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Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

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Abstract

Objective: To examine the impact of nurse staffing on patient-perceived quality of nursing care. We differentiate nurse staffing levels and nursing skill mix as two facets of nurse staffing and use a multi-dimensional instrument for patient-perceived quality of nursing care. We investigate non-linear and interaction effects.

Setting: The study setting was 3,458 hospital units in 1,017 hospitals in Germany.

Participants: We contacted 212,554 patients discharged from non-pediatric, non-intensive, and non-psychiatric hospital units who stayed at least two nights in the hospital between January and October 2019. Of those, 30,174 responded, yielding a response rate of 14.2%. Our sample included only those patients. After excluding extreme values for our nurse staffing variables and removing observations with missing values, our final sample comprised 28,136 patients ranging from 18 to 97 years of age (average: 61.12 years) who had been discharged from 3,458 distinct hospital units in 1,017 hospitals.

Primary and secondary outcome measures: Patient-perceived quality of nursing care (general nursing care, guidance provided by nurses, and patient loyalty to the hospital)

Results: For all three dimensions of patient-perceived quality of nursing care, we found that they significantly decreased as (a) nurse staffing levels decreased (with decreasing marginal effects) and (b) the proportion of assistant nurses in a hospital unit increased. The association between nurse staffing levels and quality of nursing care was more pronounced among patients who were less clinically complex, were admitted to smaller hospitals, or were admitted to medical units.

Conclusions: Our results indicate that, in addition to nurse staffing levels, nursing skill mix is crucial for providing the best possible quality of nursing care from the patient perspective and both should be considered when designing policies such as minimum staffing regulations to improve the quality of nursing care in hospitals.

Article summary

Strengths and limitations of this study

- This study combines administrative data on hospital unit level nurse staffing with a multi-dimensional survey instrument that covers three aspects of patient-perceived quality of nursing care in a sample of 28,136 patients discharged from 3,458 hospital units in Germany in 2019
- This study demonstrates that the effect of nurse staffing on patient-perceived quality of care is non-linear and depending on patient and hospital characteristics (patient case severity, hospital size, and medical versus surgical patients)
- Besides patient-to-nurse ratios, the study also adds insight on the effect of skill mix and patient-to-physician ratios on patient-perceived quality of nursing care
- The study is cross-sectional and cannot account for all potential endogeneity problems / Even though considering the hospital unit type level is advantageous to using hospital-level aggregated data, omitted variables on hospital unit and patient level might remain.

Keywords (MeSH Terms)

Nursing Staff, Hospital; Health Workforce; Nurse-Patient Relations; Nursing Care; Patient-Centered Care; Health Care Surveys

INTRODUCTION AND BACKGROUND

Nurses are responsible for delivering the highest proportion of care to patients in hospitals and therefore a main contributor to quality of hospital care. Nurses who work on units with inadequate staffing are probably not working as effective and efficient as nurses on better-staffed and better-skilled units. As a result, nurses do not have enough time for providing care and instructions, observe vital signs timely, and to respond to patients' individual needs., which leads to missed care and ultimately unfavourable clinical patient outcomes and bad patient experiences and perceptions of quality of care. A large body of empirical studies, including several literature reviews and meta-analyses, has examined how nurse staffing levels affect patient outcomes.[1–10] Most studies have thereby relied on clinical outcomes available in administrative data and e.g. found significant effects of nurse staffing on mortality, pressure ulcers, and pneumonia.[3] Several studies depict that the effect of inadequate nurse staffing on adverse events is through missed care.[11–13] In light of calls for care (and, indeed, research) to be more patient oriented and for health systems to become more responsive to patient needs and expectations,[14–16] the number of studies examining links between nurse staffing patterns and patient experiences of care – i.e., perceived quality of care – has steadily grown.[15–17] In addition, in the wake of many studies on the effects of skill mix on clinical outcomes,[see 3] recent studies investigated the association between skill mix and patient-perceived quality of care.[15, 18, 19]

Several empirical studies that have analyzed the relationship between nurse staffing levels and perceived quality of care have considered the nurse's rather than the patient's perspective.[19–22] While the former is of course crucial, there is evidence that nurses' perceptions of the quality of their work can deviate substantially from the patients' perceptions[23]. In addition, most studies that have analyzed quality of care as an outcome have used measures that are very general (e.g., single items to rate overall quality of care or patient safety).[17, 22, 24, 25] Outcome measures like these are less informative about the quality of care provided by nurses and therefore potentially less sensitive to nurse staffing. Some studies have used multi-dimensional constructs of patient satisfaction or patient experience with care. Yet, these constructs usually comprise dimensions and indicators that do not relate to nursing care, but other aspects, such as responsiveness of hospital staff, discharge information, and overall hospital rating, all of which are also indicators of other health professionals' quality of care.[11, 16, 20, 26] . Only a handful of studies have used items that ask directly about the quality of care provided by nurses, or quality of nursing care.[20–22] To our knowledge, no studies to date have used a validated, multi-item, and multi-dimensional scale for patient-perceived quality of nursing care.

Methodologically, examining the link between nurse staffing and patient outcomes is at risk of endogeneity problems, such as omitted variable bias (e.g., skill mix, hospital-unit-type and patient characteristics, or physician staffing could all be related to nurse staffing and patient outcomes) or endogenous sorting (whereby hospitals devote more resources to patients with a higher risk of adverse outcomes).[1, 4, 8, 16, 27] The risk of endogeneity increases with the level of aggregation; as many studies use staffing information at the aggregated hospital level,[6, 17, 20, 21, 28, 29] they do not consider important information at the level of hospital units [7, 30, 31] or of patients.[16, 32] At the other extreme, using micro level data on the patient level [as e.g., 32, 33] usually implies substantial primary data collection efforts and a focus on one or few organizations, hence limiting generalizability. As an in-between approach, the number of studies using data at the level of hospital units has grown,[7, 31, 34–39] yet often suffers from limited sample sizes both in terms of patients and hospitals.[15] In addition, recent evidence hints to the fact the effect of nurse staffing on quality of nursing care non-linear, i.e., the effect of an additional nurse per patient might be high if nurse staffing is low; with higher numbers of nurses, the effect of each additional nurse probably decreases.[15] Furthermore, recent studies indicate that the association between nurse staffing and patient outcomes can differ depending on patients' case severity,[8, 40] hospital size,[6, 41], and between medical versus surgical units.[8, 28] Yet most of these studies have analyzed the associations between nurse staffing and clinical patient outcomes.

The present study aims to shed further light on the association between nurse staffing and patient-perceived quality of nursing care. In particular, we examine this relationship between nurse staffing levels, nurse skill mix, and patient-perceived quality of nursing care based on large-scale survey data combined with administrative data. Especially the use of a multi-dimensional survey instrument reflecting the patient perspective on nursing quality for measuring this relationship is quite novel. Second, we addressed substantial parts of potential endogeneity by including a rich set of patient- and hospital-related control variables. Thereby, we specifically consider physician staffing and investigate to which degree physician staffing is a relevant predictor of patient-perceived quality of nursing care. In addition, we apply a fixed effects model to account for differences across hospital unit types, which seems important to reduce endogeneity problems. Finally, we allow for non-linear effects of nurse staffing on quality of nursing care and conduct sub-group analyses on patient case severity, hospital size, and medical versus surgical hospital units.

METHODS

Data and sample

This study is part of a larger project on the association between nurse staffing and quality of care.[3, 42, 43] Our study analyzed data from an online patient survey, which we combined with (a) claims data provided by the largest statutory health insurance fund in Germany and (b) data from the mandatory quality reports published annually by each hospital in the country. The combined data set comprised data from patients discharged from non-pediatric, non-intensive, and non-psychiatric hospital units between January and October 2019. We define a hospital unit as an operating unit within a hospital that focuses on specific types of patients (e.g., geriatrics or cardiology). Our sample included only those patients who stayed at least two nights in the hospital. We contacted patients in monthly waves and asked them to participate in the survey, eight weeks after they had been discharged from the hospital at the latest. The survey contained questions related to patients' perceptions of the quality of the nursing care provided during their hospital stay. Each patient was contacted only once. In total, we contacted 212,554 patients, of whom 30,174 responded, yielding a response rate of 14.2%. The sample is representative for the population of adult hospitalized patients in Germany, except for the age group 80 and above, who are slightly underrepresented.

The claims data in our data set contained patient-level information about the course of disease during each patient's hospital stay, as well as the dates of hospital admission and discharge, the type of hospital unit, and ICD codes. The quality reports contained general information at the hospital unit level, such as the number of patient cases treated and staffing numbers that relate to the situation at the end of 2017.

Nurse staffing

We obtained the nurse staffing level in each hospital unit by calculating a patient-to-nurse ratio (PTN) in line with the definition for measuring nursing workload as suggested by the National Office of Statistics in Germany.[44] The patient-to-nurse ratio indicates how many patients a nurse has to care for during an average shift and is given by:

$$PTN = \frac{occupation\ days * 24hours}{nurses * 220days * 8hours},\ with$$

$$occupation\ days = inpatient * average\ length\ of\ stay.$$

The total number of nurses (based on full-time nurses employed) comprise all registered nurses with at least three years of training and assistant nurses with at least one year of training. The numbers are

derived from the annual quality reports of each hospital, representing the situation at the end of the year and not accounting for sickness absences or other sources of within-year variations such as variation caused by holidays. To calculate occupation days, we used the number of inpatients and approximated the average length of stay or each hospital unit based on the average length of stay of more than 6.2 million inpatient cases available in our claims data set over the period 2014 to 2019. We draw on the five-year period for this approximation because we cannot observe all patients in each hospital unit in one year; to ensure robustness, we considered only those hospital units with more than 150 observations to approximate the length of stay.

In addition to staffing levels, we accounted for the skill mix in each hospital unit by calculating the ratio of assistant nurses to the total number of nurses (measured in full-time equivalents):

$$skill\ mix = \frac{assistant\ nurses}{nurses}.$$

We excluded extreme values, i.e., patient-to-nurse ratios below 1 and above 20, as well as skill-mix ratios above 25%.

Quality of nursing care

Because the definition of nursing care varies from country to country, it is necessary to use an instrument that takes country-specific regulations into account. We therefore chose the Patients' Experience of Nursing Quality in Acute Hospitals (PENQuAH) instrument developed by Blume to analyze the relationship between nurse staffing and patient outcomes.[43] The instrument was designed to evaluate patients' perceptions of quality of nursing care in German hospitals. The instrument consists of 24 items, which were chosen based on a review of the literature and interviews with nursing experts. To examine the scale's dimensionality and factor-based validity, Blume conducted exploratory and confirmatory factor analyses with a randomly split sample.[43] Their exploratory factor analysis revealed that three main dimensions captured the structure of the underlying item set: general nursing care, guidance provided by nurses, and nurse-related patient loyalty to the hospital. The results of their confirmatory factor analysis suggested a good overall model fit (CFI = 0.978; TLI = 0.976). Table 1 shows the three dimensions and exemplary related items.

--- include table 1 about here ----

We calculated each dimension of quality of nursing care by taking the arithmetic mean of the underlying items after recoding reverse-coded items. Dimensions one and two are on a scale of one to five, with five representing the best quality of nursing care, and dimension three is on a scale of one to four, with four representing the best quality of nursing care. Dimension one represents patients' perception of the general quality of nursing care. Dimension two represents patients' perception of the guidance provided by nurses. Dimension three comprises two items that capture patients' loyalty to a hospital based on the nursing care provided.

Statistical model

The results of previous studies suggest that the relationship between nurse staffing and patient outcomes varies across different types of hospital units.[8, 35, 42] To account more accurately for potential differences across the 24 unit types in our sample and to depict potential heteroscedastic structures in the error term of the regression, we applied a fixed effects model. The model is given by:

$$QoNC_{iu}^{(x)} = \alpha_0 + \alpha_{10}\,\widetilde{PTN}_{iu} + \alpha_{11}\,\widetilde{PTN}_{iu}^2 + \alpha_2\,\widetilde{skill}_{iu} + \beta_1\,\overline{PTN}_u + \beta_2\,\overline{skill}_u + \gamma C_{iu} + (v_{0u} + \varepsilon_{iu}),$$

where $QoNC_{iu}^{(x)}$ is the value of one of the three factors $x \in \{1, 2, 3\}$ for patient i admitted to unit type u, $u \in \{1, \ldots, 24\}$. α_0 is the intercept of the regression. $\widetilde{PTN}_{iu} = (PTN_{iu} - \overline{PTN}_u)$ and $\widetilde{skill}_{iu} = (skill_{iu} - \overline{skill}_u)$ with coefficients α_{10} and α_0 are the mean-centered independent nurse staffing variables of interest, which correspond to the patient-to-nurse and skill mix ratio of the hospital unit associated with patient i minus the group means $\overline{PTN}_u$ and $\overline{skill}_u$ for each unit type u. Assuming that the marginal effect of the patient-to-nurse ratio on quality of nursing care decreases as staffing levels increase, we also included a squared patient-to-nurse term with coefficient α_{11}. β_1 and β_2 are the coefficients of the between-unit effects. C_{iu} represents a vector of patient-, hospital-, and hospital-unit-related control variables at level one of the model. First, it includes the patient-to-physician (PTP) ratio, because it might correlate with the PTN ratio and also affect the outcome.[e.g., 27] Second, we account for in patient risks by including age, gender, and each patient's case severity reflected by the Patient Clinical Complexity Level (PCCL) index (0-6), which indicates the degree of comorbidities and complications for each patient. It is derived from a closed list of comorbidities and complications and is meant to predict a patient's need for hospital resources, such as nursing care.[45] We directly incorporate the PCCL index in our model because sensitivity analyses using dummy variables for each score suggested a linear relationship. Furthermore, we control for the rurality of each patient's place of residence using an index

ranging from one (urban area) to four (rural area), hospital size categories, and monthly fixed effects. v_{0u} refers to the fixed effects for the 24 hospital unit types.

As most previous studies used dichotomized outcome variables, we transformed our three quality of nursing care measures into dichotomous outcome variables and estimated a generalized version of our fixed effects model using a logit link function for comparability purposes, i.e. a logit model. To check the robustness of our main model, we replaced the Patient Clinical Complexity Level index with the Elixhauser comorbidity categories.[46]

Moreover, we conducted subgroup analyses. As suggested by previous studies, the association between nurse staffing and patient outcomes can differ depending on patients' case severity.[8, 40] To study these potential differences, we split our sample into patients with low case severity (Patient Clinical Complexity Level = 0) and those with high case severity (Patient Clinical Complexity Level > 0) and estimated our main regression model for each of the sub-samples. Additionally, we considered that our results might vary due to differences in hospital size.[6, 41] We therefore split our sample into two categories – i.e., patients admitted to hospitals with fewer than 500 beds (category "small") and patients admitted to hospitals with at least 500 beds (category "large"). Lastly, by categorizing our unit types as medical or surgical, we estimated our statistical model separately for medical and surgical patients.

Patient and Public Involvement

This study is part of a larger project on the association between nurse staffing and quality of care.[3, 42, 43] The public, i.e., a statutory health insurance, hospital managers, and patient representatives were involved in the design of the overall project. In addition, patients, practitioners (nurses, physiotherapists, doctors), and scientific experts were involved in the development of the survey (described in more detail in [3, 43]). Results of the study and the overall project will be disseminated to the participants via the statutory health insurance and via additional practice-oriented publications and newsletters.

RESULTS

Descriptive results

After excluding extreme values for our nurse staffing variables and removing observations with missing values for one or more of the control variables, our final sample comprised 28,136 patients ranging from 18 to 97 years of age (average: 61.12 years) who had been discharged from 3,458 distinct hospital units in 1,017 hospitals. 39.2% of the survey participants were female. Table 2 illustrates the distribution of patients and the average response for each of the three dimensions of quality of nursing care across the

24 types of hospital units. Overall, the variation in the distribution of patients across the 24 unit types was large. Almost 50% of the patients had been discharged from general surgery or internal medicine, followed by orthopedics, urology, neurology, trauma surgery, and cardiology, from each of which between six and ten percent of the patients had been discharged. All of the other unit types each accounted for less than three percent of the patients in our sample. In terms of our dependent variable, quality of nursing care, we obtained an average response of 4.33, 3.77, and 3.38 for the three dimensions general nursing care, guidance provided by nurses, and nurse-related patient loyalty to the hospital, respectively, indicating that the perceived quality of nursing care was above the scale average for each. In addition, we found that patient perception of the guidance provided by nurses was, on average, 0.56 scale points lower compared to the general perception of quality of nursing care. We also found that the average responses varied across hospital unit types. For instance, for dimensions one and two, the average responses for patients discharged from internal medicine were 0.24 and 0.46 scale points higher, respectively, compared to orthopedic patients.

For the patient-to-nurse and skill-mix-ratios, we obtained average values of 5.84 patients per nurse and 6.61%, respectively. The patient-to-nurse ratio ranged from 3.77 patients a nurse has to care for in heart surgery to 9.75 in rheumatology. The skill-mix ratio ranged from 3.33% assistant nurses in nuclear medicine to 13.59% assistant nurses in endocrinology (see table A.1).

---- include table 2 about here -----

Regression results

As shown in Table 3, our results indicate that the two nurse staffing variables were significantly related to quality of nursing care. An increase in the patient-to-nurse ratio significantly decreased the general quality of nursing care, the patient perception of nursing guidance, and nurse-related patient loyalty to a given hospital. Additionally, there were significantly positive associations between the squared patient-to-nurse ratio, on the one hand, and the general quality of nursing care, guidance, and patient loyalty, on the other. Hence, the negative effect of the patient-to-nurse ratio is greater when the patient-to-nurse ratio is smaller (in other words, if a nurse already has to care for a lot of patients, one additional patient has a less strong effect on quality perceptions). With regard to the skill-mix ratio, we found that an increase in the ratio of assistant nurses to the total number of nurses led to a significant decrease in general quality of nursing care, patient perception of nursing guidance, and patient loyalty. An increase

in the patient-to-physician ratio of one additional patient a physician must care for significantly decreased the quality of nursing care dimensions.

---- include table 3 about here -----

The adjusted R^2 measure indicated that our model reduces the error in predicting an individual outcome for our three dimensions of quality of nursing care by between 4.5 and 6.1%.

The regression results of the logit model indicated that an additional patient per nurse decreases the odds of a patient reporting high quality of nursing care. For nurse-related patient loyalty, this effect is significantly non-linear in the same way as in our main model (stated above). Increasing the share of assistant nurses decreases the odds of reporting high quality. An additional patient per physician does not significantly decrease the odds of reporting a high quality of quality of nursing care (see table A.2).

When we replaced the Patient Clinical Complexity Level index with the Elixhauser risk adjustment, our results remained robust.

Sub group analyses

Differentiating between patients according to their case severity, we found that the mean-centered patient-to-nurse ratio and its square are significantly associated with all three dimensions of patient-perceived quality of nursing care for patients with low case severity, but not for those with high case severity. The effects of the skill-mix ratio are also only significant for patients with low case severity, while the effects of the patient-to-physician ratio are slightly larger and only significant for high-case severity patients (except for general nursing care) (see table A.3).

When splitting our sample into patients admitted to a hospital with fewer than 500 beds and those admitted to a hospital with at least 500 beds, we found that an increase in the patient-to-nurse ratio significantly decreased general nursing care and nurse-related patient loyalty only for patients admitted to hospitals with fewer than 500 beds. Skill mix significantly affected general nursing care perceptions and nurse-related patient loyalty in small hospitals only, while it significantly affected the perception of guidance provided by nurses in small and in large hospitals. Moreover, we found a significant association between physician staffing and patient-perceived quality of nursing care for patients admitted to larger hospitals but not for patients admitted to smaller ones (see table A.4).

Finally, when we divided patients into those admitted to medical or surgical units, we found that the patient-to-nurse ratio significantly affected perceptions of guidance by nurses and nurse-related patient loyalty for medical patients only. The associations between the skill mix ratio and quality of nursing care seem largely unaffected by the sample split. Finally, it shows that medical patients were more sensitive to physician staffing compared to surgical patients (see table A.5).

DISCUSSION

Our results provide important new insights into the relationship between nurse staffing and patient outcomes, in particular, patient-perceived quality of nursing care. We found that patient-perceived quality of nursing care significantly decreased as staffing levels, measured using the patient-to-nurse ratio, decreased. This finding is in line with previous research that has examined the relationship between nurse staffing levels and general perceived quality of care measures.[15, 16, 19–22, 25, 26, 47–49] Our study adds to the previously ambiguous evidence in literature by providing insights into the specific aspects of perceived quality of nursing care that are affected by staffing levels. Evidence on the perceived quality of guidance provided by nurses has been inconsistent and scarce.[20, 22] Our results, however, corroborate and extend the findings of Zhu et al. ,[22] who found that higher staffing levels improved satisfaction with nurses' guidance on medications and medical aids, pain management, and self-help.[22] With respect to nurse-related patient loyalty, our results confirm the findings of previous studies that have found that higher nurse staffing levels in hospitals increase the likelihood of patients generally recommending a hospital to family and friends.[20, 21] Thus, nurse-related patient loyalty seems to be highly related to overall recommendation behavior. In sum, staffing levels affect whether an adequate amount of time is devoted to caring and providing instructions as well as nurses' responsiveness to patients' individual needs. Furthermore, nurse staffing levels have direct consequences for hospitals in terms of patient loyalty. Yet, those effects are not linear; instead, the negative effects become smaller with rising numbers of patients per nurse. This decreasing marginal effect of the patient-to-nurse ratio on quality of nursing care with increasing staffing levels is in line with prior research [15] and seems reasonable: when the ratio is small, each additional patient will substantially affect the amount of time and the responsiveness of a nurse, thus probably substantially reducing missed care.[11–13] In contrast, the effect will be lower when a nurse already needs to care for a high number of (potentially less complex) patients and each additional patient only has a low impact.

Our results suggest that the nurses' level of educational attainment, as measured using the skill-mix ratio, significantly influences patient-perceived quality of nursing care. This finding adds to the few

available studies on the relationship between skill mix and patient-perceived quality of care.[15, 18, 19] We found strong evidence that a higher proportion of assistant nurses, which means a lower proportion of professionalization among nursing staff, is negatively associated with all three dimensions of quality of nursing care. Nurses with lower levels of educational attainment may have less training in interacting with patients, might work less efficiently and hence have less time per patient, or both. In addition, it is conceivable that they are less experienced in providing instructions suited to a patient's particular needs – for example, with regard to medication, pain relief, or the use of medical aids. Any of these factors could lead to negative perceptions among patients of quality of nursing care and potentially also to an increased number of adverse events.[8, 17, 50]

We found that one additional patient per physician significantly reduced all three dimensions of patient-perceived quality of nursing care. This is in line with the findings of e.g. West et al.,[51] who found that both physician and nurse staffing impact intensive care unit patient mortality . However, we found that the effect sizes for physician staffing were less pronounced compared to those for nurse staffing levels, indicating that our instrument is more closely related to nurse staffing than to physician staffing. This result might indicate that patients are not fully capable of differentiating between different occupational groups when assessing quality of care in hospitals. Another explanation might be that physician staffing does in fact have an impact on quality of nursing care; if physicians have to care for a large number of patients, they might omit passing on information which nurses need to adequately care for a patient – e.g., information on the patients' needs or patient-specific treatment instructions. Additionally, stressed physicians might cause a bad civility climate, which in turn negatively impacts nurses' civility towards patients.[52, 53]

The significant association we observed between the patient-to-nurse ratio and patient-perceived quality of nursing care was driven mainly by low-severity patients. This stands in contrast to the study of West et al.,[51] which found that reductions in mortality risks from having more intensive care unit nurses is larger for patients who are the most severely ill. This might indicate that the effect of nurse staffing differs across hospital units (in particular, intensive versus non-intensive care) and/or across outcomes (in that case, patient-perceived quality of care and mortality). Additionally, for low-severity patients, the share of assistant nurses affects their perceptions of quality of nursing care, while for high-severity patients, the patient-to-physician ratio affects their perceptions of quality of nursing care. Because high-severity patients are more dependent on various health professionals and their collaborative performance, the quality of cooperation and consistency within and across occupational groups might explain their perceptions of quality of nursing care rather than staffing levels and skill mix.[53] Low-

severity patients might be less relying on different professionals, so that the composition of the nurses, as expressed in their skill mix, is of greater relevance to them.

Similarly, splitting our sample using two separate bed categories reveals that an increase in the patient-to-nurse ratio decreases patient-perceived quality of nursing care among patients admitted to hospitals with fewer than 500 beds rather than for patients admitted to hospitals with at least 500 beds. Yet, the patient-perceived guidance is only significantly affected by staffing levels in large hospitals (significant non-linear effect). While skill mix significantly affects patient-perceived general nursing care and loyalty in smaller hospitals only, it significantly relates to guidance in both small and large hospitals. Thus, we see some variation in how our variables of interest relate to the different quality of nursing care dimensions. The patient-to-physician ratio in turn only significantly affects patient-perceived quality of nursing care in large hospitals for all three quality of nursing care dimensions. This might be explained by a higher proportion of high-severity patients admitted to larger and potentially more highly specialized hospitals. In addition, in larger hospitals, collaboration across different occupational groups might be of higher importance than in smaller hospitals.

The stronger statistical significance of the relationship between nurse and physician staffing levels and quality of nursing care for medical patients compared to surgical patients seems plausible, as well. For nurse staffing, the finding is in line with previous studies that have analyzed the relationship between nurse staffing levels and patient outcomes based on administrative data and found stronger associations for medical patients.[8] The difference in effects might be explained by surgical patients being healthier (i.e., as a precondition for being eligible for surgery) and therefore being less dependent on nurses. For medical patients, the collaboration between professional groups might also be of higher relevance, which can explain the significant effects of physician staffing.

Although our study makes important contributions to understanding the relationship between nurse staffing and patient outcomes, it is not without important limitations, each of which offers avenues for further research. First, both of the nurse staffing variables used in our analysis (i.e., patient-to-nurse and skill-mix ratios) represent annual averages and do not capture day-to-day variations in nurse staffing. Similarly, even though we were able to consider several variables which are likely related to nurse staffing and patient outcomes, we might have omitted variable bias from other hospital-unit-related characteristics, such as the availability and use of technology, the share of temporary or immigrant nurses, the team climate, or absences due to sickness. These variables were not available in our data sample but might be associated with nurses' workload and also have an effect on patient outcomes.[27,

53] Thus, although this study overcomes several endogeneity issues of previous studies it cannot claim to fully address them. While the large size of our sample may compensate for some of these issues, future studies may want to draw upon or collect more finely grained data covering day-to-day variations in nurse staffing variables and should try to account for further hospital characteristics. In addition, administrative staffing measures have been shown to deviate from perceived staffing adequacy;[54, 55] therefore, accounting for the latter in relation with quality of nursing care is a valuable avenue for further research, too. Another limitation this study shares with previous research is its cross-sectional nature. As the causal order and the generalizability of our results cannot be verified, future studies would be valuable to investigate the relationships in other settings and over time. Finally, the PENQuAH instrument has only been tested in Germany. As it has been able to provide more fine-grained insights into the dimensions of patient-perceived quality of nursing care, we recommend applying, adapting, and validating it to further data samples, and adjusting it to the hospital environments of other countries.

Our results have important implications for hospital managers and health policy makers pursuing stronger patient orientation. By providing strong evidence that quality of nursing care is affected by nurse staffing, we show that nurse staffing decisions are critical for favorable patient care experiences. We find that in addition to staffing levels, nurses' skill mix is an important factor associated with quality of nursing care. Therefore, we recommend considering nurses' levels of educational attainment, qualifications and specializations when designing policies, such as minimum staffing regulations, to improve nurse staffing in hospitals.

Tables

	Dimension	exemplary items	scale
(1)	general nursing care	• From my perspective, I always received the necessary care in the hospital. • Nursing staff treated me respectfully and courteously.	1 (worst) – 5 (best)
(2)	guidance provided by nurses	• Nursing staff told or showed me how I may and should move. • Nursing staff told or showed me how to use my medical aids.	1 (worst) – 5 (best)
(3)	nurse-related loyalty	• Thinking about the nursing staff, would you select the hospital again? • Thinking about the nursing staff, would you recommend the hospital to your friends and family?	1 (worst) – 4 (best)

Table 1: Overview on dimensions of Patients' Experience of Nursing Quality in Acute Hospitals (PENQuAH) instrument

unit type	Patients	hospital units	(1) general nursing care[1]	(2) guidance[2]	(3) loyalty[3]
Internal medicine	6,260	732	4.22	3.56	3.25
Geriatrics	106	60	3.76	3.34	2.90
Cardiology	1,698	150	4.34	3.71	3.37
Nephrology	61	21	4.19	3.62	3.27
Hematology	181	66	4.37	3.71	3.47
Endocrinology	22	5	4.29	3.65	3.27
Gastroenterology	378	73	4.08	3.37	3.13
Pneumology	200	35	4.27	3.70	3.39
Rheumatology	121	14	4.34	3.57	3.38
Pulmonarymedicine	77	12	4.36	3.74	3.45
Generalsurgery	7,512	771	4.37	3.87	3.43
Traumasurgery	1,784	234	4.26	3.73	3.28
Neurosurgery	582	104	4.28	3.65	3.39
Vascularsurgery	300	86	4.39	3.87	3.45
Plasticsurgery	186	45	4.31	3.79	3.41
Thoracicsurgery	81	22	4.47	4.09	3.56
Heartsurgery	319	54	4.36	3.90	3.46
Urology	2,396	295	4.44	3.93	3.46
Orthopedics	2,753	226	4.46	4.02	3.57
Neurology	1,951	275	4.28	3.61	3.30
Nuclearmedicine	103	36	4.56	4.20	3.51
Radiotherapy	53	23	4.49	4.02	3.45
Dermatology	760	63	4.40	3.93	3.43
Dentistry	252	56	4.12	3.68	3.18
Total	**28,136**	**3,458**	**4.33**	**3.77**	**3.38**

Table 2: Quality of nursing care across unit types

[1] Mean response for general nursing care, measured on a scale of one to five, with five representing the best care.

[2] Mean response for guidance provided by nurses, measured on a measured on a scale of one to five, with five representing the best guidance.

[3] Mean response for patient loyalty to the hospital, measured on a scale of one to four, with four representing the highest loyalty.

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widetilde{PTN}$	-0.020 [0.002]	-0.023 [0.018]	-0.025 [0.000]
	(-0.033;-0.008)	(-0.041;-0.004)	(-0.038;-0.012)
$\widetilde{PTN^2}$	0.001 [0.003]	0.001 [0.030]	0.001 [0.002]
	(0.000;0.002)	(0.000;0.002)	(0.000;0.002)
$\widetilde{skill}$	-0.003 [0.000]	-0.005 [0.000]	-0.003 [0.000]
	(-0.004;-0.001)	(-0.007;-0.003)	(-0.005;-0.002)
$PCCL$	-0.048 [0.000]	-0.034 [0.000]	-0.028 [0.000]
	(-0.057;-0.040)	(-0.047;-0.022)	(-0.037;-0.019)
age	0.021 [0.000]	0.018 [0.000]	0.018 [0.000]
	(0.018;0.025)	(0.013;0.023)	(0.014;0.021)
age^2	0.000 [0.000]	0.000 [0.000]	0.000 [0.000]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.192 [0.000]	-0.276 [0.000]	-0.140 [0.000]
	(-0.210;-0.173)	(-0.303;-0.249)	(-0.159;-0.121)
$ruralty$	0.014 [0.004]	0.028 [0.000]	0.004 [0.382]
	(0.004;0.024)	(0.014;0.042)	(-0.005;0.014)
$\widetilde{PTP}$	-0.002 [0.030]	-0.002 [0.026]	-0.002 [0.013]
	(-0.003;0.000)	(-0.005;0.000)	(-0.003;0.000)
adj. R^2	**0.061**	**0.055**	**0.045**
observations	**28,136**	**28,136**	**28,136**

Table 3: Regression results

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index; $\widetilde{PTP}$: mean-centered patient-to-physician ratio

†Fixed effects for unit types, months, and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for patient-to-nurse and skill mix included but not shown.

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Author statement

All authors meet the ICMJE recommended criteria for authorship. They have:

1a) made a substantial contribution to the conception and design

1b) the acquisition, analysis, or interpretation of the data,

2a) Contributed to drafting the article or

2b) critical revision for important intellectual content

3. They have given (or undertake to give) final approval of the version to be published.

4. Have agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the article are appropriately investigated and resolved.

No further writing assistance other than basic copy-editing has been provided.

Ethical approval and informed consent

A declaration of compliance with terms of use and ethical standards from the University of Hamburg's WiSo Laboratories was obtained on January 15th, 2019 (no approval number provided). Information and consent of the survey participants were conducted in written form prior to survey participation. A copy of the written form of Informed Consent, Privacy and Confidentiality was handed out to the subjects. A further copy was provided for the archive of the WiSo Laboratories.

Data availability statement

The data are in large parts owned by a German statutory health insurer, the Techniker Krankenkasse. To fulfill the legal requirements to obtain the data, researchers must obtain permission for a specific

research question from the German Federal (Social) Insurance Office. Additionally, researchers must conclude a contract with the statutory health insurer regarding data access.

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Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

Appendix

Table A.1: Mean PTN ratio and skill mix ratio per unit type

unit type	patients	patient-to nurse ratio (mean)	skill mix ratio (mean)
internal medicine	6,260	5.92	7.54
geriatrics	106	8.75	11.91
cardiology	1,698	4.68	5.85
nephrology	61	4.78	4.70
hematology	181	5.31	5.56
endocrinology	22	8.41	13.59
gastroenterology	378	6.20	8.30
pneumology	200	4.91	7.68
rheumatology	121	9.75	9.71
pulmonary medicine	77	6.16	6.14
general surgery	7,512	5.87	6.59
trauma surgery	1,784	6.50	7.14
neurosurgery	582	5.90	5.64
vascular surgery	300	5.76	4.98
plastic surgery	186	5.01	4.30
thoracic surgery	81	5.25	6.44
heart surgery	319	3.77	5.08
urology	2,396	6.27	5.45
orthopedics	2,753	6.05	6.94
neurology	1,951	5.36	6.26
nuclear medicine	103	4.26	3.33
radiotherapy	53	5.32	5.27
dermatology	760	5.93	4.87
dentistry	252	4.85	4.41
total	**28,136**	**5.84**	**6.61**

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Table A.2: Regression results generalized random intercept model (odds ratios)

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widetilde{PTN}$	0.951 [0.010]	0.943 [0.010]	0.929 [0.000]
	(0.915;0.988)	(0.902;0.986)	(0.897;0.963)
$\widetilde{PTN^2}$	1.003 [0.035]	1.003 [0.035]	1.004 [0.001]
	(1.000;1.005)	(1.001;1.006)	(1.002;1.006)
$\widetilde{skill}$	0.995 [0.050]	0.997 [0.050]	0.991 [0.000]
	(0.991;1.000)	(0.991;1.002)	(0.986;0.995)
$PCCL$	0.876 [0.000]	0.875 [0.000]	0.944 [0.000]
	(0.851;0.900)	(0.846;0.906)	(0.922;0.967)
age	1.080 [0.000]	1.061 [0.000]	1.034 [0.000]
	(1.066;1.094)	(1.045;1.077)	(1.024;1.045)
age^2	0.999 [0.000]	1.000 [0.000]	1.000 [0.000]
	(0.999;1.000)	(0.999;1.000)	(1.000;1.000)
$gender$	0.903 [0.000]	0.934 [0.000]	0.822 [0.000]
$(= 1\ if\ female)$	(0.854;0.955)	(0.874;0.999)	(0.781;0.865)
$ruralty$	1.060 [0.000]	1.025 [0.000]	1.010 [0.463]
	(1.029;1.091)	(0.991;1.062)	(0.984;1.037)
$\widetilde{PTP}$	0.997 [0.278]	0.998 [0.278]	0.997 [0.140]
	(0.992;1.002)	(0.992;1.004)	(0.993;1.001)
observations	**28,136**	**28,136**	**28,136**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for unit types, months, and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

Table A.3: Regression results subgroup analysis case severity

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	low (PCCL=0)	high (PCCL>0)††	low (PCCL=0)	high (PCCL>0)††	low (PCCL=0)	high (PCCL>0)††
$\widetilde{PTN}$	-0.019 [0.009]	-0.022 [0.121]	-0.021 [0.051]	-0.024 [0.245]	-0.025 [0.001]	-0.022 [0.142]
	(-0.033;-0.005)	(-0.051;-0.003)	(-0.043;0.000)	(-0.063;0.016)	(-0.040;-0.010)	(-0.050;-0.007)
$\widetilde{PTN^2}$	0.001 [0.009]	0.001 [0.222]	0.001 [0.066]	0.001 [0.312]	0.001 [0.004]	0.001 [0.375]
	(0.000;0.002)	(-0.001;0.003)	(0.0000;0.003)	(-0.001;0.004)	(0.000;0.002)	(-0.001;0.003)
$\widetilde{skill}$	-0.003 [0.001]	-0.003 [0.070]	-0.005 [0.000]	-0.004 [0.079]	-0.004 [0.000]	-0.003 [0.059]
	(-0.005;-0.001)	(-0.006;0.000)	(-0.008;-0.003)	(-0.008;0.000)	(-0.005;-0.002)	(-0.006;0.000)
$PCCL$	—	-0.038 [0.000]	—	-0.008 [0.505]	—	-0.021 [0.017]
	—	(-0.055;-0.021)	—	(-0.032;0.016)	—	(-0.038;-0.004)
age	0.018 [0.000]	0.030 [0.000]	0.015 [0.000]	0.022 [0.000]	0.015 [0.000]	0.022 [0.000]
	(0.014;0.022)	(0.022;0.038)	(0.009;0.021)	(0.011;0.033)	(0.011;0.019)	(0.014;0.030)
age^2	0.000 [0.000]	0.000 [0.000]	0.000 [0.024]	0.000 [0.001]	0.000 [0.000]	0.000 [0.000]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$	-0.190 [0.000]	-0.193 [0.004]	-0.283 [0.000]	-0.252 [0.000]	-0.142 [0.000]	-0.128 [0.000]
$(= 1\ if\ female)$	(-0.211;-0.169)	(-0.231;-0.154)	(-0.315;-0.252)	(-0.306;-0.198)	(-0.164;-0.120)	(-0.167;-0.089)
$ruralty$	0.009 [0.125]	0.029 [0.004]	0.021 [0.015]	0.050 [0.000]	-0.001 [0.848]	0.020 [0.050]
	(-0.002;0.020)	(0.009;0.048)	(0.004;0.037)	(0.023;0.077)	(-0.013;0.010)	(0.000;0.039)
$\widetilde{PTP}$	-0.001 [0.175]	-0.003 [0.073]	-0.002 [0.226]	-0.005 [0.027]	-0.001 [0.120]	-0.003 [0.039]
	(-0.003;0.001)	(-0.006;0.000)	(-0.004;0.001)	(-0.010;-0.001)	(-0.003;0.000)	(-0.007;0.000)
observations	**20,624**	**7,512**	**20,624**	**7,512**	**20,624**	**7,512**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

†† Subgroup "high" comprises patients with a PCCL from 1 to 6.

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Table A.4: Regression results subgroup analysis hospital size††

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	small	large	small	large	small	large
$\widehat{PTN}$	-0.018 [0.024]	-0.015 [0.186]	-0.009 [0.447]	-0.031 [0.058]	-0.024 [0.005]	-0.014 [0.216]
	(-0.034;-0.002)	(-0.037;0.007)	(-0.033;-0.015)	(-0.063;0.001)	(-0.040;-0.007)	(-0.037;0.008)
$\widehat{PTN}^2$	0.001 [0.048]	0.001 [0.155]	0.000 [0.660]	0.002 [0.041]	0.001 [0.035]	0.001 [0.245]
	(0.000;0.002)	(0.000;0.002)	(-0.001;0.002)	(0.000;0.004)	(0.000;0.002)	(-0.001;0.002)
$\widehat{skill}$	-0.004 [0.000]	-0.002 [0.183]	-0.005 [0.002]	-0.004 [0.009]	-0.005 [0.000]	-0.001 [0.369]
	(-0.006;-0.002)	(-0.004;0.001)	(-0.008;-0.002)	(-0.008;-0.001)	(-0.007;-0.003)	(-0.003;0.001)
$PCCL$	-0.050 [0.000]	-0.046 [0.000]	-0.043 [0.000]	-0.028 [0.002]	-0.034 [0.000]	-0.022 [0.000]
	(-0.062;-0.037)	(-0.058;-0.035)	(-0.062;-0.024)	(-0.045;-0.011)	(-0.047;-0.021)	(-0.035;-0.010)
age	0.026 [0.000]	0.017 [0.000]	0.023 [0.000]	0.012 [0.002]	0.022 [0.000]	0.013 [0.000]
	(0.021;0.030)	(0.012;0.022)	(0.016;0.030)	(0.004;0.019)	(0.017;0.027)	(0.008;0.018)
age^2	0.000 [0.000]	0.000 [0.000]	0.000 [0.000]	0.000 [0.097]	0.000 [0.000]	0.000 [0.002]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$	-0.165 [0.000]	-0.223 [0.000]	-0.245 [0.000]	-0.311 [0.000]	-0.116 [0.000]	-0.166 [0.000]
$(= 1\ if\ female)$	(-0.189;-0.140)	(-0.251;-0.195)	(-0.282;-0.208)	(-0.351;-0.271)	(-0.141;-0.090)	(-0.195;-0.138)
$ruralty$	0.010 [0.148]	0.020 [0.006]	0.033 [0.001]	0.024 [0.020]	-0.007 [0.337]	0.017 [0.020]
	(0.003;0.023)	(0.006;0.034)	(0.013;0.053)	(0.004;0.044)	(-0.020;0.007)	(0.003;0.032)
$\widehat{PTP}$	0.000 [0.885]	-0.004 [0.006]	-0.001 [0.711]	-0.006 [0.007]	0.000 [0.884]	-0.005 [0.000]
	(-0.002;0.002)	(-0.006;-0.034)	(-0.003;0.002)	(-0.009;-0.002)	(-0.002;0.002)	(-0.008;-0.002)
observations	**14,387**	**13,749**	**14,387**	**13,749**	**14,387**	**13,749**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

†† subgroup small comprises hospitals with less than 500 bed; subgroup large comprises hospitals with 500 beds and more

Table A.5: Regression results subgroup analysis medical vs. surgical patients

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	medical	surgical	medical	surgical	medical	surgical
$\widehat{PTN}$	-0.014 [0.216]	-0.012 [0.159]	-0.042 [0.015]	-0.008 [0.510]	-0.058 [0.000]	-0.005 [0.594]
	(-0.037;0.008)	(-0.029;-0.005)	(-0.075;-0.008)	(-0.032;-0.016)	(-0.081;-0.034)	(-0.022;-0.013)
$\widehat{PTN}^2$	0.001 [0.245]	0.000 [0.412]	0.003 [0.003]	0.000 [0.965]	0.004 [0.000]	0.000 [0.831]
	(-0.001;0.002)	(-0.001;0.002)	(0.001;0.005)	(-0.002;0.002)	(0.002;0.005)	(-0.001;0.001)
$\widehat{skill}$	-0.001 [0.369]	-0.003 [0.006]	-0.004 [0.039]	-0.005 [0.001]	-0.003 [0.025]	-0.003 [0.002]
	(-0.003;0.001)	(-0.005;-0.001)	(-0.007;0.000)	(-0.008;-0.002)	(-0.005;0.000)	(-0.006;-0.001)
$PCCL$	-0.022 [0.000]	-0.060 [0.000]	-0.021 [0.035]	-0.051 [0.000]	-0.019 [0.006]	-0.040 [0.000]
	(-0.035;-0.010)	(-0.072;-0.047)	(0.004;-0.022)	(-0.069;-0.033)	(-0.033;-0.006)	(-0.053;-0.027)
age	0.013 [0.000]	0.023 [0.000]	0.013 [0.003]	0.021 [0.000]	0.016 [0.000]	0.021 [0.000]
	(0.008;0.018)	(0.018;0.028)	(0.004;0.022)	(0.014;0.028)	(0.010;0.022)	(0.016;0.026)
age^2	0.000 [0.002]	0.000 [0.000]	0.000 [0.085]	0.000 [0.000]	0.000 [0.000]	0.000 [0.000]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$	-0.166 [0.000]	-0.183 [0.000]	-0.294 [0.000]	-0.255 [0.000]	-0.165 [0.000]	-0.122 [0.000]
$(= 1\ if\ female)$	(-0.195;-0.138)	(-0.208;-0.159)	(-0.338;-0.250)	(-0.291;-0.219)	(-0.195;-0.134)	(-0.141;-0.097)
$ruralty$	0.017 [0.020]	0.017 [0.015]	0.018 [0.118]	0.038 [0.000]	0.001 [0.886]	0.007 [0.293]
	(0.003;0.032)	(0.003;0.030)	(-0.005;0.041)	(0.019;0.057)	(-0.017;0.015)	(-0.006;-0.021)
$\widehat{PTP}$	-0.005 [0.020]	0.001 [0.490]	-0.004 [0.024]	0.000 [0.819]	-0.004 [0.005]	0.000 [0.764]
	(-0.008;-0.002)	(-0.002;0.004)	(-0.008;-0.001)	(-0.004;0.005)	(-0.006;-0.001)	(-0.003;0.003)
observations	**11,868**	**13,769**	**11,868**	**13,769**	**11,868**	**13,769**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p. 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p. 4
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p. 5 ff.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p. 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	p. 6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p. 6 ff.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p. 6 ff.
Bias	9	Describe any efforts to address potential sources of bias	p. 8 f.
Study size	10	Explain how the study size was arrived at	p. 6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p. 6 ff.
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p. 8 f.
		(*b*) Describe any methods used to examine subgroups and interactions	p. 8 f.
		(*c*) Explain how missing data were addressed	p. 9
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n.a.
		(*e*) Describe any sensitivity analyses	p. 8 f.
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	p. 6
		(b) Give reasons for non-participation at each stage	n.a.
		(c) Consider use of a flow diagram	n.a.
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	p. 9, table A.1
		(b) Indicate number of participants with missing data for each variable of interest	n.a.
Outcome data	15*	Report numbers of outcome events or summary measures	p. 9, table 2
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear	p. 10 f., table 3

		which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	p. 8 f.
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	p. 10 f., tables A.2, A.3, A.4, A.5
Discussion			
Key results	18	Summarise key results with reference to study objectives	p. 11 f.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p. 14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p. 11 ff.
Generalisability	21	Discuss the generalisability (external validity) of the study results	p. 11 ff.
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

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Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

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Abstract

Objective: To examine the impact of nurse staffing on patient-perceived quality of nursing care. We differentiate nurse staffing levels and nursing skill mix as two facets of nurse staffing and use a multi-dimensional instrument for patient-perceived quality of nursing care. We investigate non-linear and interaction effects.

Setting: The study setting was 3,458 hospital units in 1,017 hospitals in Germany.

Participants: We contacted 212,554 patients discharged from non-pediatric, non-intensive, and non-psychiatric hospital units who stayed at least two nights in the hospital between January and October 2019. Of those, 30,174 responded, yielding a response rate of 14.2%. Our sample included only those patients. After excluding extreme values for our nurse staffing variables and removing observations with missing values, our final sample comprised 28,136 patients ranging from 18 to 97 years of age (average: 61.12 years) who had been discharged from 3,458 distinct hospital units in 1,017 hospitals.

Primary and secondary outcome measures: Patient-perceived quality of nursing care (general nursing care, guidance provided by nurses, and patient loyalty to the hospital)

Results: For all three dimensions of patient-perceived quality of nursing care, we found that they significantly decreased as (a) nurse staffing levels decreased (with decreasing marginal effects) and (b) the proportion of assistant nurses in a hospital unit increased. The association between nurse staffing levels and quality of nursing care was more pronounced among patients who were less clinically complex, were admitted to smaller hospitals, or were admitted to medical units.

Conclusions: Our results indicate that, in addition to nurse staffing levels, nursing skill mix is crucial for providing the best possible quality of nursing care from the patient perspective and both should be considered when designing policies such as minimum staffing regulations to improve the quality of nursing care in hospitals.

Article summary

Strengths and limitations of this study

- This study combines administrative data on hospital unit level nurse staffing with a multi-dimensional survey instrument that covers three aspects of patient-perceived quality of nursing care in a sample of 28,136 patients discharged from 3,458 hospital units in Germany in 2019
- This study demonstrates that the effect of nurse staffing on patient-perceived quality of care is non-linear and depending on patient and hospital characteristics (patient case severity, hospital size, and medical versus surgical patients)
- Besides patient-to-nurse ratios, the study also adds insight on the effect of skill mix and patient-to-physician ratios on patient-perceived quality of nursing care
- The study is cross-sectional and cannot account for all potential endogeneity problems / Even though considering the hospital unit type level is advantageous to using hospital-level aggregated data, omitted variables on hospital unit and patient level might remain.

Keywords (MeSH Terms)

Nursing Staff, Hospital; Health Workforce; Nurse-Patient Relations; Nursing Care; Patient-Centered Care; Health Care Surveys

INTRODUCTION AND BACKGROUND

Nurses are responsible for delivering the highest proportion of care to patients in hospitals and therefore a main contributor to quality of hospital care. Nurses who work on units with inadequate staffing are probably not working as effective and efficient as nurses on better-staffed and better-skilled units. As a result, nurses do not have enough time for providing care and instructions, observe vital signs timely, and to respond to patients' individual needs., which leads to missed care and ultimately unfavourable clinical patient outcomes and bad patient experiences and perceptions of quality of care. A large body of empirical studies, including several literature reviews and meta-analyses, has examined how nurse staffing levels affect patient outcomes.[1–10] Most studies have thereby relied on clinical outcomes available in administrative data and e.g. found significant effects of nurse staffing on mortality, pressure ulcers, and pneumonia.[3] Several studies depict that the effect of inadequate nurse staffing on adverse events is through missed care.[11–13] In light of calls for care (and, indeed, research) to be more patient oriented and for health systems to become more responsive to patient needs and expectations,[14–16] the number of studies examining links between nurse staffing patterns and patient experiences of care – i.e., perceived quality of care – has steadily grown.[15–17] In addition, in the wake of many studies on the effects of skill mix on clinical outcomes,[see 3] recent studies investigated the association between skill mix and patient-perceived quality of care.[15, 18, 19]

Several empirical studies that have analyzed the relationship between nurse staffing levels and perceived quality of care have considered the nurse's rather than the patient's perspective.[19–22] While the former is of course crucial, there is evidence that nurses' perceptions of the quality of their work can deviate substantially from the patients' perceptions[23]. In addition, most studies that have analyzed quality of care as an outcome have used measures that are very general (e.g., single items to rate overall quality of care or patient safety).[17, 22, 24, 25] Outcome measures like these are less informative about the quality of care provided by nurses and therefore potentially less sensitive to nurse staffing. Some studies have used multi-dimensional constructs of patient satisfaction or patient experience with care. Yet, these constructs usually comprise dimensions and indicators that do not relate to nursing care, but other aspects, such as responsiveness of hospital staff, discharge information, and overall hospital rating, all of which are also indicators of other health professionals' quality of care.[11, 16, 20, 26] . Only a handful of studies have used items that ask directly about the quality of care provided by nurses, or quality of nursing care.[20–22] To our knowledge, no studies to date have used a validated, multi-item, and multi-dimensional scale for patient-perceived quality of nursing care.

Methodologically, examining the link between nurse staffing and patient outcomes is at risk of endogeneity problems, such as omitted variable bias (e.g., skill mix, hospital-unit-type and patient characteristics, or physician staffing could all be related to nurse staffing and patient outcomes) or endogenous sorting (whereby hospitals devote more resources to patients with a higher risk of adverse outcomes).[1, 4, 8, 16, 27] The risk of endogeneity increases with the level of aggregation; as many studies use staffing information at the aggregated hospital level,[6, 17, 20, 21, 28, 29] they do not consider important information at the level of hospital units [7, 30, 31] or of patients.[16, 32] At the other extreme, using micro level data on the patient level [as e.g., 32, 33] usually implies substantial primary data collection efforts and a focus on one or few organizations, hence limiting generalizability. As an in-between approach, the number of studies using data at the level of hospital units has grown,[7, 31, 34–39] yet often suffers from limited sample sizes both in terms of patients and hospitals.[15] In addition, recent evidence hints to the fact the effect of nurse staffing on quality of nursing care non-linear, i.e., the effect of an additional nurse per patient might be high if nurse staffing is low; with higher numbers of nurses, the effect of each additional nurse probably decreases.[15] Furthermore, recent studies indicate that the association between nurse staffing and patient outcomes can differ depending on patients' case severity,[8, 40] hospital size,[6, 41], and between medical versus surgical units.[8, 28] Yet most of these studies have analyzed the associations between nurse staffing and clinical patient outcomes.

The present study aims to shed further light on the association between nurse staffing and patient-perceived quality of nursing care. In particular, we examine this relationship between nurse staffing levels, nurse skill mix, and patient-perceived quality of nursing care based on large-scale survey data combined with administrative data. Especially the use of a multi-dimensional survey instrument reflecting the patient perspective on nursing quality for measuring this relationship is quite novel. Second, we addressed substantial parts of potential endogeneity by including a rich set of patient- and hospital-related control variables. Thereby, we specifically consider physician staffing and investigate to which degree physician staffing is a relevant predictor of patient-perceived quality of nursing care. In addition, we apply a fixed effects model to account for differences across hospital unit types, which seems important to reduce endogeneity problems. Finally, we allow for non-linear effects of nurse staffing on quality of nursing care and conduct sub-group analyses on patient case severity, hospital size, and medical versus surgical hospital units.

METHODS

Data and sample

This study is part of a larger project on the association between nurse staffing and quality of care.[3, 42, 43] Our study analyzed data from an online patient survey. To ensure the quality of the survey, we followed the scientific standards for scale development. The entire development and validation of the survey is described elsewhere [43]. To sum up our proceeding, we drew on a systematic literature search and expert interviews to derive our initial items. We conducted two pre-tests (one paper and pencil pre-test and one online pre-test) with different participants and collected, discussed, and reported all changes made to the survey. After data collection, we performed comprehensive exploratory and confirmatory factor analyses to ensure the validity and reliability of the survey. We combined the survey data with (a) claims data provided by the largest statutory health insurance fund in Germany and (b) data from the mandatory quality reports published annually by each hospital in the country. The combined data set comprised data from patients discharged from non-pediatric, non-intensive, and non-psychiatric hospital units between January and October 2019. We define a hospital unit as an operating unit within a hospital that focuses on specific types of patients (e.g., geriatrics or cardiology). Our sample included only those patients who stayed at least two nights in the hospital. We contacted patients in monthly waves and asked them to participate in the survey, eight weeks after they had been discharged from the hospital at the latest. The survey contained questions related to patients' perceptions of the quality of the nursing care provided during their hospital stay. Each patient was contacted only once. In total, we contacted 212,554 patients, of whom 30,174 responded, yielding a response rate of 14.2%. The response rate is comparable to other large-scale patient surveys. We checked for representativeness of the study population. Compared to the general population of hospitalized patients in Germany, our sample is generally representative in observable characteristics. Only the share of patients older than 80 is lower in our sample compared to the general population of hospitalized patients in Germany. We also compared respondents to non-respondents and did not find any substantial deviations in observable characteristics.

The claims data in our data set contained patient-level information about the course of disease during each patient's hospital stay, as well as the dates of hospital admission and discharge, the type of hospital unit, and ICD codes. The quality reports contained general information at the hospital unit level, such as the number of patient cases treated and staffing numbers that relate to the situation at the end of 2017.

Nurse staffing

We obtained the nurse staffing level in each hospital unit by calculating a patient-to-nurse ratio (PTN) in line with the definition for measuring nursing workload as suggested by the National Office of Statistics in Germany.[44] The patient-to-nurse ratio indicates how many patients a nurse has to care for during an average shift and is given by:

$$PTN = \frac{occupation\ days * 24hours}{nurses * 220days * 8hours},\ with$$

$$occupation\ days = inpatient * average\ length\ of\ stay.$$

The total number of nurses (based on full-time nurses employed) comprise all registered nurses with at least three years of training and assistant nurses with at least one year of training. The numbers are derived from the annual quality reports of each hospital, representing the situation at the end of the year and not accounting for sickness absences or other sources of within-year variations such as variation caused by holidays. To calculate occupation days, we used the number of inpatients and approximated the average length of stay or each hospital unit based on the average length of stay of more than 6.2 million inpatient cases available in our claims data set over the period 2014 to 2019. We draw on the five-year period for this approximation because we cannot observe all patients in each hospital unit in one year; to ensure robustness, we considered only those hospital units with more than 150 observations to approximate the length of stay.

In addition to staffing levels, we accounted for the skill mix in each hospital unit by calculating the ratio of assistant nurses to the total number of nurses (measured in full-time equivalents):

$$skill\ mix = \frac{assistant\ nurses}{nurses}.$$

We excluded extreme values, i.e., patient-to-nurse ratios below 1 and above 20, as well as skill-mix ratios above 25%.

Quality of nursing care

Because the definition of nursing care varies from country to country, it is necessary to use an instrument that takes country-specific regulations into account. We therefore chose the Patients' Experience of Nursing Quality in Acute Hospitals (PENQuAH) instrument developed by Blume to analyze the relationship between nurse staffing and patient outcomes.[43] The instrument was designed to evaluate patients' perceptions of quality of nursing care in German hospitals. The instrument consists of

24 items, which were chosen based on a review of the literature and interviews with nursing experts. To examine the scale's dimensionality and factor-based validity, Blume conducted exploratory and confirmatory factor analyses with a randomly split sample.[43] Their exploratory factor analysis revealed that three main dimensions captured the structure of the underlying item set: general nursing care, guidance provided by nurses, and nurse-related patient loyalty to the hospital. The results of their confirmatory factor analysis suggested a good overall model fit (CFI = 0.978; TLI = 0.976). Table 1 shows the three dimensions and exemplary related items.

--- include table 1 about here ----

We calculated each dimension of quality of nursing care by taking the arithmetic mean of the underlying items after recoding reverse-coded items. Dimensions one and two are on a scale of one to five, with five representing the best quality of nursing care, and dimension three is on a scale of one to four, with four representing the best quality of nursing care. Dimension one represents patients' perception of the general quality of nursing care. Dimension two represents patients' perception of the guidance provided by nurses. Dimension three comprises two items that capture patients' loyalty to a hospital based on the nursing care provided.

Statistical model

The results of previous studies suggest that the relationship between nurse staffing and patient outcomes varies across different types of hospital units.[8, 35, 42] To account more accurately for potential differences across the 24 unit types in our sample and to depict potential heteroscedastic structures in the error term of the regression, we applied a fixed effects model. The model is given by:

$$QoNC_{iu}^{(x)} = \alpha_0 + \alpha_{10}\,\widetilde{PTN}_{iu} + \alpha_{11}\,\widetilde{PTN}_{iu}^2 + \alpha_2\,\widetilde{skill}_{iu} + \beta_1\,\overline{PTN}_u + \beta_2\,\overline{skill}_u + \gamma C_{iu} + (v_{0u} + \varepsilon_{iu}),$$

where $QoNC_{iu}^{(x)}$ is the value of one of the three factors $x \in \{1, 2, 3\}$ for patient i admitted to unit type u, $u \in \{1, \ldots, 24\}$. α_0 is the intercept of the regression. $\widetilde{PTN}_{iu} = (PTN_{iu} - \overline{PTN}_u)$ and $\widetilde{skill}_{iu} = (skill_{iu} - \overline{skill}_u)$ with coefficients α_{10} and α_0 are the mean-centered independent nurse staffing variables of interest, which correspond to the patient-to-nurse and skill mix ratio of the hospital unit associated with patient i minus the group means $\overline{PTN}_u$ and $\overline{skill}_u$ for each unit type u. Assuming that the marginal effect of the patient-to-nurse ratio on quality of nursing care decreases as staffing levels increase, we also

included a squared patient-to-nurse term with coefficient α_{11}. β_1 and β_2 are the coefficients of the between-unit effects. C_{iu} represents a vector of patient-, hospital-, and hospital-unit-related control variables at level one of the model. First, it includes the patient-to-physician (PTP) ratio, because it might correlate with the PTN ratio and also affect the outcome.[e.g., 27] Second, we account for in patient risks by including age, gender, and each patient's case severity reflected by the Patient Clinical Complexity Level (PCCL) index (0-6), which indicates the degree of comorbidities and complications for each patient. It is derived from a closed list of comorbidities and complications and is meant to predict a patient's need for hospital resources, such as nursing care.[45] We directly incorporate the PCCL index in our model because sensitivity analyses using dummy variables for each score suggested a linear relationship. Furthermore, we control for the rurality of each patient's place of residence using an index ranging from one (urban area) to four (rural area), hospital size categories, and monthly fixed effects. v_{0u} refers to the fixed effects for the 24 hospital unit types.

As most previous studies used dichotomized outcome variables, we transformed our three quality of nursing care measures into dichotomous outcome variables and estimated a generalized version of our fixed effects model using a logit link function for comparability purposes, i.e. a logit model. To check the robustness of our main model, we estimated a random effects model. Lastly, replaced the Patient Clinical Complexity Level index with the Elixhauser comorbidity categories.[46]

Moreover, we conducted subgroup analyses. As suggested by previous studies, the association between nurse staffing and patient outcomes can differ depending on patients' case severity.[8, 40] To study these potential differences, we split our sample into patients with low case severity (Patient Clinical Complexity Level = 0) and those with high case severity (Patient Clinical Complexity Level > 0) and estimated our main regression model for each of the sub-samples. Additionally, we considered that our results might vary due to differences in hospital size.[6, 41] We therefore split our sample into two categories – i.e., patients admitted to hospitals with fewer than 500 beds (category "small") and patients admitted to hospitals with at least 500 beds (category "large"). Lastly, by categorizing our unit types as medical or surgical, we estimated our statistical model separately for medical and surgical patients.

Patient and Public Involvement

This study is part of a larger project on the association between nurse staffing and quality of care.[3, 42, 43] The public, i.e., a statutory health insurance, hospital managers, and patient representatives were involved in the design of the overall project. In addition, patients, practitioners (nurses, physiotherapists, doctors), and scientific experts were involved in the development of the survey (described in more detail

in [3, 43]). Results of the study and the overall project will be disseminated to the participants via the statutory health insurance and via additional practice-oriented publications and newsletters.

RESULTS

Descriptive results

After excluding extreme values for our nurse staffing variables and removing observations with missing values for one or more of the control variables, our final sample comprised 28,136 patients ranging from 18 to 97 years of age (average: 61.12 years) who had been discharged from 3,458 distinct hospital units in 1,017 hospitals. 39.2% of the survey participants were female. Table 2 illustrates the distribution of patients and the average response for each of the three dimensions of quality of nursing care across the 24 types of hospital units. Overall, the variation in the distribution of patients across the 24 unit types was large. Almost 50% of the patients had been discharged from general surgery or internal medicine, followed by orthopedics, urology, neurology, trauma surgery, and cardiology, from each of which between six and ten percent of the patients had been discharged. All of the other unit types each accounted for less than three percent of the patients in our sample. In terms of our dependent variable, quality of nursing care, we obtained an average response of 4.33, 3.77, and 3.38 for the three dimensions general nursing care, guidance provided by nurses, and nurse-related patient loyalty to the hospital, respectively, indicating that the perceived quality of nursing care was above the scale average for each. In addition, we found that patient perception of the guidance provided by nurses was, on average, 0.56 scale points lower compared to the general perception of quality of nursing care. We also found that the average responses varied across hospital unit types. For instance, for dimensions one and two, the average responses for patients discharged from internal medicine were 0.24 and 0.46 scale points lower, respectively, compared to orthopedic patients.

For the patient-to-nurse and skill-mix-ratios, we obtained average values of 5.84 patients per nurse and 6.61%, respectively. The patient-to-nurse ratio ranged from 3.77 patients a nurse has to care for in heart surgery to 9.75 in rheumatology. The skill-mix ratio ranged from 3.33% assistant nurses in nuclear medicine to 13.59% assistant nurses in endocrinology (see table A.1).

---- include table 2 about here -----

Regression results

As shown in Table 3, our results indicate that the two nurse staffing variables were significantly related to quality of nursing care. An increase in the patient-to-nurse ratio significantly decreased the general quality of nursing care, the patient perception of nursing guidance, and nurse-related patient loyalty to a given hospital. Additionally, there were significantly positive associations between the squared patient-to-nurse ratio, on the one hand, and the general quality of nursing care, guidance, and patient loyalty, on the other. Hence, the negative effect of the patient-to-nurse ratio is greater when the patient-to-nurse ratio is smaller (in other words, if a nurse already has to care for a lot of patients, one additional patient has a less strong effect on quality perceptions). We illustrate the non-linear relationship in figure A.2 (for factor 1).

With regard to the skill-mix ratio, we found that an increase in the ratio of assistant nurses to the total number of nurses led to a significant decrease in general quality of nursing care, patient perception of nursing guidance, and patient loyalty. An increase in the patient-to-physician ratio of one additional patient a physician must care for significantly decreased the quality of nursing care dimensions.

---- include table 3 about here -----

The adjusted R^2 measure indicated that our model reduces the error in predicting an individual outcome for our three dimensions of quality of nursing care by between 4.5 and 6.1%.

The regression results of the logit model indicated that an additional patient per nurse decreases the odds of a patient reporting high quality of nursing care. For nurse-related patient loyalty, this effect is significantly non-linear in the same way as in our main model (stated above). Increasing the share of assistant nurses decreases the odds of reporting high quality. An additional patient per physician does not significantly decrease the odds of reporting a high quality of quality of nursing care (see table A.3).

When we estimated a random effects model (table A.4) and when we replaced the Patient Clinical Complexity Level index with the Elixhauser risk adjustment, our results remained robust.

Sub group analyses

Differentiating between patients according to their case severity, we found that the mean-centered patient-to-nurse ratio and its square are significantly associated with all three dimensions of patient-

perceived quality of nursing care for patients with low case severity, but not for those with high case severity. The effects of the skill-mix ratio are also only significant for patients with low case severity, while the effects of the patient-to-physician ratio are slightly larger and only significant for high-case severity patients (except for general nursing care) (see table A.5).

When splitting our sample into patients admitted to a hospital with fewer than 500 beds and those admitted to a hospital with at least 500 beds, we found that an increase in the patient-to-nurse ratio significantly decreased general nursing care and nurse-related patient loyalty only for patients admitted to hospitals with fewer than 500 beds. Skill mix significantly affected general nursing care perceptions and nurse-related patient loyalty in small hospitals only, while it significantly affected the perception of guidance provided by nurses in small and in large hospitals. Moreover, we found a significant association between physician staffing and patient-perceived quality of nursing care for patients admitted to larger hospitals but not for patients admitted to smaller ones (see table A.6).

Finally, when we divided patients into those admitted to medical or surgical units, we found that the patient-to-nurse ratio significantly affected perceptions of guidance by nurses and nurse-related patient loyalty for medical patients only. The associations between the skill mix ratio and quality of nursing care seem largely unaffected by the sample split. Finally, it shows that medical patients were more sensitive to physician staffing compared to surgical patients (see table A.7).

DISCUSSION

Our results provide important new insights into the relationship between nurse staffing and patient outcomes, in particular, patient-perceived quality of nursing care. We found that patient-perceived quality of nursing care significantly decreased as staffing levels, measured using the patient-to-nurse ratio, decreased. This finding is in line with previous research that has examined the relationship between nurse staffing levels and general perceived quality of care measures.[15, 16, 19–22, 25, 26, 47–49] Our study adds to the previously ambiguous evidence in literature by providing insights into the specific aspects of perceived quality of nursing care that are affected by staffing levels. Evidence on the perceived quality of guidance provided by nurses has been inconsistent and scarce.[20, 22] Our results, however, corroborate and extend the findings of Zhu et al. ,[22] who found that higher staffing levels improved satisfaction with nurses' guidance on medications and medical aids, pain management, and self-help.[22] With respect to nurse-related patient loyalty, our results confirm the findings of previous studies that have found that higher nurse staffing levels in hospitals increase the likelihood of patients generally recommending a hospital to family and friends.[20, 21] Thus, nurse-related patient loyalty

seems to be highly related to overall recommendation behavior. In sum, staffing levels affect whether an adequate amount of time is devoted to caring and providing instructions as well as nurses' responsiveness to patients' individual needs. Furthermore, nurse staffing levels have direct consequences for hospitals in terms of patient loyalty. Yet, those effects are not linear; instead, the negative effects become smaller with rising numbers of patients per nurse. This decreasing marginal effect of the patient-to-nurse ratio on quality of nursing care with increasing staffing levels is in line with prior research [15] and seems reasonable: when the ratio is small, each additional patient will substantially affect the amount of time and the responsiveness of a nurse, thus probably substantially reducing missed care.[11–13] In contrast, the effect will be lower when a nurse already needs to care for a high number of (potentially less complex) patients and each additional patient only has a low impact.

Our results suggest that the nurses' level of educational attainment, as measured using the skill-mix ratio, significantly influences patient-perceived quality of nursing care. This finding adds to the few available studies on the relationship between skill mix and patient-perceived quality of care.[15, 18, 19] We found strong evidence that a higher proportion of assistant nurses, which means a lower proportion of professionalization among nursing staff, is negatively associated with all three dimensions of quality of nursing care. Nurses with lower levels of educational attainment may have less training in interacting with patients, might work less efficiently and hence have less time per patient, or both. In addition, it is conceivable that they are less experienced in providing instructions suited to a patient's particular needs – for example, with regard to medication, pain relief, or the use of medical aids. Any of these factors could lead to negative perceptions among patients of quality of nursing care and potentially also to an increased number of adverse events.[8, 17, 50]

We found that one additional patient per physician significantly reduced all three dimensions of patient-perceived quality of nursing care. This is in line with the findings of e.g. West et al.,[51] who found that both physician and nurse staffing impact intensive care unit patient mortality . However, we found that the effect sizes for physician staffing were less pronounced compared to those for nurse staffing levels, indicating that our instrument is more closely related to nurse staffing than to physician staffing. This result might indicate that patients are not fully capable of differentiating between different occupational groups when assessing quality of care in hospitals. Another explanation might be that physician staffing does in fact have an impact on quality of nursing care; if physicians have to care for a large number of patients, they might omit passing on information which nurses need to adequately care for a patient – e.g., information on the patients' needs or patient-specific treatment instructions. Additionally, stressed

physicians might cause a bad civility climate, which in turn negatively impacts nurses' civility towards patients.[52, 53]

The significant association we observed between the patient-to-nurse ratio and patient-perceived quality of nursing care was driven mainly by low-severity patients. This stands in contrast to the study of West et al.,[51] which found that reductions in mortality risks from having more intensive care unit nurses is larger for patients who are the most severely ill. This might indicate that the effect of nurse staffing differs across hospital units (in particular, intensive versus non-intensive care) and/or across outcomes (in that case, patient-perceived quality of care and mortality). Additionally, for low-severity patients, the share of assistant nurses affects their perceptions of quality of nursing care, while for high-severity patients, the patient-to-physician ratio affects their perceptions of quality of nursing care. Because high-severity patients are more dependent on various health professionals and their collaborative performance, the quality of cooperation and consistency within and across occupational groups might explain their perceptions of quality of nursing care rather than staffing levels and skill mix.[53] Low-severity patients might be less relying on different professionals, so that the composition of the nurses, as expressed in their skill mix, is of greater relevance to them.

Similarly, splitting our sample using two separate bed categories reveals that an increase in the patient-to-nurse ratio decreases patient-perceived quality of nursing care among patients admitted to hospitals with fewer than 500 beds rather than for patients admitted to hospitals with at least 500 beds. Yet, the patient-perceived guidance is only significantly affected by staffing levels in large hospitals (significant non-linear effect). While skill mix significantly affects patient-perceived general nursing care and loyalty in smaller hospitals only, it significantly relates to guidance in both small and large hospitals. Thus, we see some variation in how our variables of interest relate to the different quality of nursing care dimensions. The patient-to-physician ratio in turn only significantly affects patient-perceived quality of nursing care in large hospitals for all three quality of nursing care dimensions. This might be explained by a higher proportion of high-severity patients admitted to larger and potentially more highly specialized hospitals. In addition, in larger hospitals, collaboration across different occupational groups might be of higher importance than in smaller hospitals.

The stronger statistical significance of the relationship between nurse and physician staffing levels and quality of nursing care for medical patients compared to surgical patients seems plausible, as well. For nurse staffing, the finding is in line with previous studies that have analyzed the relationship between nurse staffing levels and patient outcomes based on administrative data and found stronger associations

for medical patients.[8] The difference in effects might be explained by surgical patients being healthier (i.e., as a precondition for being eligible for surgery) and therefore being less dependent on nurses. For medical patients, the collaboration between professional groups might also be of higher relevance, which can explain the significant effects of physician staffing.

Although our study makes important contributions to understanding the relationship between nurse staffing and patient outcomes, it is not without important limitations, each of which offers avenues for further research. First, both of the nurse staffing variables used in our analysis (i.e., patient-to-nurse and skill-mix ratios) represent annual averages and do not capture day-to-day variations in nurse staffing. Similarly, even though we were able to consider several variables which are likely related to nurse staffing and patient outcomes, we might have omitted variable bias from other hospital-unit-related characteristics, such as the availability and use of technology, the share of temporary or immigrant nurses, the team climate, or absences due to sickness. These variables were not available in our data sample but might be associated with nurses' workload and also have an effect on patient outcomes.[27, 53] In addition, the model complexity and the limited sample size drove our choice to conduct subgroup instead of moderating analyses. Thus, although this study overcomes several endogeneity issues of previous studies it cannot claim to fully address them. While the large size of our sample may compensate for some of these issues, future studies may want to draw upon or collect more finely grained data covering day-to-day variations in nurse staffing variables and should try to account for further hospital characteristics. In addition, administrative staffing measures have been shown to deviate from perceived staffing adequacy;[54, 55] therefore, accounting for the latter in relation with quality of nursing care is a valuable avenue for further research, too. Another limitation this study shares with previous research is its cross-sectional nature. As the causal order and the generalizability of our results cannot be verified, future studies would be valuable to investigate the relationships in other settings and over time. Finally, the PENQuAH instrument has only been tested in Germany and our sample shows slight variations from the German hospitalized population, which might affect the generalizability of our results. As it has been able to provide more fine-grained insights into the dimensions of patient-perceived quality of nursing care, we recommend applying, adapting, and validating it to further data samples, and adjusting it to the hospital environments of other countries.

Our results have important implications for hospital managers and health policy makers pursuing stronger patient orientation. By providing strong evidence that quality of nursing care is affected by nurse staffing, we show that nurse staffing decisions are critical for favorable patient care experiences. We find that in addition to staffing levels, nurses' skill mix is an important factor associated with quality

of nursing care. Therefore, we recommend considering nurses' levels of educational attainment, qualifications and specializations when designing policies, such as minimum staffing regulations, to improve nurse staffing in hospitals.

Tables

	Dimension	# Items	exemplary items	scale
(1)	general nursing care	13	• From my perspective, I always received the necessary care in the hospital. • Nursing staff treated me respectfully and courteously.	1 (worst) – 5 (best)
(2)	guidance provided by nurses	9	• Nursing staff told or showed me how I may and should move. • Nursing staff told or showed me how to use my medical aids.	1 (worst) – 5 (best)
(3)	nurse-related loyalty	2	• Thinking about the nursing staff, would you select the hospital again? • Thinking about the nursing staff, would you recommend the hospital to your friends and family?	1 (worst) – 4 (best)

Table 1: Overview on dimensions of Patients' Experience of Nursing Quality in Acute Hospitals (PENQuAH) instrument

unit type	Patients	hospital units	(1) general nursing care[1]	(2) guidance[2]	(3) loyalty[3]
Internal medicine	6,260	732	4.22 (0.81)	3.56 (1.19)	3.25 (0.84)
Geriatrics	106	60	3.76 (1.05)	3.34 (1.14)	2.90 (0.99)
Cardiology	1,698	150	4.34 (0.74)	3.71 (1.13)	3.37 (0.76)
Nephrology	61	21	4.19 (0.85)	3.62 (1.09)	3.27 (0.83)
Hematology	181	66	4.37 (0.77)	3.71 (1.17)	3.47 (0.73)
Endocrinology	22	5	4.29 (0.70)	3.65 (1.24)	3.27 (0.69)
Gastroenterology	378	73	4.08 (0.90)	3.37 (1.21)	3.13 (0.90)
Pneumology	200	35	4.27 (0.81)	3.70 (1.24)	3.39 (0.78)
Rheumatology	121	14	4.34 (0.80)	3.57 (1.25)	3.38 (0.79)
Pulmonarymedicine	77	12	4.36 (0.74)	3.74 (1.20)	3.45 (0.70)
Generalsurgery	7,512	771	4.37 (0.75)	3.87 (1.07)	3.43 (0.75)
Traumasurgery	1,784	234	4.26 (0.79)	3.73 (1.10)	3.28 (0.81)
Neurosurgery	582	104	4.28 (0.77)	3.65 (1.10)	3.39 (0.79)
Vascularsurgery	300	86	4.39 (0.75)	3.87 (1.12)	3.45 (0.73)
Plasticsurgery	186	45	4.31 (0.75)	3.79 (1.15)	3.41 (0.78)
Thoracicsurgery	81	22	4.47 (0.73)	4.09 (1.04)	3.56 (0.73)
Heartsurgery	319	54	4.36 (0.74)	3.90 (0.96)	3.46 (0.72)
Urology	2,396	295	4.44 (0.66)	3.93 (1.03)	3.46 (0.70)
Orthopedics	2,753	226	4.46 (0.68)	4.02 (0.99)	3.57 (0.68)
Neurology	1,951	275	4.28 (0.77)	3.61 (1.17)	3.30 (0.80)
Nuclearmedicine	103	36	4.56 (0.63)	4.20 (0.94)	3.51 (0.71)
Radiotherapy	53	23	4.49 (0.61)	4.02 (0.88)	3.45 (0.70)
Dermatology	760	63	4.40 (0.69)	3.93 (1.06)	3.43 (0.73)
Dentistry	252	56	4.12 (0.84)	3.68 (1.11)	3.18 (0.88)
Total	**28,136**	**3,458**	4.33 (0.76)	3.77 (1.12)	3.38 (0.78)

Table 2: Quality of nursing care across unit types

[1] Mean response for general nursing care, measured on a scale of one to five, with five representing the best care. Standard deviation in parantheses.

[2] Mean response for guidance provided by nurses, measured on a measured on a scale of one to five, with five representing the best guidance.

[3] Mean response for patient loyalty to the hospital, measured on a scale of one to four, with four representing the highest loyalty.

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widetilde{PTN}$	-0.020 [0.002]	-0.023 [0.018]	-0.025 [<0.001]
	(-0.033;-0.008)	(-0.041;-0.004)	(-0.038;-0.012)
$\widetilde{PTN}^2$	0.001 [0.003]	0.001 [0.030]	0.001 [0.002]
	(0.000;0.002)	(0.000;0.002)	(0.000;0.002)
$\widetilde{skill}$	-0.003 [<0.001]	-0.005 [<0.001]	-0.003 [<0.001]
	(-0.004;-0.001)	(-0.007;-0.003)	(-0.005;-0.002)
$PCCL$	-0.048 [<0.001]	-0.034 [<0.001]	-0.028 [<0.001]
	(-0.057;-0.040)	(-0.047;-0.022)	(-0.037;-0.019)
age	0.021 [<0.001]	0.018 [<0.001]	0.018 [<0.001]
	(0.018;0.025)	(0.013;0.023)	(0.014;0.021)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.192 [<0.001]	-0.276 [<0.001]	-0.140 [<0.001]
	(-0.210;-0.173)	(-0.303;-0.249)	(-0.159;-0.121)
$ruralty$	0.014 [0.004]	0.028 [<0.001]	0.004 [0.382]
	(0.004;0.024)	(0.014;0.042)	(-0.005;0.014)
$\widetilde{PTP}$	-0.002 [0.030]	-0.002 [0.026]	-0.002 [0.013]
	(-0.003;0.000)	(-0.005;0.000)	(-0.003;0.000)
adj. R^2	**0.061**	**0.055**	**0.045**
observations	**28,136**	**28,136**	**28,136**

Table 3: Regression results

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index; $\widetilde{PTP}$: mean-centered patient-to-physician ratio

†Fixed effects for unit types, months, and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for patient-to-nurse and skill mix included but not shown.

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Competing/Conflicting interests

The authors declare that they have no competing or conflicting interests.

Author statement

JS and VW have originally designed the study. KD and US have acquired and analyzed the data. JS, KD, and VW have interpreted the data. KD and VW have drafted the article and JS and US have critically revised it. All authors undertake to give final approval of the version to be published and agree to be accountable for all aspects of the work. No further writing assistance other than basic copy-editing has been provided.

Ethical approval and informed consent

A declaration of compliance with terms of use and ethical standards from the University of Hamburg's WiSo Laboratories was obtained on January 15th, 2019 (no approval number provided). Information and consent of the survey participants were conducted in written form prior to survey participation. A copy of the written form of Informed Consent, Privacy and Confidentiality was handed out to the subjects. A further copy was provided for the archive of the WiSo Laboratories.

Data availability statement

The data are in large parts owned by a German statutory health insurer, the Techniker Krankenkasse. To fulfill the legal requirements to obtain the data, researchers must obtain permission for a specific research question from the German Federal (Social) Insurance Office. Additionally, researchers must conclude a contract with the statutory health insurer regarding data access.

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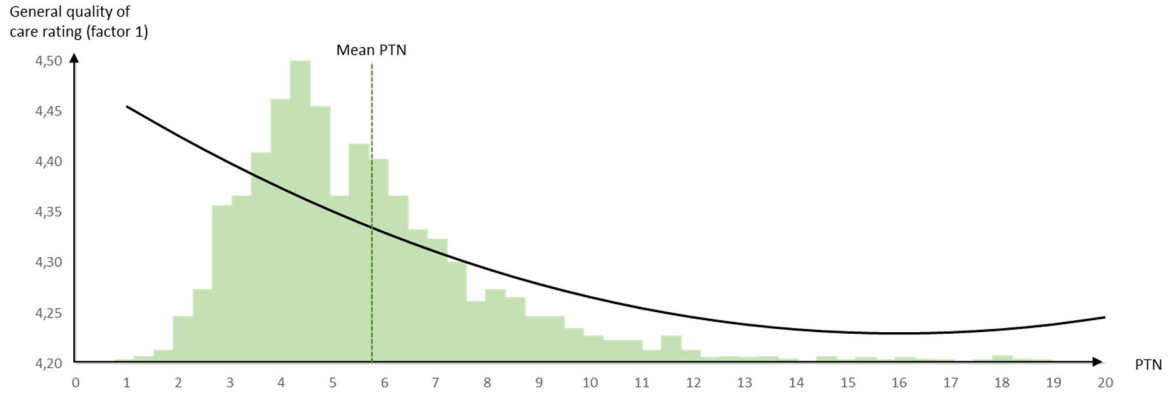
Appendix: Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

A.1: Mean PTN ratio and skill mix ratio per unit type

unit type	patients	patient-to nurse ratio (mean)	skill mix ratio (mean)
internal medicine	6,260	5.92	7.54
geriatrics	106	8.75	11.91
cardiology	1,698	4.68	5.85
nephrology	61	4.78	4.70
hematology	181	5.31	5.56
endocrinology	22	8.41	13.59
gastroenterology	378	6.20	8.30
pneumology	200	4.91	7.68
rheumatology	121	9.75	9.71
pulmonary medicine	77	6.16	6.14
general surgery	7,512	5.87	6.59
trauma surgery	1,784	6.50	7.14
neurosurgery	582	5.90	5.64
vascular surgery	300	5.76	4.98
plastic surgery	186	5.01	4.30
thoracic surgery	81	5.25	6.44
heart surgery	319	3.77	5.08
urology	2,396	6.27	5.45
orthopedics	2,753	6.05	6.94
neurology	1,951	5.36	6.26
nuclear medicine	103	4.26	3.33
radiotherapy	53	5.32	5.27
dermatology	760	5.93	4.87
dentistry	252	4.85	4.41
total	**28,136**	**5.84**	**6.61**

A.2 Illustration: Effect of an additional patient per nurse on QoNC factor 1 (ceteris paribus)



Note: the green area illustrates the distribution (histogram) of the PTN ratio and indicates the quantity of data points to substantiate the estimation depending on the PTN ratio.

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A.3: Regression results generalized random intercept model (odds ratios)

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widetilde{PTN}$	0.951 [0.010]	0.943 [0.010]	0.929 [<0.001]
	(0.915;0.988)	(0.902;0.986)	(0.897;0.963)
$\widetilde{PTN}^2$	1.003 [0.035]	1.003 [0.035]	1.004 [0.001]
	(1.000;1.005)	(1.001;1.006)	(1.002;1.006)
$\widetilde{skill}$	0.995 [0.050]	0.997 [0.050]	0.991 [<0.001]
	(0.991;1.000)	(0.991;1.002)	(0.986;0.995)
$PCCL$	0.876 [<0.001]	0.875 [<0.001]	0.944 [<0.001]
	(0.851;0.900)	(0.846;0.906)	(0.922;0.967)
age	1.080 [<0.001]	1.061 [<0.001]	1.034 [<0.001]
	(1.066;1.094)	(1.045;1.077)	(1.024;1.045)
age^2	0.999 [<0.001]	1.000 [<0.001]	1.000 [<0.001]
	(0.999;1.000)	(0.999;1.000)	(1.000;1.000)
$gender$ $(= 1\ if\ female)$	0.903 [<0.001]	0.934 [<0.001]	0.822 [<0.001]
	(0.854;0.955)	(0.874;0.999)	(0.781;0.865)
$ruralty$	1.060 [<0.001]	1.025 [<0.001]	1.010 [0.463]
	(1.029;1.091)	(0.991;1.062)	(0.984;1.037)
$\widetilde{PTP}$	0.997 [0.278]	0.998 [0.278]	0.997 [0.140]
	(0.992;1.002)	(0.992;1.004)	(0.993;1.001)
observations	**28,136**	**28,136**	**28,136**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for unit types, months, and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

A.4: Regression results random effects model

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widetilde{PTN}$	-0.006 [0.009]	-0.007 [0.045]	-0.010 [<0.001]
	(-0.011;-0.002)	(-0.014;0.000)	(-0.015;-0.005)
$\widetilde{PTN}^2$	0.001 [0.003]	0.001 [0.037]	0.001 [0.003]
	(0.000;0.002)	(0.000;0.002)	(0.000;0.002)
$\widetilde{skill}$	-0.003 [<0.001]	-0.005 [<0.001]	-0.003 [<0.001]
	(-0.004;-0.001)	(-0.007;-0.003)	(-0.005;-0.002)
$PCCL$	-0.048 [<0.001]	-0.034 [<0.001]	-0.027 [<0.001]
	(-0.057;-0.039)	(-0.047;-0.022)	(-0.036;-0.018)
age	0.022 [<0.001]	0.018 [<0.001]	0.018 [<0.001]
	(0.018;0.025)	(0.013;0.023)	(0.014;0.022)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(= 1\ if\ female)$	-0.192 [<0.001]	-0.276 [<0.001]	-0.140 [<0.001]
	(-0.210;-0.174)	(-0.303;-0.249)	(-0.159;-0.121)
$ruralty$	0.014 [0.004]	0.028 [<0.001]	0.004 [0.373]
	(0.004;0.024)	(0.014;0.042)	(-0.005;0.014)
$\widetilde{PTP}$	-0.002 [0.030]	-0.003 [0.026]	-0.002 [0.013]
	(-0.003;0.000)	(-0.005;0.000)	(-0.003;0.000)
observations	**28,136**	**28,136**	**28,136**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

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A.5: Regression results subgroup analysis case severity

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	low (PCCL=0)	high (PCCL>0)††	low (PCCL=0)	high (PCCL>0)††	low (PCCL=0)	high (PCCL>0)††
$\widehat{PTN}$	-0.019 [0.009]	-0.022 [0.121]	-0.021 [0.051]	-0.024 [0.245]	-0.025 [0.001]	-0.022 [0.142]
	(-0.033;-0.005)	(-0.051;-0.003)	(-0.043;0.000)	(-0.063;0.016)	(-0.040;-0.010)	(-0.050;-0.007)
$\widehat{PTN^2}$	0.001 [0.009]	0.001 [0.222]	0.001 [0.066]	0.001 [0.312]	0.001 [0.004]	0.001 [0.375]
	(0.000;0.002)	(-0.001;0.003)	(0.0000;0.003)	(-0.001;0.004)	(0.000;0.002)	(-0.001;0.003)
$\widehat{skill}$	-0.003 [0.001]	-0.003 [0.070]	-0.005 [<0.001]	-0.004 [0.079]	-0.004 [<0.001]	-0.003 [0.059]
	(-0.005;-0.001)	(-0.006;0.000)	(-0.008;-0.003)	(-0.008;0.000)	(-0.005;-0.002)	(-0.006;0.000)
$PCCL$	—	-0.038 [<0.001]	—	-0.008 [0.505]	—	-0.021 [0.017]
	—	(-0.055;-0.021)	—	(-0.032;0.016)	—	(-0.038;-0.004)
age	0.018 [<0.001]	0.030 [<0.001]	0.015 [<0.001]	0.022 [<0.001]	0.015 [<0.001]	0.022 [<0.001]
	(0.014;0.022)	(0.022;0.038)	(0.009;0.021)	(0.011;0.033)	(0.011;0.019)	(0.014;0.030)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [0.024]	0.000 [0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.190 [<0.001]	-0.193 [0.004]	-0.283 [<0.001]	-0.252 [<0.001]	-0.142 [<0.001]	-0.128 [<0.001]
	(-0.211;-0.169)	(-0.231;-0.154)	(-0.315;-0.252)	(-0.306;-0.198)	(-0.164;-0.120)	(-0.167;-0.089)
$ruralty$	0.009 [0.125]	0.029 [0.004]	0.021 [0.015]	0.050 [<0.001]	-0.001 [0.848]	0.020 [0.050]
	(-0.002;0.020)	(0.009;0.048)	(0.004;0.037)	(0.023;0.077)	(-0.013;0.010)	(0.000;0.039)
$\widehat{PTP}$	-0.001 [0.175]	-0.003 [0.073]	-0.002 [0.226]	-0.005 [0.027]	-0.001 [0.120]	-0.003 [0.039]
	(-0.003;0.001)	(-0.006;0.000)	(-0.004;0.001)	(-0.010;-0.001)	(-0.003;0.000)	(-0.007;0.000)
observations	**20,624**	**7,512**	**20,624**	**7,512**	**20,624**	**7,512**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

†† Subgroup "high" comprises patients with a PCCL from 1 to 6.

A.6: Regression results subgroup analysis hospital size††

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	small	large	small	large	small	large
$\widehat{PTN}$	-0.018 [0.024]	-0.015 [0.186]	-0.009 [0.447]	-0.031 [0.058]	-0.024 [0.005]	-0.014 [0.216]
	(-0.034;-0.002)	(-0.037;0.007)	(-0.033;-0.015)	(-0.063;0.001)	(-0.040;-0.007)	(-0.037;0.008)
$\widehat{PTN^2}$	0.001 [0.048]	0.001 [0.155]	0.000 [0.660]	0.002 [0.041]	0.001 [0.035]	0.001 [0.245]
	(0.000;0.002)	(0.000;0.002)	(-0.001;0.002)	(0.000;0.004)	(0.000;0.002)	(-0.001;0.002)
$\widehat{skill}$	-0.004 [<0.001]	-0.002 [0.183]	-0.005 [0.002]	-0.004 [0.009]	-0.005 [<0.001]	-0.001 [0.369]
	(-0.006;-0.002)	(-0.004;0.001)	(-0.008;-0.002)	(-0.008;-0.001)	(-0.007;-0.003)	(-0.003;0.001)
$PCCL$	-0.050 [<0.001]	-0.046 [<0.001]	-0.043 [<0.001]	-0.028 [0.002]	-0.034 [<0.001]	-0.022 [<0.001]
	(-0.062;-0.037)	(-0.058;-0.035)	(-0.062;-0.024)	(-0.045;-0.011)	(-0.047;-0.021)	(-0.035;-0.010)
age	0.026 [<0.001]	0.017 [<0.001]	0.023 [<0.001]	0.012 [0.002]	0.022 [<0.001]	0.013 [<0.001]
	(0.021;0.030)	(0.012;0.022)	(0.016;0.030)	(0.004;0.019)	(0.017;0.027)	(0.008;0.018)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]	0.000 [0.097]	0.000 [<0.001]	0.000 [0.002]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.165 [<0.001]	-0.223 [<0.001]	-0.245 [<0.001]	-0.311 [<0.001]	-0.116 [<0.001]	-0.166 [<0.001]
	(-0.189;-0.140)	(-0.251;-0.195)	(-0.282;-0.208)	(-0.351;-0.271)	(-0.141;-0.090)	(-0.195;-0.138)
$ruralty$	0.010 [0.148]	0.020 [0.006]	0.033 [0.001]	0.024 [0.020]	-0.007 [0.337]	0.017 [0.020]
	(0.003;0.023)	(0.006;0.034)	(0.013;0.053)	(0.004;0.044)	(-0.020;0.007)	(0.003;0.032)
$\widehat{PTP}$	0.000 [0.885]	-0.004 [0.006]	-0.001 [0.711]	-0.006 [0.007]	0.000 [0.884]	-0.005 [<0.001]
	(-0.002;0.002)	(-0.006;-0.034)	(-0.003;0.002)	(-0.009;-0.002)	(-0.002;0.002)	(-0.008;-0.002)
observations	**14,387**	**13,749**	**14,387**	**13,749**	**14,387**	**13,749**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

†† subgroup small comprises hospitals with less than 500 bed; subgroup large comprises hospitals with 500 beds and more

Nurse staffing and patient-perceived quality of nursing care

A.7: Regression results subgroup analysis medical vs. surgical patients

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	medical	surgical	medical	surgical	medical	surgical
$\widehat{PTN}$	-0.014 [0.216]	-0.012 [0.159]	-0.042 [0.015]	-0.008 [0.510]	-0.058 [<0.001]	-0.005 [0.594]
	(-0.037;0.008)	(-0.029;-0.005)	(-0.075;-0.008)	(-0.032;-0.016)	(-0.081;-0.034)	(-0.022;-0.013)
$\widehat{PTN^2}$	0.001 [0.245]	0.000 [0.412]	0.003 [0.003]	0.000 [0.965]	0.004 [<0.001]	0.000 [0.831]
	(-0.001;0.002)	(-0.001;0.002)	(0.001;0.005)	(-0.002;0.002)	(0.002;0.005)	(-0.001;0.001)
$\widehat{skill}$	-0.001 [0.369]	-0.003 [0.006]	-0.004 [0.039]	-0.005 [0.001]	-0.003 [0.025]	-0.003 [0.002]
	(-0.003;0.001)	(-0.005;-0.001)	(-0.007;0.000)	(-0.008;-0.002)	(-0.005;0.000)	(-0.006;-0.001)
$PCCL$	-0.022 [<0.001]	-0.060 [<0.001]	-0.021 [0.035]	-0.051 [<0.001]	-0.019 [0.006]	-0.040 [<0.001]
	(-0.035;-0.010)	(-0.072;-0.047)	(0.004;-0.022)	(-0.069;-0.033)	(-0.033;-0.006)	(-0.053;-0.027)
age	0.013 [<0.001]	0.023 [<0.001]	0.013 [0.003]	0.021 [<0.001]	0.016 [<0.001]	0.021 [<0.001]
	(0.008;0.018)	(0.018;0.028)	(0.004;0.022)	(0.014;0.028)	(0.010;0.022)	(0.016;0.026)
age^2	0.000 [0.002]	0.000 [<0.001]	0.000 [0.085]	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(= 1\ if\ female)$	-0.166 [<0.001]	-0.183 [<0.001]	-0.294 [<0.001]	-0.255 [<0.001]	-0.165 [<0.001]	-0.122 [<0.001]
	(-0.195;-0.138)	(-0.208;-0.159)	(-0.338;-0.250)	(-0.291;-0.219)	(-0.195;-0.134)	(-0.141;-0.097)
$ruralty$	0.017 [0.020]	0.017 [0.015]	0.018 [0.118]	0.038 [<0.001]	0.001 [0.886]	0.007 [0.293]
	(0.003;0.032)	(0.003;0.030)	(-0.005;0.041)	(0.019;0.057)	(-0.017;0.015)	(-0.006;-0.021)
$\widehat{PTP}$	-0.005 [0.020]	0.001 [0.490]	-0.004 [0.024]	0.000 [0.819]	-0.004 [0.005]	0.000 [0.764]
	(-0.008;-0.002)	(-0.002;0.004)	(-0.008;-0.001)	(-0.004;0.005)	(-0.006;-0.001)	(-0.003;0.003)
observations	**11,868**	**13,769**	**11,868**	**13,769**	**11,868**	**13,769**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for months and bed categories (50—299, 300—499, 500—749, and at least 750) and between-unit effects for PTN and skill mix included but not shown.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p. 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p. 4
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p. 5 ff.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p. 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	p. 6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p. 6 ff.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p. 6 ff.
Bias	9	Describe any efforts to address potential sources of bias	p. 8 f.
Study size	10	Explain how the study size was arrived at	p. 6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p. 6 ff.
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p. 8 f.
		(*b*) Describe any methods used to examine subgroups and interactions	p. 8 f.
		(*c*) Explain how missing data were addressed	p. 9
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n.a.
		(*e*) Describe any sensitivity analyses	p. 8 f.
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	p. 6
		(b) Give reasons for non-participation at each stage	n.a.
		(c) Consider use of a flow diagram	n.a.
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	p. 9, table A.1
		(b) Indicate number of participants with missing data for each variable of interest	n.a.
Outcome data	15*	Report numbers of outcome events or summary measures	p. 9, table 2
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear	p. 10 f., table 3

		which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	p. 8 f.
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	p. 10 f., tables A.2, A.3, A.4, A.5
Discussion			
Key results	18	Summarise key results with reference to study objectives	p. 11 f.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p. 14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p. 11 ff.
Generalisability	21	Discuss the generalisability (external validity) of the study results	p. 11 ff.
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

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Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

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Abstract

Objective: To examine the impact of nurse staffing on patient-perceived quality of nursing care. We differentiate nurse staffing levels and nursing skill mix as two facets of nurse staffing and use a multi-dimensional instrument for patient-perceived quality of nursing care. We investigate non-linear and interaction effects.

Setting: The study setting was 3,458 hospital units in 1,017 hospitals in Germany.

Participants: We contacted 212,554 patients discharged from non-pediatric, non-intensive, and non-psychiatric hospital units who stayed at least two nights in the hospital between January and October 2019. Of those, 30,174 responded, yielding a response rate of 14.2%. Our sample included only those patients. After excluding extreme values for our nurse staffing variables and removing observations with missing values, our final sample comprised 28,136 patients ranging from 18 to 97 years of age (average: 61.12 years) who had been discharged from 3,458 distinct hospital units in 1,017 hospitals.

Primary and secondary outcome measures: Patient-perceived quality of nursing care (general nursing care, guidance provided by nurses, and patient loyalty to the hospital)

Results: For all three dimensions of patient-perceived quality of nursing care, we found that they significantly decreased as (a) nurse staffing levels decreased (with decreasing marginal effects) and (b) the proportion of assistant nurses in a hospital unit increased. The association between nurse staffing levels and quality of nursing care was more pronounced among patients who were less clinically complex, were admitted to smaller hospitals, or were admitted to medical units.

Conclusions: Our results indicate that, in addition to nurse staffing levels, nursing skill mix is crucial for providing the best possible quality of nursing care from the patient perspective and both should be considered when designing policies such as minimum staffing regulations to improve the quality of nursing care in hospitals.

Article summary

Strengths and limitations of this study

- This study combines administrative data on hospital unit level nurse staffing with a multi-dimensional survey instrument that covers three aspects of patient-perceived quality of nursing care in a sample of 28,136 patients discharged from 3,458 hospital units in Germany in 2019
- This study demonstrates that the effect of nurse staffing on patient-perceived quality of care is non-linear and depending on patient and hospital characteristics (patient case severity, hospital size, and medical versus surgical patients)
- Besides patient-to-nurse ratios, the study also adds insight on the effect of skill mix and patient-to-physician ratios on patient-perceived quality of nursing care
- The study is cross-sectional and cannot account for all potential endogeneity problems / Even though considering the hospital unit type level is advantageous to using hospital-level aggregated data, omitted variables on hospital unit and patient level might remain.

Keywords (MeSH Terms)

Nursing Staff, Hospital; Health Workforce; Nurse-Patient Relations; Nursing Care; Patient-Centered Care; Health Care Surveys

INTRODUCTION AND BACKGROUND

Nurses are responsible for delivering the highest proportion of care to patients in hospitals and therefore a main contributor to quality of hospital care. Nurses who work on units with inadequate staffing are probably not working as effective and efficient as nurses on better-staffed and better-skilled units. As a result, nurses do not have enough time for providing care and instructions, observe vital signs timely, and to respond to patients' individual needs., which leads to missed care and ultimately unfavourable clinical patient outcomes and bad patient experiences and perceptions of quality of care. A large body of empirical studies, including several literature reviews and meta-analyses, has examined how nurse staffing levels affect patient outcomes.[1–10] Most studies have thereby relied on clinical outcomes available in administrative data and e.g. found significant effects of nurse staffing on mortality, pressure ulcers, and pneumonia.[3] Several studies depict that the effect of inadequate nurse staffing on adverse events is through missed care.[11–13] In light of calls for care (and, indeed, research) to be more patient oriented and for health systems to become more responsive to patient needs and expectations,[14–16] the number of studies examining links between nurse staffing patterns and patient experiences of care – i.e., perceived quality of care – has steadily grown.[15–17] In addition, in the wake of many studies on the effects of skill mix on clinical outcomes,[see 3] recent studies investigated the association between skill mix and patient-perceived quality of care.[15, 18, 19]

Several empirical studies that have analyzed the relationship between nurse staffing levels and perceived quality of care have considered the nurse's rather than the patient's perspective.[19–22] While the former is of course crucial, there is evidence that nurses' perceptions of the quality of their work can deviate substantially from the patients' perceptions[23]. In addition, most studies that have analyzed quality of care as an outcome have used measures that are very general (e.g., single items to rate overall quality of care or patient safety).[17, 22, 24, 25] Outcome measures like these are less informative about the quality of care provided by nurses and therefore potentially less sensitive to nurse staffing. Some studies have used multi-dimensional constructs of patient satisfaction or patient experience with care. Yet, these constructs usually comprise dimensions and indicators that do not relate to nursing care, but other aspects, such as responsiveness of hospital staff, discharge information, and overall hospital rating, all of which are also indicators of other health professionals' quality of care.[11, 16, 20, 26] . Only a handful of studies have used items that ask directly about the quality of care provided by nurses, or quality of nursing care.[20–22] To our knowledge, no studies to date have used a validated, multi-item, and multi-dimensional scale for patient-perceived quality of nursing care.

Methodologically, examining the link between nurse staffing and patient outcomes is at risk of endogeneity problems, such as omitted variable bias (e.g., skill mix, hospital-unit-type and patient characteristics, or physician staffing could all be related to nurse staffing and patient outcomes) or endogenous sorting (whereby hospitals devote more resources to patients with a higher risk of adverse outcomes).[1, 4, 8, 16, 27] The risk of endogeneity increases with the level of aggregation; as many studies use staffing information at the aggregated hospital level,[6, 17, 20, 21, 28, 29] they do not consider important information at the level of hospital units [7, 30, 31] or of patients.[16, 32] At the other extreme, using micro level data on the patient level [as e.g., 32, 33] usually implies substantial primary data collection efforts and a focus on one or few organizations, hence limiting generalizability. As an in-between approach, the number of studies using data at the level of hospital units has grown,[7, 31, 34–39] yet often suffers from limited sample sizes both in terms of patients and hospitals.[15] In addition, recent evidence hints to the fact the effect of nurse staffing on quality of nursing care non-linear, i.e., the effect of an additional nurse per patient might be high if nurse staffing is low; with higher numbers of nurses, the effect of each additional nurse probably decreases.[15] Furthermore, recent studies indicate that the association between nurse staffing and patient outcomes can differ depending on patients' case severity,[8, 40] hospital size,[6, 41], and between medical versus surgical units.[8, 28] Yet most of these studies have analyzed the associations between nurse staffing and clinical patient outcomes.

The present study aims to shed further light on the association between nurse staffing and patient-perceived quality of nursing care. In particular, we examine this relationship between nurse staffing levels, nurse skill mix, and patient-perceived quality of nursing care based on large-scale survey data combined with administrative data. Especially the use of a multi-dimensional survey instrument reflecting the patient perspective on nursing quality for measuring this relationship is quite novel. Second, we addressed substantial parts of potential endogeneity by including a rich set of patient- and hospital-related control variables. Thereby, we specifically consider physician staffing and investigate to which degree physician staffing is a relevant predictor of patient-perceived quality of nursing care. In addition, we apply a fixed effects model to account for differences across hospital unit types, which seems important to reduce endogeneity problems. Finally, we allow for non-linear effects of nurse staffing on quality of nursing care and conduct sub-group analyses on patient case severity, hospital size, and medical versus surgical hospital units.

METHODS

Data and sample

This study is part of a larger project on the association between nurse staffing and quality of care.[3, 42, 43] Our study analyzed data from an online patient survey. To ensure the quality of the survey, we followed the scientific standards for scale development. The entire development and validation of the survey is described elsewhere [43]. To sum up our proceeding, we drew on a systematic literature search and expert interviews to derive our initial items. We conducted two pre-tests (one paper and pencil pre-test and one online pre-test) with different participants and collected, discussed, and reported all changes made to the survey. After data collection, we performed comprehensive exploratory and confirmatory factor analyses to ensure the validity and reliability of the survey. We combined the survey data with (a) claims data provided by the largest statutory health insurance fund in Germany and (b) data from the mandatory quality reports published annually by each hospital in the country. The combined data set comprised data from patients discharged from non-pediatric, non-intensive, and non-psychiatric hospital units between January and October 2019. We define a hospital unit as an operating unit within a hospital that focuses on specific types of patients (e.g., geriatrics or cardiology). Our sample included only those patients who stayed at least two nights in the hospital. We contacted patients in monthly waves and asked them to participate in the survey, eight weeks after they had been discharged from the hospital at the latest. The survey contained questions related to patients' perceptions of the quality of the nursing care provided during their hospital stay. Each patient was contacted only once. In total, we contacted 212,554 patients, of whom 30,174 responded, yielding a response rate of 14.2%. The response rate is comparable to other large-scale patient surveys. We checked for representativeness of the study population. Compared to the general population of hospitalized patients in Germany, our sample is generally representative in observable characteristics. Only the share of patients older than 80 is lower in our sample compared to the general population of hospitalized patients in Germany. We also compared respondents to non-respondents and did not find any substantial deviations in observable characteristics.

The claims data in our data set contained patient-level information about the course of disease during each patient's hospital stay, as well as the dates of hospital admission and discharge, the type of hospital unit, and ICD codes. The quality reports contained general information at the hospital unit level, such as the number of patient cases treated and staffing numbers that relate to the situation at the end of 2017.

Nurse staffing

We obtained the nurse staffing level in each hospital unit by calculating a patient-to-nurse ratio (PTN) in line with the definition for measuring nursing workload as suggested by the National Office of Statistics in Germany.[44] The patient-to-nurse ratio indicates how many patients a nurse has to care for during an average shift and is given by:

$$PTN = \frac{occupation\ days * 24hours}{nurses * 220days * 8hours},\ with$$

$$occupation\ days = inpatient * average\ length\ of\ stay.$$

The total number of nurses (based on full-time nurses employed) comprise all registered nurses with at least three years of training and assistant nurses with at least one year of training. The numbers are derived from the annual quality reports of each hospital, representing the situation at the end of the year and not accounting for sickness absences or other sources of within-year variations such as variation caused by holidays. To calculate occupation days, we used the number of inpatients and approximated the average length of stay or each hospital unit based on the average length of stay of more than 6.2 million inpatient cases available in our claims data set over the period 2014 to 2019. We draw on the five-year period for this approximation because we cannot observe all patients in each hospital unit in one year; to ensure robustness, we considered only those hospital units with more than 150 observations to approximate the length of stay.

In addition to staffing levels, we accounted for the skill mix in each hospital unit by calculating the ratio of assistant nurses to the total number of nurses (measured in full-time equivalents):

$$skill\ mix = \frac{assistant\ nurses}{nurses}.$$

We excluded extreme values, i.e., patient-to-nurse ratios below 1 and above 20, as well as skill-mix ratios above 25%.

Quality of nursing care

Because the definition of nursing care varies from country to country, it is necessary to use an instrument that takes country-specific regulations into account. We therefore chose the Patients' Experience of Nursing Quality in Acute Hospitals (PENQuAH) instrument developed by Blume to analyze the relationship between nurse staffing and patient outcomes.[43] The instrument was designed to evaluate patients' perceptions of quality of nursing care in German hospitals. The instrument consists of

24 items, which were chosen based on a review of the literature and interviews with nursing experts. To examine the scale's dimensionality and factor-based validity, Blume conducted exploratory and confirmatory factor analyses with a randomly split sample.[43] Their exploratory factor analysis revealed that three main dimensions captured the structure of the underlying item set: general nursing care, guidance provided by nurses, and nurse-related patient loyalty to the hospital. The results of their confirmatory factor analysis suggested a good overall model fit (CFI = 0.978; TLI = 0.976). Table 1 shows the three dimensions and exemplary related items.

--- include table 1 about here ----

We calculated each dimension of quality of nursing care by taking the arithmetic mean of the underlying items after recoding reverse-coded items. Dimensions one and two are on a scale of one to five, with five representing the best quality of nursing care, and dimension three is on a scale of one to four, with four representing the best quality of nursing care. Dimension one represents patients' perception of the general quality of nursing care. Dimension two represents patients' perception of the guidance provided by nurses. Dimension three comprises two items that capture patients' loyalty to a hospital based on the nursing care provided.

Statistical model

The results of previous studies suggest that the relationship between nurse staffing and patient outcomes varies across different types of hospital units.[8, 35, 42] To account more accurately for potential differences across the 24 unit types in our sample and to depict potential heteroscedastic structures in the error term of the regression, we applied a fixed effects model. The model is given by:

$$QoNC_{iu}^{(x)} = \alpha_0 + \alpha_{10}\,\widetilde{PTN}_{iu} + \alpha_{11}\,\widetilde{PTN}_{iu}^2 + \alpha_2\,\widetilde{skill}_{iu} + \beta_1\,\overline{PTN}_u + \beta_2\,\overline{skill}_u + \gamma C_{iu} + (v_{0u} + \varepsilon_{iu}),$$

where $QoNC_{iu}^{(x)}$ is the value of one of the three factors $x \in \{1, 2, 3\}$ for patient i admitted to unit type u, $u \in \{1, \ldots, 24\}$. α_0 is the intercept of the regression. $\widetilde{PTN}_{iu} = (PTN_{iu} - \overline{PTN}_u)$ and $\widetilde{skill}_{iu} = (skill_{iu} - \overline{skill}_u)$ with coefficients α_{10} and α_0 are the mean-centered independent nurse staffing variables of interest, which correspond to the patient-to-nurse and skill mix ratio of the hospital unit associated with patient i minus the group means $\overline{PTN}_u$ and $\overline{skill}_u$ for each unit type u. Assuming that the marginal effect of the patient-to-nurse ratio on quality of nursing care decreases as staffing levels increase, we also

included a squared patient-to-nurse term with coefficient α_{11}. β_1 and β_2 are the coefficients of the between-unit effects. C_{iu} represents a vector of patient-, hospital-, and hospital-unit-related control variables at level one of the model. First, it includes the patient-to-physician (PTP) ratio, because it might correlate with the PTN ratio and also affect the outcome.[e.g., 27] Second, we account for in patient risks by including age, gender, and each patient's case severity reflected by the Patient Clinical Complexity Level (PCCL) index (0-6), which indicates the degree of comorbidities and complications for each patient. It is derived from a closed list of comorbidities and complications and is meant to predict a patient's need for hospital resources, such as nursing care.[45] We directly incorporate the PCCL index in our model because sensitivity analyses using dummy variables for each score suggested a linear relationship. Furthermore, we control for the rurality of each patient's place of residence using an index ranging from one (urban area) to four (rural area), four hospital size categories (50—299, 300—499, 500—749, and at least 750), and monthly fixed effects. v_{0u} refers to the fixed effects for the 24 hospital unit types.

As most previous studies used dichotomized outcome variables, we transformed our three quality of nursing care measures into dichotomous outcome variables and estimated a generalized version of our fixed effects model using a logit link function for comparability purposes, i.e. a logit model. To check the robustness of our main model, we estimated a random effects model. Lastly, replaced the Patient Clinical Complexity Level index with the Elixhauser comorbidity categories.[46]

Moreover, we conducted subgroup analyses. As suggested by previous studies, the association between nurse staffing and patient outcomes can differ depending on patients' case severity.[8, 40] To study these potential differences, we split our sample into patients with low case severity (Patient Clinical Complexity Level = 0) and those with high case severity (Patient Clinical Complexity Level > 0) and estimated our main regression model for each of the sub-samples. Additionally, we considered that our results might vary due to differences in hospital size.[6, 41] We therefore split our sample into two categories – i.e., patients admitted to hospitals with fewer than 500 beds (category "small") and patients admitted to hospitals with at least 500 beds (category "large"). Lastly, by categorizing our unit types as medical or surgical, we estimated our statistical model separately for medical and surgical patients.

Patient and Public Involvement

This study is part of a larger project on the association between nurse staffing and quality of care.[3, 42, 43] The public, i.e., a statutory health insurance, hospital managers, and patient representatives were involved in the design of the overall project. In addition, patients, practitioners (nurses, physiotherapists,

doctors), and scientific experts were involved in the development of the survey (described in more detail in [3, 43]). Results of the study and the overall project will be disseminated to the participants via the statutory health insurance and via additional practice-oriented publications and newsletters.

RESULTS

Descriptive results

After excluding extreme values for our nurse staffing variables and removing observations with missing values for one or more of the control variables, our final sample comprised 28,136 patients ranging from 18 to 97 years of age (average: 61.12 years) who had been discharged from 3,458 distinct hospital units in 1,017 hospitals. 39.2% of the survey participants were female. Table 2 illustrates the distribution of patients and the average response for each of the three dimensions of quality of nursing care across the 24 types of hospital units. Overall, the variation in the distribution of patients across the 24 unit types was large. Almost 50% of the patients had been discharged from general surgery or internal medicine, followed by orthopedics, urology, neurology, trauma surgery, and cardiology, from each of which between six and ten percent of the patients had been discharged. All of the other unit types each accounted for less than three percent of the patients in our sample. In terms of our dependent variable, quality of nursing care, we obtained an average response of 4.33, 3.77, and 3.38 for the three dimensions general nursing care, guidance provided by nurses, and nurse-related patient loyalty to the hospital, respectively, indicating that the perceived quality of nursing care was above the scale average for each. In addition, we found that patient perception of the guidance provided by nurses was, on average, 0.56 scale points lower compared to the general perception of quality of nursing care. We also found that the average responses varied across hospital unit types. For instance, for dimensions one and two, the average responses for patients discharged from internal medicine were 0.24 and 0.46 scale points lower, respectively, compared to orthopedic patients.

For the patient-to-nurse and skill-mix-ratios, we obtained average values of 5.84 patients per nurse and 6.61%, respectively. The patient-to-nurse ratio ranged from 3.77 patients a nurse has to care for in heart surgery to 9.75 in rheumatology. The skill-mix ratio ranged from 3.33% assistant nurses in nuclear medicine to 13.59% assistant nurses in endocrinology (see Appendix 1).

---- include table 2 about here -----

Regression results

As shown in Table 3, our results indicate that the two nurse staffing variables were significantly related to quality of nursing care. An increase in the patient-to-nurse ratio significantly decreased the general quality of nursing care, the patient perception of nursing guidance, and nurse-related patient loyalty to a given hospital. Additionally, there were significantly positive associations between the squared patient-to-nurse ratio, on the one hand, and the general quality of nursing care, guidance, and patient loyalty, on the other. Hence, the negative effect of the patient-to-nurse ratio is greater when the patient-to-nurse ratio is smaller (in other words, if a nurse already has to care for a lot of patients, one additional patient has a less strong effect on quality perceptions). We illustrate the non-linear relationship in Appendix 2 (for factor 1).

With regard to the skill-mix ratio, we found that an increase in the ratio of assistant nurses to the total number of nurses led to a significant decrease in general quality of nursing care, patient perception of nursing guidance, and patient loyalty. An increase in the patient-to-physician ratio of one additional patient a physician must care for significantly decreased the quality of nursing care dimensions.

---- include table 3 about here -----

The adjusted R^2 measure indicated that our model reduces the error in predicting an individual outcome for our three dimensions of quality of nursing care by between 4.5 and 6.1%.

The regression results of the logit model indicated that an additional patient per nurse decreases the odds of a patient reporting high quality of nursing care. For nurse-related patient loyalty, this effect is significantly non-linear in the same way as in our main model (stated above). Increasing the share of assistant nurses decreases the odds of reporting high quality. An additional patient per physician does not significantly decrease the odds of reporting a high quality of quality of nursing care (see Appendix 3).

When we estimated a random effects model (Appendix 4) and when we replaced the Patient Clinical Complexity Level index with the Elixhauser risk adjustment, our results remained robust.

Sub group analyses

Differentiating between patients according to their case severity, we found that the mean-centered patient-to-nurse ratio and its square are significantly associated with all three dimensions of patient-

perceived quality of nursing care for patients with low case severity, but not for those with high case severity. The effects of the skill-mix ratio are also only significant for patients with low case severity, while the effects of the patient-to-physician ratio are slightly larger and only significant for high-case severity patients (except for general nursing care) (see Appendix 5).

When splitting our sample into patients admitted to a hospital with fewer than 500 beds and those admitted to a hospital with at least 500 beds, we found that an increase in the patient-to-nurse ratio significantly decreased general nursing care and nurse-related patient loyalty only for patients admitted to hospitals with fewer than 500 beds. Skill mix significantly affected general nursing care perceptions and nurse-related patient loyalty in small hospitals only, while it significantly affected the perception of guidance provided by nurses in small and in large hospitals. Moreover, we found a significant association between physician staffing and patient-perceived quality of nursing care for patients admitted to larger hospitals but not for patients admitted to smaller ones (see Appendix 6).

Finally, when we divided patients into those admitted to medical or surgical units, we found that the patient-to-nurse ratio significantly affected perceptions of guidance by nurses and nurse-related patient loyalty for medical patients only. The associations between the skill mix ratio and quality of nursing care seem largely unaffected by the sample split. Finally, it shows that medical patients were more sensitive to physician staffing compared to surgical patients (see Appendix 7).

DISCUSSION

Our results provide important new insights into the relationship between nurse staffing and patient outcomes, in particular, patient-perceived quality of nursing care. We found that patient-perceived quality of nursing care significantly decreased as staffing levels, measured using the patient-to-nurse ratio, decreased. This finding is in line with previous research that has examined the relationship between nurse staffing levels and general perceived quality of care measures.[15, 16, 19–22, 25, 26, 47–49] Our study adds to the previously ambiguous evidence in literature by providing insights into the specific aspects of perceived quality of nursing care that are affected by staffing levels. Evidence on the perceived quality of guidance provided by nurses has been inconsistent and scarce.[20, 22] Our results, however, corroborate and extend the findings of Zhu et al. ,[22] who found that higher staffing levels improved satisfaction with nurses' guidance on medications and medical aids, pain management, and self-help.[22] With respect to nurse-related patient loyalty, our results confirm the findings of previous studies that have found that higher nurse staffing levels in hospitals increase the likelihood of patients generally recommending a hospital to family and friends.[20, 21] Thus, nurse-related patient loyalty

seems to be highly related to overall recommendation behavior. In sum, staffing levels affect whether an adequate amount of time is devoted to caring and providing instructions as well as nurses' responsiveness to patients' individual needs. Furthermore, nurse staffing levels have direct consequences for hospitals in terms of patient loyalty. Yet, those effects are not linear; instead, the negative effects become smaller with rising numbers of patients per nurse. This decreasing marginal effect of the patient-to-nurse ratio on quality of nursing care with increasing staffing levels is in line with prior research [15] and seems reasonable: when the ratio is small, each additional patient will substantially affect the amount of time and the responsiveness of a nurse, thus probably substantially reducing missed care.[11–13] In contrast, the effect will be lower when a nurse already needs to care for a high number of (potentially less complex) patients and each additional patient only has a low impact.

Our results suggest that the nurses' level of educational attainment, as measured using the skill-mix ratio, significantly influences patient-perceived quality of nursing care. This finding adds to the few available studies on the relationship between skill mix and patient-perceived quality of care.[15, 18, 19] We found strong evidence that a higher proportion of assistant nurses, which means a lower proportion of professionalization among nursing staff, is negatively associated with all three dimensions of quality of nursing care. Nurses with lower levels of educational attainment may have less training in interacting with patients, might work less efficiently and hence have less time per patient, or both. In addition, it is conceivable that they are less experienced in providing instructions suited to a patient's particular needs – for example, with regard to medication, pain relief, or the use of medical aids. Any of these factors could lead to negative perceptions among patients of quality of nursing care and potentially also to an increased number of adverse events.[8, 17, 50]

We found that one additional patient per physician significantly reduced all three dimensions of patient-perceived quality of nursing care. This is in line with the findings of e.g. West et al.,[51] who found that both physician and nurse staffing impact intensive care unit patient mortality . However, we found that the effect sizes for physician staffing were less pronounced compared to those for nurse staffing levels, indicating that our instrument is more closely related to nurse staffing than to physician staffing. This result might indicate that patients are not fully capable of differentiating between different occupational groups when assessing quality of care in hospitals. Another explanation might be that physician staffing does in fact have an impact on quality of nursing care; if physicians have to care for a large number of patients, they might omit passing on information which nurses need to adequately care for a patient – e.g., information on the patients' needs or patient-specific treatment instructions. Additionally, stressed

physicians might cause a bad civility climate, which in turn negatively impacts nurses' civility towards patients.[52, 53]

The significant association we observed between the patient-to-nurse ratio and patient-perceived quality of nursing care was driven mainly by low-severity patients. This stands in contrast to the study of West et al.,[51] which found that reductions in mortality risks from having more intensive care unit nurses is larger for patients who are the most severely ill. This might indicate that the effect of nurse staffing differs across hospital units (in particular, intensive versus non-intensive care) and/or across outcomes (in that case, patient-perceived quality of care and mortality). Additionally, for low-severity patients, the share of assistant nurses affects their perceptions of quality of nursing care, while for high-severity patients, the patient-to-physician ratio affects their perceptions of quality of nursing care. Because high-severity patients are more dependent on various health professionals and their collaborative performance, the quality of cooperation and consistency within and across occupational groups might explain their perceptions of quality of nursing care rather than staffing levels and skill mix.[53] Low-severity patients might be less relying on different professionals, so that the composition of the nurses, as expressed in their skill mix, is of greater relevance to them.

Similarly, splitting our sample using two separate bed categories reveals that an increase in the patient-to-nurse ratio decreases patient-perceived quality of nursing care among patients admitted to hospitals with fewer than 500 beds rather than for patients admitted to hospitals with at least 500 beds. Yet, the patient-perceived guidance is only significantly affected by staffing levels in large hospitals (significant non-linear effect). While skill mix significantly affects patient-perceived general nursing care and loyalty in smaller hospitals only, it significantly relates to guidance in both small and large hospitals. Thus, we see some variation in how our variables of interest relate to the different quality of nursing care dimensions. The patient-to-physician ratio in turn only significantly affects patient-perceived quality of nursing care in large hospitals for all three quality of nursing care dimensions. This might be explained by a higher proportion of high-severity patients admitted to larger and potentially more highly specialized hospitals. In addition, in larger hospitals, collaboration across different occupational groups might be of higher importance than in smaller hospitals.

The stronger statistical significance of the relationship between nurse and physician staffing levels and quality of nursing care for medical patients compared to surgical patients seems plausible, as well. For nurse staffing, the finding is in line with previous studies that have analyzed the relationship between nurse staffing levels and patient outcomes based on administrative data and found stronger associations

for medical patients.[8] The difference in effects might be explained by surgical patients being healthier (i.e., as a precondition for being eligible for surgery) and therefore being less dependent on nurses. For medical patients, the collaboration between professional groups might also be of higher relevance, which can explain the significant effects of physician staffing.

Although our study makes important contributions to understanding the relationship between nurse staffing and patient outcomes, it is not without important limitations, each of which offers avenues for further research. First, both of the nurse staffing variables used in our analysis (i.e., patient-to-nurse and skill-mix ratios) represent annual averages and do not capture day-to-day variations in nurse staffing. Similarly, even though we were able to consider several variables which are likely related to nurse staffing and patient outcomes, we might have omitted variable bias from other hospital-unit-related characteristics, such as the availability and use of technology, the share of temporary or immigrant nurses, the team climate, or absences due to sickness. These variables were not available in our data sample but might be associated with nurses' workload and also have an effect on patient outcomes.[27, 53] In addition, the model complexity and the limited sample size drove our choice to conduct subgroup instead of moderating analyses. Thus, although this study overcomes several endogeneity issues of previous studies it cannot claim to fully address them. While the large size of our sample may compensate for some of these issues, future studies may want to draw upon or collect more finely grained data covering day-to-day variations in nurse staffing variables and should try to account for further hospital characteristics. In addition, administrative staffing measures have been shown to deviate from perceived staffing adequacy;[54, 55] therefore, accounting for the latter in relation with quality of nursing care is a valuable avenue for further research, too. Another limitation this study shares with previous research is its cross-sectional nature. As the causal order and the generalizability of our results cannot be verified, future studies would be valuable to investigate the relationships in other settings and over time. Finally, the PENQuAH instrument has only been tested in Germany and our sample shows slight variations from the German hospitalized population, which might affect the generalizability of our results. As it has been able to provide more fine-grained insights into the dimensions of patient-perceived quality of nursing care, we recommend applying, adapting, and validating it to further data samples, and adjusting it to the hospital environments of other countries.

Our results have important implications for hospital managers and health policy makers pursuing stronger patient orientation. By providing strong evidence that quality of nursing care is affected by nurse staffing, we show that nurse staffing decisions are critical for favorable patient care experiences. We find that in addition to staffing levels, nurses' skill mix is an important factor associated with quality

of nursing care. Therefore, we recommend considering nurses' levels of educational attainment, qualifications and specializations when designing policies, such as minimum staffing regulations, to improve nurse staffing in hospitals.

Tables

	Dimension	# Items	exemplary items	scale
(1)	general nursing care	13	• From my perspective, I always received the necessary care in the hospital. • Nursing staff treated me respectfully and courteously.	1 (worst) – 5 (best)
(2)	guidance provided by nurses	9	• Nursing staff told or showed me how I may and should move. • Nursing staff told or showed me how to use my medical aids.	1 (worst) – 5 (best)
(3)	nurse-related loyalty	2	• Thinking about the nursing staff, would you select the hospital again? • Thinking about the nursing staff, would you recommend the hospital to your friends and family?	1 (worst) – 4 (best)

Table 1: Overview on dimensions of Patients' Experience of Nursing Quality in Acute Hospitals (PENQuAH) instrument

unit type	Patients	hospital units	(1) general nursing care[1]	(2) guidance[2]	(3) loyalty[3]
Internal medicine	6,260	732	4.22 (0.81)	3.56 (1.19)	3.25 (0.84)
Geriatrics	106	60	3.76 (1.05)	3.34 (1.14)	2.90 (0.99)
Cardiology	1,698	150	4.34 (0.74)	3.71 (1.13)	3.37 (0.76)
Nephrology	61	21	4.19 (0.85)	3.62 (1.09)	3.27 (0.83)
Hematology	181	66	4.37 (0.77)	3.71 (1.17)	3.47 (0.73)
Endocrinology	22	5	4.29 (0.70)	3.65 (1.24)	3.27 (0.69)
Gastroenterology	378	73	4.08 (0.90)	3.37 (1.21)	3.13 (0.90)
Pneumology	200	35	4.27 (0.81)	3.70 (1.24)	3.39 (0.78)
Rheumatology	121	14	4.34 (0.80)	3.57 (1.25)	3.38 (0.79)
Pulmonary medicine	77	12	4.36 (0.74)	3.74 (1.20)	3.45 (0.70)
General surgery	7,512	771	4.37 (0.75)	3.87 (1.07)	3.43 (0.75)
Trauma surgery	1,784	234	4.26 (0.79)	3.73 (1.10)	3.28 (0.81)
Neurosurgery	582	104	4.28 (0.77)	3.65 (1.10)	3.39 (0.79)
Vascular surgery	300	86	4.39 (0.75)	3.87 (1.12)	3.45 (0.73)
Plastics urgery	186	45	4.31 (0.75)	3.79 (1.15)	3.41 (0.78)
Thoracic surgery	81	22	4.47 (0.73)	4.09 (1.04)	3.56 (0.73)
Heart surgery	319	54	4.36 (0.74)	3.90 (0.96)	3.46 (0.72)
Urology	2,396	295	4.44 (0.66)	3.93 (1.03)	3.46 (0.70)
Orthopedics	2,753	226	4.46 (0.68)	4.02 (0.99)	3.57 (0.68)
Neurology	1,951	275	4.28 (0.77)	3.61 (1.17)	3.30 (0.80)
Nuclear medicine	103	36	4.56 (0.63)	4.20 (0.94)	3.51 (0.71)
Radiotherapy	53	23	4.49 (0.61)	4.02 (0.88)	3.45 (0.70)
Dermatology	760	63	4.40 (0.69)	3.93 (1.06)	3.43 (0.73)
Dentistry	252	56	4.12 (0.84)	3.68 (1.11)	3.18 (0.88)
Total	**28,136**	**3,458**	4.33 (0.76)	3.77 (1.12)	3.38 (0.78)

Table 2: Quality of nursing care across unit types

[1] Mean response for general nursing care, measured on a scale of one to five, with five representing the best care. Standard deviation in parantheses.

[2] Mean response for guidance provided by nurses, measured on a measured on a scale of one to five, with five representing the best guidance.

[3] Mean response for patient loyalty to the hospital, measured on a scale of one to four, with four representing the highest loyalty.

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widetilde{PTN}$	-0.020 [0.002]	-0.023 [0.018]	-0.025 [<0.001]
	(-0.033;-0.008)	(-0.041;-0.004)	(-0.038;-0.012)
$\widetilde{PTN}^2$	0.001 [0.003]	0.001 [0.030]	0.001 [0.002]
	(0.000;0.002)	(0.000;0.002)	(0.000;0.002)
$\widetilde{skill}$	-0.003 [<0.001]	-0.005 [<0.001]	-0.003 [<0.001]
	(-0.004;-0.001)	(-0.007;-0.003)	(-0.005;-0.002)
$PCCL$	-0.048 [<0.001]	-0.034 [<0.001]	-0.028 [<0.001]
	(-0.057;-0.040)	(-0.047;-0.022)	(-0.037;-0.019)
age	0.021 [<0.001]	0.018 [<0.001]	0.018 [<0.001]
	(0.018;0.025)	(0.013;0.023)	(0.014;0.021)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.192 [<0.001]	-0.276 [<0.001]	-0.140 [<0.001]
	(-0.210;-0.173)	(-0.303;-0.249)	(-0.159;-0.121)
$rurality$	0.014 [0.004]	0.028 [<0.001]	0.004 [0.382]
	(0.004;0.024)	(0.014;0.042)	(-0.005;0.014)
$\widetilde{PTP}$	-0.002 [0.030]	-0.002 [0.026]	-0.002 [0.013]
	(-0.003;0.000)	(-0.005;0.000)	(-0.003;0.000)
adj. R^2	**0.061**	**0.055**	**0.045**
observations	**28,136**	**28,136**	**28,136**

Table 3: Regression results

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widetilde{PTN}$: mean-centered patient-to-nurse ratio; $\widetilde{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index; $\widetilde{PTP}$: mean-centered patient-to-physician ratio

†Fixed effects for the 24 unit types, months, and bed categories and between-unit effects for patient-to-nurse and skill mix included but not shown.

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Competing/Conflicting interests

The authors declare that they have no competing or conflicting interests.

Author statement

JS and VW have originally designed the study. KD and US have acquired and analyzed the data. JS, KD, and VW have interpreted the data. KD and VW have drafted the article and JS and US have critically revised it. All authors undertake to give final approval of the version to be published and agree to be accountable for all aspects of the work. No further writing assistance other than basic copy-editing has been provided.

Ethical approval and informed consent

A declaration of compliance with terms of use and ethical standards from the University of Hamburg's WiSo Laboratories was obtained on January 15th, 2019 (no approval number provided). Information and consent of the survey participants were conducted in written form prior to survey participation. A copy of the written form of Informed Consent, Privacy and Confidentiality was handed out to the subjects. A further copy was provided for the archive of the WiSo Laboratories.

Data availability statement

The data are in large parts owned by a German statutory health insurer, the Techniker Krankenkasse. To fulfill the legal requirements to obtain the data, researchers must obtain permission for a specific research question from the German Federal (Social) Insurance Office. Additionally, researchers must conclude a contract with the statutory health insurer regarding data access.

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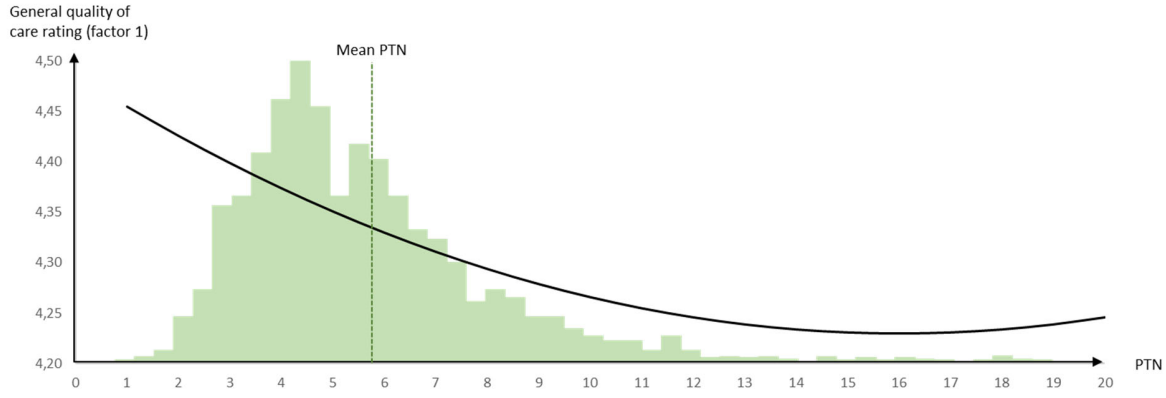
Appendix: Nurse staffing and patient-perceived quality of nursing care: A cross-sectional analysis of survey and administrative data in German hospitals

Appendix 1: Mean PTN ratio and skill mix ratio per unit type

unit type	patients	patient-to nurse ratio (mean)	skill mix ratio (mean)
internal medicine	6,260	5.92	7.54
geriatrics	106	8.75	11.91
cardiology	1,698	4.68	5.85
nephrology	61	4.78	4.70
hematology	181	5.31	5.56
endocrinology	22	8.41	13.59
gastroenterology	378	6.20	8.30
pneumology	200	4.91	7.68
rheumatology	121	9.75	9.71
pulmonary medicine	77	6.16	6.14
general surgery	7,512	5.87	6.59
trauma surgery	1,784	6.50	7.14
neurosurgery	582	5.90	5.64
vascular surgery	300	5.76	4.98
plastic surgery	186	5.01	4.30
thoracic surgery	81	5.25	6.44
heart surgery	319	3.77	5.08
urology	2,396	6.27	5.45
orthopedics	2,753	6.05	6.94
neurology	1,951	5.36	6.26
nuclear medicine	103	4.26	3.33
radiotherapy	53	5.32	5.27
dermatology	760	5.93	4.87
dentistry	252	4.85	4.41
total	**28,136**	**5.84**	**6.61**

Appendix 2 Illustration: Effect of an additional patient per nurse on QoNC factor 1 (ceteris paribus)



Note: the green area illustrates the distribution (histogram) of the PTN ratio and indicates the quantity of data points to substantiate the estimation depending on the PTN ratio.

Nurse staffing and patient-perceived quality of nursing care

Appendix 3: Regression results generalized random intercept model (odds ratios)

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widehat{PTN}$	0.951 [0.010]	0.943 [0.010]	0.929 [<0.001]
	(0.915;0.988)	(0.902;0.986)	(0.897;0.963)
$\widehat{PTN^2}$	1.003 [0.035]	1.003 [0.035]	1.004 [0.001]
	(1.000;1.005)	(1.001;1.006)	(1.002;1.006)
$\widehat{skill}$	0.995 [0.050]	0.997 [0.050]	0.991 [<0.001]
	(0.991;1.000)	(0.991;1.002)	(0.986;0.995)
$PCCL$	0.876 [<0.001]	0.875 [<0.001]	0.944 [<0.001]
	(0.851;0.900)	(0.846;0.906)	(0.922;0.967)
age	1.080 [<0.001]	1.061 [<0.001]	1.034 [<0.001]
	(1.066;1.094)	(1.045;1.077)	(1.024;1.045)
age^2	0.999 [<0.001]	1.000 [<0.001]	1.000 [<0.001]
	(0.999;1.000)	(0.999;1.000)	(1.000;1.000)
$gender$ $(= 1\ if\ female)$	0.903 [<0.001]	0.934 [<0.001]	0.822 [<0.001]
	(0.854;0.955)	(0.874;0.999)	(0.781;0.865)
$rurality$	1.060 [<0.001]	1.025 [<0.001]	1.010 [0.463]
	(1.029;1.091)	(0.991;1.062)	(0.984;1.037)
$\widehat{PTP}$	0.997 [0.278]	0.998 [0.278]	0.997 [0.140]
	(0.992;1.002)	(0.992;1.004)	(0.993;1.001)
observations	**28,136**	**28,136**	**28,136**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for the 24 unit types, months, bed categories and between-unit effects for PTN and skill mix included but not shown.

Appendix 4: Regression results random effects model

effect†	(1) general nursing care	(2) guidance	(3) loyalty
$\widehat{PTN}$	-0.006 [0.009]	-0.007 [0.045]	-0.010 [<0.001]
	(-0.011;-0.002)	(-0.014;0.000)	(-0.015;-0.005)
$\widehat{PTN^2}$	0.001 [0.003]	0.001 [0.037]	0.001 [0.003]
	(0.000;0.002)	(0.000;0.002)	(0.000;0.002)
$\widehat{skill}$	-0.003 [<0.001]	-0.005 [<0.001]	-0.003 [<0.001]
	(-0.004;-0.001)	(-0.007;-0.003)	(-0.005;-0.002)
$PCCL$	-0.048 [<0.001]	-0.034 [<0.001]	-0.027 [<0.001]
	(-0.057;-0.039)	(-0.047;-0.022)	(-0.036;-0.018)
age	0.022 [<0.001]	0.018 [<0.001]	0.018 [<0.001]
	(0.018;0.025)	(0.013;0.023)	(0.014;0.022)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(= 1\ if\ female)$	-0.192 [<0.001]	-0.276 [<0.001]	-0.140 [<0.001]
	(-0.210;-0.174)	(-0.303;-0.249)	(-0.159;-0.121)
$rurality$	0.014 [0.004]	0.028 [<0.001]	0.004 [0.373]
	(0.004;0.024)	(0.014;0.042)	(-0.005;0.014)
$\widehat{PTP}$	-0.002 [0.030]	-0.003 [0.026]	-0.002 [0.013]
	(-0.003;0.000)	(-0.005;0.000)	(-0.003;0.000)
observations	**28,136**	**28,136**	**28,136**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for the 24 unit types, months, bed categories and between-unit effects for PTN and skill mix included but not shown.

Nurse staffing and patient-perceived quality of nursing care

Appendix 5: Regression results subgroup analysis case severity

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	low (PCCL=0)	high (PCCL>0)††	low (PCCL=0)	high (PCCL>0)††	low (PCCL=0)	high (PCCL>0)††
$\widehat{PTN}$	-0.019 [0.009]	-0.022 [0.121]	-0.021 [0.051]	-0.024 [0.245]	-0.025 [0.001]	-0.022 [0.142]
	(-0.033;-0.005)	(-0.051;-0.003)	(-0.043;0.000)	(-0.063;0.016)	(-0.040;-0.010)	(-0.050;-0.007)
$\widehat{PTN^2}$	0.001 [0.009]	0.001 [0.222]	0.001 [0.066]	0.001 [0.312]	0.001 [0.004]	0.001 [0.375]
	(0.000;0.002)	(-0.001;0.003)	(0.0000;0.003)	(-0.001;0.004)	(0.000;0.002)	(-0.001;0.003)
$\widehat{skill}$	-0.003 [0.001]	-0.003 [0.070]	-0.005 [<0.001]	-0.004 [0.079]	-0.004 [<0.001]	-0.003 [0.059]
	(-0.005;-0.001)	(-0.006;0.000)	(-0.008;-0.003)	(-0.008;0.000)	(-0.005;-0.002)	(-0.006;0.000)
$PCCL$	—	-0.038 [<0.001]	—	-0.008 [0.505]	—	-0.021 [0.017]
	—	(-0.055;-0.021)	—	(-0.032;0.016)	—	(-0.038;-0.004)
age	0.018 [<0.001]	0.030 [<0.001]	0.015 [<0.001]	0.022 [<0.001]	0.015 [<0.001]	0.022 [<0.001]
	(0.014;0.022)	(0.022;0.038)	(0.009;0.021)	(0.011;0.033)	(0.011;0.019)	(0.014;0.030)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [0.024]	0.000 [0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.190 [<0.001]	-0.193 [0.004]	-0.283 [<0.001]	-0.252 [<0.001]	-0.142 [<0.001]	-0.128 [<0.001]
	(-0.211;-0.169)	(-0.231;-0.154)	(-0.315;-0.252)	(-0.306;-0.198)	(-0.164;-0.120)	(-0.167;-0.089)
$rurality$	0.009 [0.125]	0.029 [0.004]	0.021 [0.015]	0.050 [<0.001]	-0.001 [0.848]	0.020 [0.050]
	(-0.002;0.020)	(0.009;0.048)	(0.004;0.037)	(0.023;0.077)	(-0.013;0.010)	(0.000;0.039)
$\widehat{PTP}$	-0.001 [0.175]	-0.003 [0.073]	-0.002 [0.226]	-0.005 [0.027]	-0.001 [0.120]	-0.003 [0.039]
	(-0.003;0.001)	(-0.006;0.000)	(-0.004;0.001)	(-0.010;-0.001)	(-0.003;0.000)	(-0.007;0.000)
observations	**20,624**	**7,512**	**20,624**	**7,512**	**20,624**	**7,512**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for the 24 unit types, months, bed categories and between-unit effects for PTN and skill mix included but not shown.

†† Subgroup "high" comprises patients with a PCCL from 1 to 6.

Appendix 6: Regression results subgroup analysis hospital size††

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	small	large	small	large	small	large
$\widehat{PTN}$	-0.018 [0.024]	-0.015 [0.186]	-0.009 [0.447]	-0.031 [0.058]	-0.024 [0.005]	-0.014 [0.216]
	(-0.034;-0.002)	(-0.037;0.007)	(-0.033;-0.015)	(-0.063;0.001)	(-0.040;-0.007)	(-0.037;0.008)
$\widehat{PTN^2}$	0.001 [0.048]	0.001 [0.155]	0.000 [0.660]	0.002 [0.041]	0.001 [0.035]	0.001 [0.245]
	(0.000;0.002)	(0.000;0.002)	(-0.001;0.002)	(0.000;0.004)	(0.000;0.002)	(-0.001;0.002)
$\widehat{skill}$	-0.004 [<0.001]	-0.002 [0.183]	-0.005 [0.002]	-0.004 [0.009]	-0.005 [<0.001]	-0.001 [0.369]
	(-0.006;-0.002)	(-0.004;0.001)	(-0.008;-0.002)	(-0.008;-0.001)	(-0.007;-0.003)	(-0.003;0.001)
$PCCL$	-0.050 [<0.001]	-0.046 [<0.001]	-0.043 [<0.001]	-0.028 [0.002]	-0.034 [<0.001]	-0.022 [<0.001]
	(-0.062;-0.037)	(-0.058;-0.035)	(-0.062;-0.024)	(-0.045;-0.011)	(-0.047;-0.021)	(-0.035;-0.010)
age	0.026 [<0.001]	0.017 [<0.001]	0.023 [<0.001]	0.012 [0.002]	0.022 [<0.001]	0.013 [<0.001]
	(0.021;0.030)	(0.012;0.022)	(0.016;0.030)	(0.004;0.019)	(0.017;0.027)	(0.008;0.018)
age^2	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]	0.000 [0.097]	0.000 [<0.001]	0.000 [0.002]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(=1\ if\ female)$	-0.165 [<0.001]	-0.223 [<0.001]	-0.245 [<0.001]	-0.311 [<0.001]	-0.116 [<0.001]	-0.166 [<0.001]
	(-0.189;-0.140)	(-0.251;-0.195)	(-0.282;-0.208)	(-0.351;-0.271)	(-0.141;-0.090)	(-0.195;-0.138)
$rurality$	0.010 [0.148]	0.020 [0.006]	0.033 [0.001]	0.024 [0.020]	-0.007 [0.337]	0.017 [0.020]
	(0.003;0.023)	(0.006;0.034)	(0.013;0.053)	(0.004;0.044)	(-0.020;0.007)	(0.003;0.032)
$\widehat{PTP}$	0.000 [0.885]	-0.004 [0.006]	-0.001 [0.711]	-0.006 [0.007]	0.000 [0.884]	-0.005 [<0.001]
	(-0.002;0.002)	(-0.006;-0.034)	(-0.003;0.002)	(-0.009;-0.002)	(-0.002;0.002)	(-0.008;-0.002)
observations	**14,387**	**13,749**	**14,387**	**13,749**	**14,387**	**13,749**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for the 24 unit types, months, bed categories and between-unit effects for PTN and skill mix included but not shown.

†† subgroup small comprises hospitals with less than 500 bed; subgroup large comprises hospitals with 500 beds and more

Nurse staffing and patient-perceived quality of nursing care

Appendix 7: Regression results subgroup analysis medical vs. surgical patients

effect†	(1) general nursing care		(2) guidance		(3) loyalty	
	medical	surgical	medical	surgical	medical	surgical
$\widehat{PTN}$	-0.014 [0.216]	-0.012 [0.159]	-0.042 [0.015]	-0.008 [0.510]	-0.058 [<0.001]	-0.005 [0.594]
	(-0.037;0.008)	(-0.029;-0.005)	(-0.075;-0.008)	(-0.032;-0.016)	(-0.081;-0.034)	(-0.022;-0.013)
$\widehat{PTN^2}$	0.001 [0.245]	0.000 [0.412]	0.003 [0.003]	0.000 [0.965]	0.004 [<0.001]	0.000 [0.831]
	(-0.001;0.002)	(-0.001;0.002)	(0.001;0.005)	(-0.002;0.002)	(0.002;0.005)	(-0.001;0.001)
$\widehat{skill}$	-0.001 [0.369]	-0.003 [0.006]	-0.004 [0.039]	-0.005 [0.001]	-0.003 [0.025]	-0.003 [0.002]
	(-0.003;0.001)	(-0.005;-0.001)	(-0.007;0.000)	(-0.008;-0.002)	(-0.005;0.000)	(-0.006;-0.001)
$PCCL$	-0.022 [<0.001]	-0.060 [<0.001]	-0.021 [0.035]	-0.051 [<0.001]	-0.019 [0.006]	-0.040 [<0.001]
	(-0.035;-0.010)	(-0.072;-0.047)	(0.004;-0.022)	(-0.069;-0.033)	(-0.033;-0.006)	(-0.053;-0.027)
age	0.013 [<0.001]	0.023 [<0.001]	0.013 [0.003]	0.021 [<0.001]	0.016 [<0.001]	0.021 [<0.001]
	(0.008;0.018)	(0.018;0.028)	(0.004;0.022)	(0.014;0.028)	(0.010;0.022)	(0.016;0.026)
age^2	0.000 [0.002]	0.000 [<0.001]	0.000 [0.085]	0.000 [<0.001]	0.000 [<0.001]	0.000 [<0.001]
	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)	(0.000;0.000)
$gender$ $(= 1\ if\ female)$	-0.166 [<0.001]	-0.183 [<0.001]	-0.294 [<0.001]	-0.255 [<0.001]	-0.165 [<0.001]	-0.122 [<0.001]
	(-0.195;-0.138)	(-0.208;-0.159)	(-0.338;-0.250)	(-0.291;-0.219)	(-0.195;-0.134)	(-0.141;-0.097)
$rurality$	0.017 [0.020]	0.017 [0.015]	0.018 [0.118]	0.038 [<0.001]	0.001 [0.886]	0.007 [0.293]
	(0.003;0.032)	(0.003;0.030)	(-0.005;0.041)	(0.019;0.057)	(-0.017;0.015)	(-0.006;-0.021)
$\widehat{PTP}$	-0.005 [0.020]	0.001 [0.490]	-0.004 [0.024]	0.000 [0.819]	-0.004 [0.005]	0.000 [0.764]
	(-0.008;-0.002)	(-0.002;0.004)	(-0.008;-0.001)	(-0.004;0.005)	(-0.006;-0.001)	(-0.003;0.003)
observations	**11,868**	**13,769**	**11,868**	**13,769**	**11,868**	**13,769**

P-values in square brackets, 95%-confidence intervals in parentheses

Abbreviations: $\widehat{PTN}$: mean-centered patient-to-nurse ratio; $\widehat{skill}$: mean-centered skill-mix ratio; PCCL: Patient Clinical Complexity Level index

†Fixed effects for the 24 unit types, months, bed categories and between-unit effects for PTN and skill mix included but not shown.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	p. 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	p. 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p. 4
Objectives	3	State specific objectives, including any prespecified hypotheses	p. 5
Methods			
Study design	4	Present key elements of study design early in the paper	p. 5 ff.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p. 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	p. 6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p. 6 ff.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p. 6 ff.
Bias	9	Describe any efforts to address potential sources of bias	p. 8 f.
Study size	10	Explain how the study size was arrived at	p. 6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p. 6 ff.
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	p. 8 f.
		(*b*) Describe any methods used to examine subgroups and interactions	p. 8 f.
		(*c*) Explain how missing data were addressed	p. 9
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n.a.
		(*e*) Describe any sensitivity analyses	p. 8 f.
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	p. 6
		(b) Give reasons for non-participation at each stage	n.a.
		(c) Consider use of a flow diagram	n.a.
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	p. 9, table A.1
		(b) Indicate number of participants with missing data for each variable of interest	n.a.
Outcome data	15*	Report numbers of outcome events or summary measures	p. 9, table 2
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear	p. 10 f., table 3

		which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	p. 8 f.
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n.a.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	p. 10 f., tables A.2, A.3, A.4, A.5
Discussion			
Key results	18	Summarise key results with reference to study objectives	p. 11 f.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p. 14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p. 11 ff.
Generalisability	21	Discuss the generalisability (external validity) of the study results	p. 11 ff.
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p. 18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.