005(0.001, 0.032)	**< 0.001**	0.003(0.001, 0.052)	**< 0.001**

Abbreviations dNCR: delayed neurocognitive recovery; CCI: Charlson Comorbidity Index; CES-D 10: the 10-item Center for Epidemiologic Studies Depression Scale; ASA: American Society of Anesthesiologists; vmHRV: resting vagally mediated heart rate variability; HF: high-frequency power spectra; CI: confidence interval; OR: odds ratio

Model 3: Univariate logistic regression analysis. Boldface values indicate $p < 0.05$

Model 4: Model adjusted for age, CCI, CES-D 10, ASA, and active housework

associated with enhanced vmHRV (LnHF). In a multivariate linear regression model adjusted for age, CCI, CES-D 10, and ASA, the association between active housework and vmHRV (LnHF) remained statistically significant ($R = 0.764$, $R^2 = 0.584$, $F = 37.952$, $p < 0.001$).

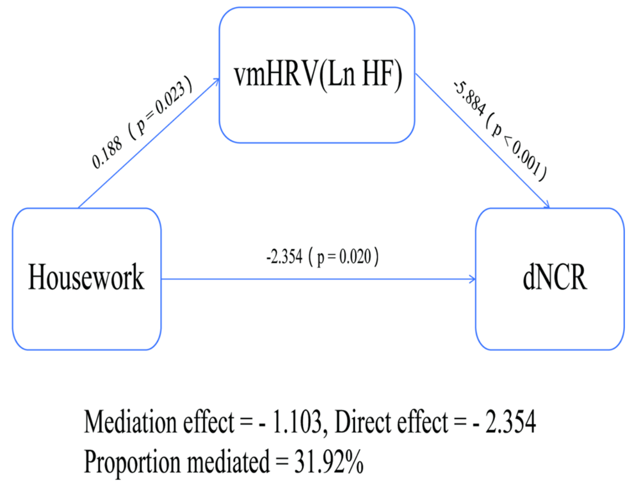


Fig. 2 Mediation model of active housework, vmHRV (Ln HF), and dNCR Notes: Proportion mediated (%) = Mediation effect / (Direct effect + Mediation effect); Mediation model adjusted for age, ASA, CCI, and CES-D 10

Associations between vmHRV (LnHF) and dNCR

The results of the univariate regression analysis indicated a significant correlation between vmHRV (LnHF) and dNCR, as shown in Model 3 [OR = 0.005, 95% CI (0.001 to 0.032), $p < 0.001$] (Table 3). Guided by the Directed Acyclic Graph, active housework was identified as a confounding factor when analyzing the relationship between vmHRV (LnHF) and dNCR. After adjusting for confounding factors, including active housework, the association remained significant [OR = 0.003, 95% CI (0.001 to 0.052), $p < 0.001$] (Table 3: Model 4).

Mediation analyses

The interaction was further investigated to better understand the mediation effect of vagal activity on the relationship between active housework and dNCR. As shown in Fig. 2, the mediation model indicated a significant total effect of active housework on dNCR (path c: β_c = -2.354; SE = 1.008; $p = 0.020$). Specifically, active housework showed a positive association with the mediator vmHRV (LnHF) (path a: $\beta_a = 0.188$; SE = 0.081; $p = 0.023$), and vmHRV (LnHF) significantly predicted dNCR (path b: β_b = -5.884; SE = 1.498; $p < 0.001$). The indirect effect of active housework on dNCR through vmHRV (LnHF) was significant, with the 95% bootstrap confidence interval not including zero, indicating a significant mediation effect. In the direct effect, the 95% bootstrap confidence interval also excluded zero, indicating that vmHRV (LnHF) partially mediated the effect of active housework on dNCR. It was estimated that approximately 31.92% of the total effect was mediated by vmHRV (LnHF).

Discussion

The present study investigated the association between active housework before surgery and dNCR in elderly patients, while also observing the role of vagal activity in this relationship. Our results indicated that active housework can reduce the occurrence of dNCR, and our analysis suggests that approximately 31.92% of this association was mediated by vmHRV (LnHF). This finding provides statistical support for the notion that vagal activity may be a potential mechanism through which active housework contributes to improving dNCR in the early postoperative period.

The beneficial effects of physical activity on cognition and brain health have been well documented and supported by strong evidence that higher levels of physical activity are associated with a reduced risk of cognitive impairment, including Alzheimer's disease [28]. Both moderate and low-intensity physical activity have been shown to positively affect cognitive function. Chen et al. [29] measured daily steps and subjective cognitive ability in older adults, demonstrating an inverse dose-response relationship between daily steps and rate of subjective cognitive decline. Susie et al. [27] assessed daily leisure activity levels in elective surgery patients using a leisure activity scale and suggested that regular physical activity may reduce the incidence and severity of postoperative delirium. Guidelines from the World Health Organization [30] and the American College of Sports Medicine [31] indicate that physical activity in the elderly population includes all behaviors resulting in energy expenditure, such as daily activities like housework, shopping, and gardening, in addition to specific organized exercise programs. In this study, we used PASE questionnaire, a validated instrument designed to assess physical activity in older adults, to collect and evaluate the types and intensities of daily physical activities of our patients. After weighting the scores of various activities and applying second-order cluster analysis, the top three activity types identified were lawn work/yard care, caring for another person, and heavy housework. These moderate-intensity physical activities, all related to housework, reflect the predominant characteristics of physical activity among the elderly cohort in this study. The study's findings indicate that active housework before surgery can significantly reduce the incidence of dNCR.

Physical activity can improve cognitive function through various mechanisms, with modification in the autonomic nervous system being one of them. HRV, a common and primary indicator of autonomic nervous system function, reflects the status of both sympathetic and parasympathetic activity and is known for its high reproducibility. Hildenborg et al. [32] demonstrated that preoperative HRV can predict divergent inflammatory responses following surgical intervention, and HRV measurements are considered potential early markers for cognitive impairment [33]. In this study, we primarily assessed the baseline autonomic nervous system function of patients by analyzing 5-minute electrocardiographic signals. Following the Task Force guidelines, we mainly employed frequency domain measurements to obtain HF and LF components. The modulation of HRV is believed to influence cognitive processes through its impact on prefrontal cortex activity, with the high-frequency components of HRV being particularly indicative of parasympathetic modulation and vagal influence [34]. The results of our study indicate a significant correlation between active housework and HRV, specifically with vmHRV (LnHF) (supplement Fig. 2).

Additionally, our study also found that higher vmHRV (LnHF) was associated with a reduced incidence of dNCR. Furthermore, through mediation analysis, we identified vagal activity as a mediating factor through which active housework reduces the risk of dNCR. Our findings provided statistical support for the notion that vagal activity may be a potential mechanism by which active housework confers cognitive protection postoperatively. These results are consistent with previous work from our research group, showing that vagus nerve stimulation or activation of the cholinergic anti-inflammatory pathway can improve perioperative neurocognitive function. Consequently, the assessment of vmHRV (LnHF) could also serve as a predictive tool for early postoperative dNCR.

The results of this study have important implications for clinical practice. Firstly, it emphasizes the role of active housework in improving early postoperative dNCR in elderly patients. By assessing the daily physical activity levels of elderly patients preoperatively, the risk of developing dNCR can be predicted. Encouraging elderly patients undergoing elective surgery to engage in active housework may enhance cognitive reserve and prevent the onset of postoperative cognitive dysfunction. Secondly, healthcare professionals can monitor the recovery process by assessing HRV and adjust treatment plans accordingly. Early intervention in patients with preoperative autonomic dysfunction or reduced vagal activity may improve vagal function. In conclusion, preoperative active housework, as a simple, cost-effective, and feasible intervention that can enhance the state of the autonomic nervous system, promotes the recovery of neurocognitive function in elderly patients postoperatively. It should receive widespread attention and be emphasized in the education of elderly patients undergoing elective surgery.

This study, as a prospective nested case-control study, provides valuable and novel insights into protective measures for perioperative neurocognitive function in elderly patients undergoing elective surgery and, to some extent, elucidates the causal relationship between exposure and outcome. However, there are several limitations. First, the small sample size, which primarily focused on elderly patients undergoing unilateral knee replacement surgery with general anesthesia combined with nerve block, may affect the generalizability of the results. Second, although the study was initially designed to ensure homogeneous treatment and to exclude as many confounding factors as possible, there may still be some unknown confounding factors. Third, the exploration of the potential mechanisms by which housework affects dNCR is statistically significant but requires further confirmation by basic research. Finally, the assessment of housework is mainly based on self-reported questionnaires, which may introduce some information bias due to their subjective nature. However, this is also an advantage of survey questionnaires as they are easy to implement in clinical practice. In summary, this study provides a new perspective for the prediction and prevention of neurocognitive disorders in elderly patients during the perioperative period, but further validation is needed through future large-sample clinical trials and basic research.

Conclusion

Active housework, combined with higher vagal activity, is significantly associated with a reduced incidence of dNCR, with vagal activity identified as a mediating variable. This study provides valuable insights for predicting and preventing the risk of perioperative neurocognitive disorders in elderly patients.

Abbreviations

dNCR	delayed Neurocognitive Recovery
vmHRV	resting vagally mediated Heart Rate Variability
ASA	American Society of Anesthesiologists
BMI	Body Mass Index
MMSE	Mini-Mental State Examination
PASE	Physical Activity Scale for the Elderly
HF	High-Frequency
LF	Low-Frequency
CAM	Confusion Assessment Method
CCI	Charlson Comorbidity Index
CES-D10	the 10-item Center for Epidemiologic Studies Depression Scale
ADL	Activities of Daily Living
OR	Odds Ratio
DAG	Directed Acyclic Graph
ROC	Receiver Operating Characteristic

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12871-025-02968-5 .

Supplementary Material 1: Supplementary table 1 Sensitivity analysis: Multivariate logistic regression model showing associations between active housework and dNCR.

Supplementary Material 2: Supplementary Fig. 1 The second-order cluster diagram of PASE scores. (a) The characteristics and quality of the second-order clustering model; (b) The features of the two types of physical activity clusters after clustering; (c) The ranking of the proportion of each activity type from highest to lowest.

Supplementary Material 3: Supplementary Fig. 2 Analysis of the receiver operating characteristic for the predictive value of dNCR in Model 2.

Acknowledgements

The authors thank all the participants and all the research staff.

Author contributions

JFN contributed to the conception and design of the study, drafted the manuscript. XL managed and analyzed the data. PXY and FG contributed to data acquisition, and followed up the patients. XPW and QZ contributed to preparing the figures. QJW provided financial support and guidance on the research protocol. All authors read and approved the final manuscript.

Funding

This work was supported by the Hebei Province Graduate Professional Degree Quality Teaching Case Library Construction Project [grant number KCJPZ2023022]; and the Hebei Provincial Science and Technology Department's Precision Medicine Joint Fund Key Project [grant number H2021206021].

Data availability

The datasets utilized and analyzed during the current study are available from the corresponding author on reasonable request through the provided link: https://pan.baidu.com/s/1Jqp_fhWtoc5nSqSyX2CQzA.

Declarations

Ethics approval and consent to participate

The Ethics Committee of the Third Hospital of Hebei Medical University approved on the Chinese Clinical Trail (No.2023-018-1), which was registered on the Chinese Clinical Trail Registry (www.http://chictr.org.cn, registration No. ChiCTR2300070834, registration date: April 24, 2023). Before surgery, all patients signed informed consent forms.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Anesthesiology, Hebei Medical University Third Hospital, Shijiazhuang, Hebei 050051, China
[2]Department of Anesthesiology, Jincheng People's Hospital, Jincheng, Shanxi 048000, China
[3]Department of Anesthesiology, Hebei Children' Hospital, Shijiazhuang, Hebei 050031, China

Received: 22 July 2024 / Accepted: 12 February 2025
Published online: 21 February 2025

References

1. Holecki T, Rogalska A, Sobczyk K, Woźniak-Holecka J, Romaniuk P. Global Elderly migrations and their impact on Health Care systems. Front Public Health. 2020;8:386.
2. Evered L, Silbert B, Knopman DS, Scott DA, DeKosky ST, Rasmussen LS, et al. Recommendations for the nomenclature of cognitive change associated with anaesthesia and surgery—2018. Br J Anaesth. 2018;121(5):1005–12.
3. Moller J, Cluitmans P, Rasmussen L, Houx P, Rasmussen H, Canet J, et al. Long-term postoperative cognitive dysfunction in the elderly: ISPOCD1 study. Lancet. 1998;351(9106):857–61.
4. Monk TG, Weldon BC, Garvan CW, Dede DE, van der Aa MT, Heilman KM, et al. Predictors of cognitive dysfunction after major noncardiac surgery. Anesthesiology. 2008;108(1):18–30.
5. Reynish E, Hapca S, Walesby R, Pusram A, Bu F, Burton JK et al. Understanding health-care outcomes of older people with cognitive impairment and/or dementia admitted to hospital: a mixed-methods study [Internet]. Southampton (UK): NIHR Journals Library; 2021 [cited 2024 Jan 21]. (Health Services

and Delivery Research). Available from: http://www.ncbi.nlm.nih.gov/books/NBK569785/
6. Evered LA, Silbert BS. Postoperative cognitive dysfunction and noncardiac surgery. Anesth Analg. 2018;127(2):496–505.
7. Lin X, Chen Y, Zhang P, Chen G, Zhou Y, Yu X. The potential mechanism of postoperative cognitive dysfunction in older people. Exp Gerontol. 2020;130:110791.
8. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, et al. The physical activity guidelines for americans. JAMA. 2018;320(19):2020–8.
9. Iso-Markku P, Kujala UM, Knittle K, Polet J, Vuoksimaa E, Waller K. Physical activity as a protective factor for dementia and Alzheimer's disease: systematic review, meta-analysis and quality assessment of cohort and case-control studies. Br J Sports Med. 2022;56(12):701–9.
10. Blondell SJ, Hammersley-Mather R, Veerman JL. Does physical activity prevent cognitive decline and dementia? A systematic review and meta-analysis of longitudinal studies. BMC Public Health. 2014;14:510.
11. Paluch AE, Bajpai S, Bassett DR, Carnethon MR, Ekelund U, Evenson KR, et al. Daily steps and all-cause mortality: a meta-analysis of 15 international cohorts. Lancet Public Health. 2022;7(3):e219–28.
12. Vancampfort D, Stubbs B, Lara E, Vandenbulcke M, Swinnen N, Koyanagi A. Correlates of sedentary behavior in middle-aged and old age people with mild cognitive impairment: a multinational study. Int Psychogeriatr. 2019;31(4):579–89.
13. Feng H, Zhang Z, Lyu W, Kong X, Li J, Zhou H et al. The effects of Appropriate Perioperative Exercise on Perioperative Neurocognitive disorders: a Narrative Review. Mol Neurobiol. 2023.
14. Yajima S, Nakanishi Y, Ogasawara RA, Imasato N, Hirose K, Katsumura S, et al. Housework participation and mortality in Japanese male patients undergoing cancer surgery: a propensity score-matched study. Prev Med. 2024;180:107896.
15. De Miguel Z, Khoury N, Betley MJ, Lehallier B, Willoughby D, Olsson N, et al. Exercise plasma boosts memory and dampens brain inflammation via clusterin. Nature. 2021;600(7889):494–9.
16. Besnier F, Labrunée M, Pathak A, Pavy-Le Traon A, Galès C, Sénard JM, et al. Exercise training-induced modification in autonomic nervous system: an update for cardiac patients. Ann Phys Rehabil Med. 2017;60(1):27–35.
17. Nicolas S, Dohm-Hansen S, Lavelle A, Bastiaanssen TFS, English JA, Cryan JF, et al. Exercise mitigates a gut microbiota-mediated reduction in adult hippocampal neurogenesis and associated behaviours in rats. Transl Psychiatry. 2024;14(1):195.
18. Thayer JF, Åhs F, Fredrikson M, Sollers JJ, Wager TD. A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. Neurosci Biobehavioral Reviews. 2012;36(2):747–56.
19. Thayer JF, Brosschot JF. Psychosomatics and psychopathology: looking up and down from the brain. Psychoneuroendocrinology. 2005;30(10):1050–8.
20. Thayer JF, Lane RD. Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. Neurosci Biobehav Rev. 2009;33(2):81–8.
21. Vaughan K, Miller WC. Validity and reliability of the Chinese translation of the physical activity scale for the Elderly (PASE). Disabil Rehabil. 2013;35(3):191–7.
22. Washburn RA, Smith KW, Jette AM, Janney CA. The physical activity scale for the Elderly (PASE): development and evaluation. J Clin Epidemiol. 1993;46(2):153–62.
23. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Eur Heart J. 1996;17(3):354–81.
24. Peden CJ, Miller TR, Deiner SG, Eckenhoff RG, Fleisher LA, Fleisher L, et al. Improving perioperative brain health: an expert consensus review of key actions for the perioperative care team. Br J Anaesth. 2021;126(2):423–32.
25. Hughes CG, Boncyk CS, Culley DJ, Fleisher LA, Leung JM, McDonagh DL, et al. American Society for Enhanced Recovery and Perioperative Quality Initiative Joint Consensus Statement on Postoperative Delirium Prevention. Anesth Analg. 2020;130(6):1572–90.
26. Chen H, Mui AC. Factorial validity of the Center for Epidemiologic Studies Depression Scale short form in older population in China. Int Psychogeriatr. 2014;26(1):49–57.
27. Lee SS, Lo Y, Verghese J. Physical activity and risk of postoperative delirium. J Am Geriatr Soc. 2019;67(11):2260–6.
28. Erickson KI, Hillman C, Stillman CM, Ballard RM, Bloodgood B, Conroy DE, et al. Physical activity, cognition, and brain outcomes: a review of the 2018 physical activity guidelines. Med Sci Sports Exerc. 2019;51(6):1242–51.
29. Chen ST, Stevinson C, Tian T, Chen LJ, Ku PW. Accelerometer-measured daily steps and subjective cognitive ability in older adults: a two-year follow-up study. Exp Gerontol. 2020;133:110874.
30. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451–62.
31. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, et al. Exercise and physical activity for older adults. Med Sci Sports Exerc. 2009;41(7):1510.
32. Hildenborg M, Kåhlin J, Granath F, Schening A, Granström A, Ebberyd A, et al. The Neuroimmune response to surgery– an exploratory study of Trauma-Induced changes in Innate Immunity and Heart Rate Variability. Front Immunol. 2022;13:911744.
33. Forte G, Favieri F, Casagrande M. Heart Rate Variability and Cognitive Function: A Systematic Review. Front Neurosci [Internet]. 2019 Jul 9 [cited 2024 Apr 14];13. Available from: https://www.frontiersin.org/journals/neuroscience/articles/https://doi.org/10.3389/fnins.2019.00710/full
34. Berntson GG, Bigger JT, Eckberg DL, Grossman P, Kaufmann PG, Malik M, et al. Heart rate variability: origins, methods, and interpretive caveats. Psychophysiology. 1997;34(6):623–48.

Publisher's note