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A 'busy day' effect on perinatal complications of delivery on weekends: a retrospective cohort study

Jonathan M Snowden,[1] Katy Backes Kozhimannil,[2] Ifeoma Muoto,[3] Aaron B Caughey,[3] K John McConnell[4]

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[1]Department of Obstetrics & Gynecology/Public Health & Preventive Medicine, Oregon Health & Science University, Portland, Oregon, USA
[2]Division of Health Policy and Management, University of Minnesota School of Public Health, Minneapolis, Minnesota, USA
[3]Department of Obstetrics & Gynecology, Oregon Health & Science University, Portland, Oregon, USA
[4]Emergency Medicine, Oregon Health and Science University, Portland, Oregon, USA

Correspondence to
Dr Jonathan M Snowden, Department of Obstetrics & Gynecology/Public Health & Preventive Medicine, Oregon Health & Science University, 3181 SW Sam Jackson, Mail Code: L-466, Portland, OR 97239, USA; snowden@ohsu.edu

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ABSTRACT

Objective To evaluate whether busy days on a labour and delivery unit are associated with maternal and neonatal complications of childbirth in California hospitals, accounting for weekday/weekend births.

Design This is a population-based retrospective cohort study.

Setting Linked vital statistics/patient discharge data for California births between 2009 and 2010 from the Office of Statewide Health Planning and Development.

Participants All singleton, cephalic, non-anomalous California births between 2009 and 2010 (N=724 967).

Main outcomes The key exposure was high daily obstetric volume, defined as giving birth on a day when the number of births exceeded the hospital-specific 75th percentile of daily delivery volume. Outcomes were a range of maternal and neonatal complications.

Results Several maternal and neonatal complications were increased on high-volume days and weekends following adjustment for maternal demographics, annual hospital birth volume and teaching hospital status. For example, compared with low-volume weekdays, the odds of Apgar <7 on low-volume weekend days and high-volume weekend days were 11% (adjusted OR (aOR) 1.11, CI 1.03 to 1.21) and 29% higher (aOR 1.29, CI 1.10 to 1.52), respectively. High volume was associated with increased odds of neonatal seizures on weekdays (aOR 1.33, CI 1.01 to 1.71) and haemorrhage on weekends (aOR 1.11, CI 1.01 to 1.22). After accounting for between-hospital variation, weekend delivery remained significantly associated with increased odds of Apgar score <7, neonatal intensive care unit admission, prolonged maternal length of stay and the odds of neonatal seizures remained increased on high-volume weekdays.

Conclusions Our findings suggest that weekend delivery is a consistent risk factor for a range of perinatal complications and there may be variability in how well hospitals handle surges in volume.

INTRODUCTION

Although childbirth is a leading reason for hospitalisation, current initiatives to improve the quality of obstetric care suffer from a lack of data to inform these efforts.[1] Recent studies have documented wide variation in hospital-level rates of obstetric procedures and complications[2 3] and alarming differences in complication rates between weekdays and weekends in obstetric units,[4] but the drivers of this variation remain incompletely characterised. In recent years, large studies have found null associations between obstetric processes of care and quality metrics,[5] and between recently adopted quality measures (ie, elective early-term delivery) and perinatal morbidity.[6] In light of these developments, there is growing interest in identifying which system factors (eg, provider factors, hospital-level characteristics) affect the quality of obstetric care, and also which quality outcomes are sensitive to evidence-based improvements in processes of care.

The concept of capacity strain in healthcare systems has received increasing attention in recent years.[7] Capacity strain refers to the process by which quality of care deteriorates beyond a certain threshold (eg, of patient volume, acuity or both), above which systems do not function optimally. In other fields of medicine (eg, emergency medicine[8] and critical care[9]), fluctuations in admission/patient load have been demonstrated to affect the quality of care. Only a small number of studies have examined perinatal outcomes during times of high volume,[10 11] and no current evidence addresses maternal outcomes during times of obstetric unit capacity strain in the contemporary US context. This evidence gap is especially pressing, given the increasing prevalence of severe maternal morbidity (eg, postpartum haemorrhage) and maternal death in the USA.[12 13]

To fill this evidence gap, we analysed the relationship between daily obstetric volume, a measure of labour and delivery unit capacity strain, and maternal and neonatal complications of delivery. We hypothesised that delivery on a high-volume day would be associated with increased perinatal complications.

METHODS

This was a retrospective cohort study of births in the US state of California between 2009 and 2010, employing linked vital statistics/patient discharge data. The California Patient Discharge Data, Vital Statistics Birth Certificate Data and Vital Statistics Death Certificate Data are linked and maintained by the Office of Statewide Health Planning and Development (OSHPD), Healthcare Information Resource Center, under the California Health and Human Services Agency.[14] This data set has been used broadly to track maternal/child health outcomes and to assess the quality of obstetric care.[15 16] The database includes patient discharge data (including diagnosis and procedure codes) for antepartum admissions in the 9 months prior to delivery, and linked maternal/infant admissions in the year after delivery, as well as data from the US Standard Certificate of Live Birth. Details of data linkage and quality control are described in detail elsewhere.[11] We obtained human subjects approval from the California OSHPD Committee for the Protection of Human Subjects. The linked data set did not contain potential patient privacy/identification information, so informed consent was exempted.

We employed a previously published algorithm to define hospital-specific high-volume days (ie, unusually busy days in a labour and delivery unit).[11] We defined high daily volume in reference to each hospital's distribution of daily deliveries. This hospital-specific daily volume distribution was calculated by summing the number of births in that hospital on each day during the study period (2009–2010). A hospital day was defined as high volume (relative to that hospital's typical delivery load) if the number of births on that day exceeded that of hospital's 75th percentile for daily births. Therefore, each hospital had a unique definition of a high-volume day, based on its overall delivery volume. Outcomes on high-volume days were compared with outcomes on days that were not designated as high volume by this protocol: low-volume/average-volume days.

To assess the impact of daily obstetric volume on perinatal complications and processes of care, we analysed several maternal and neonatal outcomes. Consistent with prior studies on quality of maternity care,[2 17] we chose three broad categories of maternal complications. Individual adverse outcomes are rare in obstetrics, so we chose broad categories to enable sufficient number of events and statistical power. Outcomes were defined by *International Classification of Diseases, 9th Revision* (ICD-9), diagnosis and procedures codes from the maternal patient discharge data.

The first maternal outcome was obstetric infection, which included one or more of the following: chorioamnionitis, endometritis and wound infection subsequent to caesarean delivery. The other maternal outcomes were haemorrhage (a composite of postpartum haemorrhage diagnosis codes and maternal blood transfusion procedure codes), severe perineal lacerations (third or fourth degree), prolonged maternal length of stay (LOS; LOS >3 days for vaginal deliveries and >5 days for caesarean deliveries) and a composite maternal outcome, which indicated the presence of one or more of the outcomes described above.

Neonatal outcomes were also chosen based on the literature on quality of obstetric care[18 19] as follows: birth trauma, neonatal seizures (defined using ICD-9 codes), 5-min Apgar score <7, admission to the neonatal intensive care unit (NICU), neonatal death (all defined using vital statistics data) and composite neonatal outcome (any one or more of the neonatal complications).

Analyses included vertex-presenting, non-anomalous, singleton livebirths in California hospitals between 2009 and 2010. The births not included in this category do add to the workload on the day of their delivery (sometimes disproportionately so); therefore, we excluded these births after calculating the hospital-level daily volume distribution and defining high-volume days. Also excluded from analyses of complications were women with prior caesarean (as defined by ICD-9 code 654.2X) who delivered by repeat caesarean, as a large majority of these would be scheduled caesareans and therefore not at risk for key outcomes (eg, severe perineal lacerations). We excluded hospitals that were open for <23 months of the 24-month study period. In the lowest volume hospitals, it became logistically challenging to define high-volume days (eg, the 75th percentile of daily deliveries was one birth). To minimise these challenges and allow for a meaningful distinction between 'high volume' and 'low volume days,' we imposed a minimum birth volume for inclusion in our analysis (1000 births during the study period). The final analytical sample included 214 California maternity hospitals with at least 1000 births between 2009 and 2010. We employed complete-case analysis, so observations with missing outcomes of interest were excluded.

We considered day of the week as an effect modifier, given the differences that characterise hospital

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staffing and resources on weekends as compared with weekdays.[20 21] We examined unadjusted associations between delivery on a high-volume day and perinatal complications using the χ^2 test as well as the Fisher's exact test, where necessary. This cross-tabulation was stratified by the day of week (weekend vs weekday), to enable analysis of both the 'weekend effect' and the potential 'busy day effect'.

We fit multivariable logistic regression models to analyse the impact of daily obstetric volume on perinatal complications, controlling for maternal and hospital characteristics. For each outcome, we progressively fit a series of three regression models: first, examining the separate effects of daily volume and weekend, then assessing day-of-week/daily volume interaction and, finally, examining whether hospital-level differences explained the findings. All models were adjusted for hospital-level clustering, and robust SEs were estimated using the clustered Huber–White variance estimator.[22]

Model 1 analysed the separate effects of weekend delivery and high daily volume, while controlling for maternal and hospital characteristics. The maternal characteristics included in this main-term model were race/ethnicity (non-Hispanic black, Hispanic, or Asian-American, compared with the referent category of non-Hispanic white), advanced maternal age (≥35 years), educational attainment (≥12 years vs <12), parity (nulliparous vs multiparous), insurance status (public/none vs private) and initiation of prenatal care in the first trimester. Hospital characteristics in the model were teaching hospital (defined as the presence of obstetrics–gynaecology residents on obstetric rotations) and hospital birth volume (defined using previously published categories for annual birth volume:[16] <1200 births per year, 1200–2399 births, 2400–3599 births and ≥3600 annual births).

Model 2 examined the joint impact of daily obstetric volume and weekend delivery on study outcomes. In this model, we tested for possible interactions between 'weekend effects' and 'busy day effects'. Several hospital system factors differ between weekdays and weekends in hospitals (eg, physician and nursing staffing levels, average patient acuity),[20 21] which may make hospitals particularly susceptible to capacity strain during weekends. In model 2, we categorised births as high-volume weekend deliveries (ie, the joint weekend/busy day effect), high-volume weekday deliveries, low-volume weekend deliveries and low-volume weekday deliveries (referent category). Except for the interaction, model 2 was fit using the same approach as model 1.

The final model (model 3) was a joint daily obstetric volume/weekend model that controlled for differences between hospitals using fixed-effects analysis. In this final model, busy days/weekend days were examined in the same manner as model 2, and fixed effects were included for hospitals. Conceptually, this model is analogous to including a dummy variable for each hospital. The fixed-effects model adjusts for unobserved hospital factors that are constant at the hospital level, in addition to measured factors (eg, teaching status, birth volume). This enables us to assess whether hospital-level factors explained any 'weekend effect' or 'busy day effect' observed in our findings.

Other factors related to obstetric management may differ between weekend/weekday and high-volume versus low-volume days, for example, operative vaginal delivery. Operative vaginal delivery may result from day of week or daily volume, but may not in itself cause these exposures. If weekend delivery affects operative vaginal delivery rates and this affects severe perineal lacerations, then operative vaginal delivery rate is a causal intermediate, or a mediating factor in the pathway between delivery volume and health outcomes. Because controlling for causal intermediates is unnecessary to control for confounding bias and may introduce other forms of bias into effect estimation,[23] we did not adjust for these obstetric management factors in our main analysis but we explored their potential mediating effects in our first sensitivity analysis. We achieved this by fitting model 2 second time, this time controlling for caesarean delivery and operative vaginal delivery (both attempted and successful operative vaginal delivery).

Most research to date on the weekend effect and busy days have analysed the day of birth as the index day for defining both busy days and weekend births[11 24] (as compared with the day of maternal hospital admission). However, recent research has considered alternative definition of index day for defining weekend birth, for example, day of birth for neonatal outcomes and day of admission for maternal outcomes.[4] Because obstetric unit factors on the day of admission may be associated with patient outcomes (especially in the case of maternal outcomes), we conducted a second sensitivity analyses wherein we defined weekend and busy day using maternal admission day rather than day of birth as the index day. Hospital admission can be temporally removed from birth so that factors on admission day would be unlikely to affect birth outcomes (eg, due to admission to the antepartum service for monitoring weeks before birth). Our data did not permit differentiation of hospital admission from admission to labour and delivery specifically, so we restricted this sensitivity analysis to women who delivered within 2 days of hospital admission. This definition captured a large majority of women and would be expected to capture nearly all women admitted for delivery, given modern labour management norms.[25 26]

Data management and analysis were conducted using Stata (V.12, StataCorp, College Station, Texas, USA) and R (V.2.13.1, R Foundation for Statistical Computing, Vienna, Austria).

Patient involvement: This was an analysis of deidentified secondary data. No patients were involved in the study.

RESULTS

There were 724 967 deliveries in 214 California hospitals between 2009 and 2010 that met study criteria. Of these deliveries, 226 593 (31.2%) occurred on high-volume days and 177 233 (24.5%) occurred on weekends. Hispanic women were the largest racial/ethnic group in the sample (47.5%); 15.8% of women were of advanced maternal age and 51.8% were publicly insured. The demographic characteristics of women who gave birth on high-volume days did not differ meaningfully from women who delivered on low/average-volume days (table 1). The demographic profile of women who delivered on weekends was largely similar to women delivering on weekdays.

Unadjusted rates of most perinatal complications were higher on weekend days as compared with weekdays (table 2). In regression models controlling for confounders (model 1), there was a consistent 'weekend effect' for maternal complications, with increased odds among weekend births (table 3). Odds of obstetric infection were 9% greater on weekends than on weekdays (adjusted OR (aOR), 1.09; 95% CI 1.05 to 1.13), as were odds of composite maternal complication (aOR, 1.12; 95% CI 1.10 to 1.15). For neonatal outcomes, only depressed Apgar score (aOR, 1.14; 95% CI 1.06 to 1.23) and composite infant outcome (1.04; 1.01 to 1.06) were more frequent on weekend days, compared with week days.

In this separate-effects model (model 1; table 3), busy days were associated with increased rates of prolonged maternal LOS (aOR, 1.05; 95% CI 1.02 to 1.09) and neonatal seizures (aOR, 1.26; 1.01, 1.57). The odds of neonatal seizures and depressed Apgar score were reduced among the highest volume hospitals.

There were significant joint effects of weekend delivery and high daily volume on several perinatal complications (models 2 and 3). Giving birth on a high-volume weekend was associated with the highest odds of perinatal complications in the interaction model (model 2). In other words, the 'busy day' effect was more pronounced on weekend days, and the 'weekend effect' was strongest on high-volume days. For example, obstetric infection was 24% more common on busy weekend days compared with the referent of low/average-volume weekdays (aOR, 1.24; 95% CI 1.12 to 1.37; table 4); odds of composite maternal outcome were elevated as well (aOR, 1.20; 95% CI 1.14 to 1.27). Odds of Apgar score <7 and NICU admission were also highest on busy weekend days (aOR: 1.29, 95% CI 1.10 to 1.52; aOR: 1.11, 95% CI 1.01 to 1.21; respectively). The absence of the weekend effect on the composite infant outcome (aOR, 1.06; 95% CI 0.99 to 1.14) was probably due to the fact that this outcome was heavily driven by birth trauma, which did not vary by weekday/weekend delivery.

Compared with low-volume weekdays, low-volume weekend days were also consistently associated with significant increases in maternal complications of delivery (table 4; eg, aOR for obstetric infection: 1.06, 95% CI 1.02 to 1.10; prolonged LOS aOR: 1.19, 95% CI 1.15 to 1.23) and some neonatal complications of delivery (eg, aOR for NICU admissions: 1.06, 95% CI 1.02 to 1.10). These increases, however, were not as pronounced as the increases

Table 1 Maternal characteristics of 2009–2010 California births (n (%)), stratified by weekday/weekend and daily volume

Maternal characteristic	Overall (N=724 967)	Weekday: Low/average-volume day (N=345 097)	Weekday: High-volume day (N=202 647)	Weekend: Low/average-volume day (N=153 287)	Weekend: High-volume day (N=23 946)
Race/ethnicity*					
White	224 897 (31.0)	108 553 (31.5)	63 392 (31.3)	45 844 (29.9)	7108 (29.7)
Black	38 083 (5.3)	18 472 (5.4)	9984 (4.9)	8250 (5.4)	1377 (5.8)
Hispanic	343 920 (47.5)	161 867 (46.9)	97 226 (48.0)	73 505 (48.0)	11 322 (47.3)
Asian-American	90 871 (12.5)	43 286 (12.6)	24 594 (12.1)	19 861 (13.0)	3130 (13.1)
Other	27 045 (3.7)	12 848 (3.7)	7389 (3.7)	5803 (3.8)	1005 (4.2)
Maternal age ≥35 years	114 337 (15.8)	55 549 (16.1)	31 795 (15.7)	23 300 (15.2)	3693 (15.4)
Education ≥12 years†	342 424 (49.1)	164 419 (49.6)	95 367 (49.0)	71 553 (48.6)	11 085 (47.9)
Nulliparous‡	335 755 (46.4)	158 650 (46.0)	93 179 (46.0)	72 642 (47.4)	11 284 (47.2)
Public insurance§	375 694 (51.8)	177 401 (51.4)	106 030 (52.3)	80 293 (52.4)	11 970 (50.0)
Prenatal care initiation first trimester¶	590 568 (83.1)	281 531 (83.2)	165 582 (83.2)	124 518 (83.0)	18 937 (81.3)

*151 missing for race/ethnicity.
†28 123 missing for educational status.
‡609 missing for parity.
§13 missing for insurance status.
¶14 116 missing for prenatal care utilisation.

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Table 2 Unadjusted rates (%) of adverse outcomes on high-volume versus low/average-volume days, stratified by weekday/weekend

					Weekday			Weekend		
	Overall	Weekday	Weekend	p Value	Low/ average-volume day	High-volume day	p Value	Low/ average-volume day	High-volume day	p Value
Maternal										
Obstetric infection	3.1	**3.0**	**3.4**	**<0.001**	**3.0**	**2.9**	**0.037**	**3.3**	**3.9**	**<0.001**
Haemorrhage	3.7	**3.7**	**3.9**	**<0.001**	**3.8**	**3.5**	**<0.001**	**3.8**	**4.3**	**0.001**
Severe perineal laceration	2.4	**2.4**	**2.6**	**<0.001**	2.4	2.3	0.304	2.7	2.5	0.119
Prolonged LOS*	3.7	**3.5**	**4.2**	**<0.001**	3.5	3.5	0.161	**4.1**	**4.7**	**<0.001**
Composite maternal	11.3	**11.0**	**12.4**	**<0.001**	**11.1**	**10.8**	**0.010**	**12.3**	**13.2**	**<0.001**
Neonatal										
Birth trauma	3.5	3.5	3.5	0.539	3.5	3.5	0.403	3.5	3.5	0.624
Neonatal seizures	0.1	0.1	0.1	0.830	0.1	0.1	0.074	0.1	0.1	0.821
Apgar score <7	0.7	**0.6**	**0.8**	**<0.001**	0.6	0.6	0.927	**0.7**	**0.9**	**0.012**
NICU admission	4.2	**4.1**	**4.5**	**<0.001**	**4.2**	**4.1**	**0.026**	**4.5**	**4.8**	**0.047**
Neonatal death	0.2	0.1	0.2	0.339	0.2	0.1	0.141	0.2	0.1	0.156
Composite infant	7.9	**7.8**	**8.2**	**<0.001**	**7.9**	**7.7**	**0.011**	8.1	8.5	0.075

Bold typeface indicates p<0.05.
*Prolonged LOS defined as LOS >3 days for vaginal deliveries and >5 days for caesarean deliveries.
LOS, length of stay; NICU, neonatal intensive care unit.

observed for busy weekend days. High-volume weekdays generally did not have different odds of perinatal complications as compared with low/average-volume weekdays, with the exception of neonatal seizures (aOR: 1.33, 95% CI 1.01 to 1.74) and haemorrhage (aOR: 0.95, 95% CI 0.91 to 0.98).

After fitting fixed-effects models that controlled for between-hospital variations (model 3; table 5), the impact of weekend delivery persisted while the impact of high daily volume either diminished or disappeared altogether. For example, the findings for delivery on a low-volume weekend were almost identical to model 2 whereas for high-volume weekend, the ORs were attenuated as compared with model 2 (eg, aOR for composite maternal outcome: 1.05, 95% CI 1.00 to 1.10). While the effect size was reduced, findings remained significant for several maternal complications as well as Apgar score and NICU admissions. As in model 2, high-volume weekday was rarely associated with any negative perinatal outcomes, except neonatal seizures, after adjusting for variation between hospitals.

The results remained unchanged after controlling for operative vaginal delivery and caesarean delivery,

Table 3 Main effects of daily volume, weekend and hospital volume category on the odds of perinatal outcomes based on model 1*

Outcome	High-volume day	Weekend	Volume category 1†	Volume category 2†	Volume category 3†
Maternal					
Obstetric infection	1.01 (0.97 to 1.05)	**1.09 (1.05 to 1.13)**	0.93 (0.62 to 1.40)	0.99 (0.69 to 1.43)	1.02 (0.68 to 1.53)
Haemorrhage	0.97 (0.93 to 1.00)	**1.05 (1.01 to 1.08)**	1.26 (0.86 to 1.85)	1.08 (0.76 to 1.56)	1.10 (0.73 to 1.65)
Severe perineal lacerations	0.98 (0.94 to 1.01)	**1.08 (1.04 to 1.12)**	1.10 (0.93 to 1.30)	1.06 (0.93 to 1.21)	**1.19 (1.04 to 1.36)**
Prolonged LOS‡	**1.05 (1.02 to 1.09)**	**1.21 (1.17 to 1.25)**	1.03 (0.66 to 1.61)	0.90 (0.66 to 1.24)	0.85 (0.63 to 1.15)
Composite maternal	1.00 (0.98 to 1.02)	**1.12 (1.10 to 1.15)**	1.09 (0.82 to 1.44)	1.00 (0.79 to 1.26)	1.01 (0.79 to 1.30)
Neonatal					
Birth trauma	0.99 (0.96 to 1.03)	0.99 (0.95 to 1.03)	1.32 (0.86 to 2.03)	1.03 (0.73 to 1.46)	1.04 (0.73 to 1.48)
Neonatal seizures	**1.26 (1.01 to 1.57)**	1.04 (0.81 to 1.32)	**1.81 (1.27 to 2.58)**	**1.69 (1.23 to 2.34)**	**1.67 (1.23 to 2.27)**
Apgar score <7	1.04 (0.97 to 1.12)	**1.14 (1.06 to 1.23)**	**1.98 (1.46 to 2.67)**	**1.36 (1.05 to 1.77)**	**1.30 (1.00 to 1.69)**
NICU admission	0.99 (0.95 to 1.03)	1.07 (1.04 to 1.11)	0.82 (0.49 to 1.38)	1.41 (0.87 to 2.29)	1.33 (0.94 to 1.86)
Neonatal death	0.88 (0.77 to 1.02)	0.99 (0.85 to 1.14)	1.31 (0.88 to 1.96)	0.84 (0.63 to 1.12)	1.04 (0.77 to 1.42)
Composite infant	0.99 (0.96 to 1.02)	**1.04 (1.01 to 1.06)**	1.13 (0.79 to 1.62)	1.24 (0.90 to 1.72)	1.20 (0.92 to 1.56)

Bold typeface indicates p<0.05.
*Results are OR (95% CI); models controlled for hospital volume category, maternal race/ethnicity, advanced maternal age, education, parity, insurance status, prenatal care and teaching hospital. Models estimated robust SEs accounting for hospital-level clustering.
†Hospital volume categories: category 1, 50–1119 annual births; category 2, 1200–2399 annual births; category 3, 2400–3599 annual births; as compared with referent, category 4, ≥3600 annual births.
‡Prolonged LOS defined as LOS >3 days for vaginal deliveries and >5 days for caesarean deliveries.
LOS, length of stay; NICU, neonatal intensive care unit.

Table 4 Joint impact of daily volume and weekend delivery (model 2*) on perinatal outcomes

Outcome	Low/average-volume weekday	High-volume weekday	Low/average-volume weekend	High-volume weekend
Model 2 (interaction model)				
Maternal				
Obstetric infection	Ref.	0.98 (0.94 to 1.02)	**1.06 (1.02 to 1.10)**	**1.24 (1.12 to 1.37)**
Haemorrhage	Ref.	**0.95 (0.91 to 0.98)**	1.02 (0.98 to 1.06)	**1.11 (1.01 to 1.22)**
Severe perineal laceration	Ref.	0.98 (0.95 to 1.02)	**1.09 (1.04 to 1.14)**	1.02 (0.91 to 1.13)
Prolonged LOS†	Ref.	1.03 (0.99 to 1.07)	**1.19 (1.15 to 1.23)**	**1.38 (1.28 to 1.49)**
Composite maternal	Ref.	0.99 (0.96 to 1.01)	**1.10 (1.08 to 1.13)**	**1.20 (1.14 to 1.27)**
Neonatal				
Birth trauma	Ref.	0.99 (0.95 to 1.04)	0.99 (0.95 to 1.03)	0.99 (0.90 to 1.08)
Neonatal seizures	Ref.	**1.33 (1.01 to 1.74)**	1.11 (0.83 to 1.49)	1.03 (0.62 to 1.71)
Apgar score <7	Ref.	1.02 (0.94 to 1.10)	**1.11 (1.03 to 1.21)**	**1.29 (1.10 to 1.52)**
NICU admission	Ref.	0.98 (0.93 to 1.03)	**1.06 (1.02 to 1.10)**	**1.11 (1.01 to 1.21)**
Neonatal death	Ref.	0.91 (0.78 to 1.07)	1.02 (0.88 to 1.19)	0.72 (0.46 to 1.12)
Composite infant	Ref.	0.98 (0.95 to 1.02)	1.03 (1.00 to 1.06)	1.06 (0.99 to 1.14)

Bold typeface indicates p<0.05.
*Results are OR (95% CI); model controlled for hospital volume category, maternal race/ethnicity, advanced maternal age, education, parity, insurance status, prenatal care and teaching hospital. Models estimated robust SEs accounting for hospital-level clustering.
†Prolonged LOS defined as LOS >3 days for vaginal deliveries and >5 days for caesarean deliveries.
LOS, length of stay; NICU, neonatal intensive care unit.

with the exception of the composite infant outcome and severe perineal laceration which were significantly increased in this first sensitivity analysis (see online supplementary table S1). In the second sensitivity analysis that considered day of maternal hospital admission rather than day of birth as the index day to designate a day as busy or a weekend, findings were also largely consistent with our main findings and with prior research considering day of birth versus day of hospital admission.[4] Specifically, maternal outcomes were largely similar when using admission day as compared with birthday: busy weekend days had highest rates of maternal complications (with the exception of prolonged LOS where the increased odds observed in the main analyses was reversed) (see online supplementary table S2).

We believe that this finding highlights the importance of capacity strain on the delivery day, rather than the admission day. Considering the time immediately surrounding birth as a 'sensitive period' for capacity strain effects on birth outcomes, it follows logically that women who deliver on weekends have more

Table 5 Joint impact of daily volume and weekend delivery (model 3*), controlling for hospital-level factors

Outcome	Low/average-volume weekday	High-volume weekday	Low/average-volume weekend	High-volume weekend
Model 3 (interaction model with fixed effects)				
Maternal				
Obstetric infection	Ref.	1.03 (1.00 to 1.07)	**1.05 (1.01 to 1.09)**	1.02 (0.93 to 1.11)
Haemorrhage	Ref.	0.98 (0.95 to 1.01)	1.01 (0.98 to 1.06)	**0.92 (0.85 to 0.98)**
Severe perineal laceration	Ref.	0.99 (0.95 to 1.03)	**1.09 (1.05 to 1.14)**	1.03 (0.93 to 1.13)
Prolonged LOS†	Ref.	**1.06 (1.03 to 1.09)**	**1.18 (1.14 to 1.22)**	**1.25 (1.17 to 1.34)**
Composite maternal	Ref.	1.02 (1.00 to 1.04)	**1.10 (1.07 to 1.12)**	**1.05 (1.00 to 1.10)**
Neonatal				
Birth trauma	Ref.	1.00 (0.97 to 1.04)	0.99 (0.95 to 1.03)	0.96 (0.89 to 1.05)
Neonatal seizures	Ref.	**1.34 (1.03 to 1.74)**	1.10 (0.82 to 1.48)	0.95 (0.57 to 1.57)
Apgar score <7	Ref.	1.04 (0.96 to 1.12)	**1.10 (1.02 to 1.20)**	**1.21 (1.04 to 1.40)**
NICU admission	Ref.	1.00 (0.97 to 1.03)	**1.06 (1.02 to 1.10)**	**1.09 (1.01 to 1.18)**
Neonatal death	Ref.	0.91 (0.78 to 1.06)	1.02 (0.88 to 1.19)	0.74 (0.48 to 1.15)
Composite infant	Ref.	1.00 (0.98 to 1.02)	1.02 (0.99 to 1.05)	1.04 (0.97 to 1.11)

Bold typeface indicates p<0.05.
*Results are OR (95% CI); model controlled for maternal race/ethnicity, advanced maternal age, education, parity, insurance status and prenatal care. Models included hospital fixed-effects and estimated robust SEs accounting for hospital-level clustering.
†Prolonged LOS defined as LOS >3 days for vaginal deliveries and >5 days for caesarean deliveries.
LOS, length of stay; NICU, neonatal intensive care unit.

complications and longer LOS. In contrast, women who are admitted on weekends may not have the sensitive period of their labour/birth affected by weekend systems capacity. In particular, women who are admitted on the weekend and deliver on a weekday experience the more robust staffing associated with weekday delivery during the time of their birth. In contrast, associations between weekend/daily volume and neonatal complications largely attenuated or disappeared when using maternal hospital admission day rather than birthday as index day, with the exception of neonatal seizures where the busy-weekend day effect was more pronounced. This is consistent with the expectation that maternal complications, but not neonatal complications, would be sensitive to admission day factors as well as birthday factors.

DISCUSSION

In this study, we examined whether perinatal complications of childbirth varied by daily obstetric volume and timing of delivery (weekend vs weekday) among California hospitals. We found evidence of capacity strain in the form of both 'busy day' and 'weekend effects,' with maternal and some neonatal complications being more common on weekends and most common on high-volume weekends. In other words, weekend delivery and high daily volume had compounding effects, with births on high-volume weekend days having the highest odds of perinatal complications. Although modest in magnitude, these associations were observed across several outcomes and modelling strategies, suggesting that findings may reflect increased odds of complications during these susceptible times.

The finding of increased perinatal complications on high-volume weekend days was as we hypothesised and is consistent with prior research demonstrating that weekend days are more susceptible to capacity strain.[11] This is consistent with some[27] (but not all[24]) prior studies examining delivery during off-hours. These increases in complication rates were typically in the range of 10–20%. In contrast, taking into account the differences between hospitals in fixed-effects models, the 'busy day' effect mostly went away. Although these days were associated with the highest effect sizes in this study, the association between high daily volume and complications was notably weakened or absent in models with hospital fixed effects. The differences between results from models 2 and 3 suggest that adverse outcomes associated with high daily volume are partly attributable to hospital characteristics. For instance, we found higher hospital annual birth volume to be protective in some of our models. This contrasts with the 'weekend effect,' which appears to be more consistent and unrelated to factors that vary between hospitals.

This study is not without limitations. These data are observational, and causality is difficult to establish, although randomisation is not practical in this context. Linked vital statistics data and patient discharge data are more reliable and accurate than either data source on its own,[28] yet such administrative data have known limitations with respect to data quality.[29] Although we used the most recent OSHPD data available at the time of our analysis, our data are still 5–6 years old and it is possible that our estimates could vary with more recent data. Some neonatal outcomes, such as neonatal death and neonatal seizures, are rare, which may have limited our statistical power to detect differences for these outcomes.

While we analysed a previously published metric of labour and delivery capacity strain,[11] this is only one metric. Prior capacity strain research from critical care and emergency department settings has considered multiple ways of operationalising 'capacity strain,' including average patient acuity, bed occupancy on admission date and number of new admissions on a given date.[7 30] Future research should explore additional ways to define capacity strain in obstetrics, particularly focusing on the issues of (1) the potential contribution of patient acuity to capacity strain and (2) the role of day of admission versus day of birth. In our study, we found that system factors on day of birth were meaningfully associated with both maternal and neonatal complications, but system factors on admission day were only associated with maternal complications. The key exception was neonatal seizures, odds of which were increased on busy weekend days. This finding is not explained by our hypothesised explanation, and future research should examine whether it can be replicated, and if so, what explains this increase in neonatal morbidity. Future research should also examine whether these broad findings hold in other populations and other healthcare systems. Finally, we excluded hospitals with fewer than 1000 births during the study period because we did not expect meaningful variation in daily volume among these hospitals. This restriction limits the generalisability of our findings to very low-volume hospitals, many of which are in rural areas.[31] Generalisability may also be limited because these data come from only one US state.

Weekends in hospitals are characterised by lower levels of staffing, resource availability and preparedness for emergent situations.[20] This suggests that in addition to safety concerns, deliveries on high-volume days and/or weekends could also result in less efficiency. This might explain some of the increases we observed in efficiency-related outcomes such as prolonged maternal LOS. Future research and quality improvement initiatives may address the particular challenges of census fluctuation and preparedness/efficiency on obstetric units on weekends. This analysis adds to the growing literature on capacity strain and perinatal complications of childbirth. These findings provide further evidence that weekend births have higher rates of complications, and delivering a baby on a busy weekend day may further increase the risk of perinatal complications. The 'busy day effect,' however, was driven by differences between hospitals, indicating that there is variability in how well hospitals can handle a surge in volume. In contrast, the 'weekend effect' remained unchanged in models controlling for hospital-level factors, indicating that it is consistent across hospitals in our sample.

Identifying the potential contribution of hospital-level factors to adverse perinatal outcomes has been an increasing focus of recent research;[32–34] these findings suggest that such hospital-level factors do influence the quality of maternity care. Although recent studies of hospital-level factors have found null associations between some hospital-level factors (eg, the obstetric hospitalist staffing model[32] and condition-specific obstetric protocols[35]) and perinatal outcomes, the search for meaningful hospital-level factors should continue. Research on hospital-level factors in obstetric care (eg, staffing models and use of protocols) has grown in recent years. More research on these topics is needed, and future research should also examine the role that hospital administration and management can play in obstetric care quality; such factors have been demonstrated to affect patient outcomes in other areas of inpatient medicine.[36 37] Such information would fill evidence gaps, helping identify hospital-level and policy levers to improve maternal outcomes of childbirth.

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REFERENCES

1 Janakiraman V, Ecker J. Quality in obstetric care: measuring what matters. *Obstet Gynecol* 2010;116:728–32.
2 Glance LG, Dick AW, Glantz JC, *et al*. Rates of major obstetrical complications vary almost fivefold among US hospitals. *Health Aff (Millwood)* 2014;33:1330–6.
3 Kozhimannil KB, Law MR, Virnig BA. Cesarean delivery rates vary tenfold among US hospitals; reducing variation may address quality and cost issues. *Health Aff (Millwood)* 2013;32:527–35.
4 Palmer WL, Bottle A, Aylin P. Association between day of delivery and obstetric outcomes: observational study. *BMJ* 2015;351:h5774.
5 Grobman WA, Bailit JL, Rice MM, *et al*. Can differences in obstetric outcomes be explained by differences in the care provided? The MFMU Network APEX study. *Am J Obstet Gynecol* 2014;211:147.e1–16.
6 Howell EA, Zeitlin J, Hebert PL, *et al*. Association between hospital-level obstetric quality indicators and maternal and neonatal morbidity. *JAMA* 2014;312:1531–41.
7 Halpern SD. ICU capacity strain and the quality and allocation of critical care. *Curr Opin Crit Care* 2011;17:648–57.
8 Bernstein SL, Aronsky D, Duseja R, *et al*. The effect of emergency department crowding on clinically oriented outcomes. *Acad Emerg Med* 2009;16:1–10.
9 Wagner J, Gabler NB, Ratcliffe SJ, *et al*. Outcomes among patients discharged from busy intensive care units. *Ann Intern Med* 2013;159:447–55.
10 Tucker J. Patient volume, staffing, and workload in relation to risk-adjusted outcomes in a random stratified sample of UK neonatal intensive care units: a prospective evaluation. *Lancet* 2002;359:99–107.
11 Snowden JM, Darney BG, Cheng YW, *et al*. Systems factors in obstetric care: the role of daily obstetric volume. *Obstet Gynecol* 2013;122:851–7.
12 Bateman BT, Berman MF, Riley LE, *et al*. The epidemiology of postpartum hemorrhage in a large, nationwide sample of deliveries. *Anesth Analg* 2010;110:1368–73.
13 Creanga AA, Berg CJ, Syverson C, *et al*. Pregnancy-related mortality in the United States, 2006–2010. *Obstet Gynecol* 2015;125:5–12.
14 Danielsen B. Probabilistic Record Linkages for Generating a Comprehensive Epidemiological Research File on Maternal and Infant Health: Health Information Solutions/California Dept of Public Health, 2002.
15 Fridman M, Korst LM, Chow J, *et al*. Trends in maternal morbidity before and during pregnancy in California. *Am J Public Health* 2014;104(Suppl 1):S49–57.
16 Snowden JM, Cheng YW, Emeis CL, *et al*. The impact of hospital obstetric volume on maternal outcomes in term, non-low-birthweight pregnancies. *Am J Obstet Gynecol* 2015;212:380.e1–9.
17 Asch DA, Nicholson S, Srinivas S, *et al*. Evaluating obstetrical residency programs using patient outcomes. *JAMA* 2009;302:1277–83.
18 Mann S, Pratt S, Gluck P, *et al*. Assessing quality obstetrical care: development of standardized measures. *Jt Comm J Qual Patient Saf* 2006;32:497–505.
19 Bailit JL. Measuring the quality of inpatient obstetrical care. *Obstet Gynecol Surv* 2007;62:207–13.
20 Bendavid E, Kaganova Y, Needleman J, *et al*. Complication rates on weekends and weekdays in US hospitals. *Am J Med* 2007;120:422–8.
21 Kostis WJ, Demissie K, Marcella SW, *et al*. Weekend versus weekday admission and mortality from myocardial infarction. *N Engl J Med* 2007;356:1099–109.
22 Williams RL. A note on robust variance estimation for cluster-correlated data. *Biometrics* 2000;56:645–6.
23 Cole SR, Hernan MA. Fallibility in estimating direct effects. *Int J Epidemiol* 2002;31:163–5.
24 Gould JB, Qin C, Marks AR, *et al*. Neonatal mortality in weekend vs weekday births. *JAMA* 2003;289:2958–62.

25 Zhang J, Landy HJ, Branch DW, *et al*. Contemporary patterns of spontaneous labor with normal neonatal outcomes. *Obstet Gynecol* 2010;116:1281–7.
26 Laughon SK, Branch DW, Beaver J, *et al*. Changes in labor patterns over 50 years. *Am J Obstet Gynecol* 2012;206:419.e1–9.
27 Pasupathy D, Wood AM, Pell JP, *et al*. Time of birth and risk of neonatal death at term: retrospective cohort study. *BMJ* 2010;341:c3498.
28 Lain SJ, Hadfield RM, Raynes-Greenow CH, *et al*. Quality of data in perinatal population health databases: a systematic review. *Med Care* 2012;50:e7–20.
29 Goff SL, Pekow PS, Markenson G, *et al*. Validity of using ICD-9-CM codes to identify selected categories of obstetric complications, procedures and co-morbidities. *Paediatr Perinat Epidemiol* 2012;26:421–9.
30 McCarthy ML, Ding R, Pines JM, *et al*. Comparison of methods for measuring crowding and its effects on length of stay in the emergency department. *Acad Emerg Med* 2011;18:1269–77.
31 Kozhimannil KB, Hung P, Prasad S, *et al*. Birth volume and the quality of obstetric care in rural hospitals. *J Rural Health* 2014;30:335–43.
32 Feldman DS, Bollman DL, Fridman M, *et al*. Do laborists improve delivery outcomes for laboring women in California community hospitals? *Am J Obstet Gynecol* 2015;213:587.e1–13.
33 Korst LM, Feldman DS, Bollman DL, *et al*. Cross-sectional survey of California childbirth hospitals: implications for defining maternal levels of risk-appropriate care. *Am J Obstet Gynecol* 2015;213:527.e1–12.
34 Korst LM, Feldman DS, Bollman DL, *et al*. Variation in childbirth services in California: a cross-sectional survey of childbirth hospitals. *Am J Obstet Gynecol* 2015;213:523.e1–8.
35 Bailit JL, Grobman WA, McGee P, *et al*. Does the presence of a condition-specific obstetric protocol lead to detectable improvements in pregnancy outcomes? *Am J Obstet Gynecol* 2015;213:86.e1–6.
36 McConnell KJ, Lindrooth RC, Wholey DR, *et al*. Management practices and the quality of care in cardiac units. *JAMA Intern Med* 2013;173:684–92.
37 Bradley EH, Curry LA, Spatz ES, *et al*. Hospital strategies for reducing risk-standardized mortality rates in acute myocardial infarction. *Ann Intern Med* 2012;156:618–26.