Georgia Birth Weight EDA

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2024-05-15

```
birthwt <- read.csv("data/cdc birthwt.csv")

names(birthwt) <- c("mother.id", "birth.order", "birth.weight", "maternal.age", "child.id")

# define breaks in maternal age factor
breaks <- c(min(birthwt$maternal.age), 20, 30, 40,
            max(birthwt$maternal.age))

birthwt <- birthwt %>%
  mutate(
    # create maternal age factor
    maternal.age.factor = cut(maternal.age, breaks=breaks, include.lowest = T),
    # create birth weight factor
    birth.weight.factor = ifelse(birth.weight < 2500,
                                 ifelse(birth.weight < 1500,
                                        "Very low (less than 1500g)",
                                        "Low (less than 2500g)"),
                                 "Not low"),
    # create birth weight binary factor
    birth.weight.binary = ifelse(birth.weight < 2500,
                                 "Low (less than 2500g)",
                                 "Not low")) %>%
  # define birth order (and above) as factors
  mutate_at(vars(birth.order, birth.weight.factor, birth.weight.binary),
            as.factor)

# create a interpregnancy variable
birthwt <- birthwt %>%
  arrange(mother.id, birth.order) %>%
  group_by(mother.id) %>%
  mutate(interval = maternal.age - lag(maternal.age)) %>%
  ungroup()

birthwt %>% filter(interval < 0)
```

```
## # A tibble: 2 x 9
##   mother.id birth.order birth.weight maternal.age child.id maternal.age.factor
##       <int> <fct>              <int>        <int>    <int> <fct>
## 1     57939 3                   3430           19     1063 [12,20]
## 2    212988 3                   2470           20     3648 [12,20]
## # i 3 more variables: birth.weight.factor <fct>, birth.weight.binary <fct>,
## #   interval <int>
```

```r
# mothers 57939 and 212988 both have negative intervals for their third births
# we will remove all their data and do not expect measurable changes in future
# analysis, their data is not special among the sample
birthwt <- birthwt %>% filter(!mother.id %in% c(57939, 212988))
```

Validation

```r
# validate each mother has 5 children
birthwt %>%
  group_by(mother.id) %>%
  summarize(Count = n()) %>%
  all(.$Count == 5)
```

```
## [1] TRUE
```

```r
# summarize numeric variables
birthwt %>%
  select(birth.weight, maternal.age) %>%
  summary
```

```
##   birth.weight   maternal.age
##  Min.   : 312   Min.   :12.00
##  1st Qu.:2850   1st Qu.:18.00
##  Median :3175   Median :21.00
##  Mean   :3156   Mean   :21.65
##  3rd Qu.:3515   3rd Qu.:24.00
##  Max.   :5528   Max.   :42.00
```

Exploratory data analysis

Birth weight

Birth weight is an infant's weight that is optimally measured in the hours following birth.

The World Health Organization (WHO) defines low birth weight as below 2500 g (5.5 lbs / 5 lbs 8 oz) and very low birth weight as below 1500 g (3.3 lbs / 3 lbs 5 oz). An infant with a low birth weight is often also premature, and at greater risk of health complications (e.g., underdeveloped lungs, inability to maintain body temperature, difficulty gaining weight, intestinal disease, bleeding in the brain, and sudden death).

Factors that are believed to cause low birth weight include maternal health and age, and multiple-baby pregnancies. Effects from race are also believed to impact birth weight: among Americans, Black mothers are twice as likely as white mothers to have low birth weights.

In some cases, the validity of birth weight data is of concern, as measures may be taken days after birth, after which significant weight loss may have occurred. We assume the source of our data to be valid.

1. What are the quartiles and average birth weight among all mothers? What quantile defines the threshold of low birth weights? How many births fall into each quartile and each category of (low / not low)?
2. Describe the distribution of all birth weights.

3. Describe the distribution of each mother's average birth weight. How does this distribution compare to that of all birth weights?

```
######################################################################
# Birth weight
######################################################################

# numeric summary of birth weight
round(c(mean = mean(birthwt$birth.weight),
        sd = sd(birthwt$birth.weight),
        IQR = IQR(birthwt$birth.weight),
        range = diff(range(birthwt$birth.weight)),
        quantile(birthwt$birth.weight)), 2)
```

```
##    mean      sd     IQR   range      0%     25%     50%     75%    100%
## 3156.13  570.25  665.00 5216.00  312.00 2850.00 3175.00 3515.00 5528.00
```

```
# numeric summary of individual average birth weight
birthwt %>%
  group_by(mother.id) %>%
  summarize(avg.weight = mean(birth.weight)) %>%
  reframe(c(mean = mean(avg.weight),
            sd = sd(avg.weight),
            IQR = IQR(avg.weight),
            quantile(avg.weight))) %>%
  round(2) %>% as.list
```

```
## $`c(...)`
##    mean      sd     IQR      0%     25%     50%     75%    100%
## 3156.13  416.70  532.35 1690.40 2891.80 3166.80 3424.15 4745.80
```

```
# size of each quartile
birthwt %>%
  mutate(quartile.range = cut(birth.weight,
                              breaks = quantile(birthwt$birth.weight),
                              include.lowest = TRUE,
                              dig.lab = 5)) %>%
  group_by(quartile.range) %>%
  summarize(n = length(quartile.range)) %>%
  mutate(quartile = 1:4) %>%
  select(Quartile=quartile, Range=quartile.range, Size=n) %>%
  kable(caption = "Quartiles of birth weight")
```

Table 1: Quartiles of birth weight

Quartile	Range	Size
1	[312,2850]	1100
2	(2850,3175]	1097
3	(3175,3515]	1109
4	(3515,5528]	1074

```r
# number of low births
birthwt %>%
  group_by(birth.weight.factor) %>%
  summarize(n = length(birth.weight.factor),
            prop = round(n / nrow(.), 2)) %>%
  arrange(desc(n)) %>%
  select(birth.weight.factor, n, prop) %>%
  kable(caption = "Sizes of birth weight groups",
        col.names = c("Weight group", "N", "Proportion"))
```

Table 2: Sizes of birth weight groups

Weight group	N	Proportion
Not low	3933	0.90
Low (less than 2500g)	389	0.09
Very low (less than 1500g)	58	0.01

```r
# distribution of all birth weights
gg_bw_all <- birthwt %>%
  ggplot(aes(x = birth.weight, y = after_stat(density))) +
    geom_histogram(bins = 30) +
    xlab("Birth weight") + ylab("") +
    geom_vline(xintercept = c(1500, 2500), color = c("red", "blue")) +
    geom_vline(xintercept = quantile(birthwt$birth.weight), color = "grey") +
    theme_bw()

# distribution of mothers' average birth weight
# must compute quartiles separately
quartiles <- birthwt %>%
  group_by(mother.id) %>%
  summarize(avg.weight = mean(birth.weight)) %>%
  reframe(quantile(avg.weight)) %>% as.list

gg_bw_indv <- birthwt %>%
  group_by(mother.id) %>%
  summarize(avg.weight = mean(birth.weight)) %>%
  ggplot(aes(x = avg.weight, y = after_stat(density))) +
    geom_histogram(bins = 30) +
    xlab("Average birth weight") + ylab("") +
    labs(caption = "Quartiles marked by vertical grey lines") +
    geom_vline(xintercept = c(1500, 2500), color = c("red", "blue")) +
    geom_vline(xintercept = quartiles[[1]], color = "grey") +
    theme_bw()

gridExtra::grid.arrange(gg_bw_all, gg_bw_indv)
```

Maternal age

Maternal age is the age at which a mother gives birth. Previous studies suggest that maternal age is associated with birth weight (younger and older mothers have greater rates of preterm births).

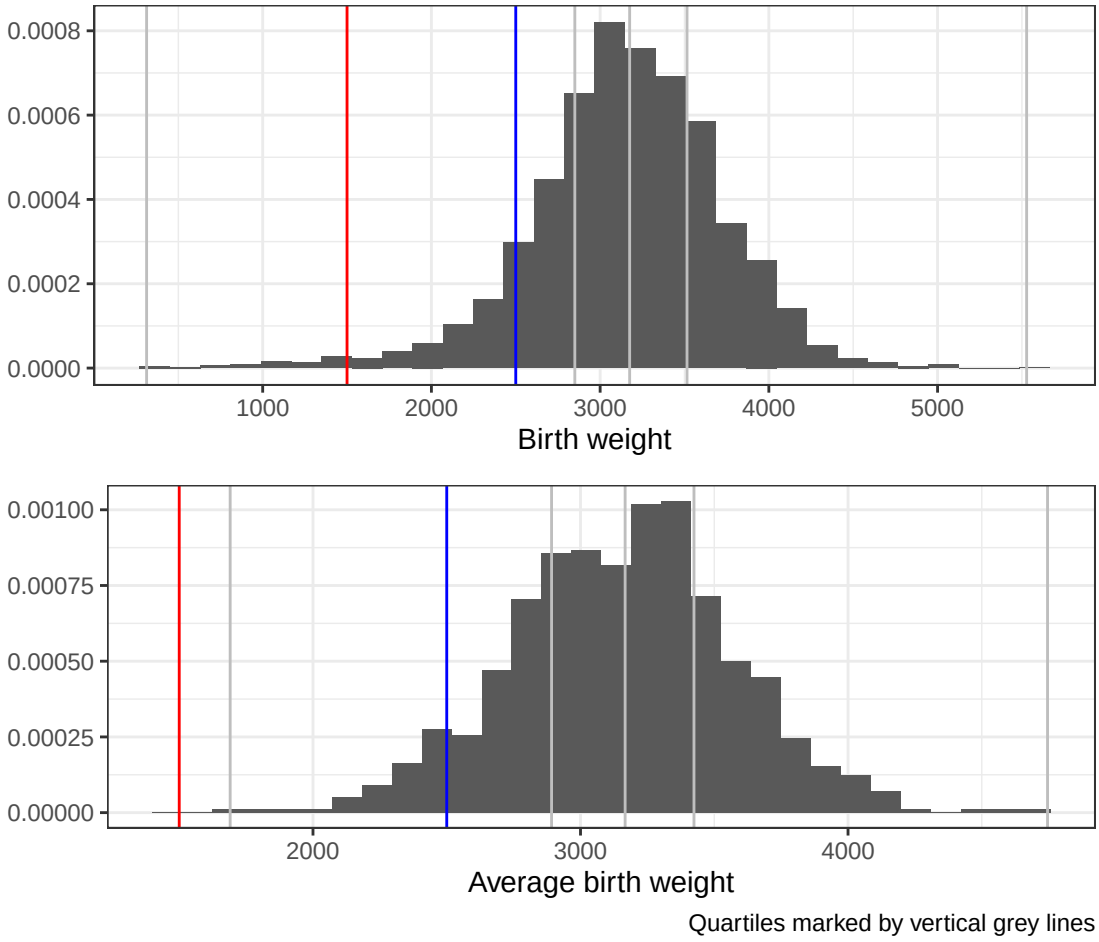


Figure 1: Distributions of birth weight with thresholds of low (blue) and very low (red) birth weight

1. What are the quartiles and average maternal age among all mothers? What quantile defines the thresholds of middle aged? How many births fall into each quantile and each category of (young / middle age)?

2. Describe the distribution of all maternal ages.

3. Describe the distribution of each mother's average maternal age. How does this distribution compare to that of all maternal ages?

```
#####################################################################
# Maternal age

# numeric summary of maternal age
round(c(mean = mean(birthwt$maternal.age),
        sd = sd(birthwt$maternal.age),
        IQR = IQR(birthwt$maternal.age),
        range = diff(range(birthwt$maternal.age)),
        quantile(birthwt$maternal.age)), 2)
```

```
##  mean    sd   IQR range    0%   25%   50%   75%  100%
## 21.65  4.63  6.00 30.00 12.00 18.00 21.00 24.00 42.00
```

```
# numeric summary of individual average maternal age
birthwt %>%
  group_by(mother.id) %>%
  summarize(avg.age = mean(maternal.age)) %>%
  reframe(c(mean = mean(avg.age),
            sd = sd(avg.age),
            IQR = IQR(avg.age),
            quantile(avg.age))) %>%
  round(2) %>% as.list
```

```
## $`c(...)`
##  mean    sd   IQR    0%   25%   50%   75%  100%
## 21.65  3.70  4.25 15.40 19.00 20.80 23.25 38.20
```

```
# size of each quartile
birthwt %>%
  mutate(quartile.range = cut(maternal.age,
                              breaks = quantile(birthwt$maternal.age),
                              include.lowest = TRUE)) %>%
  group_by(quartile.range) %>%
  summarize(n = length(quartile.range)) %>%
  mutate(quartile = 1:4) %>%
  select(quartile, quartile.range, n) %>%
  kable(caption = "Quantiles of maternal age",
        col.names = c("Quartile", "Range", "Size"))
```

Table 3: Quantiles of maternal age

Quartile	Range	Size
1	[12,18]	1211
2	(18,21]	1188
3	(21,24]	955
4	(24,42]	1026

```
# condensed version of above code (this has worse readability):
# table(cut(birthwt$maternal.age,
#           breaks = quantile(birthwt$maternal.age),
#           include.lowest = T))

# size of each age group
birthwt <- birthwt %>%
  # create new age group variable
  mutate(age.group = cut(maternal.age,
                         breaks = c(0, 18, 25, 35, 45),
                         right = F))

birthwt %>%
  group_by(age.group) %>%
  summarize(n = length(age.group),
            prop = round(n / nrow(.), 2)) %>%
  kable(caption = "Sizes of maternal age groups",
        col.names = c("Group", "Size", "Proportion"))
```

Table 4: Sizes of maternal age groups

Group	Size	Proportion
[0,18)	789	0.18
[18,25)	2565	0.59
[25,35)	959	0.22
[35,45)	67	0.02

```
# distribution of all maternal ages
gg_ma_all <- birthwt %>%
  ggplot(aes(x = maternal.age, y = after_stat(density))) +
    geom_histogram(bins = 30) +
    xlab("Maternal age") + ylab("") +
    scale_x_continuous(breaks = seq(15, 40, by = 5)) +
    geom_vline(xintercept = quantile(birthwt$maternal.age), color = "grey") +
    theme_bw()

# distribution of mothers' average maternal age
# must compute quartiles separately
quartiles <- birthwt %>%
  group_by(mother.id) %>%
  summarize(avg.age = mean(maternal.age)) %>%
  reframe(quantile(avg.age)) %>% as.list
```

```r
gg_ma_indv <- birthwt %>%
  group_by(mother.id) %>%
  summarize(avg.age = mean(maternal.age)) %>%
  ggplot(aes(x = avg.age, y = after_stat(density))) +
    geom_histogram(bins = 30) +
    xlab("Average maternal age") + ylab("") +
    labs(caption = "Quartiles marked by vertical grey lines") +
    geom_vline(xintercept = quartiles[[1]], color = "grey") +
    theme_bw()

gridExtra::grid.arrange(gg_ma_all, gg_ma_indv)
```

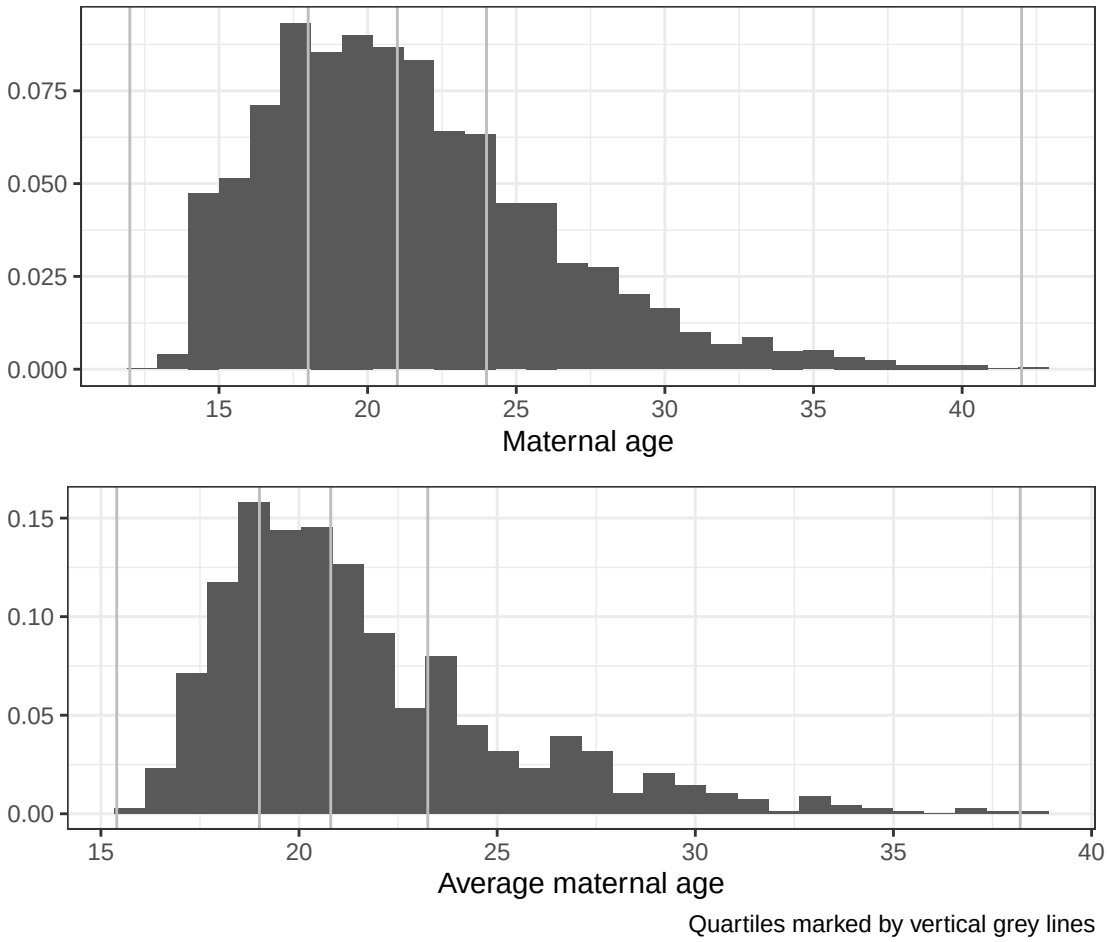


Figure 2: Distributions of maternal age and average maternal age. Average maternal age is average age of a mother over their five births- it is unique to each mother.

Interpregnancy interval

Interpregnancy interval is the time elapsed between one child's birth and the subsequent child's conception, often measured in months. This interval can be brief: mothers may become pregnant as early as four weeks after delivery.4 Similar to maternal age, extremely short and long intervals are associated with health

risks for the mother and second-born child. Interpregnancy intervals less than 18 months introduce moderate risk to children and significant risk is associated with intervals shorter than 6 months; intervals greater than 5-10 years is associated with increased risk of adverse health outcomes for both mother and child.4

With available data, our best estimate of this interval is the difference in maternal age between two subsequent births, measured in years, which in certain cases may be a slight underestimate.

1. What are the group sizes and mode for all interval values?
2. Describe the distribution of all intervals.
3. Describe the distribution of each mother's interval mode. How does this distribution compare to that of all intervals?

Interdelivery interval is the time elapsed between two subsequent births. May we more accurately estimate this interval using our data? Not necessarily- the accuracy of using the difference in maternal ages to estimate an interpregnancy versus an interdelivery interval varies by situation and relies on information unavailable to us. We have no workaround for this issue, other than to define short and long intervals according to respective thresholds (which differ by ?? 9 months?) and examine the extent to which results agree.

```
######################################################################
# Interpregnancy interval
######################################################################

# distribution of maternal age interval
birthwt %>%
  filter(!is.na(interval) & interval >= 0) %>%
  group_by(Interval = interval) %>%
  summarize(Count = n()) %>%
  mutate(Percentage = paste(round(100 * Count/sum(Count), 2), "%", sep = "")) %>%
  kable()
```

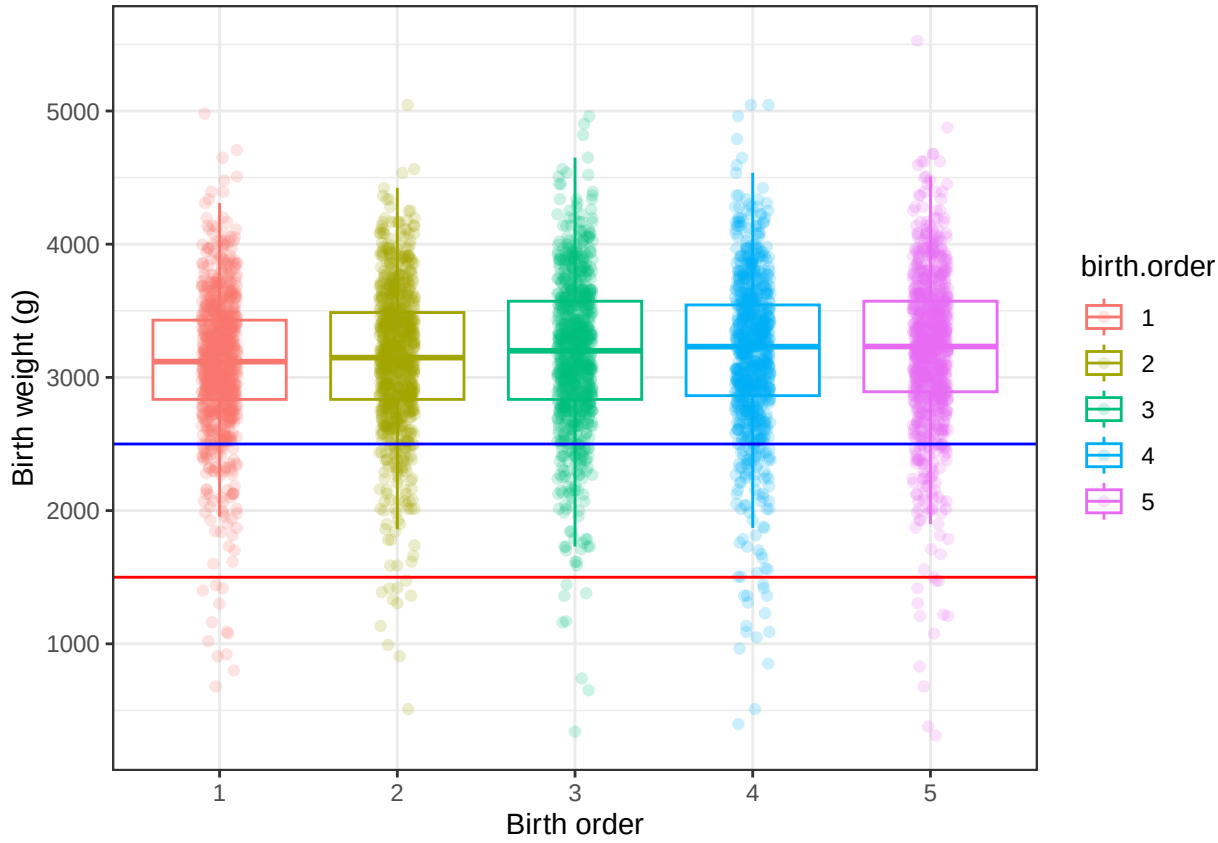
Interval	Count	Percentage
0	35	1%
1	1465	41.81%
2	1335	38.1%
3	398	11.36%
4	166	4.74%
5	73	2.08%
6	21	0.6%
7	9	0.26%
8	2	0.06%

Visualizing relationships with birth weight

Boxplots

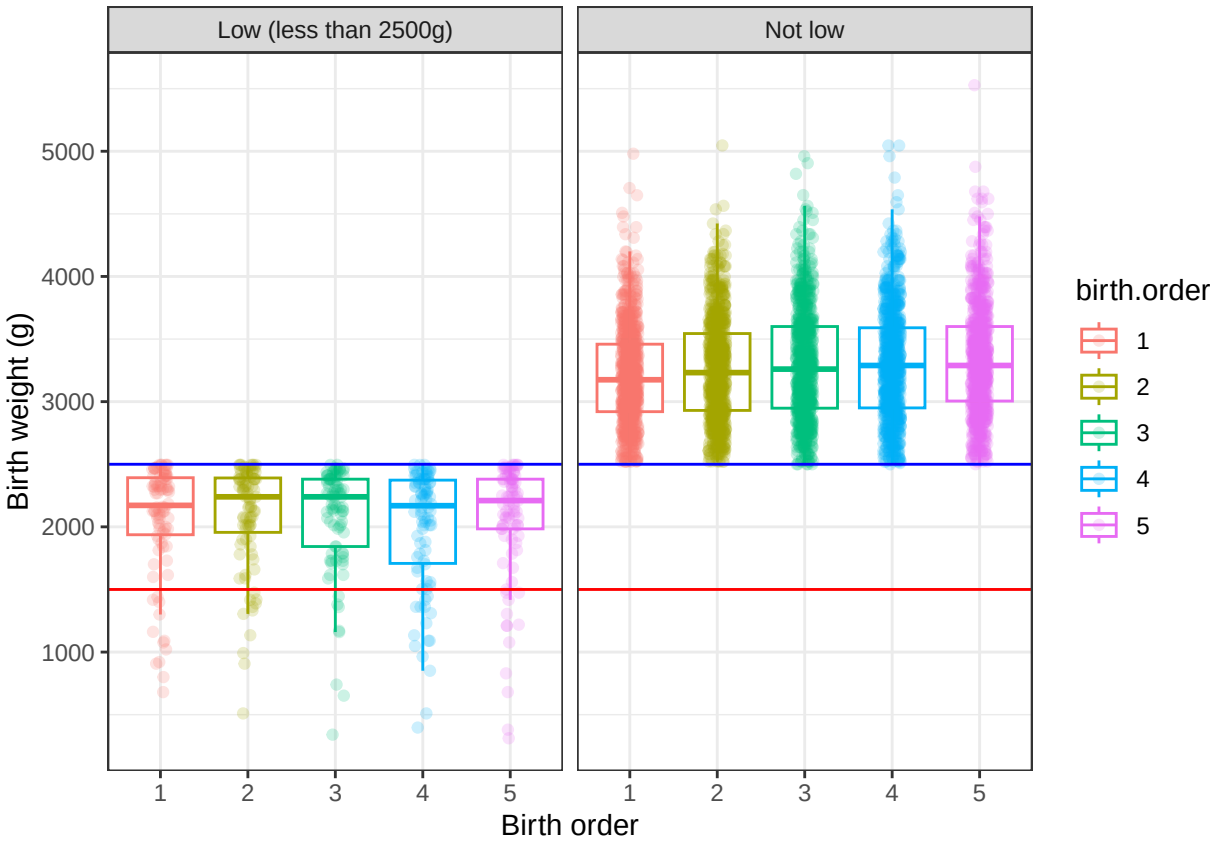
1. Produce boxplots of birth weights across birth order for all mothers, marking the threshold for low birth weight. Is there a visual trend?

```
gg1.weight.order <- birthwt %>%
  ggplot(aes(x = birth.order, y = birth.weight, group = birth.order,
             color = birth.order)) +
    geom_boxplot(outlier.shape = NA) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    geom_hline(yintercept = 2500, color = "blue") +
    geom_hline(yintercept = 1500, color = "red") +
    xlab("Birth order") + ylab("Birth weight (g)") +
    theme_bw()

gg1.weight.order
```



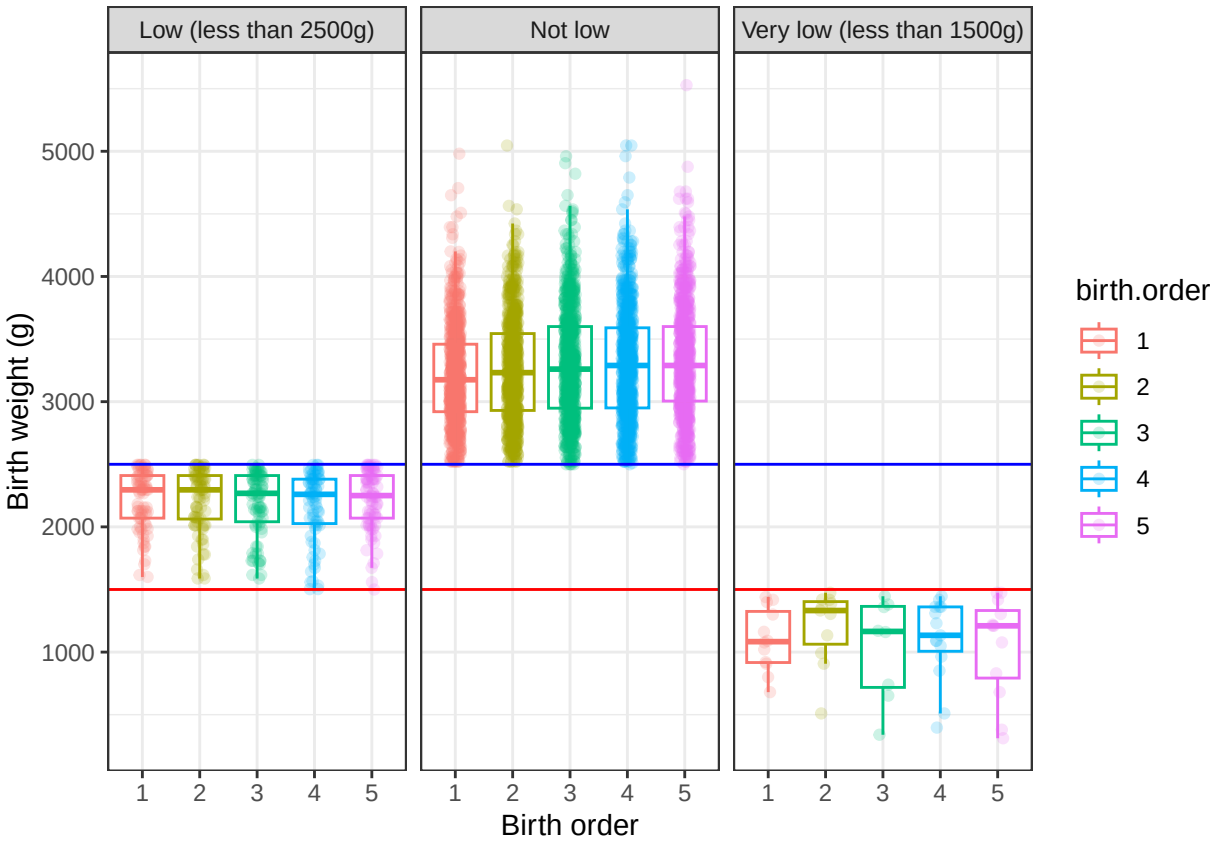
(a) Stratify the plot by low / not low birth weight

```
gg1.weight.order + facet_wrap(vars(birth.weight.binary))
```



(b) Stratify the plot by very low / low / not low birth weight

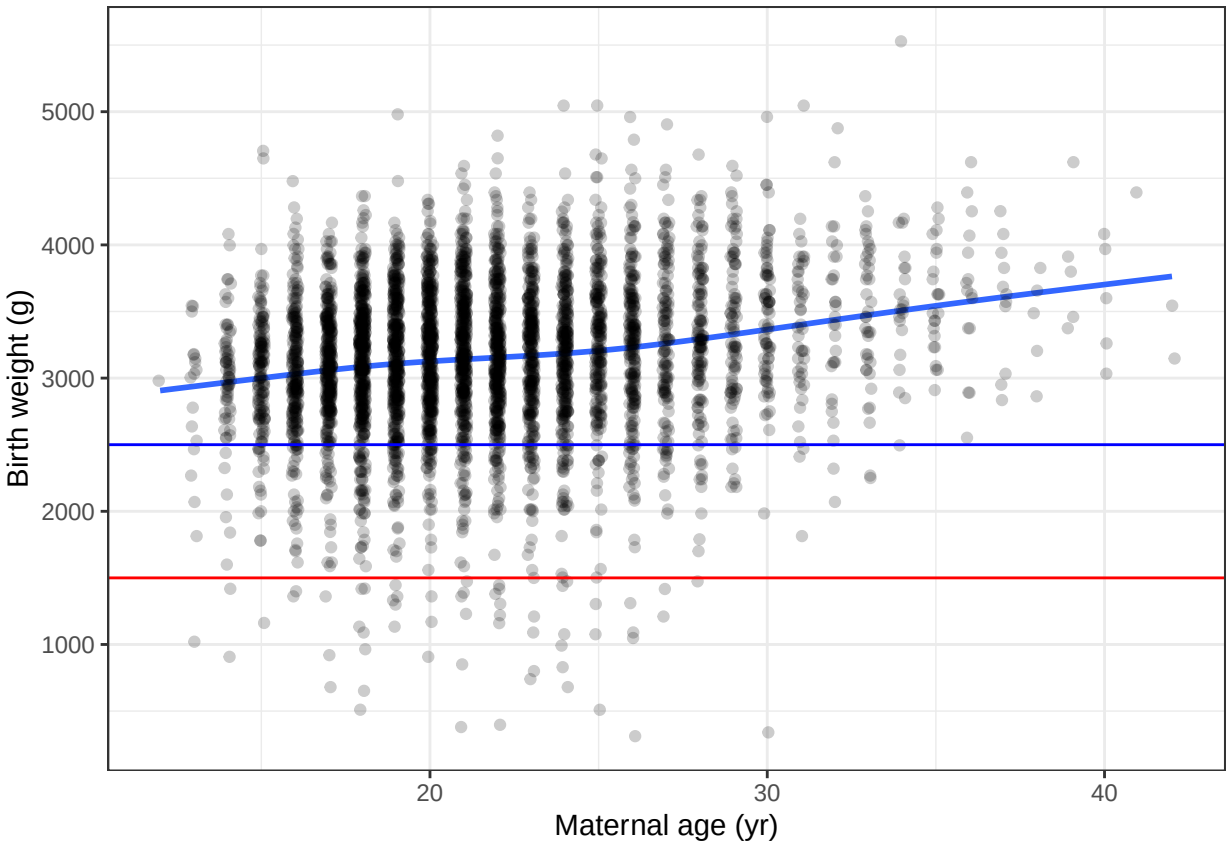
```
gg1.weight.order + facet_wrap(vars(birth.weight.factor))
```



2. Produce a boxplot of birth weight across maternal age for all mothers, marking the threshold for low birth weight. Is there a visual trend?

```
gg2.weight.age <- birthwt %>%
  ggplot(aes(x = maternal.age, y = birth.weight)) +
    geom_smooth(se = F) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    geom_hline(yintercept = 2500, color = "blue") +
    geom_hline(yintercept = 1500, color = "red") +
    xlab("Maternal age (yr)") + ylab("Birth weight (g)") +
    theme_bw()

gg2.weight.age
```

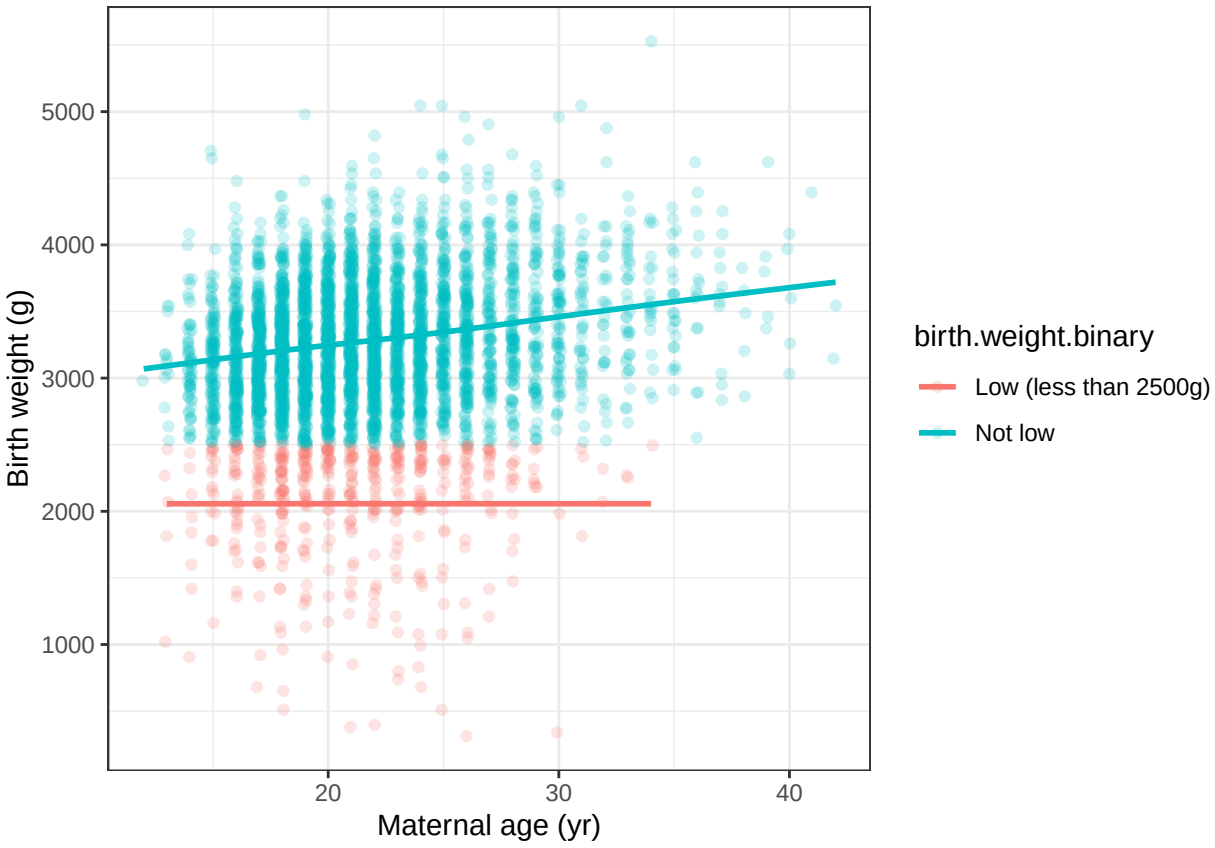
```
## `geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```



(a) Stratify the plot by low / not low birth weight

```
gg2a.weight.age <- birthwt %>%
  ggplot(aes(x = maternal.age, y = birth.weight,
             group = birth.weight.binary, color = birth.weight.binary)) +
    geom_smooth(se = F) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    # geom_hline(yintercept = 2500, color = "blue") +
    # geom_hline(yintercept = 1500, color = "red") +
    xlab("Maternal age (yr)") + ylab("Birth weight (g)") +
    theme_bw()

gg2a.weight.age
```

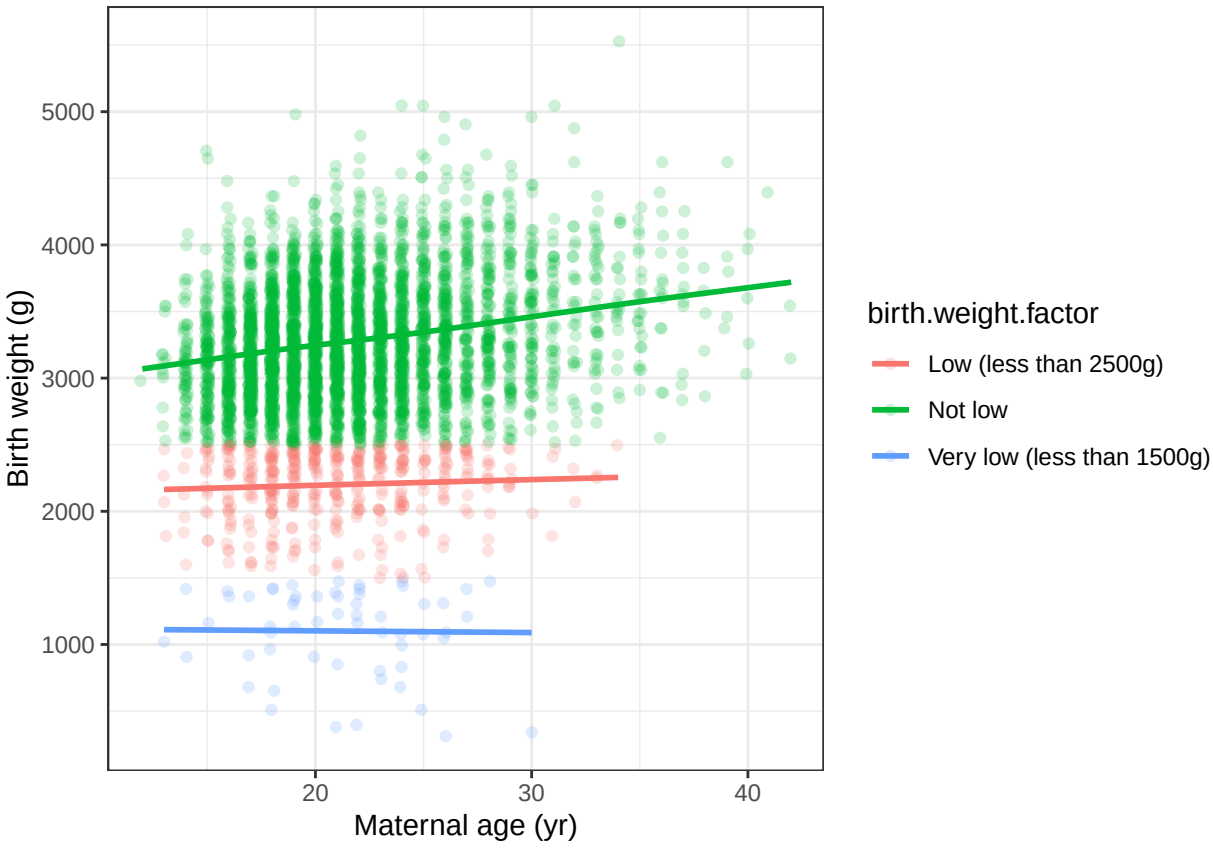
```
## `geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```



(b) Stratify the plot by very low / low / not low birth weight

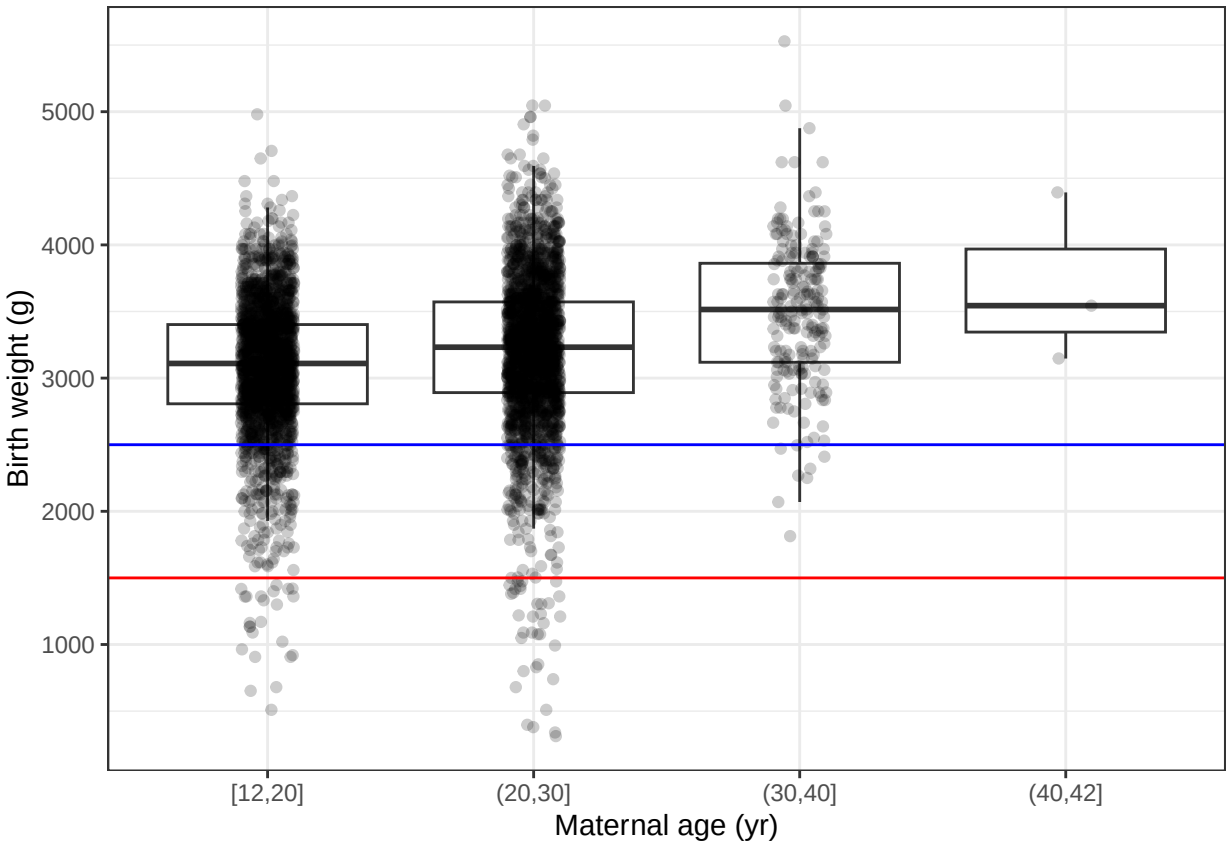
```
gg2b.weight.age <- birthwt %>%
  ggplot(aes(x = maternal.age, y = birth.weight,
             group = birth.weight.factor, color = birth.weight.factor)) +
    geom_smooth(se = F) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    # geom_hline(yintercept = 2500, color = "blue") +
    # geom_hline(yintercept = 1500, color = "red") +
    xlab("Maternal age (yr)") + ylab("Birth weight (g)") +
    theme_bw()

gg2b.weight.age
```

```
## `geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```

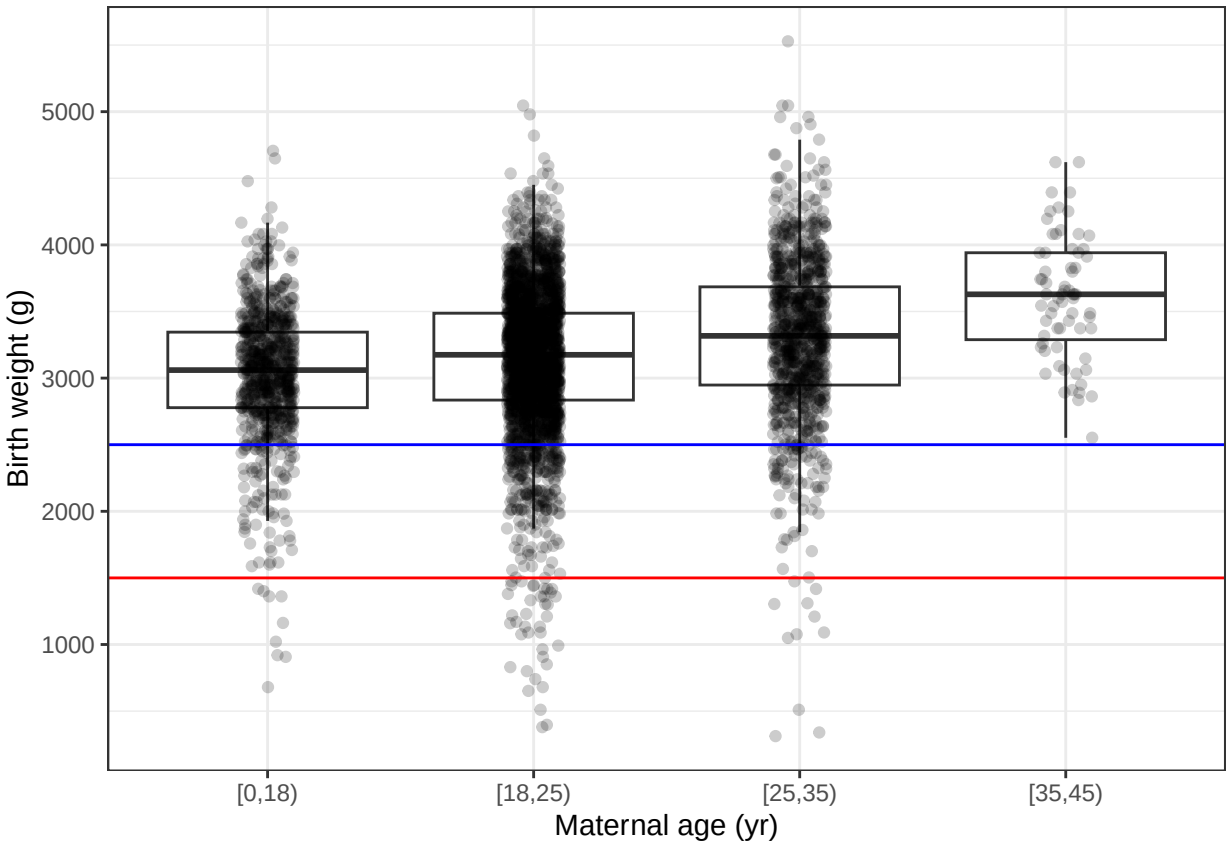


(c) Repeat the above for birth weight across maternal age factor

```
# using age grouped by decade
gg2c.weight.age <- birthwt %>%
  ggplot(aes(x = maternal.age.factor, y = birth.weight)) +
    geom_boxplot(outlier.shape = NA) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    geom_hline(yintercept = 2500, color = "blue") +
    geom_hline(yintercept = 1500, color = "red") +
    xlab("Maternal age (yr)") + ylab("Birth weight (g)") +
    theme_bw()

gg2c.weight.age
```

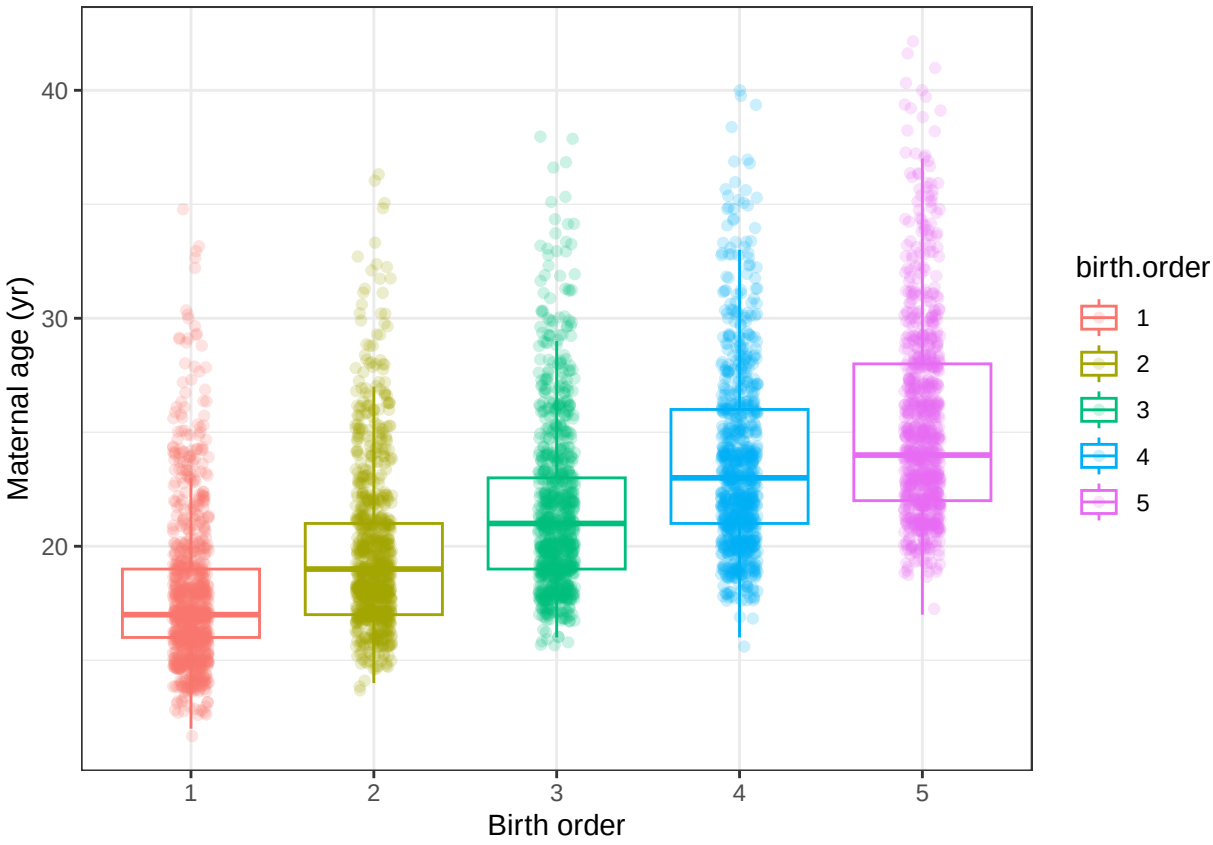



```
# using age grouped by popular age cutoffs
gg2c.weight.age <- birthwt %>%
  ggplot(aes(x = age.group, y = birth.weight)) +
    geom_boxplot(outlier.shape = NA) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    geom_hline(yintercept = 2500, color = "blue") +
    geom_hline(yintercept = 1500, color = "red") +
    xlab("Maternal age (yr)") + ylab("Birth weight (g)") +
    theme_bw()

gg2c.weight.age
```



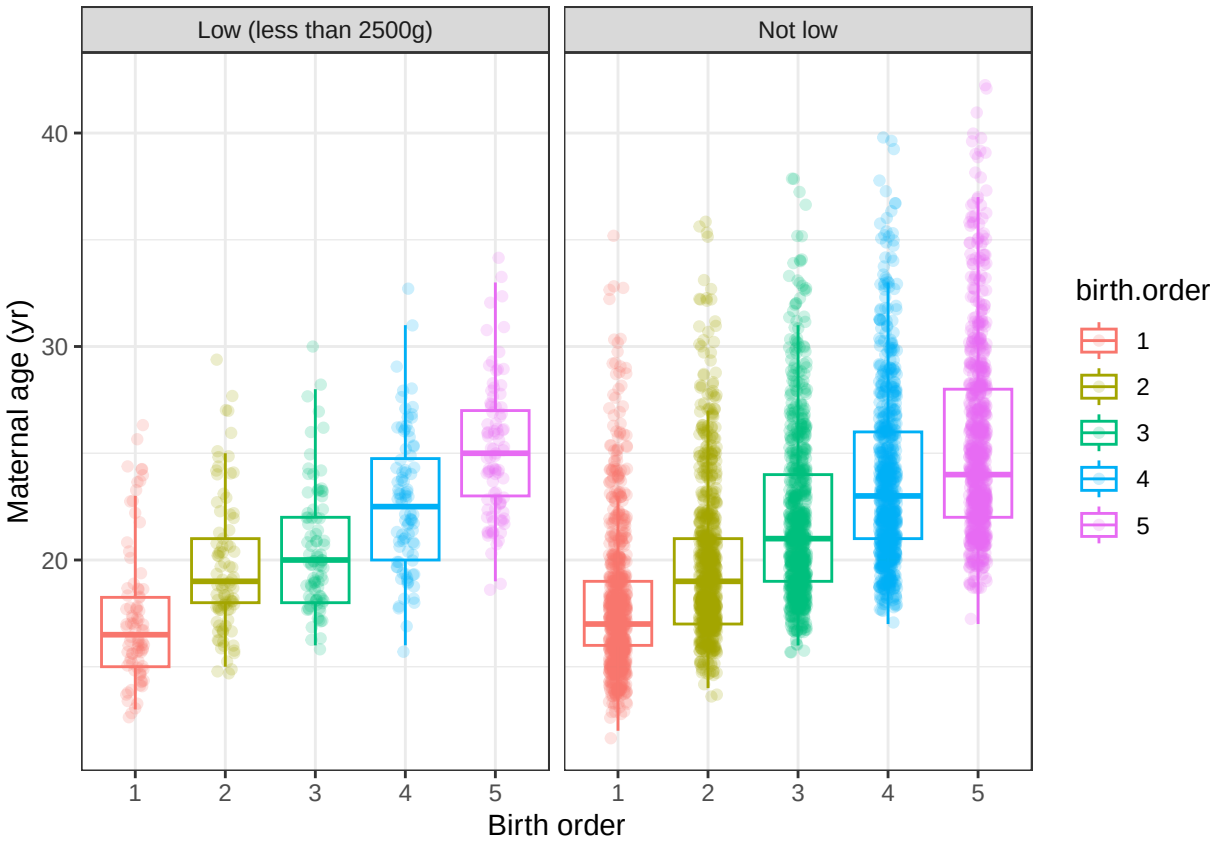
3. Produce boxplots of maternal age across birth order for all mothers. Is there a visual trend?

```
gg3.age.order <- birthwt %>%
  ggplot(aes(x = birth.order, y = maternal.age, group = birth.order,
             color = birth.order)) +
    geom_boxplot(outlier.shape = NA) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    xlab("Birth order") + ylab("Maternal age (yr)") +
    theme_bw()

gg3.age.order
```



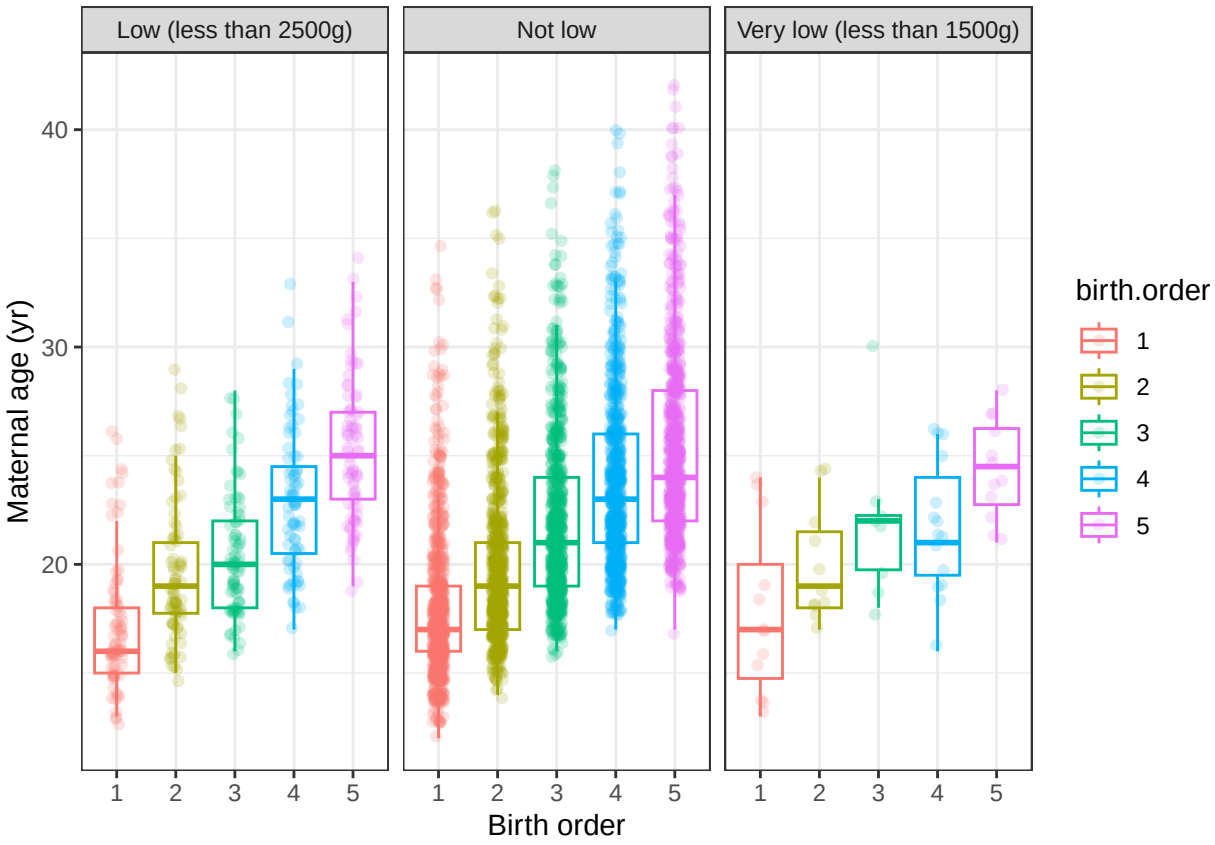
(a) Stratify the plot by low / not low birth weight

```
gg3.age.order + facet_wrap(vars(birth.weight.binary))
```



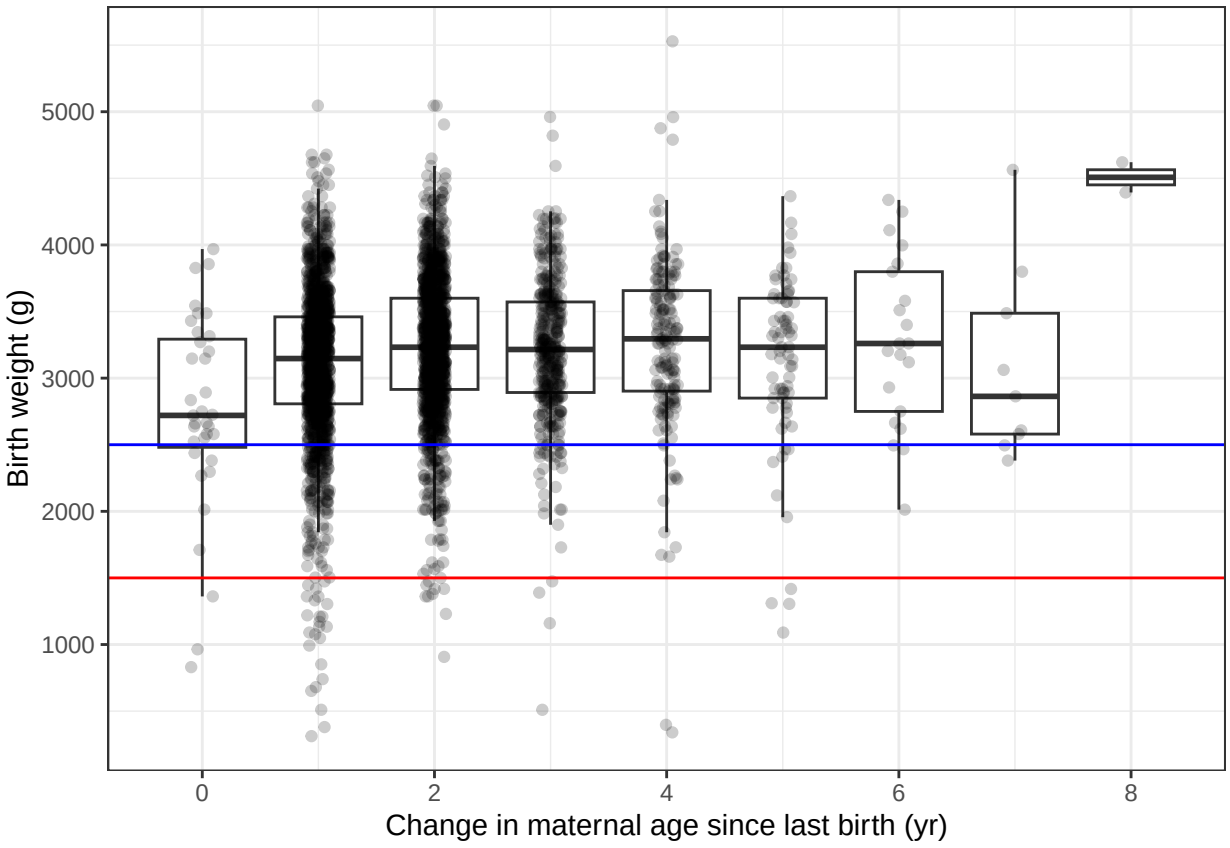
(b) Stratify the plot by very low / low / not low birth weight

```
gg3.age.order + facet_wrap(vars(birth.weight.factor))
```



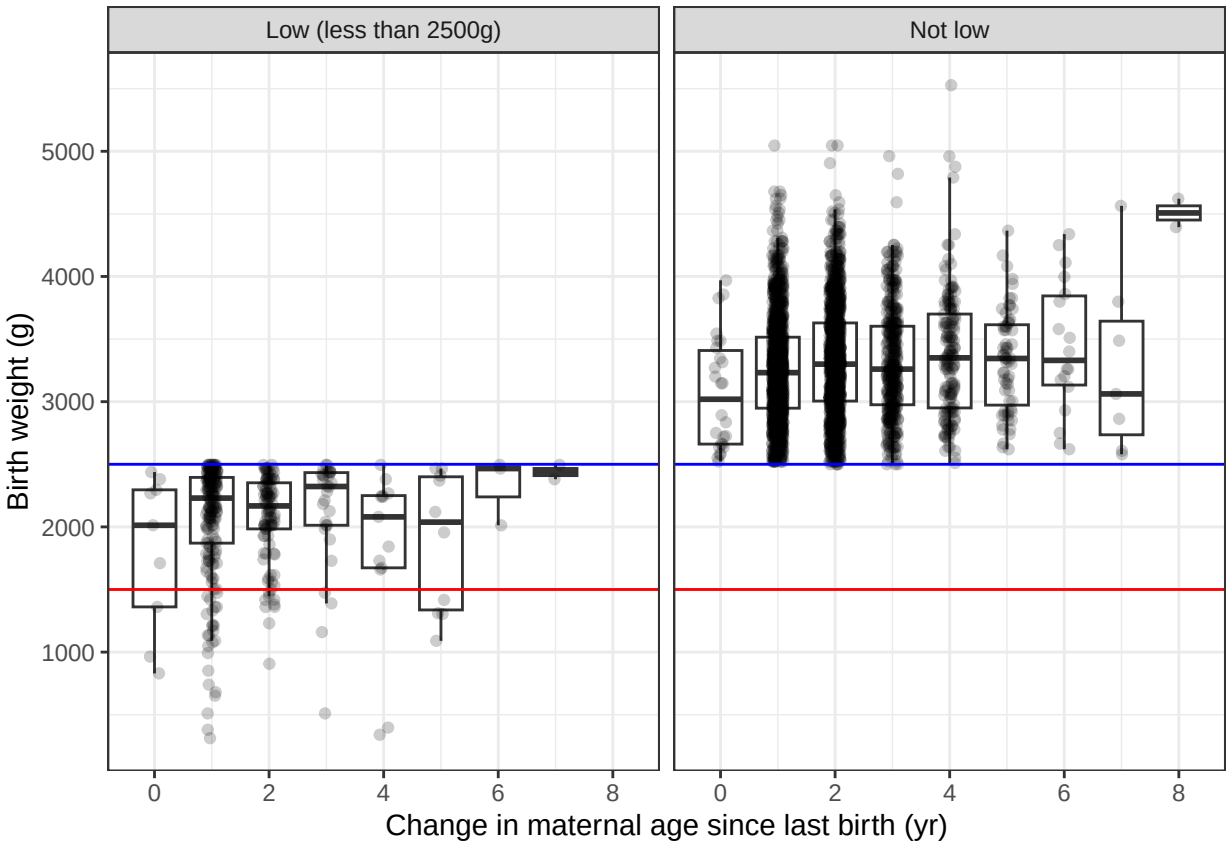
4. Produce a boxplot of birth weight across interval for non-firstborns (such that interval is defined), marking the threshold for low birth weight. Is there a visual trend?

```
gg4.weight.interval <- birthwt %>%
  filter(!is.na(interval)) %>%
  ggplot(aes(x = interval, y = birth.weight, group = interval)) +
    geom_boxplot(outlier.shape = NA) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    geom_hline(yintercept = 2500, color = "blue") +
    geom_hline(yintercept = 1500, color = "red") +
    xlab("Change in maternal age since last birth (yr)") +
    ylab("Birth weight (g)") +
    theme_bw()

gg4.weight.interval
```



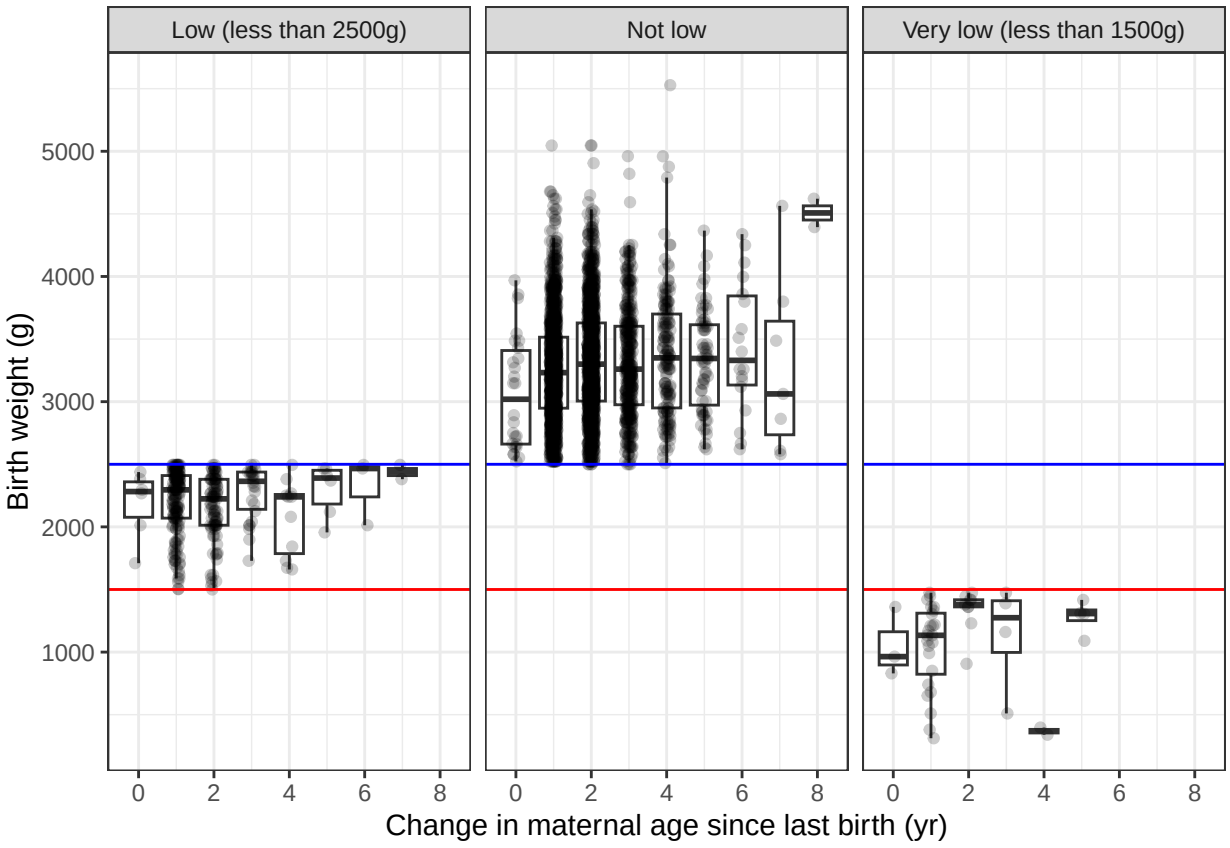
(a) Stratify the plot by low / not low birth weight

```
gg4.weight.interval + facet_wrap(vars(birth.weight.binary))
```



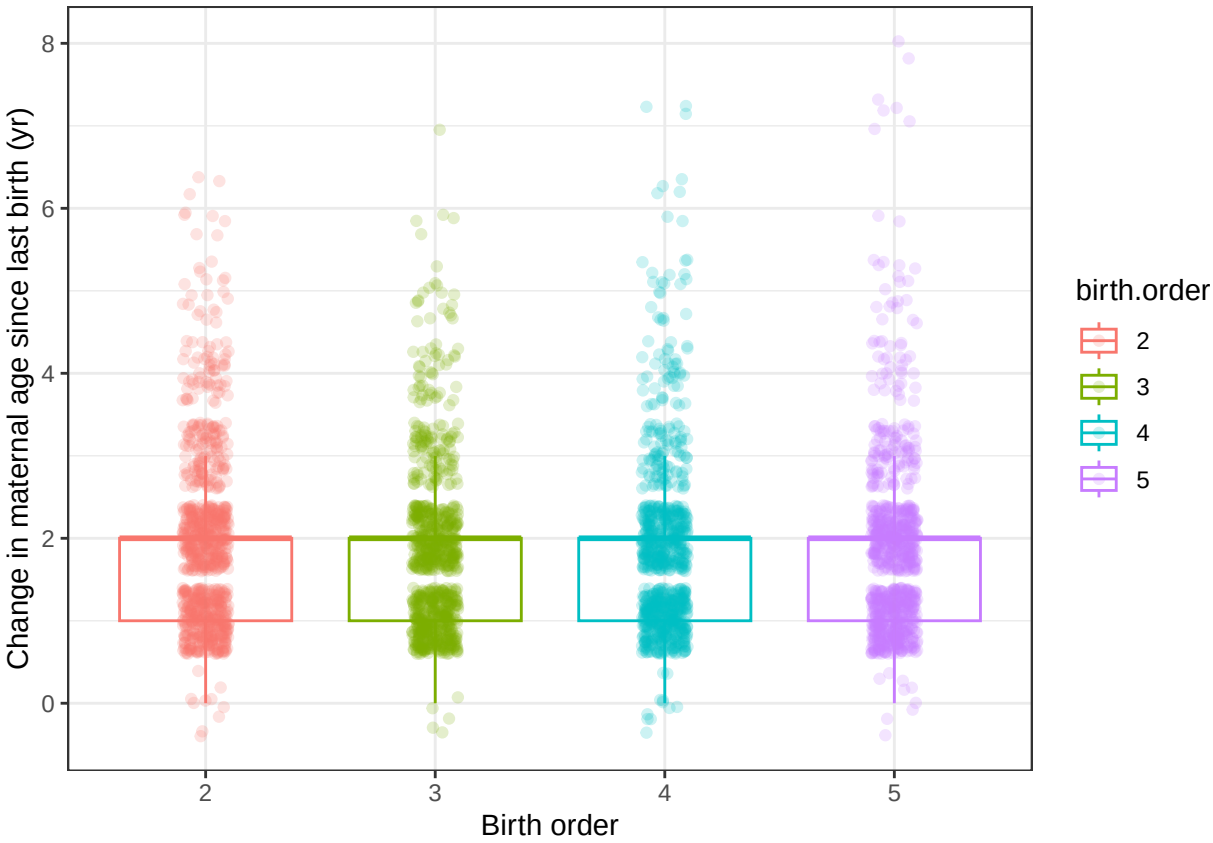
(b) Stratify the plot by very low / low / not low birth weight

```
gg4.weight.interval + facet_wrap(vars(birth.weight.factor))
```



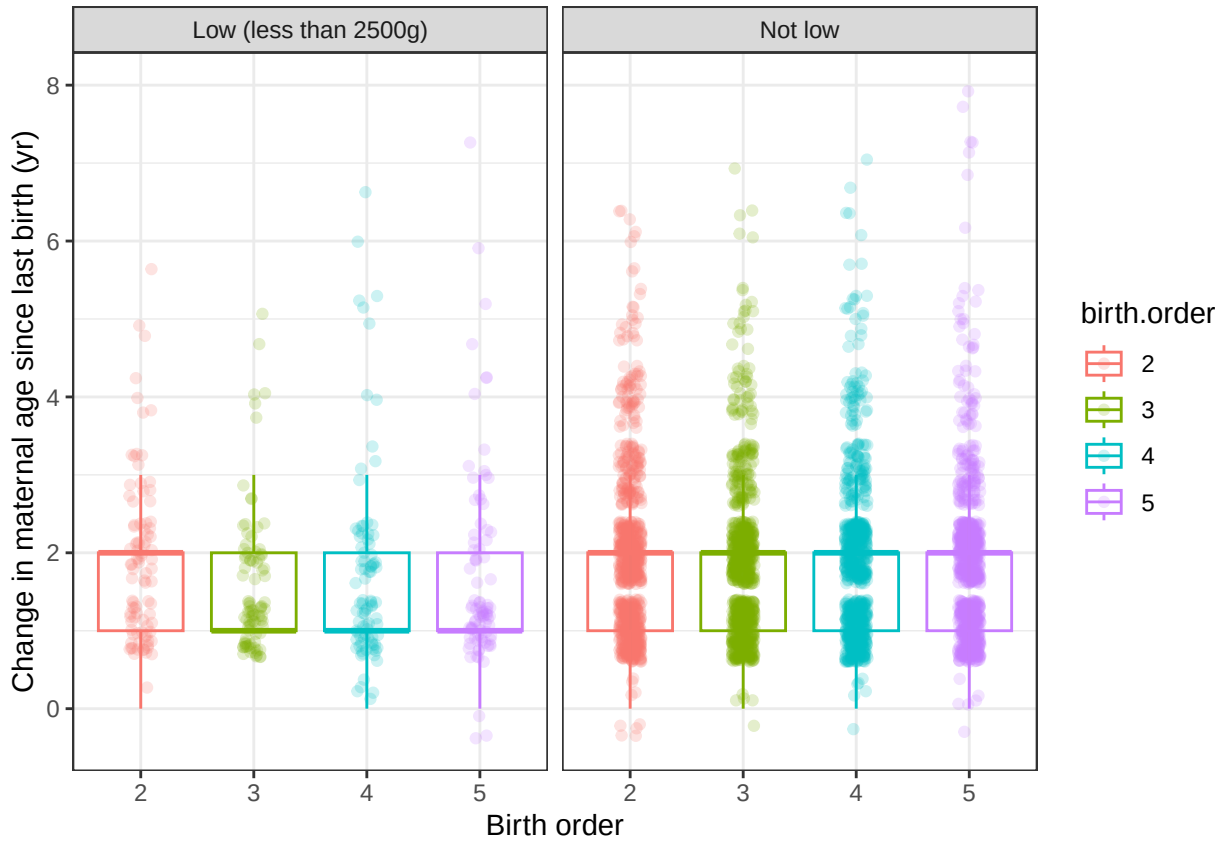
5. Produce a boxplot of interval across birth order for all non-firstborns (such that interval is defined). Is there a visual trend?

```
gg5.interval.order <- birthwt %>%
  filter(!is.na(interval)) %>%
  ggplot(aes(x = birth.order, y = interval, group = birth.order,
             color = birth.order)) +
    geom_boxplot(outlier.shape = NA, alpha = 0.1) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    xlab("Birth order") + ylab("Change in maternal age since last birth (yr)") +
    theme_bw()

gg5.interval.order
```



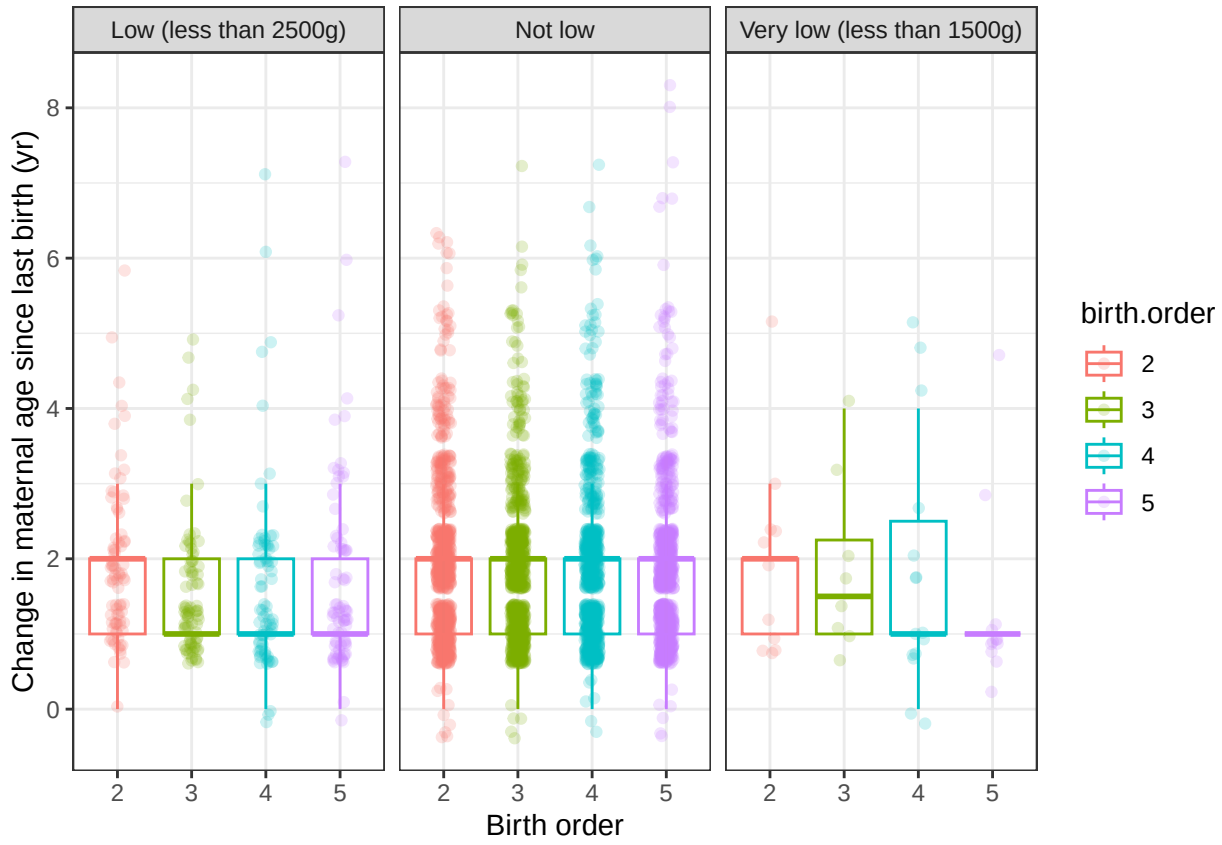
(a) Stratify the plot by low / not low birth weight

```
gg5.interval.order + facet_wrap(vars(birth.weight.binary))
```



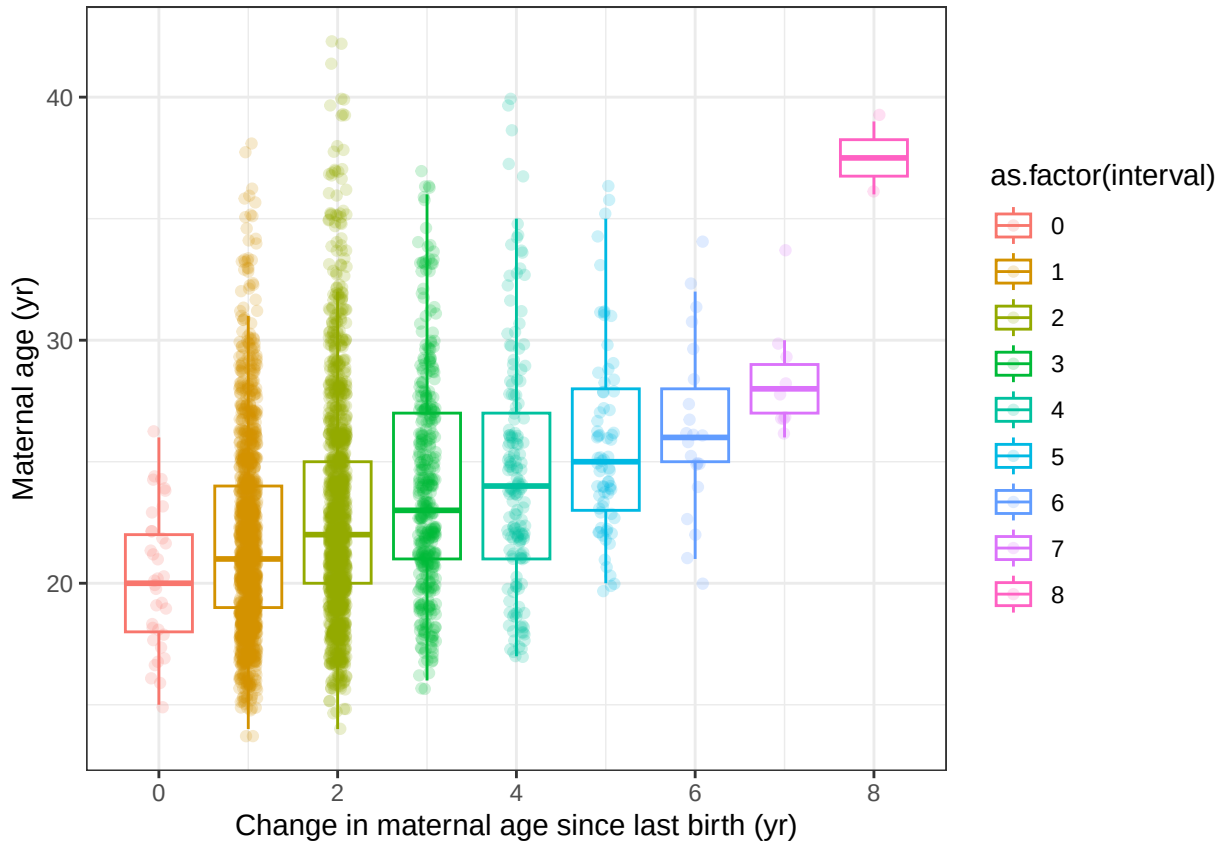
(b) Stratify the plot by very low / low / not low birth weight

```
gg5.interval.order + facet_wrap(vars(birth.weight.factor))
```



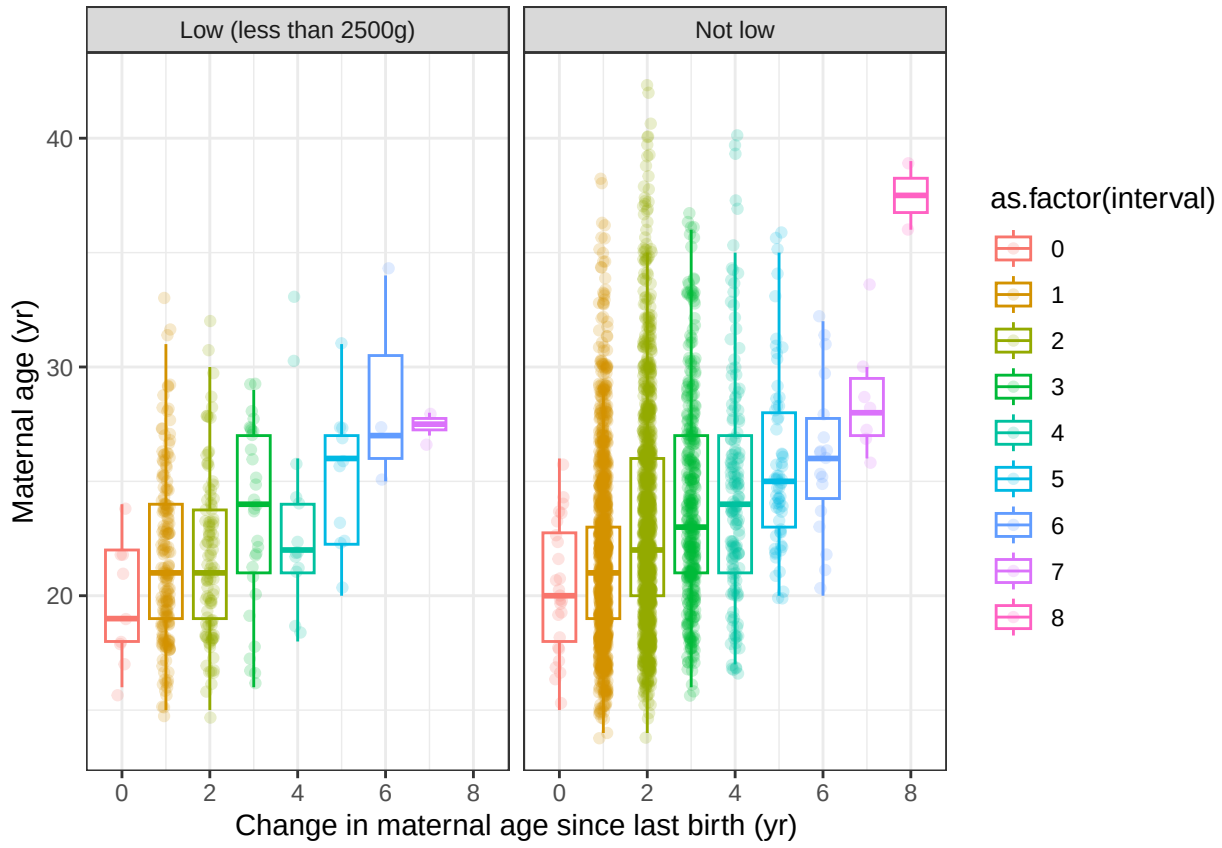
6. Produce a boxplot of maternal age across interval for all non-firstborns (such that interval is defined). Is there a visual trend?

```
gg6.interval.age <- birthwt %>%
  filter(!is.na(interval)) %>%
  ggplot(aes(x = interval, y = maternal.age, group = interval,
             color = as.factor(interval))) +
    geom_boxplot(outlier.shape = NA) +
    geom_jitter(width = 0.1, alpha = 0.2) +
    xlab("Change in maternal age since last birth (yr)") +
    ylab("Maternal age (yr)") +
    theme_bw()

gg6.interval.age
```



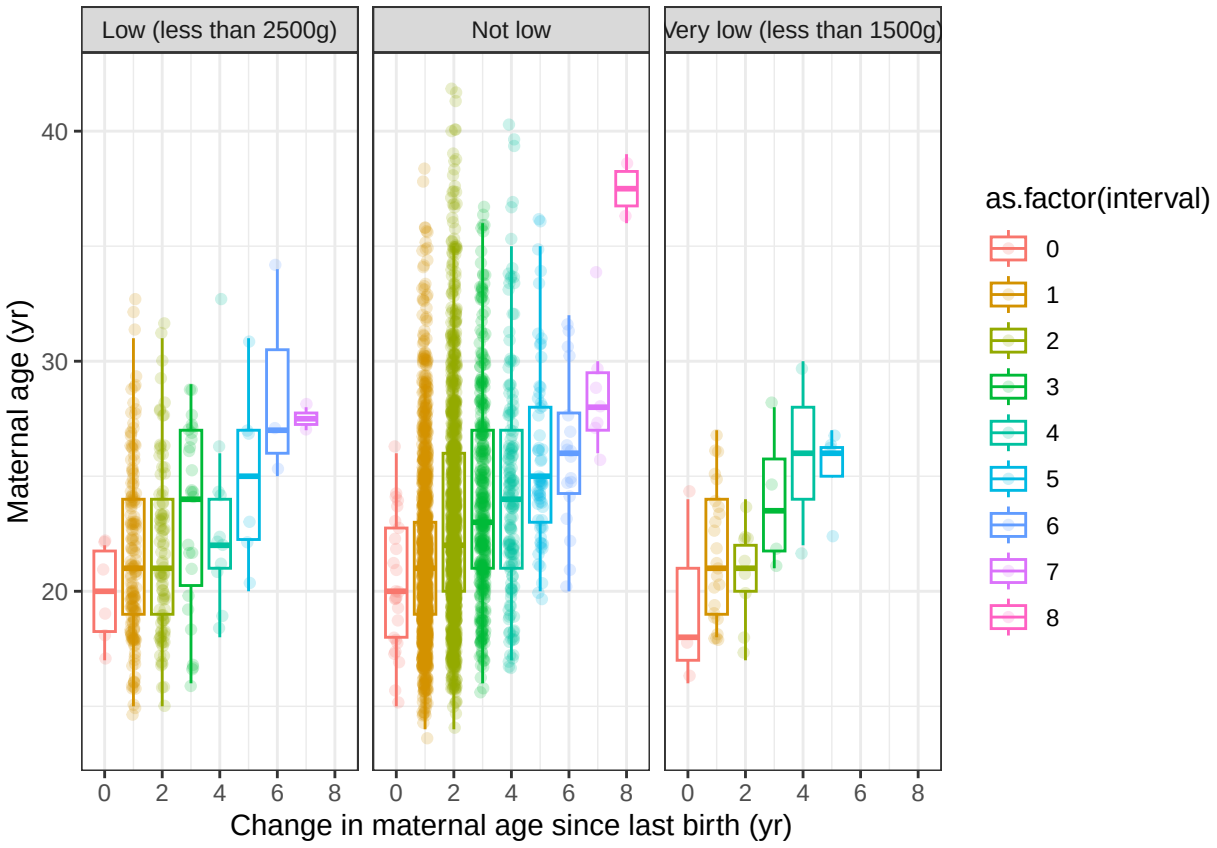
(a) Stratify the plot by low / not low birth weight

```
gg6.interval.age + facet_wrap(vars(birth.weight.binary))
```



(b) Stratify the plot by very low / low / not low birth weight

```
gg6.interval.age + facet_wrap(vars(birth.weight.factor))
```



Spaghetti plots

7. Produce a spaghetti plot of birth weights versus birth order, marking the threshold for low birth weight; include individual and overall averages. Does baseline birth weight seem to inform subsequent values?

(a) Color the plot by age group
(b) Color the plot by interval

8. Produce a spaghetti plot of birth weights versus maternal age, marking the threshold for low birth weight; include individual and overall averages. Does baseline birth weight seem to inform subsequent values?

(a) Color the plot by (i) age group, (ii) interval

9. Produce a spaghetti plot of percent in birth weight group versus maternal age. Repeat for number in birth weight group versus maternal age. Compare the two. Does the most common birth weight group change as mothers age?

Modeling

Modeling birth weight from interpregnancy interval (and more?)

Consider two response variables: birth weight, which is a continuous variable measured in grams, and low-weight birth, a binary indicator variable.

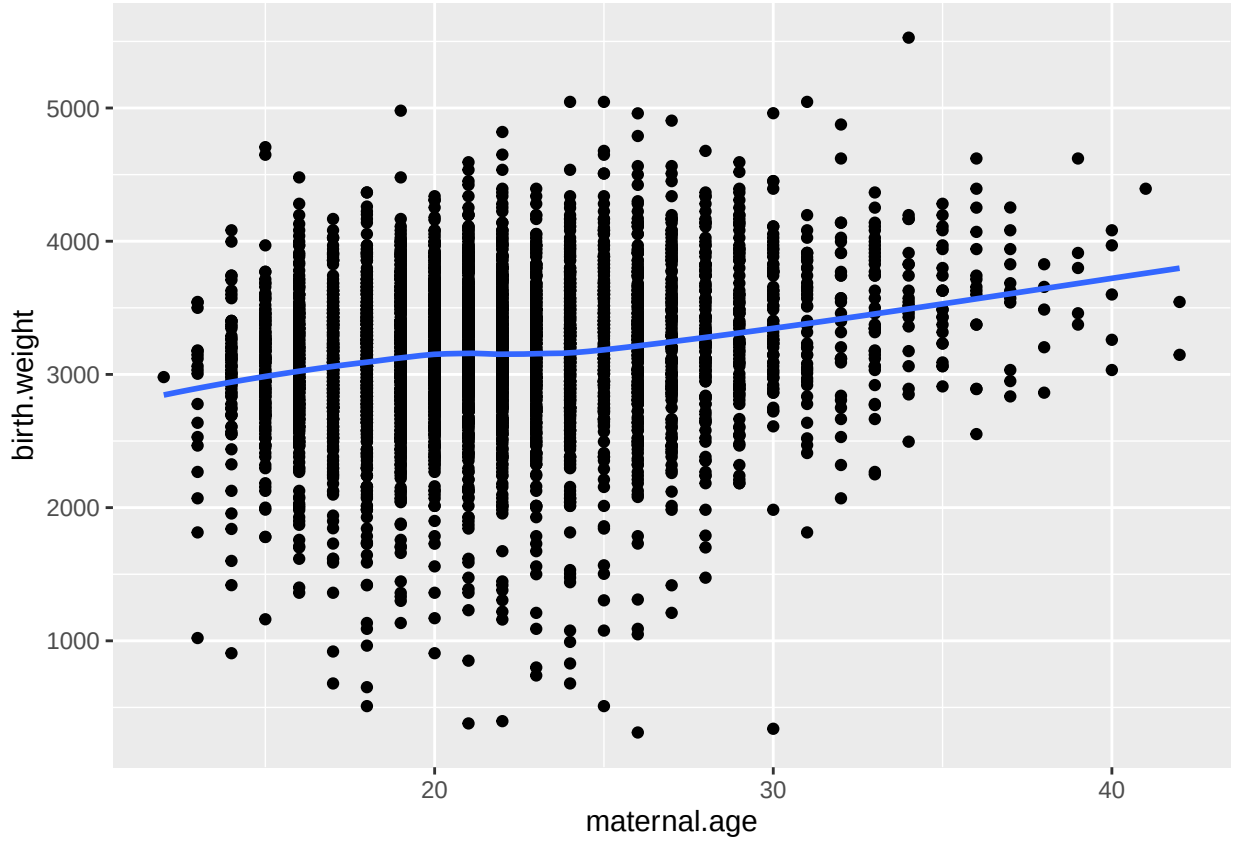
1. Model birth weight using a linear mixed effects model and interpret its coefficients.
2. Model birth weight using a linear fixed effects model and interpret its coefficients.
3. Compare the estimates and standard errors of the two models. Do they suggest different conclusions about effects? Do you believe a nonlinear model is well-motivated?
4. Model low-weight birth using logistic regression and interpret its coefficients.

Birth weight vs covariates

Covariates: Maternal age, interpregnancy interval, birth order

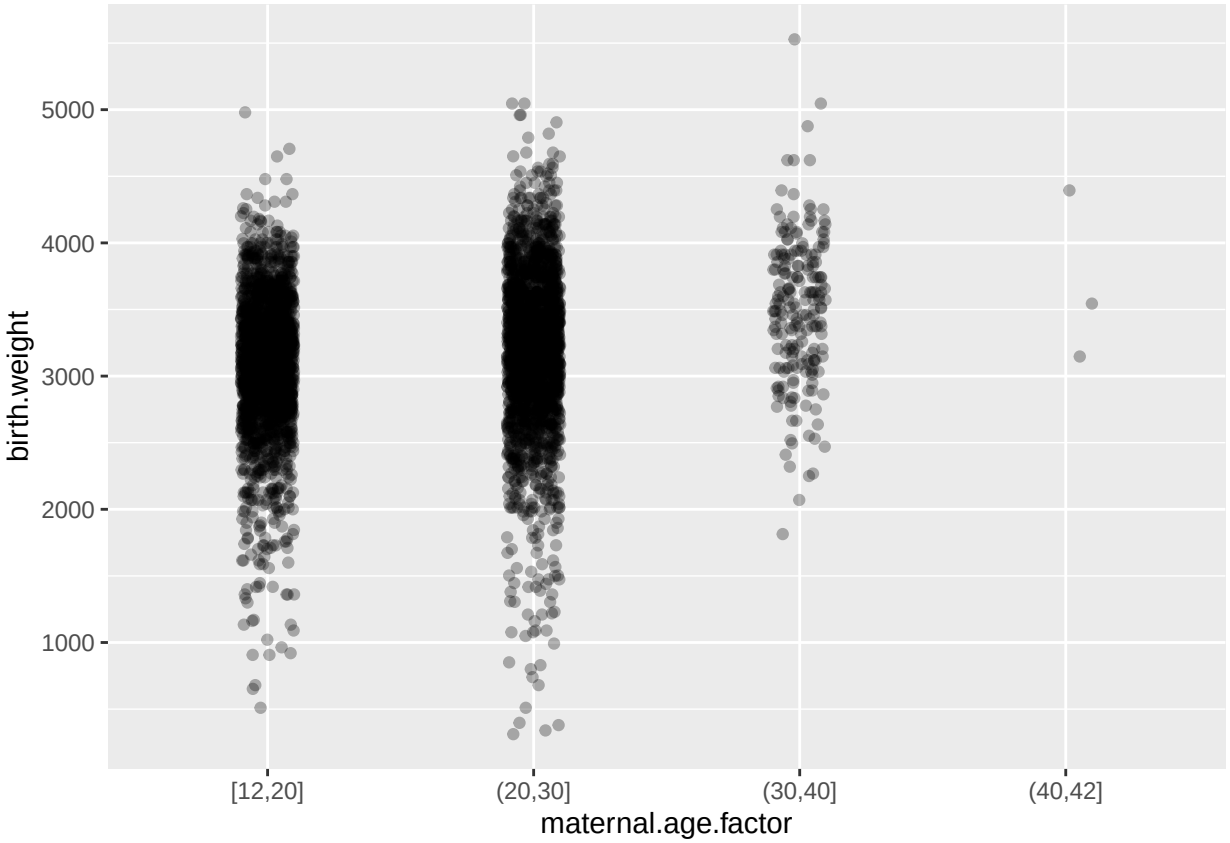
```
# plot birth weight vs maternal age
birthwt %>%
  ggplot(aes(x = maternal.age, y = birth.weight)) +
  geom_point() +
  geom_smooth(method = "loess", se = F)
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



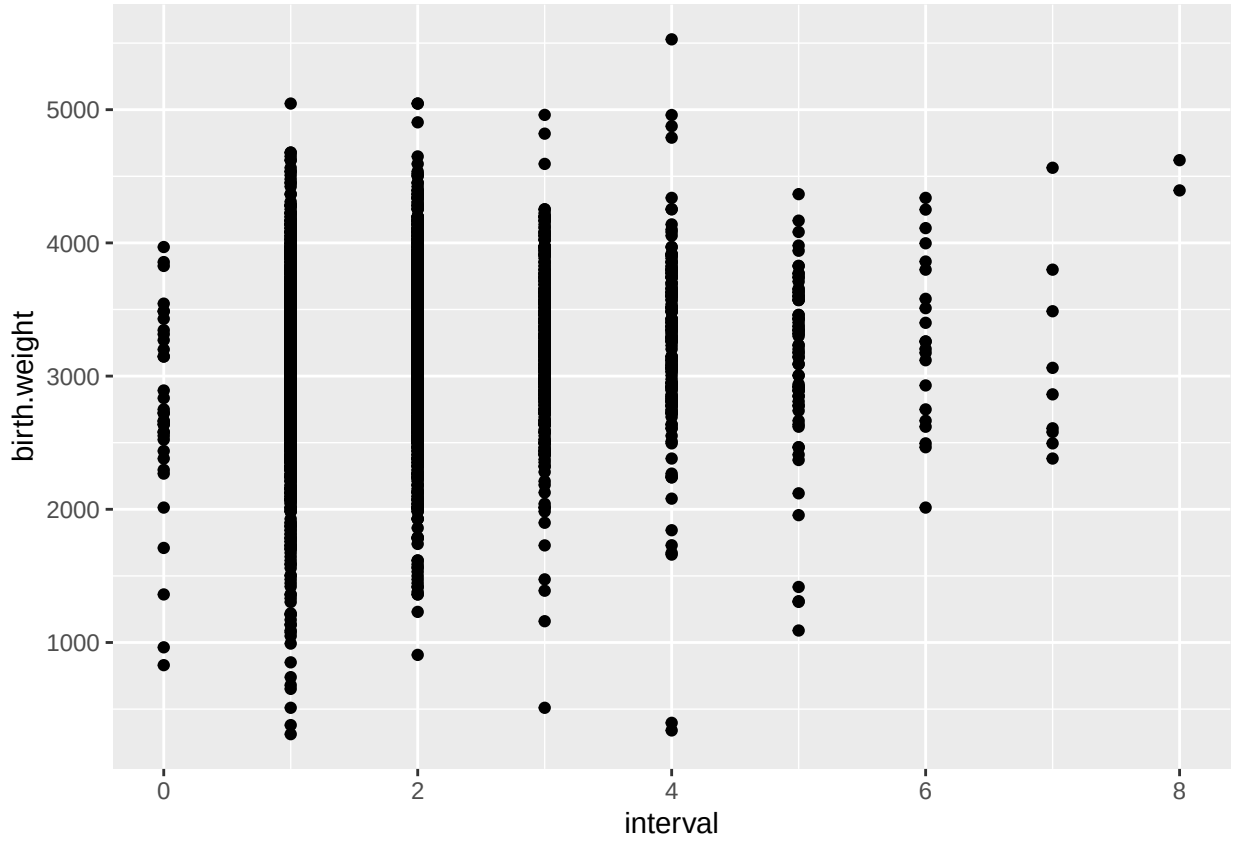

```
birthwt %>%
  ggplot(aes(x = maternal.age.factor, y = birth.weight)) +
  geom_jitter(width = 0.1, height = 0, alpha = 0.3) +
  geom_smooth(method = "loess", se = F)
```

```
## `geom_smooth()` using formula = 'y ~ x'
```

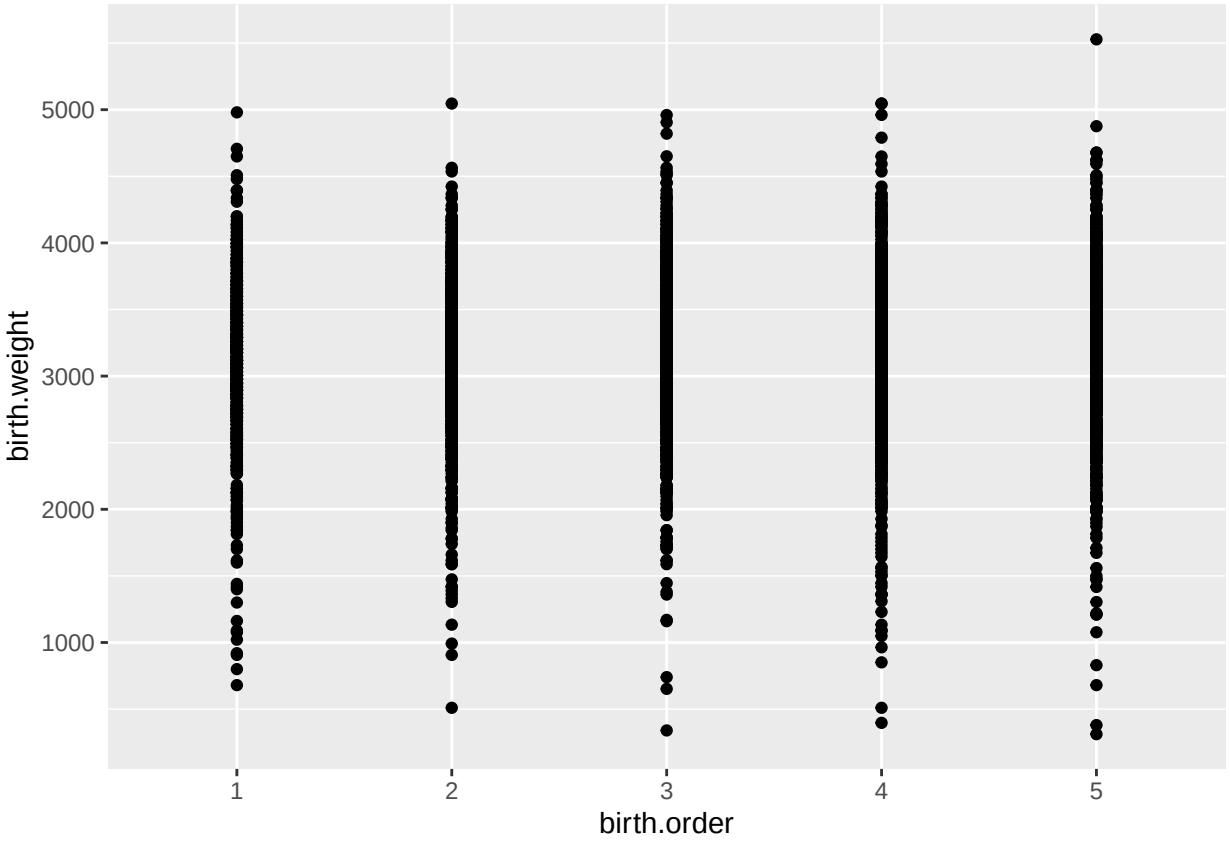



```
# plot birth weight vs interpregnancy interval
birthwt %>%
  ggplot(aes(y = birth.weight, x = interval)) +
  geom_point()
```

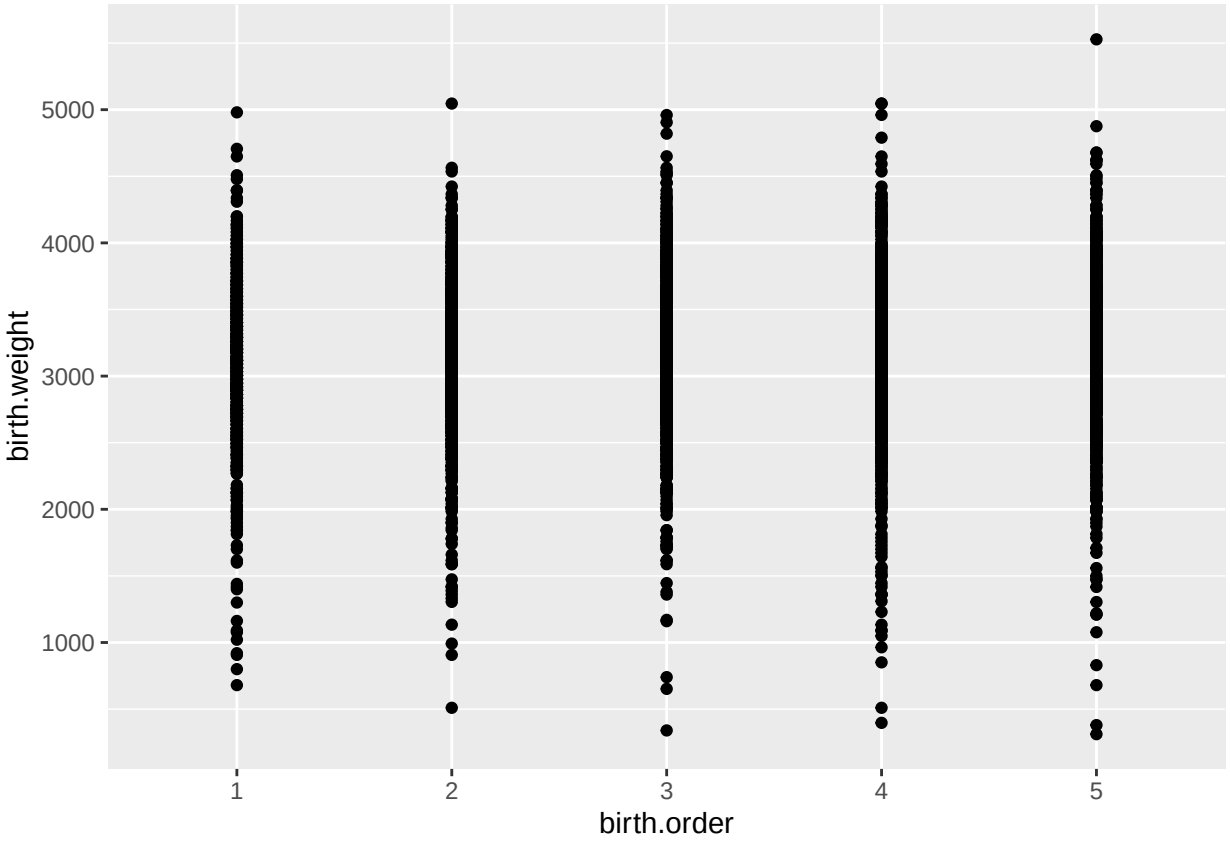
```
## Warning: Removed 876 rows containing missing values (‘geom_point()‘).
```




```
# plot birth weight vs birth order
birthwt %>%
  ggplot(aes(y = birth.weight, x = birth.order)) +
  geom_point()
```




```
# plot birth weight vs birth order
birthwt %>%
  ggplot(aes(y = birth.weight, x = birth.order)) +
  geom_point()
```


5000
4000
3000
2000
1000
birth.weight
1
2
3
4
5
birth.order