OBJECTIVE: To determine whether a single-family room (SFR) NICU, including factors associated with the change to a SFR NICU, is associated with improved medical and neurobehavioral outcomes.

METHODS: Longitudinal, prospective, quasi-experimental cohort study conducted between 2008 and 2012 comparing medical and neurobehavioral outcomes at discharge in infants born <1500 g. Participants included 151 infants in an open-bay NICU and 252 infants after transition to a SFR NICU. Structural equation modeling was used to determine the role of mediators of relations between type of NICU and medical and neurobehavioral outcomes.

RESULTS: Statistically significant results (all $P \leq .05$) showed that infants in the SFR NICU weighed more at discharge, had a greater rate of weight gain, required fewer medical procedures, had a lower gestational age at full enteral feed and less sepsis, showed better attention, less physiologic stress, less hypertonicity, less lethargy, and less pain. NICU differences in weight at discharge, and rate of weight gain were mediated by increased developmental support; differences in number of medical procedures were mediated by increased maternal involvement. NICU differences in attention were mediated by increased developmental support. Differences in stress and pain were mediated by maternal involvement. Nurses reported a more positive work environment and attitudes in the SFR NICU.

CONCLUSIONS: The SFR is associated with improved neurobehavioral and medical outcomes. These improvements are related to increased developmental support and maternal involvement. 

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WHAT KNOWN ON THIS SUBJECT: The single-family room (SFR) NICU is a major response to improve care and reduce developmental morbidity in preterm infants. However, no studies have examined how and why this model is associated with changes in medical and neurobehavioral outcome.

WHAT THIS STUDY ADDS: This study shows improved medical and neurodevelopmental outcome in infants hospitalized in the SFR model of care. More important, improvements occurred specifically in relation to increases in maternal involvement and developmental support afforded by the SFR environment.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

ABBREVIATIONS
NINSS—NICU Network Neurobehavioral Scale
NTISS—Neonatal Therapeutic Intervention Scoring System
SEM—structural equation modeling
SFR—single-family room

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KEY WORDS
single-family room NICU, preterm infant, medical outcome, neurobehavior, maternal involvement, developmental support

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Accepted for publication Jul 24, 2014

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FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

MANUSCRIPT PROCESSING: Manuscript management for this article was handled by the PEDIATRICS Editorial Office.
The prevalence of preterm birth in the United States is a significant public health problem that has increased over the past 2 decades. Medical care has improved survival rates for preterm infants, especially those born <1000 g, yet nearly half of these infants suffer long-term neurodevelopmental impairment and/or serious health consequences. There is mounting expectation that caring for infants in single-family rooms (SFR) will improve parent involvement and reduce the developmental morbidity of these infants. Subsequently, there has been widespread adoption of the SFR model of care in the NICU instead of the traditional open-bay model. Although there are few studies comparing these 2 models of care, most have reported beneficial effects of the SFR NICU. These include a shorter interval until full enteral feedings; fewer apneic events; reductions in mortality, nosocomial sepsis, length of stay, rehospitalization, cost, and noise; increases in breastfeeding; family-centered care, parental visitation, privacy and satisfaction; more positive staff perceptions of the environment and job quality; and less nurse anxiety. However, negative effects have also been reported including increased number of staff, poorer quality of staff interaction, and increased maternal stress. Alterations in brain structure and function have also been reported among infants in private NICU rooms in a NICU with poor family involvement.

Two critical issues have not been systematically addressed: (1) the effect of the SFR NICU on neurodevelopmental outcome of the infant and (2) how and why positive and negative effects of the SFR NICU occur. Unraveling these processes will enable us to design NICUs that improve clinical care. We performed a prospective, longitudinal study to examine associations between NICU (open-bay vs SFR) designs and medical and neurobehavioral outcomes at hospital discharge after implementation of the SFR NICU. We also examined, for the first time, factors that could help explain or mediate potential differences across NICU designs. We hypothesized that infants cared for in the SFR NICU would have better medical and neurobehavioral outcomes than infants cared for in the open-bay NICU. We also hypothesized that medical and neurobehavioral differences between NICUs could be explained in part by developmental support, parenting factors, and family-centered care.

**METHODS**

Infants born <1500 g were enrolled from Women & Infants Hospital of Rhode Island: 151 infants cared for in the open-bay NICU and 252 cared for in the SFR NICU (see online Supplemental Fig 3 for details of the 2 NICUs). Consecutive new admissions were recruited from the open-bay NICU over 18 months in 2008–2009 before the unit was moved to a new SFR NICU. After a 3-month hiatus, consecutive new admissions were enrolled in the SFR NICU over 31 months from 2010 through 2012. These were 2 distinct cohorts, 1 hospitalized in the open-bay and the other hospitalized in the SFR NICU. Patients were enrolled between 2 weeks after birth and 2 weeks before hospital discharge. The health care providers throughout the study were neonatal attending physicians, fellows, residents, nurses, and nurse practitioners. Exclusion criteria included; non-English speaking or <18-year-old mother, infant congenital anomalies, NICU stay <2 weeks, death, or transfer. The study was approved by the hospital institutional review board, and written informed consent was obtained from all participants including nurse participants. The consent rate was 78% in the open-bay and 82% in the SFR NICU. We are the only source for high-risk neonatal intensive care in our region. The racial/ethnic distribution and demographics of our sample closely matched the 2010 Rhode Island census, reflecting the population basis of our clinical services.

**Medical and Neurobehavioral Outcomes**

Medical outcomes were prospectively defined and abstracted from the hospital electronic database and included length of stay, weight at discharge, postmenstrual age at discharge, rate of weight gain, head circumference at discharge, gestational age at full enteral feeding, necrotizing enterocolitis, intraventricular hemorrhage, periventricular leukomalacia, retinopathy of prematurity, sepsis, any use of supplemental oxygen, continuous positive airway pressure or mechanical ventilation, or incidence of bronchopulmonary dysplasia (BPD). The Neonatal Therapeutic Intervention Scoring System (NTISS) is a measure of therapeutic intensity and provides an index of neonatal illness severity and resource utilization throughout length of stay in the NICU and was also used. Neurobehavioral outcome was assessed using the NICU Network Neurobehavioral Scale (NNNS) administered 3 or 4 days before hospital discharge by the same 2 examiners in the SFR and open-bay NICUs. Pain scores (Premature Infant Pain Profile) were completed by the nursing staff of each shift and were abstracted from medical records.

**Mediators**

Questionnaires were administered to the parents 3 or 4 days before discharge. Sufficient data were only available for the mothers. The questionnaires measured the degree of family-centered care (Family Centered Care Survey), maternal stress (Parent Stressor Scale: NICU), depression (Beck Depression Inventory), and satisfaction (Press Ganey NICU Survey). Measures of maternal involvement included maternal presence, breast/bottle feeding, kangaroo (skin to skin), and maternal care (eg, feeding, bathing, changing diapers) abstracted from electronic documentation. Developmental support was measured by the number of occupational
therapy sessions in which occupational therapists and nurses collaborated on the development and implementation of a care plan (see Developmental Support in the online Supplemental Information for detailed description).

Questionnaires were administered to nurses at yearly intervals to measure stress (Expanded Nursing Stress Scale), burnout (Maslach Burnout Inventory), professionalism in the NICU (Professional Practice Environment Scale), and family-centered care (Family Centered Care Survey). We also measured medical practices every 6 months.

Statistical Methods

Univariate comparisons between the 2 NICUs for the medical, neurobehavioral, and mediator variables were examined with independent samples $t$ tests for continuous variables or $\chi^2$ for dichotomous variables. Statistical power was 80% to detect small to moderate differences (Cohen’s $d = 0.29$). Structural equation modeling (SEM) was used to determine if statistically significant relations between type of NICU and medical and neurobehavioral outcomes were explained by mediating factors. We first developed latent factors of closely related variables to represent mediating constructs. A 2-factor solution fit the data on parenting characteristics based on excellent standard model fit indices, $\chi^2 (12) = 12.60, P = .20$, comparative fit index $= 1.00$ and root mean square error of approximation $= 0.01$. The maternal involvement factor included number of days per week of parental presence, maternal care, kangaroo care, and feeding. The psychosocial factor included satisfaction, stress, and depression. Developmental support and family-centered care remained as single variables. We then used these mediators in a series of SEMs for each of the medical and neurobehavioral measures that showed statistically significant univariate differences between the 2 NICUs. Associations in these SEMs are reported as standardized $\beta$ coefficients ($\beta$). Statistical analyses were performed in SPSS 17.0 and Mplus 6.0. A 2-sided $\alpha$ level of .05 was used for all analyses.

RESULTS

Univariate Analysis

There were no differences between characteristics of the subjects in the open-bay and SFR NICUs (Table 1). Statistically significant results (Table 2, all $P \leq .05$) showed that infants in the SFR NICU weighed more at discharge, had a greater rate of weight gain, required fewer medical procedures, had a lower gestational age at full enteral feeds, and had less sepsis. Infants in the SFR also demonstrated increased attention, less physiologic stress, less hypertonicity, less lethargy, and less pain (Table 3). There were no statistically significant effects for gestational age at NNNS testing. There were no differences between the two NICUs in medical practices (Table 4).

Compared with the open-bay NICU, mothers in the SFR NICU reported more satisfaction ($M = 4.87, SD = 0.27$ vs $M = 4.43, SD = 0.65, P < .00$), less stress ($M = 2.76, SD = 0.79$ vs $M = 3.12, SD = 0.79, P < .000$), and more family-centered care ($M = 3.73, SD = 0.26$ vs $M = 3.47, SD = 0.38, P < .00$). Mothers were more involved in the care of their infant ($M = 4.5, SD = 1.7$ vs $M = 3.6, SD = 1.5$, days per week, $P < .000$), and more mothers provided kangaroo care in the SFR NICU (92% vs 81%, $P = .013$). The number of infants who received developmental support increased from 46% in the open-bay to 65% in the SFR NICU ($P < .000$). The number of developmental support sessions per week also increased in the SFR NICU ($M = 10.36, SD = 8.48$ vs $M = 6.60, SD = 5.76$, $P < .000$). Nurses in the SFR NICU reported less overall stress ($P = .033$), a more professional practice environment ($P = .050$), less emotional exhaustion ($P < .000$), more personal accomplishment ($P = .035$), and more family-centered care ($P < .000$) than those in the open-bay NICU. The survey response rates were similar in the 2 NICUs (open-bay 57%, SFR 51%) and comparable to response rates to mail surveys published in medical journals.

SEM Analysis

The SEMs of the medical outcomes showed that the statistically significant differences between the 2 NICUs (Table 2) in weight at discharge, rate of weight gain, and NTISS procedures scores were no longer statistically significant when mediators were included in the analysis.

### TABLE 1 Characteristics of the Subjects in the Open-Bay and SFR NICUs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Open-Bay ($n = 151$)</th>
<th>SFR ($n = 252$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth wt (g), M (SD)</td>
<td>1033 (261)</td>
<td>1050 (278)</td>
</tr>
<tr>
<td>Gestational age at birth (wk), M (SD)</td>
<td>28.2 (2.3)</td>
<td>28.3 (2.4)</td>
</tr>
<tr>
<td>Infant gender, female, n (%)</td>
<td>78 (53)</td>
<td>123 (49)</td>
</tr>
<tr>
<td>Infant race, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>95 (65)</td>
<td>164 (71)</td>
</tr>
<tr>
<td>African American</td>
<td>21 (14)</td>
<td>20 (9)</td>
</tr>
<tr>
<td>Asian</td>
<td>5 (3)</td>
<td>6 (3)</td>
</tr>
<tr>
<td>Multiracial</td>
<td>26 (18)</td>
<td>42 (18)</td>
</tr>
<tr>
<td>Maternal ethnicity, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>27 (18)</td>
<td>44 (19)</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>121 (82)</td>
<td>191 (81)</td>
</tr>
<tr>
<td>Maternal partner status, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Has a partner</td>
<td>131 (89)</td>
<td>210 (89)</td>
</tr>
<tr>
<td>No partner</td>
<td>16 (11)</td>
<td>25 (11)</td>
</tr>
<tr>
<td>Maternal educational status, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than high school, n (%)</td>
<td>40 (27)</td>
<td>76 (33)</td>
</tr>
<tr>
<td>High school graduate or above, n (%)</td>
<td>106 (73)</td>
<td>138 (67)</td>
</tr>
</tbody>
</table>
(Fig 1). There was more developmental support in the SFR NICU (positive β coefficient, $\beta = 0.27$, $P < .000$), and more developmental support was related to greater weight at discharge ($\beta = 0.49$, $P < .000$) and a greater rate of weight gain ($\beta = 0.17$, $P = .012$). This indicates that the effects of the SFR NICU on weight at discharge and weight gain were due to, or fully mediated by, developmental support. Similarly, there was more maternal involvement in the SFR NICU ($\beta = 0.24$, $P < .000$), and this increased maternal involvement was related to fewer medical procedures on the NTISS, fully mediating the relation between type of NICU and NTISS procedures score. None of the SEMs for sepsis were statistically significant.

The SEMs of the neurobehavioral outcomes showed that the statistically significant differences between the 2 NICUs in attention, stress, and pain (Table 3) were also mediated by developmental support or maternal involvement (Fig 2). The increased developmental support in the SFR NICU was related to better attention scores on the NNNS ($\beta = 0.15$, $P = .052$), indicating full mediation of the relation between the SFR NICU and attention. The relation between the SFR NICU and less stress on the NNNS was mediated by maternal involvement. The increased maternal involvement in the SFR NICU ($\beta = 0.24$, $P < .000$) was related to less stress ($\beta = -0.15$, $P < .014$). However, this was partial mediation as shown by the relation between the SFR NICU and less stress ($\beta = -0.16$, $P < .000$). This indicates that there was both less stress in the SFR NICU and that some of the reduction in stress was related to increased maternal involvement. Similarly, maternal involvement was a partial mediator of the reduction in pain in the SFR NICU (Fig 2c) as indicated by the relation between increased maternal involvement in the SFR NICU ($0.24$, $P < .000$) related to lower pain scores ($\beta = -0.17$, $P < .000$), whereas the reduction in pain due to the SFR NICU alone remained ($\beta = -0.39$, $P < .000$).

Because the infants with more maternal involvement could also be the same infants with more developmental support, we computed a $\chi^2$ based on a median split of the developmental support and maternal involvement variables. There were no statistically significant differences ($P > .05$) among the number of infants with more maternal involvement and more developmental support ($n = 129$), more maternal involvement and less developmental support ($n = 79$), less maternal involvement and less developmental support ($n = 91$), and less maternal involvement and more developmental support ($n = 102$). This lack of association between amount of developmental support and amount of maternal involvement was supported by correlations showing that these factors were associated with different infant characteristics. The amount of developmental support was correlated with lower birth weight ($r = -0.30$, $P < .000$) and gestational age at birth ($r = -0.35$, $P < .000$), greater rate of weight gain ($r = 0.19$, $P < .000$), lower gestational age at first enteral feed ($r = -0.13$, $P = .008$) higher rate of weight at discharge ($r = 0.67$, $P < .000$), higher NTISS total score ($r = 0.42$, $P < .000$), more sepsis ($r = 0.17$, $P = .000$), and greater rate of weight gain ($r = 0.34$, $P < .000$).

### TABLE 3 Neurobehavioral Outcomes of Infants in the Open-Bay and SFR NICUs

<table>
<thead>
<tr>
<th>Neurobehavioral Outcome</th>
<th>Open-Bay Mean (SD)</th>
<th>SFR Mean (SD)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habituation</td>
<td>7.4 (1.9)</td>
<td>7.7 (1.6)</td>
<td>.192</td>
</tr>
<tr>
<td>Attention</td>
<td>4.5 (1.2)</td>
<td>4.8 (1.3)</td>
<td>.012</td>
</tr>
<tr>
<td>Handling</td>
<td>0.25 (0.20)</td>
<td>0.28 (0.23)</td>
<td>.296</td>
</tr>
<tr>
<td>Quality of movement</td>
<td>4.5 (0.5)</td>
<td>4.6 (0.6)</td>
<td>.084</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>5.4 (0.7)</td>
<td>5.6 (0.7)</td>
<td>.081</td>
</tr>
<tr>
<td>Nonoptimal reflexes</td>
<td>5.1 (2.1)</td>
<td>5.2 (2.2)</td>
<td>.795</td>
</tr>
<tr>
<td>Physiologic stress</td>
<td>0.20 (0.31)</td>
<td>0.10 (0.25)</td>
<td>&lt;.000</td>
</tr>
<tr>
<td>Arousal</td>
<td>3.5 (0.5)</td>
<td>3.5 (0.6)</td>
<td>.888</td>
</tr>
<tr>
<td>Hypertonicity</td>
<td>0.12 (0.35)</td>
<td>0.05 (0.22)</td>
<td>.021</td>
</tr>
<tr>
<td>Hypotonicity</td>
<td>0.32 (0.56)</td>
<td>0.29 (0.54)</td>
<td>.628</td>
</tr>
<tr>
<td>Asymmetric reflexes</td>
<td>1.2 (1.5)</td>
<td>1.1 (1.1)</td>
<td>.248</td>
</tr>
<tr>
<td>Excitability</td>
<td>2.0 (1.6)</td>
<td>1.9 (1.9)</td>
<td>.552</td>
</tr>
<tr>
<td>Lethargy</td>
<td>6.2 (2.6)</td>
<td>5.6 (2.4)</td>
<td>.024</td>
</tr>
<tr>
<td>Premature Infant Pain Score</td>
<td>2.0 (0.4)</td>
<td>1.6 (0.4)</td>
<td>&lt;.000</td>
</tr>
</tbody>
</table>
and more necrotizing enterocolitis \((r = 0.15, \ P = .002)\). By contrast, the amount of maternal involvement was related to higher birth weight \((r = 0.14, \ P = .006)\) and gestational age at birth \((r = 0.16, \ P = .001)\), lower weight at discharge \((r = -0.123, \ P = .013)\), lower NTISS total score \((r = -0.13, \ P = .012)\), and higher socioeconomic status \((r = 0.37, \ P < .000)\).

**DISCUSSION**

We found significant improvements in medical and neurobehavioral outcomes at discharge, maternal involvement and psychosocial status, family-centered care, developmental support, and nurses’ attitudes related to the SFR model. Previous studies have not measured factors that mediate relations between SFR NICU effects and medical and neurobehavioral outcomes. The neurobehavioral improvements that we observed are important because the NNNS has been shown to predict long-term developmental outcome.\(^26\) Thus, the SFR NICU is associated with infant recovery and may reduce the likelihood and/or severity of later impairment. Medical practices did not differ between NICUs and cannot explain the observed beneficial effects of the SFR NICU including increased weight at discharge, greater rate of weight gain, lower NTISS procedures score, lower gestational age at full enteral feeding, and less sepsis. The incidence of BPD did not differ between NICUs. This is especially apparent in the use of supplemental oxygen, continuous positive airway pressure, or mechanical ventilation.

Not only have we shown improvements in delivery of care and infant outcomes associated with the SFR NICU, we have also provided, for the first time, insight into how and why these improvements may occur. The SFR NICU was associated with increases in developmental support and maternal involvement. These increases were associated with higher weight at discharge, greater rate of weight gain, use of fewer medical procedures, better attention, less stress, and less pain. In other work,\(^27\) more parental presence and more holding by caregivers in the NICU was related to better scores on the NNNS. Our results suggest that improved medical and neurobehavioral outcome was associated with the model of care in the SFR NICU because this model provides the opportunity for more developmental support and more maternal involvement.

Developmental support was related to factors indicative of smaller infants with more medical problems, whereas maternal involvement was related to larger, healthier infants and higher socioeconomic status. This is important because it suggests that these mediators

---

**FIGURE 1**

Structural Equation Models showing single family room NICU effects mediated by developmental support on weight at discharge (A), developmental support on rate of weight gain (B), and maternal involvement on NTISS procedures score (C). Associations in these models are reported as standardized beta coefficients \((\beta)\). *\(P < .05\) **\(P < .01\) ***\(P < .001\)

| TABLE 4 | Changes in Medical Practice |
|-----------------|-----------------|-----------------|
| Medical Practice | Open-Bay | SFR | \(P\) |
| Gestational age at first trophic feed (wk), M (SD) | 29.5 (2.8) | 29.1 (2.1) | .43 |
| Intubated at <1 hr of age, n (%) | 20 (32) | 27 (44) | .20 |
| Given surfactant at <1 hr of age, n (%) | 12 (60) | 18 (67) | .64 |
| Given steroids for ventilator dependence, n (%) | 3 (5) | 2 (3) | .68 |
| Given nitric oxide, n (%) | 4 (7) | 5 (9) | .67 |
| Given methylxanthesis, n (%) | 46 (74) | 50 (81) | .39 |
| Noninvasive modes of ventilation, n (%) | 8 (13) | 10 (16) | .61 |
| Given steroids for hypotension, n (%) | 3 (5) | 2 (3) | .65 |
| Given blood products, n (%) | 30 (48) | 27 (44) | .58 |
| Receive indomethacin for IVH prevention, n (%) | 35 (57) | 42 (68) | .20 |
| Receive antibiotics during first wk, n (%) | 14 (23) | 21 (34) | .16 |
| Receive fluconazole for fungal prophylaxis, n (%) | 1 (2) | 3 (5) | .31 |

IVH, intraventricular hemorrhage.
are having an impact on different populations of preterm infants and that both are necessary elements for an improved model of care. Developmental support and maternal involvement are practices that directly affect the infant, and this might help us understand why these practices are effective. The maternal psychosocial factor and family-centered care were not significant mediators, which could be because their effects are more indirect. These indirect measures are important in their own right but are not necessarily related to infant medical or neurobehavioral outcome. The differences that we observed also identify important strategies for future interventions to improve outcome in these fragile infants.

We found full and partial mediation effects on medical and neurobehavioral outcomes as well as outcomes that showed no mediation effects. This could be because there are mediators or elements of the SFR NICU yet to be identified and raises a fundamental issue about the SFR NICU; are improvements solely related to an environment that is more conducive to changes in care, or are there elements of the physical space itself that are related to improve infant outcome? SFR NICUs are not all built the same. They vary on dimensions such as sight lines (that is, the number of rooms in the visual field of nurses and parents). A narrow visual field can contribute to staff concerns about infant safety and feelings of isolation among nurses and parents. In comparative research, the magnitude of the contrast between the open-bay ("baseline condition") and SFR NICUs in terms of factors that inhibit maternal involvement and developmental support, such as extreme crowding (Supplemental Fig 3) and noise can determine the magnitude of effects observed between SFR versus other types of NICUs. In addition to striking changes in physical space, successful adaptation to the SFR NICU requires extensive staff preparation to facilitate the transition to the SFR NICU. We used novel techniques incorporating simulation technology to optimize staff participation in planning and preparation. It is our impression that nurses in the SFR NICU reported more positive attitudes due in part to the expanded sight lines and the extent of staff preparation for our transition to the SFR NICU.

Although most studies on the effects of the SFR NICU show beneficial effects, some do not. Some of these inconsistencies could be due to methodologic issues. The inclusion of higher birth weight infants may not show benefits of the SFR NICU because of a shorter length of stay. SFR NICUs that service mostly underprivileged patients may show different effects than those that service other sociodemographic populations. Although we identified 2 important factors, maternal involvement and developmental support, that mediate relations between the SFR NICU and infant outcome, there could be other important factors that we did not measure. Thus, we caution other investigators that a simple comparison of a SFR with another type of NICU may be inadequate to explain potential differences, be they positive or negative, and that it is critical to study why such differences are observed. In addition, until we know more about how the SFR model of care is used in different NICUs, the generalizability of findings from any 1 study (including ours) will be limited. The pre–post design could be considered a limitation of our study. However, it is equally likely that random assignment of patients to different models of care could lead to selection bias, differential treatment by staff in the 2 NICUs due to staff and parental preferences. The current study used

![Structural Equation Models showing single family room NICU effects mediated by developmental support on NNNS attention (A), maternal involvement on NNNS stress (B), and maternal involvement on NNNS pain (C). Associations in these models are reported as standardized beta coefficients (β). *P < .05 **P < .01 ***P < .001](image-url)
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Single-Family Room Care and Neurobehavioral and Medical Outcomes in Preterm Infants

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*Pediatrics* 2014;134;754; originally published online September 22, 2014; DOI: 10.1542/peds.2013-4252

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Single-Family Room Care and Neurobehavioral and Medical Outcomes in Preterm Infants

Barry M. Lester, Katheleen Hawes, Beau Abar, Mary Sullivan, Robin Miller, Rosemarie Bigsby, Abbot Laptook, Amy Salisbury, Marybeth Taub, Linda L. Lagasse and James F. Padbury

*Pediatrics* 2014;134;754; originally published online September 22, 2014;
DOI: 10.1542/peds.2013-4252

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