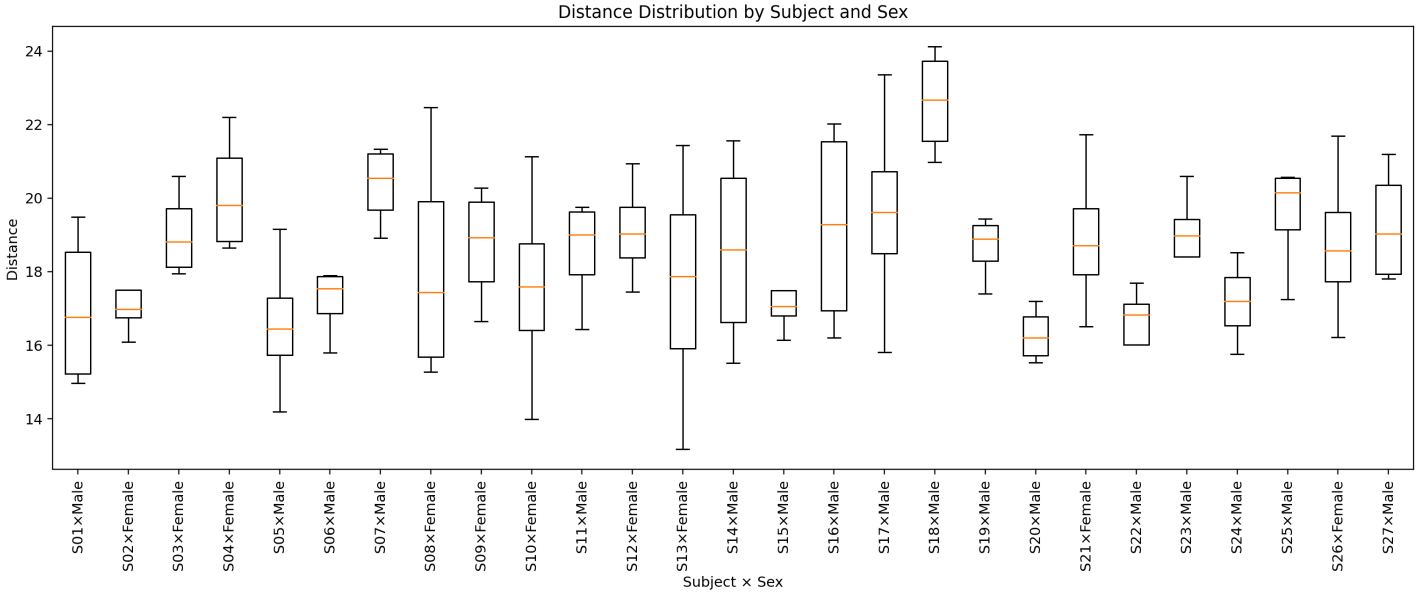
Longitudinal Mixed-Effects Modeling Portfolio

Distance Distribution by Subject and Sex

```
# 2.1 Boxplot: Distance by Subject and Sex
p_box_subject_sex <- ggplot(df, aes(x = interaction(Subject, Sex), y = distance, fill = Sex)) +
  geom_boxplot(outlier.alpha = 0.35) +
  labs(
    title = "Distance Distribution by Subject and Sex",
    x = "Subject × Sex",
    y = "Distance"
  ) +
  theme_bw() +
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1))

ggsave(file.path(out_dir, "01_boxplot_subject_sex.png"), p_box_subject_sex,
       width = 14, height = 6, dpi = 220)

print(p_box_subject_sex)
```



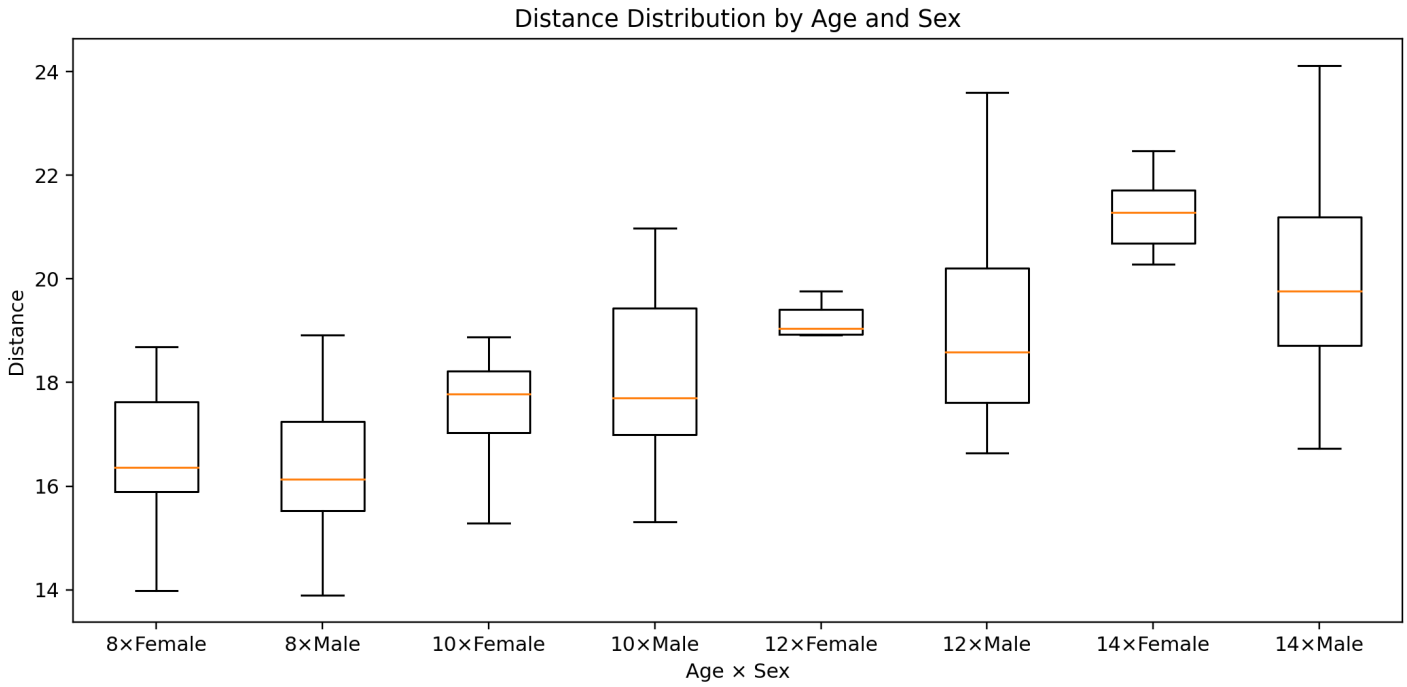
Interpretation: Strong between-subject variability supports subject-level random intercepts.

Distance Distribution by Age and Sex

```
# 2.2 Boxplot: Distance by Age and Sex
p_box_age_sex <- ggplot(df, aes(x = interaction(age, Sex), y = distance, fill = Sex)) +
  geom_boxplot(outlier.alpha = 0.35) +
  labs(
    title = "Distance Distribution by Age and Sex",
    x = "Age × Sex",
    y = "Distance"
  ) +
  theme_bw() +
  theme(axis.text.x = element_text(angle = 0))

ggsave(file.path(out_dir, "02_boxplot_age_sex.png"), p_box_age_sex,
       width = 10, height = 5, dpi = 220)

print(p_box_age_sex)
```



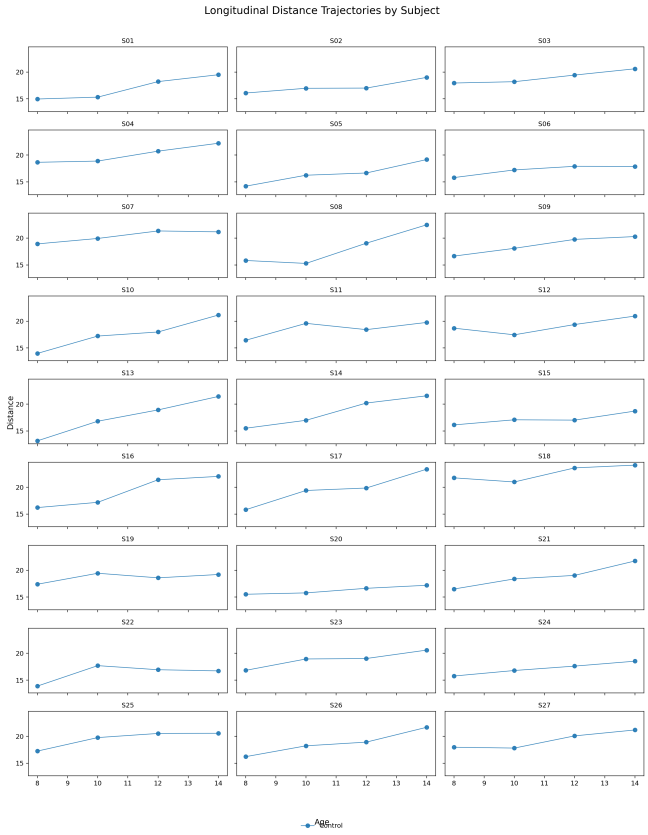
Interpretation: Distance increases with age; patterns suggest potential age×Sex interaction.

Longitudinal Distance Trajectories by Subject

```
# 2.3 Spaghetti plot: longitudinal trajectories by subject (faceted)
p_spaghetti <- ggplot(df, aes(x = age, y = distance, color = Group)) +
  geom_point(alpha = 0.75) +
  geom_line(aes(group = Subject), alpha = 0.60) +
  facet_wrap(~ Subject) +
  labs(
    title = "Longitudinal Distance Trajectories by Subject",
    x = "Age",
    y = "Distance"
  ) +
  theme_bw() +
  theme(legend.position = "bottom")

ggsave(file.path(out_dir, "03_spaghetti_by_subject.png"), p_spaghetti,
       width = 14, height = 10, dpi = 220)

print(p_spaghetti)
```



Interpretation: Individual growth patterns differ, supporting random slope specification.

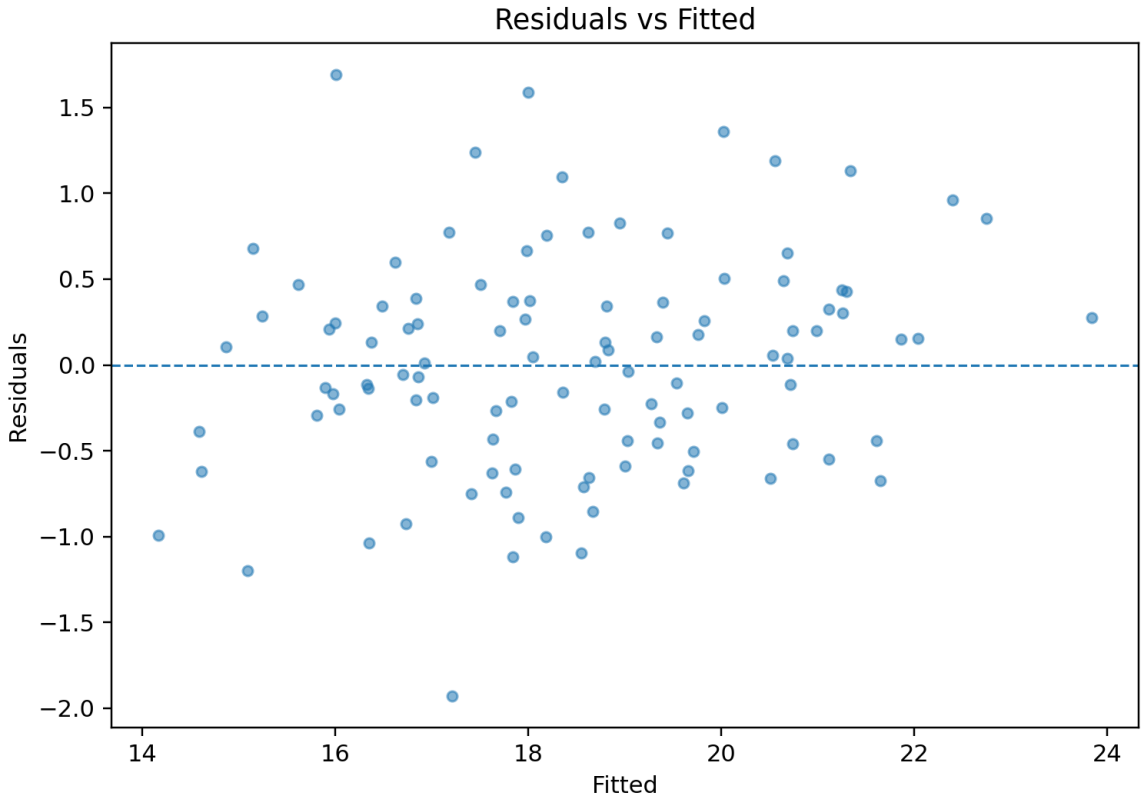
Residuals vs Fitted

```
# 4) Model Diagnostics (Pearson residuals)
resid_df <- tibble(
  fitted = fitted(m_full),
  resid  = resid(m_full, type = "pearson")
)

p_resid_fitted <- ggplot(resid_df, aes(x = fitted, y = resid)) +
  geom_point(alpha = 0.55) +
  geom_hline(yintercept = 0, linetype = "dashed") +
  labs(title = "Residuals vs Fitted (Pearson)", x = "Fitted", y = "Residuals") +
  theme_bw()

ggsave(file.path(out_dir, "04_residuals_vs_fitted.png"),
       p_resid_fitted, width = 7, height = 5, dpi = 220)

print(p_resid_fitted)
```



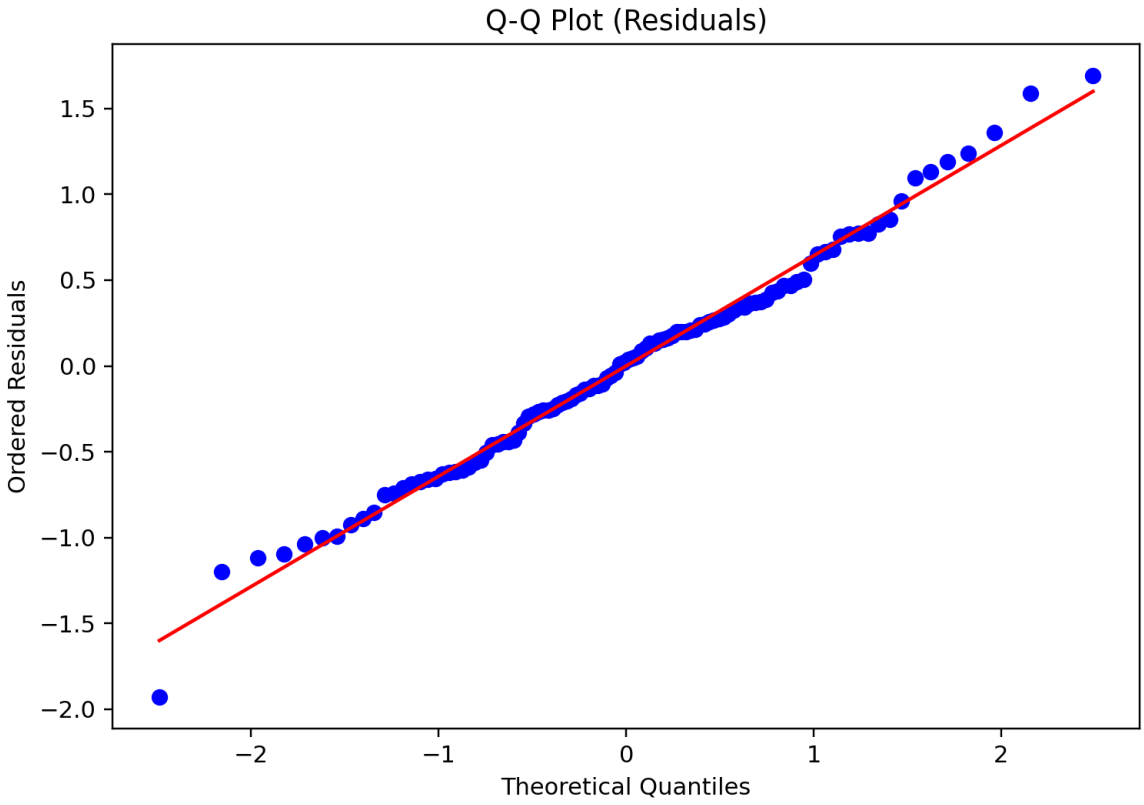
Interpretation: Residuals are centered around zero with no dominant structure; assumptions appear reasonable.

Q-Q Plot (Residuals)

```
# 4) Model Diagnostics — Q-Q Plot
p_qq <- ggplot(resid_df, aes(sample = resid)) +
  stat_qq(alpha = 0.5) +
  stat_qq_line() +
  labs(title = "Q-Q Plot (Pearson Residuals)",
       x = "Theoretical Quantiles", y = "Sample Quantiles") +
  theme_bw()

ggsave(file.path(out_dir, "05_qq_plot.png"),
       p_qq, width = 7, height = 5, dpi = 220)

print(p_qq)
```



Interpretation: Residual distribution aligns with normality assumption.

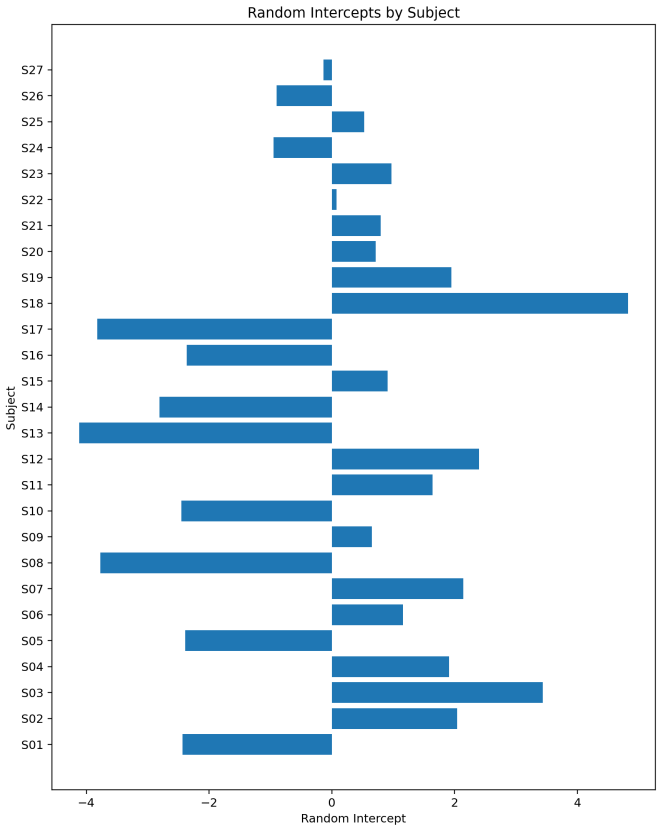
Random Intercepts by Subject

```
# Random effects inspection
re <- ranef(m_full)
re$Subject <- rownames(re)

# Random intercepts
p_re_int <- ggplot(re, aes(x = reorder(Subject, `(Intercept)`), y = `(Intercept)`)) +
  geom_col(alpha = 0.85) +
  coord_flip() +
  labs(title = "Random Intercepts by Subject", x = "Subject", y = "Random Intercept") +
  theme_bw()

ggsave(file.path(out_dir, "06_random_intercepts.png"),
       p_re_int, width = 8, height = 10, dpi = 220)

print(p_re_int)
```



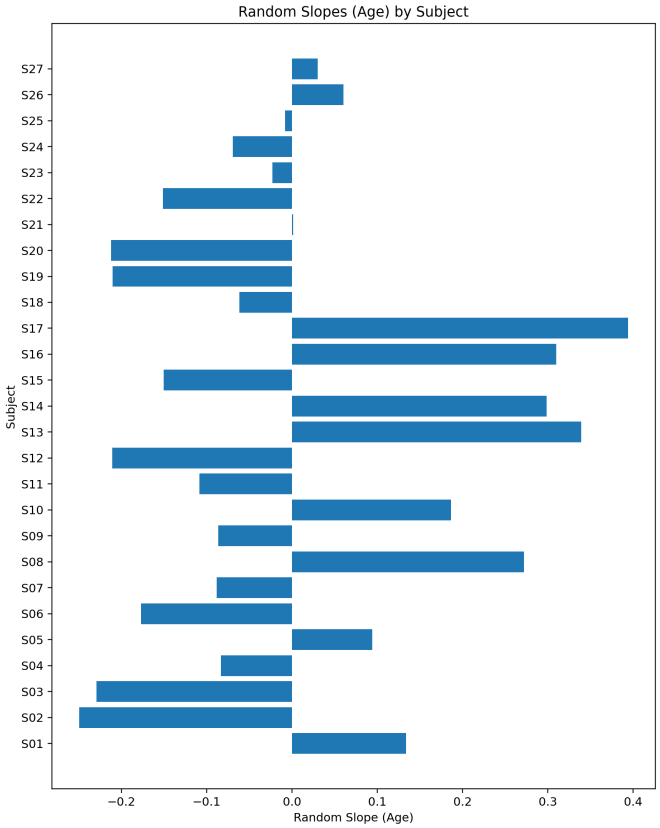
Interpretation: Substantial baseline variability across individuals.

Random Slopes (Age) by Subject

```
# Random slopes (Age)
p_re_slope <- ggplot(re, aes(x = reorder(Subject, age), y = age)) +
  geom_col(alpha = 0.85) +
  coord_flip() +
  labs(title = "Random Slopes (Age) by Subject", x = "Subject", y = "Random Slope") +
  theme_bw()

ggsave(file.path(out_dir, "07_random_slopes.png"),
       p_re_slope, width = 8, height = 10, dpi = 220)

print(p_re_slope)
```



Interpretation: Heterogeneous growth rates across subjects.

Fixed-Effects Predictions (Marginal Trends)

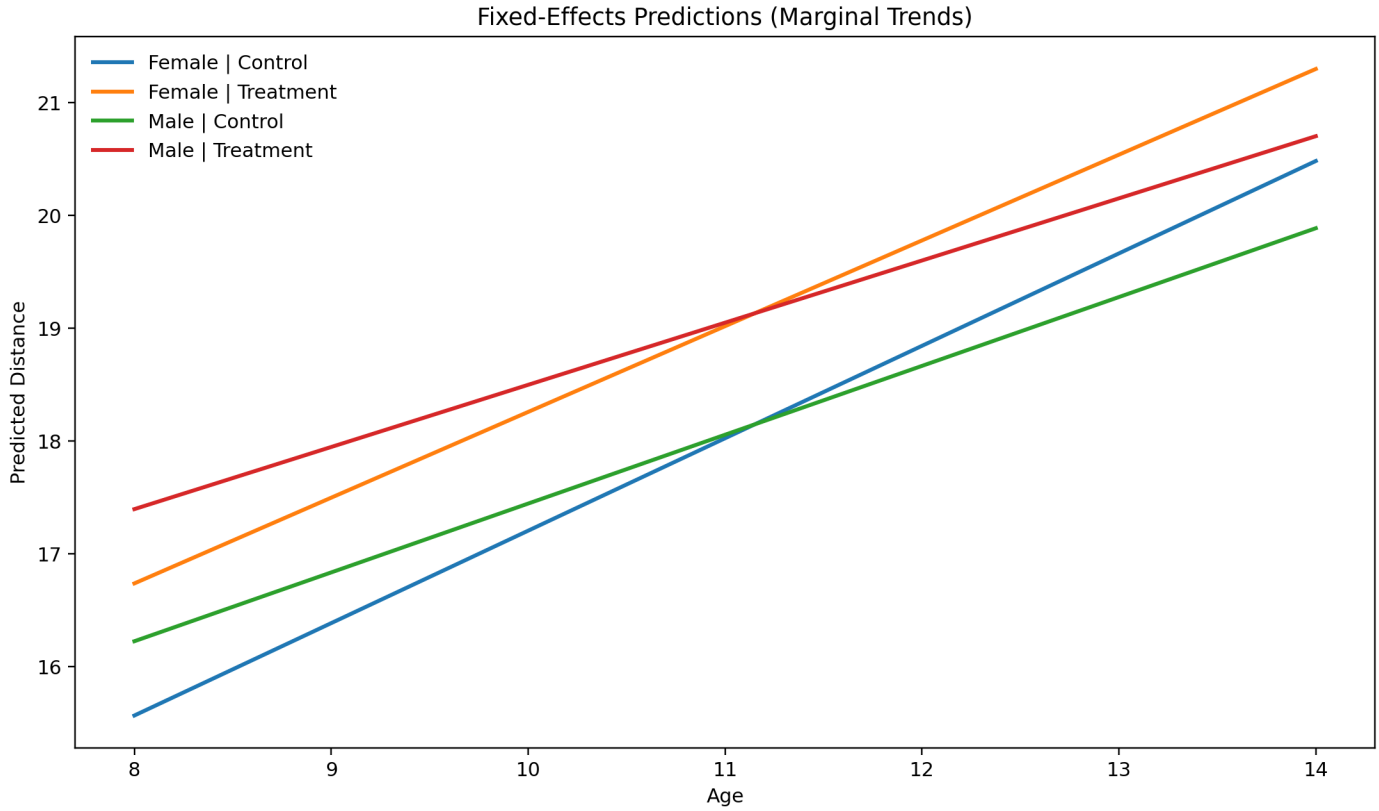
```
# 5) Predictions — Fixed-effects marginal trends
pred_grid <- expand_grid(
  age = seq(min(df$age), max(df$age), by = 0.25),
  Sex = levels(df$Sex),
  Group = levels(df$Group),
  Subject = df$Subject[1]  # placeholder (fixed-effects only)
)

pred_grid$pred_fixed <- predict(m_full, newdata = pred_grid, level = 0)

p_pred <- ggplot(pred_grid, aes(x = age, y = pred_fixed, color = Sex, linetype = Group)) +
  geom_line(linewidth = 1.2) +
  labs(
    title = "Fixed-Effects Predictions (Marginal Trends)",
    x = "Age",
    y = "Predicted Distance",
    color = "Sex",
    linetype = "Group"
  ) +
  theme_bw() +
  theme(legend.position = "bottom")

ggsave(file.path(out_dir, "08_fixed_effect_predictions.png"),
       p_pred, width = 10, height = 6, dpi = 220)

print(p_pred)
```



Interpretation: Predicted trajectories increase with age; interaction effects indicate differentiated growth patterns.