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Research Article

Keywords: proprioception, dizziness, falls, causal inference

Posted Date: May 24th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2961710/v1

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Abstract

Purpose

Using a statistical approach to causal inference, to test the association between balance disorders and pain, providing a higher level of evidence.

Methods

Analysis of the Prevalence of Balance Disorders and Pain Based on NHANES Data To analyze the difference between the prevalence of pain in the balance disorder population and the balance population, logistic analysis was used to calculate the odds ratio (OR) of the effect of balance disorder on pain. Differences between groups and odds ratios were then calculated after propensity score matching of the two groups according to demographic characteristics.

Results

The weighted prevalence of balance disorders was 26.09%, and the weighted prevalence of pain, neck pain, and low back pain was 48.25%, 22.63%, and 39.22%, respectively. The prevalence of pain, neck pain, and low back pain was higher in the pre- and post-matched pain disorder group than in the balanced group (Before PSM, pain, 605(71.94%) VS 1070(48.09%), 95%CI, 20.17–27.53%. After PSM, pain, 605(71.94%) VS 409(48.63%), 95%CI, 18.76–27.85%). Multifactorial logistic regression, controlling for other variables, showing pain odds ratios associated with balance disorders (Before PSM, OR, 2.61, 95%CI, 2.192 to 3.110, p < 0.001. After PSM, OR, 2.747, 95%CI, 2.240 to 3.370, p < 0.001).

Conclusion

In the U.S. adult population over the age of 40, those with balance disorders had more pain, neck pain, and low back pain than those without balance disorders; there is a strong association between balance problems and pain. Balance is a risk factor for pain.

Introduction

Balance disorders, including dizziness, loss of balance, and falling, can lead to falls and injuries, as well as physical and psychological problems. Balance disorders are not only shared in the elderly but also in children. However, balance problems have more severe consequences in older adults, and mortality associated with balance disorders in older adults are increasing. Therefore, the pain questionnaire in the 2003–2004 National Health and Nutrition Examination Survey (NHANES) directly states, "This is of importance because of the increasing morbidity and mortality associated with balance disorders among
older persons in the U.S.” Pain is a prevalent condition that affects more than 100 million adults in the United States, making it one of the leading causes of health problems worldwide. Pain can be caused by various diseases, and its effects on the body are multifaceted, affecting not only physical health but also mental health. It has been suggested that dizziness, psychological disorders, and pain should be considered multifaceted, interacting, and interfering problems.

Balance is a stable state in which the body is placed, an ability to automatically adjust and maintain posture. It is a complex process that involves input from multiple sensory systems, closely related to vision, vestibular function, proprioception, and the central nervous system. The central nervous system achieves control of movement, balance, posture, and joint stability through sensorimotor control, which requires the integrity of all sensory systems. Proprioception is essential to sensorimotor control because it integrates and functions at all levels of the central nervous system with visual and vestibular information. Numerous studies have shown that the presence of pain has an impact on proprioception and interferes with sensorimotor control. In addition, pain affects body perception at the central nervous level. Thus, in theory, we believe that balance disorders and pain are correlated through the interplay of the central nervous system and proprioception.

Most previous studies have focused on the pathogenesis, risk factors, treatment, and prognosis of balance disorders and pain, but there is a lack of large clinical trials on the relationship between pain and balance disorders. We hypothesize that people with balance disorders are more likely to have a variety of pain problems. The 2003–2004 National Health and Nutrition Examination Survey (NHANES) included a balance and pain questionnaire, and we used propensity value score matching to analyze NHANES data, comparing differences in pain between people with and without balance disorders. We hope that statistical causal inference will confirm the strong association between balance and pain.

**Methods**

**Study design and participants**

The NHANES is a series of cross-sectional surveys conducted on a biennial basis to assess the health status of the United States population. Participants are chosen from a nationally representative civilian, non-institutionalized population. The study protocol is approved by the Institutional Review Board of the National Center for Health Statistics, and all participants provide written informed consent. NHANES is unique in that it combines a personal interview with a standardized physical examination and laboratory tests. The interviews take place in the participant’s home or at the Mobile Examination Center (MEC), while the physical examinations and laboratory tests are carried out at the MEC.

In the 2003–2004 cycle, 3,299 participants who were aged 40 and over completed the Balanced Questionnaire. Based on their responses to the “Dizzy/Balance/Falling Problem,” participants with unknown demographic profiles for matching needs were excluded, the participants were categorized into two groups: the balance disorder participants (N = 841) and the non-balance disorder participants (N =
To ensure a balanced distribution of covariates, the two groups underwent 1:1 greedy nearest neighbor matching. Propensity scores were calculated using information on age, gender, race, education, marital status, household size, and income from the Person Demographics File. This process resulted in 841 matched pairs of subjects, which were then divided into two groups: the balance disorder group and the balance group (see Fig. 1). During the same survey cycle, the Miscellaneous Pain section of the survey was completed by 5,041 individuals aged 20 or older. Pain was assessed based on the responses to the Miscellaneous Pain questionnaire.

**Statistical Analysis**

Data were analyzed using SAS OnDemand for Academics (SAS Institute Inc., Cary, NC, USA). For continuous variables, means ± standard deviations were calculated, while counts and percentages were used for categorical variables. Prevalence rates were weighted and standardized according to NHANES statistical guidelines. The level of statistical significance was set at 0.05. To ensure the comparability of key variables between the two groups, a propensity score matching model was constructed. The propensity score common support domain was selected as the matching range, and a 1:1 greedy nearest neighbor matching with a caliper of 0.25 was employed to pair the two groups with and without balance problems. Comparisons between the groups were conducted using the t-test for continuous variables and the chi-squared test for categorical variables. After matching, the effect of concealment bias on the results of the pain analysis was evaluated using the McNemar test, which is a dichotomous outcome measure. The $\Gamma$ value was calculated for sensitivity analysis, and a $\Gamma$ value greater than 2 was considered indicative of low sensitivity and robust results\(^\text{14}\). To analyze the effect of balance on pain, logistic regression was used. The adjusted odds ratio (OR) and corresponding 95% confidence intervals (CI) were used to describe the associations between the variables.

**Results**

**Characteristics**

In the 2003–2004 Balance Questionnaire survey, 3299 individuals responded, among whom 912 (weighted prevalence of 26.09%) reported dizziness, balance, or falling issues. Of the respondents, 663 (weighted prevalence of 19.69%) reported dizziness, 613 (weighted prevalence of 16.76%) reported balance problems, and 271 (weighted prevalence of 6.79%) reported falling problems. In the miscellaneous pain section of the survey, 5041 individuals participated, with 2349 (weighted prevalence of 48.25%) reporting joint pain, aching, or stiffness, 1018 (weighted prevalence of 22.63%) reporting neck pain, and 1912 (weighted prevalence of 39.22%) reporting low back pain. Excluding participants who provided incomplete information, there were 841 participants in the balance disorder group and 2225 participants in the no balance disorder group. As demonstrated in Table 1, all variables showed significant differences between the two groups, except for marital status and household size, which did not differ. After matching for propensity scores, the 841 respondents who reported balance disorders were
paired with individuals from the balance group. The standardized mean differences of all variables were significantly lower than the suggested upper limit of 0.25, indicating that the standard variables were well balanced after matching (Fig. 2)\textsuperscript{15,16}. Demographic characteristics did not differ significantly after matching (Table 1).
Table 1
Basic characteristics of participants before and after propensity score matching (PSM).

<table>
<thead>
<tr>
<th></th>
<th>Before PSM</th>
<th>After PSM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Balance Disorder N = 841</td>
<td>Balance N = 2225</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>341</td>
<td>1170</td>
</tr>
<tr>
<td>Female</td>
<td>500</td>
<td>1055</td>
</tr>
<tr>
<td>Age</td>
<td>64.7 ± 13.9</td>
<td>61.11 ± 13.6</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic White</td>
<td>538</td>
<td>1231</td>
</tr>
<tr>
<td>Non-Hispanic Black</td>
<td>124</td>
<td>441</td>
</tr>
<tr>
<td>Mexican American</td>
<td>138</td>
<td>434</td>
</tr>
<tr>
<td>Other Race</td>
<td>24</td>
<td>62</td>
</tr>
<tr>
<td>Other Hispanic</td>
<td>17</td>
<td>57</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less Than High School</td>
<td>299</td>
<td>689</td>
</tr>
<tr>
<td>High School Diploma</td>
<td>239</td>
<td>530</td>
</tr>
<tr>
<td>More Than High School</td>
<td>303</td>
<td>1006</td>
</tr>
<tr>
<td>Marital Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>763</td>
<td>2004</td>
</tr>
<tr>
<td>Unmarried</td>
<td>78</td>
<td>221</td>
</tr>
<tr>
<td>Household a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 to 6</td>
<td>820</td>
<td>2155</td>
</tr>
<tr>
<td>7 or more</td>
<td>21</td>
<td>70</td>
</tr>
<tr>
<td>Income b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ 0 to $ 19,999</td>
<td>318</td>
<td>554</td>
</tr>
<tr>
<td>$ 20,000 and Over</td>
<td>523</td>
<td>1671</td>
</tr>
</tbody>
</table>

Comparison Between the two groups

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*a* Household size, Total number of people in the Household.

*b* Income, Annual Household Income.
There were differences in pain, neck pain and low back pain between the two groups before matching, all with P values less than 0.001, as indicated by the 95% confidence interval for the simultaneous rate difference. (Table 2). Single-factor logistic regression indicated that balance was a risk factor for pain with an odds ratio (OR) of 2.767 and 95% confidence intervals of 2.330 to 3.286. Multi-factor logistic regression adding gender, age, race, education, marriage, family size, and income yielded a odds ratio (OR) of 2.611 and 95% confidence intervals of 2.192 to 3.110. Two regressions modeling the weighted odds ratio (OR) and 95% confidence interval were 2.618 (2.616 to 2.621) and 2.475 (2.473 to 2.478), respectively, in the same direction. (Table 3). To balance the demographic variables between the two groups, this study was propensity value matched and the matched rate difference between the two groups was 23.31% with 95% confidence interval 18.76–27.85% for pain, 16.89% with 95% confidence interval 12.85–20.92% for neck pain, and 18.67% and 95% confidence interval 14.01–23.33% for low back pain. (Table 2). The two matched groups were then subjected to logistic regression analysis, and the one-way unweighted and weighted dominance ratios and 95% confidence intervals were 2.708 (2.212 to 3.315) and 2.331 (2.329 to 2.334), respectively. The results of the multifactorial regression model controlling for sex, age, race, education, marriage, family size, and income showed a dominance ratio of 2.747 with 95% confidence intervals of 2.240 to 3.370. The weighted dominance ratio and 95% confidence intervals of the multifactor model were 2.485, 2.482 to 2.482, and 2.482 to 2.487. (Table 3). Propensity matching still indicates that balance is a risk factor for pain. For the variability of pain between the two groups after matching, we calculated Ω values according to the dichotomous variable results ,Ω = 2.20, p = 0.055. Ω denotes the metric for the sensitivity analysis after matching. If Ω > 2, it can be considered that the sensitivity of the study is low, and the influence of hidden bias has been eliminated¹⁷.
### Table 2
Comparison of pain between two groups before and after propensity score matching (PSM).

<table>
<thead>
<tr>
<th></th>
<th>Pain</th>
<th>Neck Pain</th>
<th>Low Back Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes, n(%)</td>
<td>Yes, n(%)</td>
<td>Yes, n(%)</td>
</tr>
<tr>
<td>Balance Disorder (n = 841)</td>
<td>605 (71.94%)</td>
<td>277 (32.94%)</td>
<td>449 (53.39%)</td>
</tr>
<tr>
<td>Balance (Before PSM) (n = 2225)</td>
<td>1070 (48.09%)</td>
<td>372 (16.72%)</td>
<td>731 (32.85%)</td>
</tr>
<tr>
<td>Rate difference</td>
<td>23.85%</td>
<td>16.22%</td>
<td>20.54%</td>
</tr>
<tr>
<td>95% CI&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.17–27.53%</td>
<td>12.68–19.75%</td>
<td>16.64–24.43%</td>
</tr>
<tr>
<td>P value</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Balance Disorder (n = 841)</td>
<td>605 (71.94%)</td>
<td>277 (32.94%)</td>
<td>449 (53.39%)</td>
</tr>
<tr>
<td>Balance (After PSM) (n = 841)</td>
<td>409 (48.63%)</td>
<td>135 (16.05%)</td>
<td>292 (34.72%)</td>
</tr>
<tr>
<td>Rate difference</td>
<td>23.31%</td>
<td>16.89%</td>
<td>18.67%</td>
</tr>
<tr>
<td>95% CI&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.76–27.85%</td>
<td>12.85–20.92%</td>
<td>14.01–23.33%</td>
</tr>
<tr>
<td>P value</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

<sup>a</sup> CI denotes confidence interval.

### Table 3
Logistic regression analyzed the relationship between balance and pain before and after propensity score matching (PSM).

<table>
<thead>
<tr>
<th></th>
<th>Before PSM</th>
<th>95% CI&lt;sup&gt;a&lt;/sup&gt;</th>
<th>P value</th>
<th>After PSM</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Factor OR&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.767</td>
<td>2.330 to 3.286</td>
<td>&lt; 0.001</td>
<td>2.708</td>
<td>2.212 to 3.315</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Single factor weighting OR</td>
<td>2.618</td>
<td>2.616 to 2.621</td>
<td>&lt; 0.001</td>
<td>2.331</td>
<td>2.329 to 2.334</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Multi-factor OR</td>
<td>2.611</td>
<td>2.192 to 3.110</td>
<td>&lt; 0.001</td>
<td>2.747</td>
<td>2.240 to 3.370</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Multi-factor weighting OR</td>
<td>2.475</td>
<td>2.473 to 2.478</td>
<td>&lt; 0.001</td>
<td>2.485</td>
<td>2.482 to 2.487</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

<sup>a</sup> CI denotes confidence interval.

<sup>b</sup> OR, Odds Ratio.

**Discussion**
The NHANES is a large sample size survey that monitors the health and nutritional status across the United States. The NHANES 2003–2004 has done questionnaires on balance disorders and pain, and the results of the surveys are professionally reliable. We divided the balance questionnaire population into two groups and matched propensity value scores based on demographic data to control for hidden bias due to confounding factors. After matching, with a statistically significant difference between the two groups and a significantly higher prevalence of pain in the balance-impaired population than in the non-balance-impaired population. Sensitivity analysis also confirmed the robust validity of the results. The effect of balance impairment on pain was also confirmed by logistic regression analysis after matching. We applied the statistical causal inference method, the correlation between pain and balance problems is supported by our study. To our knowledge, this is the first study of the relationship between balance disorders and pain using large cross-sectional survey data.

In a UK survey, 21.5% reported balance problems, and 11.1% reported dizziness problems. In our study, after data weighting, 26.09% people had balance problems and 19.69% people had dizziness problems. It is because of the increasing morbidity and mortality associated with balance disorders among older adults that the Balance Questionnaire was done in the United States. Maintenance of balance is a multi-systemic operating system that requires the integration of visual, proprioceptive, and vestibular functions, as well as the central nervous system. The consequences of balance disorders are also complex, including physical, psychological, and social problems. Some scholarly studies have shown that balance disorders are also associated with an increased risk of death from certain chronic diseases. The International Association for Study of Pain (IASP) defines pain as “An unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage.” And the experience of pain is complex, with effects on quality of life, psychological disorders, sleep disturbances, work attendance, health care burden, etc. A 2016 review found that the prevalence of chronic pain in the UK ranged from 35.0–51.3%. The estimated prevalence of chronic pain in US adults in the same year ranged from 11–40%. Our statistics for the NHANES 2003–2004 data showed that the weighted prevalence of pain was 48.25% over the age of 20. So, the pain problem is indeed a widespread social problem and health care burden. Pain can also lead to a more serious social problem, substance abuse, and dependence.

Proprioception is the body's ability to sense its own position and movement and is essential for balance. Studies on the elderly have shown that reduced proprioceptive function, decreased muscle strength, and increased reaction time can lead to deficits in balance. Balance disorders can lead to limited mobility, poor mood, reduced quality of life, and can lead to falls, and falls can lead to pain. Pain, through changes in muscle tone, can reduce the accuracy of proprioceptive information, leading to balance problems that cause falls. Balance disorders and pain appear to be closely related because of falls, and because falls can have serious consequences, falls have become a focus of scholarly research. Falls have become a major public health concern, and falls can lead to fractures; in older adults, fractures from falls can be fatal. For example, hip fractures in older adults have a high mortality...
rate and are the most common fractures in older adults\textsuperscript{34}. However, we found that only 271 of the 912 people with dizzy/balance/falling problems reported falling problems, which is only about 30%. Dizziness and balance problems were reported by a high percentage of 663 and 613 people, respectively.

The production of pain and balance is a complex process that requires the involvement of the central nervous system and a combined effect at the peripheral level\textsuperscript{37,38}. Scientists have long been interested in the relationship between dizziness/balance and pain\textsuperscript{39}. The vicious cycle of pain and balance interact through central reflexes, and muscle tone control\textsuperscript{39–42}. Malmstrom et al.\textsuperscript{8} showed in a study of patients referred to a vestibular disorders clinic for balance disorders and a psychiatric clinic for anxiety or depression that there may be an interaction between persistent dizziness, mood, and Neck-Shoulder-Back pain. Iglebekk et al.\textsuperscript{42} Used the Structured symptom questionnaire, Modified dizziness handicap inventory (DHI), and DHI subscales to investigate a group of patients with chronic musculoskeletal pain in Norway and Denmark. The investigations concluded that patients with complex chronic musculoskeletal disorders might have undiagnosed vestibular disorders. Our study also showed that a higher proportion of people with balance disorders before propensity score matching had pain problems than the surveyed respondents. The number of people with different types of pain was also higher in the group with balance disorders than in the group without balance disorders after propensity score matching, and the difference between the two was statistically significant on statistical analysis. Neck pain is more common in people with balance disorders. It can be explained by the effect of neck pain on sensorimotor control and the impact of cervical vertigo on proprioception\textsuperscript{43,44}. Several studies have confirmed the effects of low back pain on muscle control, proprioception, and balance posture, which could also explain why low back pain is prevalent in the balance-impaired population\textsuperscript{38,45–47}.

We applied the statistical method of causal inference and demonstrated that the generation of pain can be caused by a balance disorder. Even considering the complexity of the mechanisms by which both occur, we can conclude that there is a strong association between balance disorders and pain. Based on this, it is important for health care professionals to consider whether or not balance disorders are the cause of pain when they see a patient with pain. Individual differences significantly influence pain conditions, heterogeneity exists, and pain prevention and treatment decisions depend on many factors. The recent U.S. National Pain Strategy report emphasizes self-management programs, indicating an interdisciplinary approach to pain prevention, management, and treatment\textsuperscript{48}. It is hoped that the impact of balance will be considered in pain treatment and self-management, especially for some patients with chronic pain. Based on our research and experience, it should be possible to improve chronic pain in some patients by promoting balanced treatment and management.

In this study, in this 2003–2004 survey, the balance questionnaire was administered to people over 40, and the results cannot be generalized to people under 40. Unfortunately, balance questionnaires have not been administered in NHANES since 2004. To date, quantitative assessment of balance has been limited primarily to laboratory settings, which may underestimate the challenges of what is happening.
Conclusion

In the U.S. adult population over the age of 40, those with balance disorders had more pain, neck pain, and low back pain than those without balance disorders; there is a strong association between balance problems and pain. Balance is a risk factor for pain.

Declarations

Acknowledgements

Not applicable.

Authors’ contributions

Xiaoxian Tu and Feng Hu: Organized this research project, conducted it, and wrote the first draft. Zhiyuan Tu: Organized this research project, conducted it. Wenming Zhang: Conceptualize this research project, review and critique the first draft. Zhe Wu: Participated in all phases of researching, analyzing, and writing for this study.

Funding

This study was initiated by the School Management Project of Fujian University of Chinese Medicine (XB2020154), and the funds need to be raised by oneself. No specific funding was received for this work.

Availability of data and materials

The datasets generated and/or analysed during the current study are available in the NHANES repository, https://www.cdc.gov/nchs/nhanes/index.htm.

Ethics approval and consent to participate

The Ethics Committee of Fujian Provincial Corps Hospital of Chinese People's Armed Police Force concluded that this study used publicly accessible nonidentifiable data, was used only for statistical analysis and reporting, and was exempt from ethical review.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

References


Figures

Figure 1

Selection of study participants.
Figure 2

Standardized mean differences of variables between the two groups. In matched observations, the differences in standardized means of all variables were significantly lower compared to all observations.