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Nurse Staffing and Medication Errors: Cross-Sectional or Longitudinal Relationships?

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Abstract: We used autoregressive latent trajectory (ALT) modeling to examine the relationship between change in nurse staffing and change in medication errors over 6 months in 284 general medical-surgical nursing units. We also investigated the impact of select hospital and nursing unit characteristics on the baseline level and rate of change in medication errors. We found essentially no support for a nurse staffing–medication error relationship either cross-sectionally or longitudinally. Few hospital or nursing unit characteristics had significant relationships to either the baseline level or rate of change in medication errors. However, ALT modeling is a promising technique that can promote a deeper understanding of the theoretically complex relationships that may underlie the nurse staffing–medication error relationship. © 2008 Wiley Periodicals, Inc. Res Nurs Health 32:18–30, 2009

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The relationship between nurse staffing and medication errors continues to be of significant policy concern, 9 years after the publication of the Institute of Medicine's *To Err is Human* (Kohn, Corrigan, & Donaldson, 2000). Surprisingly few researchers have examined this relationship specifically, and results are inconsistent because of different units of analysis (hospital vs. nursing unit), different measures of nurse staffing (proportion of registered nurses [RNs] vs. nursing hours per patient day), different approaches to conceptualization and operationalization of medication errors, and different approaches to risk adjustment (Blegen, 2006; Carlton & Blegen, 2006). These studies are also limited because they examine the staffing–medication error relationship in isolation, rather than within a larger organizational context. In addition, no researcher has yet examined the relationship between *change* in nurse staffing and *change* in medication errors, or described trajectories of change in this relationship over time.

Such an examination has significant managerial and methodological implications. From a management perspective, the knowledge gleaned from a longitudinal examination could provide critical information to nurse executives and nurse managers about whether changes in nurse staffing result in immediate or delayed consequences for quality and patient safety. This information could contribute substantially to more informed

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managerial decision-making about staffing and scheduling. From a methodological perspective, if there is an identifiable and statistically significant pattern of change in the relationship between nurse staffing and medication errors, then future researchers should recognize the time-dependent nature of these observed patterns by incorporating longitudinal aspects of research design. Therefore, the purpose of the study reported here was to examine the relationships between change in acute care unit nurse staffing and change in medication errors, and to describe the trajectories of that change over a 6-month period of time.

REVIEW OF LITERATURE

Despite the importance of the nurse's role in preventing medication errors, and a growing body of evidence relating nurse staffing to quality and patient safety outcomes, very few researchers have explored the relationship between nurse staffing and medication errors for general medical-surgical patients at the nursing unit level. In an early study, Blegen, Good, and Reed (1998), examined the relationship between nurse staffing (defined as hours of care from all nursing personnel [all hours] and hours of care provided by RNs [RN proportion]) and medication errors per 10,000 doses, on 42 inpatient nursing units in a single large university hospital. Using multivariate regression models, they found a negative but not statistically significant relationship between all hours and medication errors. The relationship between RN proportion and errors, however, was strongly negative, and statistically significant. An interesting aspect of this finding was that the relationship was nonlinear: when RN proportion exceeded 87.5%, medication errors increased. In a follow-up study, Blegen and Vaughn (1998) examined the same relationship on 30 units in 11 hospitals, and confirmed the earlier findings, including that of a nonlinear relationship between RN proportion and medication errors.

In a Canadian study using a somewhat different definition of nurse staffing—the mix of nursing staff employed on the patient care unit—McGillis Hall, Doran, and Pink (2004) examined the staffing–medication error relationship in 77 medical, surgical, and obstetric units in 19 urban teaching hospitals. Using multi-level hierarchical linear modeling, they found a statistically significant relationship between a higher proportion of professional nurses on the nursing staff and lower rates of medication errors.

More recently, in an expansion of the definition of medication errors, Seago, Williamson, and Atwood (2006) examined failure-to-rescue from medication errors, which they defined as the number of injuries from medication errors. Nurse staffing was defined in a variety of ways: skill mix was operationalized as the proportion of RN hours divided by total hours; RN hours was operationalized as total RN hours divided by total patient days; all other hours was operationalized as all non-RN hours divided by total patient days; and total hours was defined as both RN and non-RN hours divided by total patient days. Using 48 months of data from three acute care patient units in a large urban tertiary care hospital, the authors found that neither skill mix nor RN hours was associated with failure-to rescue from medication errors, but that total hours and all other hours were both associated with increases in failure-to-rescue from medication errors.

This small set of studies provides preliminary support for the nurse staffing–medication error relationship. However, firm conclusions should be made cautiously because sample sizes tended to be small, nurse staffing definitions varied across studies, and the researchers did not take into account the broader organizational context, which may have a powerful influence on how nurse staffing affects medication errors.

CONCEPTUAL MODEL

We used structural contingency theory (SCT) to guide model specification (Donaldson, 1999). The basic premise of SCT is that organizational effectiveness depends upon how well an organization's *structure* relates to its *context*. Thus, SCT suggests that there is no single best way to structure work in an organization to achieve effective performance and optimal outcomes. Rather, effectiveness depends on structuring the work in ways that are compatible with the organization's context.

Context

Context incorporates two major dimensions. The first is the organization's environment, which encompasses both external and internal factors that have an influence on how the organization operates. The distinction between external and internal depends upon the unit of analysis selected for study. Because the nursing unit was the unit of analysis for this study, the nursing unit's external environment was comprised of relevant characteristics of the hospital in which it operated. These include the hospital's teaching status and its size, both of which have been included in previous research on staffing and medication errors (Cho, Ketefian, Barkauskas, & Smith, 2003; Mark et al., 2007; Mark, Salyer, & Wan, 2003). The internal environment was specified using selected characteristics of the nursing unit itself, including the number of beds on the unit, the uncertainty of the nurses' work, occupancy rate, and the availability of unit-based services to support medication delivery. These nursing unit characteristics are related to uncertainty, nurses' workload, fatigue, time pressure, and work interruptions, all of which have been implicated as causes of medication errors (Rogers, Hwang, Scott, Aiken, & Dinges, 2004; Roseman & Booker, 1995).

The second major contextual dimension is what organization theorists refer to as the organization's technology. In popular use, the word *technology* is frequently interpreted as information technology, high technology, the use of certain machines, or sophisticated procedures. However, from the classic perspective of contingency theory, the two relevant dimensions of technology are the nature of the raw materials (i.e., how severely ill patients are) and the work processes involved (nursing care required; Donaldson, 1999; Lawrence & Lorsch, 1967; Thompson, 1967). Technology, like environment, must be considered in relation to the selected unit of analysis. Consequently, technology is often conceptualized as related to patient severity of illness at the hospital level or acuity at the nursing unit level (Mark et al., 2003; Overton, Schneck, & Hazlett, 1977; Perrow, 1967). Therefore, technology was included at both the hospital level (the hospital's case mix index), and at the nursing unit level (patient acuity).

Structure

Organizational structure is defined as the relatively enduring allocation of work roles and administrative mechanisms that allow the organization to conduct, coordinate and control its work activities (Jackson & Morgan, 1986; Mark et al., 2007). In this case, structure refers to nurse staffing.

Effectiveness

Although there are multiple, and frequently conflicting definitions of effectiveness in the SCT literature, we selected one that is consistent with a goal-oriented approach (Scott, 2003). In other words, organizations are effective to the extent that they meet highly valued goals. Patient safety is one of those goals, and one measure of patient safety is reflected in medication errors. The major constructs of SCT and the variables used in this study to represent them are shown in Figure 1.

In addition to the SCT framework, which guided variable selection, we developed a theoretical model of the underlying relationships among these variables over time. Specifically, for both nurse staffing and medication errors, the predetermined contextual variables were hypothesized to influence the initial baseline values (i.e., the intercept, considered to be a latent construct), and the rate of change (i.e., the slope, also a random latent construct). Second, staffing measured at Time 1 was expected to influence staffing at Time 2; staffing measured at Time 2 was hypothesized to influence the value of staffing measured at Time 3; the same relationships were hypothesized for the relationships of medication errors over time. Third, the staffing variable was

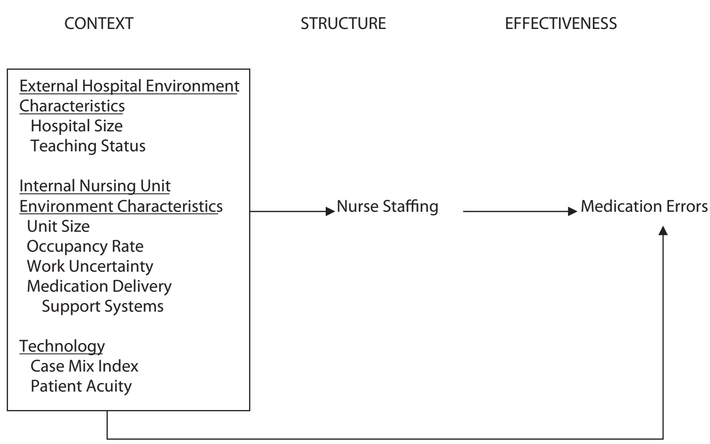

FIGURE 1. Structural contingency model.

hypothesized to have both contemporaneous and lagged effects on medication errors. In other words, staffing measured at, say, Time 1 was expected not only to influence medication errors at Time 1, but also medication errors at Time 2; staffing measured at Time 2 was expected to have effects on medication errors measured at Time 2, as well as medication errors measured at Time 3, and so on. Figure 2 graphically displays the initial model we tested.

METHODS

Design

Data for this study came from the Outcomes Research in Nursing Administration Project-II (ORNA-II), which used a prospective, non-experimental, longitudinal, causal modeling design. It is a large, multi-site organizational study to investigate relationships between hospital context and structure and organizational, nurse, and patient outcomes (Mark et al., 2007). Data were collected in 2003 and 2004. The analysis reported here is a secondary analysis of data obtained in the larger study.

We calculated power following MacCallum, Brown, and Sugawara (1996) with power defined as the ability to detect the difference between a good fitting and a poor fitting model. Using the statistic Root Mean Square Error of Approximation (RMSEA), a value $<.05$ indicates a good fitting model, whereas a value $>.08$ indicates a poor fitting model. For the final model for medication errors with time varying and time constant predictors, with 68 degrees of freedom and a sample size of 284, the power is .967.

Sample

The ORNA-II sample comprised acute care hospitals with at least 99 licensed beds that were accredited by The Joint Commission. After excluding federal, for-profit, and psychiatric facilities, hospitals for the ORNA sample were randomly selected from the 2002 American Hospital Association (AHA) *Guide to Hospitals* (2003). Data were obtained from two medical, surgical, or medical-surgical units in each hospital. The sample for this study was 284 nursing units in 145 hospitals. Six nursing units were lost to attrition for a variety of different reasons. Institutional Review Board approval was obtained at the study's home institution as well as at all participating institutions.

Data

There were three sources of data for the study. The first source was the AHA *Annual Survey of Hospitals* (2004). This voluntary survey of hospitals in the United States (response rate approximately 80%) provides data on ownership/control, services offered, system membership, utilization, managed care contracts, accreditation

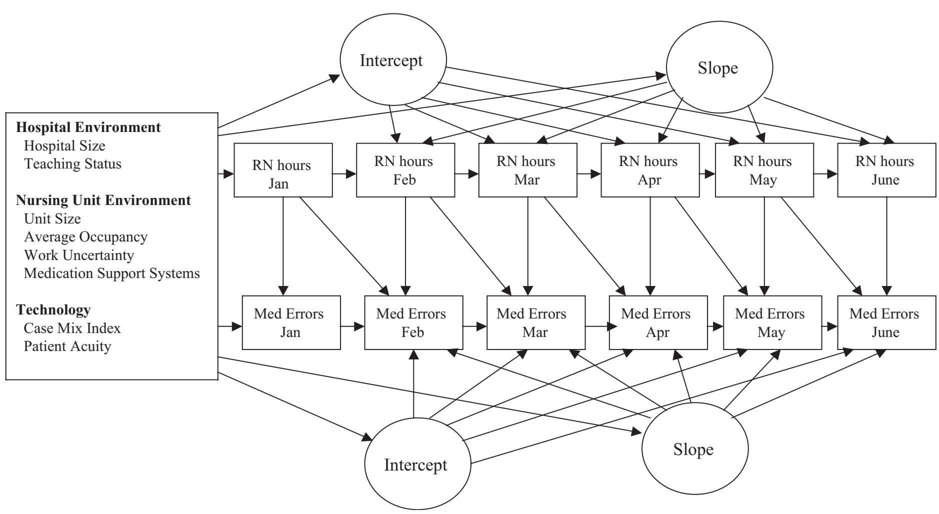

FIGURE 2. Hypothesized bivariate autoregressive latent trajectory model of the relationship between nurse staffing and medication errors.

and approvals, facility personnel and expenses. The AHA data provided information on hospital size and teaching status.

The second source of data was surveys of RNs who had been employed on their units for a minimum of 3 months, and who were currently working a minimum of 20 hours per week. Data collection from RNs participating in the ORNA-II study took place on three different occasions over 6 months. Data on the perceptual measures included in the analysis reported here (work uncertainty, medication delivery support services, and patient acuity) were collected once during the first period of data collection. RNs (4,911) completed these surveys, a response rate of 75%.

The third source of data was from on-site study coordinators, selected by each hospital to assist with ORNA-II data collection. All study coordinators participated in 1½ day training program conducted by the ORNA-II research team, which provided detailed information about the study purpose and procedures for data collection. Study coordinators provided data on unit size, occupancy rate, case mix index, and medication errors.

Several steps were taken to insure data integrity. First, all study coordinators were provided with a procedure manual that included the information presented during the training program. Second, on arrival in the research office, the research team immediately reviewed all data, and study coordinators were contacted by telephone, fax, or e-mail to resolve data discrepancies. Finally, calculations required for the measurement of selected variables were completed in the research office to insure that the same formulae were used.

Measures

Prior to presenting information about the measurement of specific variables, we first discuss our approach to evaluating reliability, within group agreement, reliability of the aggregated data, and validity of data obtained from staff RNs. Internal consistency reliability of the perceptual measures of work uncertainty and patient acuity was evaluated with Cronbach's alpha (Cronbach's alpha is not reported for medication support services, which was measured with a checklist). Within group agreement, a measure of the extent to which different nurses made the same ratings, and which forms the justification for aggregating data from the individual to the nursing unit level, was based on the r_{wg} statistic (minimum values for aggregation are equal to or greater than .70; James, Demaree, & Wolf, 1984; Lindell, Brandt, & Whitney, 1999). The reliability of the aggregated data was further evaluated by calculating the proportion of variance explained by group membership using the intraclass correlation coefficient (ICC(1)) and mean rater reliability using ICC(2). ICC(2), which is an estimate of the reliability of the group means, is estimated with the use of mean squares from a one-way random-effects ANOVA (Bliese, 2000). Values of .70 or higher indicate acceptable group-level reliability (Bleise). Construct validity was evaluated using the results of principal components factor analysis.

Contextual variables

External hospital environment. Hospital size was measured as the number of open and staffed beds. We measured *teaching status* as the ratio of medical and dental residents to the number of hospital beds. Data on both of these variables were obtained from the AHA *Annual Survey of Hospitals*.

Internal nursing unit environment. Unit size was measured as the number of beds on the unit. *Occupancy rate* was defined with the numerator as the total number of patient days for a specific month and the denominator as the number of days in that month. This figure was then divided by the number of beds on the unit. Data on both of these variables were obtained from study coordinators. We measured *work uncertainty* on the unit using a seven-item questionnaire (Salyer, 1996) about the frequency of interruptions or unanticipated events on the unit (total scale Cronbach's alpha = .85; ICC(1) = .169; ICC(2) = .778; r_{wg} = .797; 2 factors explained 75% of the variance). *Services to support medication delivery* were measured with a summed 6-item checklist in which RNs rated specific services, such as support for transcribing orders, use of computerized physician order entry systems, and unit dose system, as *not available*, *inconsistently available*, or *consistently available* (Mark et al., 2003; ICC[1] = .262; ICC[2] = .860; r_{wg} = .837).

Technology. Hospital level technology was measured by the hospital's Medicare Case Mix Index, obtained from study coordinators. Technology at the unit level was measured as *patient acuity* using a questionnaire developed by Overton et al. (1977) and twice revised by Mark (Mark & Hagenmueller, 1994; Mark et al., 2003). Nurses were asked to estimate the proportion of patients on their unit with complex problems (e.g., how many patients require the use of technical equipment, medications through central venous lines, or frequent monitoring). Higher scores indicated higher levels of patient acuity. Total scale Cronbach's alpha = .81; ICC(1) = 124; ICC(s) = .711;

$r_{wg} = .924$; three factors explained 61% of the variance in scores.

Structural variables

Nurse staffing. We used two related indices of nurse staffing. The first index was the proportion of nursing care hours delivered by RNs, a measure that represents the amount of RN care that is available to patients on a unit. We also measured the proportion of RN full-time equivalents (FTEs) among the total nursing staff on each unit by dividing the number of full-time equivalent RNs by the number of total full-time equivalent nursing staff. We included all RNs who provided direct care. This measure provides information about the unit's capacity to deliver nursing care. The correlation of .577 between the two measures suggests they are tapping related but non-redundant dimensions. Study coordinators provided staffing data for 6 consecutive months.

Effectiveness

Medication errors. Effectiveness was measured as the number of monthly medication errors documented by incident report for 6 consecutive months, scaled to 1,000 patient days. Medication errors were defined as an error in medication administration (wrong patient, drug, dose, time, or route). We did not include physician's medication prescribing errors or pharmacy medication delivery errors. Data on medication errors were obtained from study coordinators.

Statistical Analysis

We analyzed data with the Mplus statistical program (Muthén & Muthén, 1998–2006) and used autoregressive latent trajectory (ALT) modeling (Bollen & Curran, 2004; Curran & Willoughby, 2003; Wan, Zhang, & Unruh, 2006). ALT represents a new development in the analysis of longitudinal data. It combines elements of an older approach to modeling change called autoregressive modeling (AR) and a newer model of change referred to as latent growth modeling or latent trajectory (LT) modeling. AR models examine relations over time as time-adjacent comparisons among the repeated measures. For instance, in our study, the current value of medication errors is regressed on its prior value. An AR model can also examine lagged effects, such as the effect of staffing in one month on medication errors in the next month, and so on. AR models look at the average group change from time point to time point so the effects for each nursing unit are assumed to be the same for every unit. Thus, AR models do not allow for unit-level differences in the underlying trajectories of change over time in medication errors.

LT models, on the other hand, use the repeated measures to estimate an underlying latent trajectory and allow each nursing unit to deviate from this overall average trajectory. This allows each nursing unit to have its own specific trajectory over time for the repeated measures. However, the repeated measures are "smoothed" over time; in other words, they are not given the same attention as in an AR model, and the focus of the analysis is the trajectory and what variables predict it. LT models also permit inclusion of other explanatory variables to better understand differences in nursing units' starting points (intercepts) and rates of change (slopes) over time. Thus, in our study, each nursing unit could have a different intercept and slope for the medication error variables.

ALT models combine the AR and LT approaches and allow investigation of both the autoregressive structure (i.e., the influence of the previous value of staffing and of medication errors on current values and their cross-lagged values), and the underlying trajectory of the medication errors as well as the influence of other explanatory variables on these relationships. These variables can be time invariant, such as hospital size and teaching status, as well as time varying, where a variable takes on a different value at each time point.

In ALT models, there are several classes of coefficients that are of interest. The first class of coefficients results from the regression of the intercepts of the medication error variables on the predictors (i.e., hospital size, teaching status, case mix index, patient acuity, unit size, average unit occupancy, work uncertainty, medication support services). These coefficients illustrate how hospital and nursing unit environmental characteristics affect the initial level (i.e., the intercept) of medication errors on the unit. The second group of coefficients results from the regressions of the medication error slopes on these same predictor variables. These coefficients show how the predictors affect the rate of change in medication errors. The third group of coefficients results from the regression of each month's medication error variable on preceding levels of medication errors (the autoregressive portion of the model). These coefficients estimate the extent to which medication errors in one month predict medication errors in the next month. The fourth group of coefficients results from the regression of the medication error variables on the time specific nurse staffing variable (i.e., the influence of previous values of the variables on future values and their lagged effects). These coefficients show how nurse staffing affects current and future levels of medication errors on the unit. Standard structural equation model measures of fit were used (i.e., chi square, comparative fit index [CFI], Tucker-Lewis Index [TLI], root mean square error of approximation [RMSEA], and standardized root mean square residual [SRMR]) to evaluate the goodness of fit of the hypothesized model to the data.

RESULTS

Descriptive Results

Descriptive statistics for all study variables are presented in Table 1. The average number of beds among the 284 units ranged from 13 to 80. The proportion of total nursing staff that was RNs, as well as the proportion of care hours delivered by RNs varied from .55 to .56 over the 6 consecutive months. Medication errors per 1,000 inpatient days varied from 5.36 to 6.22 over the same period of time.

Initial Nurse Staffing and Medication Error Models

As an initial step, AR, LT, and ALT models without predictors were run for both nurse staffing and medication errors, to determine which model provided a plausible structure for the data. AR, LT, and ALT models were run for both proportion of RN hours and proportion of RN FTEs. Because the results were similar for both measures of nurse staffing, we report the findings only for proportion of RN hours. (Analyses using proportion of RN FTEs are available upon request from the lead author.) The goodness of fit statistics for the staffing model indicated that the LT model, which allows each unit to have its own intercept and slope, did not fit the data ($\chi^2 = 318.194$, $df = 16$, $p < .0001$ CFI $= .786$, TLI $= .799$, RMSEA $= .258$, SRMR $= .048$). The AR model, which allows prior values of nurse staffing to determine the current level of staffing, fit much better, with goodness of fit statistics: $\chi^2 = 58.51$, $df = 10$, $p < .0001$, CFI $= .966$, TLI $= .948$, RMSEA $= .13$, and SRMR $= .02$. The ALT model, however, did not converge, indicating that it was not a good model for the data.

For medication errors, the ALT model (using a log transformation to reduce the skewness of the data) fit the data well ($\chi^2 = 7.05$, $df = 8$, $p = .5315$, CFI $= 1.0$, TLI $= 1.0$, RMSEA $< .0001$, and SRMR $= .030$). Both the LT and ALT model were superior to the autoregressive model. The LT model and the ALT model were closely equivalent, with the smaller SRMR favoring the ALT model. In the ALT model the magnitude of the autoregressive parameters tended to decrease with time, suggesting a decreasing ability of prior levels of medication errors to predict subsequent levels over the 6-month time period. The LT portion of the model had a statistically significant mean initial level (intercept) of the log of medication errors, but the rate of change (slope) was not statistically significant. On average, the unit's initial level of the log of medication errors was .546 and, on average, the rate of change was stable over time. However, there was significant variance in both the initial level and slope, indicating that there are important differences among the units in terms of their trajectories of medication errors over time that should be incorporated in a model. We also found a statistically significant negative correlation ($-.776$) between the intercept and slope, indicating that units that had a high initial level of medication errors had a slower rate of change over time. This model explained between 39% and 53% of the variance in the 6 monthly medication errors.

ALT Model for Nursing Staffing and Medication Errors

A bivariate ALT model, which considers two sets of repeated measures over time, was initially tested for both nurse staffing and medication errors simultaneously (see Fig. 2). The model specified latent intercepts and slopes for both nurse staffing and medication errors. It also included time adjacent autoregressive coefficients for nursing staffing and medication errors and cross-lagged effects of nurse staffing on medication errors. The bivariate ALT model failed to converge, indicating the model did not fit the data well. This is not surprising given the failure of the univariate ALT model for nurse staffing reported above. Given the adequate fit of the autoregressive model for nurse staffing, the latent intercept and slope for nurse staffing was removed from the bivariate ALT model. This model also failed to converge.

ALT Model for Medication Errors With Time Varying and Time Constant Predictors

As an alternative to the model in Figure 2, we modeled medication errors and included proportion of RN hours as a time varying predictor. The

Table 1. Means and Standard Deviations for Variables in the Model

	Mean	*SD*	Minimum	Maximum
Organizational context				
Hospital environment				
Hospital size	342.97	182.67	75.00[a]	1242.00
Teaching status	.13	.25	.00	1.23
Nursing unit context				
Nursing unit environment				
Unit size	33.59	11.18	13.00	80.00
Occupancy rate	.79	.11	.37	.97
Work uncertainty	26.86	3.50	15.79	37.40
Medication support systems	8.82	1.20	3.71	11.35
Technology				
Case mix index	1.44	.32	.89	3.67
Patient acuity	45.57	3.60	3.71	56.67
Structure				
Nurse staffing				
RN proportion, January	.56	.14	.18	1.00
RN proportion, February	.56	.14	.18	1.00
RN proportion, March	.55	.14	.22	1.00
RN proportion, April	.55	.16	.15	1.00
RN proportion, May	.55	.17	.15	1.00
RN proportion, June	.56	.17	.15	1.00
RN hours, January	.55	.15	.17	1.00
RN hours, February	.56	.15	.17	1.00
RN hours, March	.55	.15	.15	1.00
RN hours, April	.55	.16	.15	1.00
RN hours, May	.55	.16	.15	1.00
RN hours, June	.55	.16	.15	1.00
Effectiveness				
Medication errors				
Medication errors, January	5.79	7.60	.00	84.51
Medication errors, February	5.36	5.51	.00	34.77
Medication errors, March	5.30	5.36	.00	34.73
Medication errors, April	6.22	6.34	.00	44.85
Medication errors, May	5.84	6.18	.00	40.44
Medication errors, June	6.04	6.66	.00	50.00

RN, registered nurse.
[a]The sampling frame included hospitals with 99 or more licensed beds. However, some hospitals reported fewer than 99 open beds.

revised model is presented in Figure 3. Variables representing the hospital environment, nursing unit environment and technology were also added as time constant predictors. The goodness of fit statistics show that the ALT model with predictors fit well with the data ($\chi^2 = 71.576$, $df = 68$, $p = .36$, CFI = .991, TLI = .987, RMSEA = .014, SRMR = .028). Table 2 presents the results of the model.

Of the time constant predictors, only unit size (.038) was significantly related to the initial value of medication errors (i.e., the intercept). Larger units had higher initial levels of medication errors per 1,000 patients. The hospital environment variables of hospital size and teaching status were not related to the initial level (intercept). The technology variables of case mix and patient acuity were also not related to the initial level (intercept).

Concerning the slope, teaching status and case mix index were significantly related to the slope. Greater involvement in teaching was associated with larger increases (.267) in medication errors over time. Case mix had an opposite effect. Units in hospitals with a higher case mix tended to have smaller increases (−.349) in medication errors over time. Hospital size, the nursing unit environment variables, and patient acuity were not related to the rate of change in medication errors over time.

We hypothesized both direct and lagged effects from the time varying predictor of proportion of

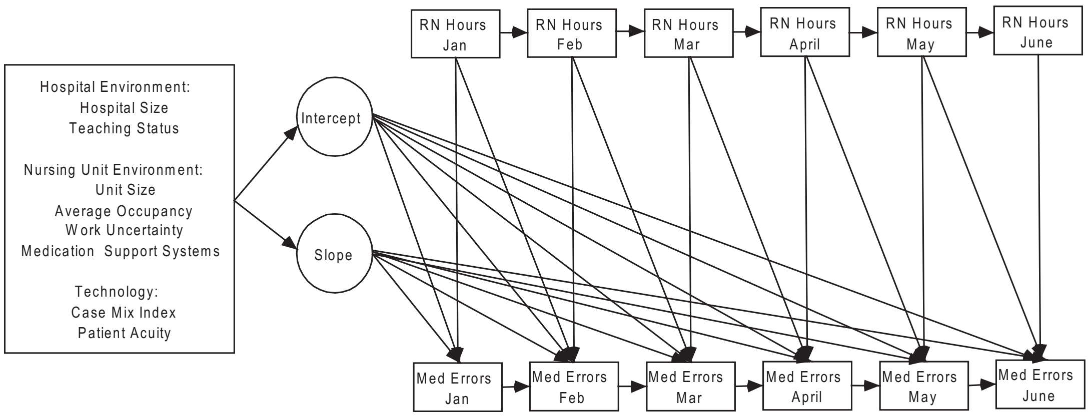

FIGURE 3. Autoregressive latent trajectory model of medication errors with time invariant and time varying predictors.

RN hours to medication errors, but there was no significant lagged effect between proportion of RN hours and medication errors except for April RN hours on May medication errors (7.636). A higher proportion of RN hours in April was related to more reported medication errors in May. The direct effect between the RN hours and medication errors was significant for one of the six time points. The May RN hours had a negative statistically significant association (−8.971) with May medication errors. These findings suggest that there is only weak evidence that proportion of RN hours has a concurrent effect on medication errors, where high monthly levels of RNs hours are associated with lower monthly levels of medication errors. The proportion of RN hours appears to have a weak lagged effect on medication errors. Overall, the ALT model with time varying and time constant predictors explained from 37% to 68% of the variance in the 6 monthly medication errors.

DISCUSSION

Medication errors remain one of the most common patient safety-related adverse events in acute care hospitals, yet knowledge of how nurse staffing affects these errors is still quite limited. We were interested in increasing our understanding of one aspect of the nurse staffing–medication error relationship, specifically how changes in nurse staffing affected changes in medication errors. Using structural contingency theory as our conceptual model, we proposed that organizational context (external and internal environment and technology) and organizational structure (nurse staffing) would affect both the initial level of medication errors as well as their rate of change over a 6-month period of time. We also hypothesized that changes in nurse staffing would affect changes in medication errors from one month to the next. We found only limited support for these relationships.

To summarize, two hospital characteristics that represented the external environment as a dimension of organizational context were significantly related to the rate of change (i.e., slope) in medication errors. Hospitals with a higher case mix index had smaller increases in medication errors over time, perhaps because these hospitals, recognizing the inherent risks of treating a severely ill patient mix, have been able to institutionalize a culture of safety or have developed an effective infrastructure that supports safe medication practices. In contrast, hospitals that were more actively involved in teaching had larger increases in medication errors over time, possibly reflecting continuous attending and housestaff rotation that may contribute to communication and coordination problems with nursing staff, problems that are then reflected in medication errors.

Interestingly, nursing unit characteristics that were expected to affect medication errors, such as average occupancy, the uncertainty of the work, and systems to support medication administration, had no effect on either the initial level of medication errors or on the rate of change over time. Unit size, however, was significantly related to the initial level (i.e., the intercept) of medication errors, with larger nursing units reporting more medication errors per thousand patient days. Although unit size has not previously

Table 2. Parameter Estimates, Standard Errors and Critical Values for Variables in Autoregressive Latent Trajectory Model for Medication Errors, January–June

	B	*SE*	Critical Value	*b*
Intercept on				
Hospital environment				
Hospital size	−.156	.098	−1.597	−.141
Teaching status	−.335	.632	−.530	−.042
Nursing unit environment				
Unit size	.038*	.013	2.961	.211
Average Occupancy	−.360	1.428	−.252	−.02
Work uncertainty	−.042	.048	−.882	−.073
Medication support systems	.247	.157	1.576	.146
Technology				
Case mix index	.656	.472	1.389	.102
Patient acuity	.002	.041	.059	.004
Slope on				
Hospital environment				
Hospital size	.010	.021	.453	.051
Teaching status	.267*	.132	2.023	.193
Nursing unit environment				
Unit size	−.004	.003	−1.379	−.135
Average occupancy	−.153	.353	−.433	−.048
Work complexity	.010	.012	.805	.099
Medication support systems	−.027	.027	−.986	−.091
Technology				
Case mix index	−.349*	.177	−1.971	−.317
Patient acuity	−.010	.009	−1.151	−.108
Medication errors, January on				
RN hours, January	−.382	.879	−.435	−.023
Medication errors, February on				
Medication errors, January	−.081	.084	−.963	−.087
RN hours, January	−1.948	2.67	−.729	−.127
RN hours, February	1.552	2.533	.613	.101
Medication errors, March on				
Medication errors, February	−.029	.067	−.442	−.027
RN hours, February	−1.281	4.277	−.299	−.076
RN hours, March	.245	4.272	.057	.015
Medication errors, April on				
Medication errors, March	.033	.071	.467	.036
RN hours, March	−1.312	1.060	−1.238	−.084
RN hours, April	.506	1.125	.450	.034
Medication errors, May on				
Medication errors, April	.069	.070	.986	.066
RN hours, April	7.636*	3.516	2.172	.487
RN hours, May	−8.971*	3.550	−2.527	−.567
Medication errors, June on				
Medication errors, May	.073	.117	.619	.076
RN hours, May	−2.065	2.935	−.704	−.137
RN hours, June	.777	2.914	.267	.052

RN, registered nurse.
*$p < .05$.

been reported to be related to medication errors, deleterious effects of larger unit size have been related to nurses' perceptions of the adequacy of staffing (Mark, Salyer, & Harless, 2002) as well as nurse and patient satisfaction and the incidence of patient falls (Mark et al., 2003). On larger nursing units, the complexity and time demands of communicating with a large number of co-workers (other nurses, physicians, and pharmacists) may increase the likelihood of communication breakdowns associated with the medication administration process, resulting in errors.

Finally, there was no evidence of a lagged effect of nurse staffing on medication errors, indicating that the impact of nurse staffing is immediate (i.e., occurring within the same month) rather than delayed (i.e., occurring in subsequent months). However, this finding should be tempered by recognizing that, of 16 coefficients relating staffing to medication errors, only two were statistically significant. Thus, overall, the results provide little support for the existence of a nurse staffing–medication error relationship.

We now examine possible reasons for these findings. One important reason, and a limitation of our study, is that our measure of medication errors relied on incident report data. Although the use of incident report data was the only feasible data collection strategy for our project, one that involved almost 150 hospitals, using incident report data for medication errors is likely to produce underreporting (Blegen, 2006). Researchers are, however, faced with a dilemma in that collecting medication error data in large multi-site studies requires the use of strategies that minimize costs and time burden on data collectors who are likely to be volunteers and whose participation in the research is likely to be beyond their regular job responsibilities. Although other methods of collecting medication error data, such as direct observation, may provide richer and perhaps more reliable data, the tradeoff is the enormous cost and burden imposed upon data collectors. Because there is no current method of collecting medication error data that simultaneously meets criteria for validity (in terms of *what* is reported), reliability (in terms of the *number* of errors reported), and economy (in terms of data collection *time* and *cost*), researchers are forced to make tradeoffs, maximizing some criteria, while dealing with the limitations imposed by criteria met in a less satisfactory fashion.

Another reason for the lack of significant findings, and, again, another limitation of the study, is the limited variability in the nurse staffing measures. As shown in Table 1, variability in nurse staffing, measured either as proportion of RN hours or proportion of RN full-time equivalents, was extremely small, with means ranging only from 55% to 56%, and standard deviations ranging only from 14% to 17%. Because our study was restricted to medical units, surgical units, and medical-surgical units, our sample did not contain units that would be likely to have had markedly higher or lower staffing levels. Including a broader array of nursing units would probably have increased the variability in nurse staffing. Such a restriction in range may have effectively masked the relationship that actually exists between staffing and medication errors.

In addition, obtaining staffing data on a monthly basis, rather than on a daily, or even shift-level basis, probably further obscured differences in staffing and thus restricted the range we observed. Monthly estimates of nurse staffing may lack sufficient sensitivity to capture the relationship between nurse staffing and medication errors. Daily measures of staffing, acuity, and work uncertainty or even estimates obtained for a specific shift may be more useful in studying the relationship between nurse staffing and medication errors. It is also possible that information about staffing and patient acuity at the time of an adverse event, in contrast to information about average or typical staffing and acuity levels, may provide more sensitive measures.

Unfortunately, however, there currently is no empirical or theoretical guidance to suggest the correct approach to how often staffing and acuity should be measured. Additionally, there is no consensus on the most appropriate measure of nurse staffing, and whether alternative measures (i.e., hours per patient day, RN full-time equivalents, nurse to patient ratios) perform differently when used to investigate specific types of research questions (Mark, 2006; Spetz, Donaldson, Ayden, & Brown, 2008). Thus, the use of other measures of nurse staffing might yield different results. It is therefore incumbent upon researchers to rely on the specific research questions being investigated, the conceptual model guiding the research, and the setting in which the research is being conducted.

Our study did not confirm the hypothesized relationships between nurse staffing and medication errors, perhaps because of underreporting, lack of variability in the data, and measures of key variables that were perhaps too infrequent. We have suggested that the use of a more diverse sample of nursing units as well as more frequent measurement of both nurse staffing, work uncertainty and medication errors would yield a richer data set. However, the use of ALT modeling represents a methodological advancement over previous studies that use cross-sectional data and analytic techniques that cannot account for trajectories of change in relationships over time. As we build theoretical models that recognize the complexity of how multifaceted organizational processes interact over time to contribute to improving patient safety, the statistical techniques we rely upon must also fully capture this complexity. Although ALT requires rigorous specification of the underlying theoretical model, and can be extremely challenging from programming and computational perspectives, it does offer promise as a means to assure that complex theoretical models reflecting organizational reality can be appropriately tested statistically, thus contributing to knowledge development about improving the safety of care in acute care hospitals.

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