

Quick returns, sleep, sleepiness and stress – An intra-individual field study on objective sleep data and diary data¹

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Model output & sensitivity analyses

Below reads the model output for all original models, together with the results from the sensitivity analyses.

For all outcomes, sensitivity tests of unpaired t-tests were performed, using only data from the second measurement day. The purpose of these analyses was to check sensitivity to order effects, as day-day transitions tended to follow directly after quick returns (evening-day-day). As a result, there could be nonlinear order effects or nonlinear interactions with the order of shifts, that we couldn't control for in the models. In the sensitivity analysis, the degree of deviance between estimates are of interest but not the p-values.

For stress and sleepiness during work hours, we also conducted sensitivity tests on the pre-registered operationalizations. We checked the degree of deviance in estimates from a strict operationalization including only data from work hours, to the operationalization used in the analysis which included ratings 15 minutes prior to beginning work and 15 minutes after ending ones work. In the strict operationalization, we would only include ratings at 10 and 13 for a person working 07.15-15.45. In the

pre-registered operationalization, the ratings at 07 and 16 are also included in the analysis.

For sleep length, objective (Fragmentation index) and subjective (KSD-SQI) sleep quality - the pre-registered plan was to perform paired sample t-test. To control for order effects, mlm-models were analyzed instead. Here, the results from paired t-tests are also presented to show how they potentially differ.

Stress during work

Original model output:

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
```

```
Formula: stress_work ~ shift + tid + order + (shift + order | id)
```

```
Data: d_stress
```

```
REML criterion at convergence: 3021.1
```

```
Scaled residuals:
```

```
   Min    1Q  Median    3Q   Max
-2.91789 -0.58570 -0.03652  0.58197  3.14185
```

```
Random effects:
```

```
Groups Name      Variance Std.Dev. Corr
id      (Intercept) 2.3084  1.5193
        shiftQR    1.4642  1.2100 -0.55
        order      0.1629  0.4036 -0.34 -0.09
Residual      1.7444  1.3208
Number of obs: 799, groups: id, 89
```

```
Fixed effects:
```

```
      Estimate Std. Error    df t value Pr(>|t|)
(Intercept)  3.70440   0.22105  77.85440  16.758 < 2e-16 ***
shiftQR      0.26101   0.17853  67.79905   1.462  0.1484
tid10        0.57132   0.12406  563.79564   4.605 5.10e-06 ***
tid13        0.81321   0.12398  565.32958   6.559 1.22e-10 ***
tid16        0.39585   0.16907  603.88289   2.341  0.0195 *
order        0.21175   0.08304  34.52508   2.550  0.0154 *
```

```
---
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Correlation of Fixed Effects:
```

```
      (Intr) shiftQR tid10 tid13 tid16
shiftQR -0.595
tid10    -0.303  0.008
tid13    -0.308  0.013  0.530
```

```
tid16 -0.225 0.020 0.388 0.391
order -0.515 0.213 0.008 0.011 -0.006
```

Sensitivity analysis, unpaired t-test

Welch Two Sample t-test

```
data: qr and dd
t = 0.91085, df = 56.818, p-value = 0.3662
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.4016352 1.0717984
sample estimates:
mean of x mean of y
4.428030 4.092949
```

The estimated difference of the unpaired t-test (diff = 0.34) is close to the estimated effect of shift in the mlm-model ($\beta = 0.26$).

Sensitivity analysis of the operationalization of stress at work

Linear mixed model fit by REML. t-tests use Satterthwaite's method [lmerModLmerTest]

Formula: stressw ~ shift + order + tid + (shift + order | id)
Data: dtib

REML criterion at convergence: 2959.7

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.90064	-0.58177	-0.03499	0.57732	3.12991

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
id	(Intercept)	2.3401	1.5298	
	shiftQR	1.4739	1.2140	-0.57
	order	0.1497	0.3869	-0.35 -0.04
Residual		1.7584	1.3260	

Number of obs: 781, groups: id, 89

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	3.6851	0.2230	78.7652	16.523	< 2e-16 ***
shiftQR	0.2858	0.1794	68.1471	1.593	0.11581
order	0.2091	0.0825	35.3231	2.535	0.01584 *
tid10	0.5867	0.1254	549.9513	4.680	3.62e-06 ***
tid13	0.8231	0.1251	551.1589	6.578	1.11e-10 ***
tid16	0.5049	0.1811	593.0499	2.788	0.00547 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

```

      (Intr) shftQR order tid10 tid13
shiftQR -0.604
order   -0.519  0.238
tid10   -0.307  0.009  0.010
tid13   -0.311  0.014  0.011  0.535
tid16   -0.216  0.024 -0.007  0.369  0.372

```

The estimated effect of shift in the model with the strict operationalization ($\beta = 0.29$) does not deviate from that of the pre-registered operationalization in the original model ($\beta = 0.26$).

Sleepiness during work

Original model output:

```

Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: KSS_work ~ shift + tid + order + (shift + order | id)
Data: d_KSSwork

REML criterion at convergence: 2899.1

Scaled residuals:
   Min    1Q  Median    3Q   Max
-2.9316 -0.6066 -0.0899  0.6317  3.2473

Random effects:
Groups Name      Variance Std.Dev. Corr
id      (Intercept) 2.67123  1.6344
        shiftQR    0.58547  0.7652  -0.38
        order     0.04274  0.2067  -0.84  0.05
Residual      1.55736  1.2479
Number of obs: 810, groups: id, 90

Fixed effects:
              Estimate Std. Error    df t value Pr(>|t|)
(Intercept)  4.59868    0.27246  67.02732 16.878 < 2e-16 ***
shiftQR      0.45039    0.13163  69.05962  3.422  0.00105 **
tid10       -0.92996    0.11634  621.99887 -7.994  6.39e-15 ***
tid13       -0.63573    0.11636  624.11652 -5.463  6.75e-08 ***
tid16        0.24345    0.15629  662.46565  1.558  0.11979
order        0.08464    0.05650  42.57929  1.498  0.14155
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
      (Intr) shftQR tid10 tid13 tid16
shiftQR -0.489
tid10   -0.234  0.009
tid13   -0.236  0.012  0.528

```

```
tid16 -0.167 0.020 0.392 0.394
order -0.832 0.290 0.010 0.011 -0.008
```

Sensitivity analysis, unpaired t-test

Welch Two Sample t-test

```
data: qr and dd
t = 1.6364, df = 49.549, p-value = 0.1081
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.1342752 1.3137624
sample estimates:
mean of x mean of y
4.833333 4.243590
```

The estimated difference of the unpaired t-test (diff = 0.59) is close to the estimated effect of shift in the mlm-model ($\beta = 0.45$).

Sensitivity analysis of operationalisation

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: kssw ~ shift + tid + order + (shift | id)
Data: dtib
```

REML criterion at convergence: 2843.9

Scaled residuals:

```
Min 1Q Median 3Q Max
-2.8546 -0.6157 -0.0920 0.6186 3.2796
```

Random effects:

```
Groups Name Variance Std.Dev. Corr
id (Intercept) 1.3182 1.1481
shiftQR 0.6671 0.8168 -0.43
Residual 1.5722 1.2539
Number of obs: 792, groups: id, 90
```

Fixed effects:

```
Estimate Std. Error df t value Pr(>|t|)
(Intercept) 4.66408 0.24472 338.76148 19.059 < 2e-16 ***
shiftQR 0.41462 0.13399 99.20887 3.094 0.00256 **
tid10 -0.91859 0.11758 619.56219 -7.813 2.41e-14 ***
tid13 -0.62473 0.11747 621.33661 -5.318 1.46e-07 ***
tid16 0.18640 0.16719 657.07006 1.115 0.26531
order 0.06992 0.05308 471.10156 1.317 0.18838
---
```

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

```
(Intr) shftQR tid10 tid13 tid16
shiftQR -0.507
tid10 -0.266 0.010
tid13 -0.268 0.014 0.533
tid16 -0.184 0.026 0.374 0.376
order -0.767 0.295 0.012 0.013 -0.005
```

The estimated effect of shift in the model with the strict operationalization ($\beta = 0.41$) does not deviate from that of the pre-registered operationalization ($\beta = 0.45$).

Sleepiness during leisure.

Original model output:

Linear mixed model fit by REML. t-tests use Satterthwaite's method [lmerModLmerTest]
Formula: KSS_leisure ~ shift + tid + order + (shift | id)
Data: d_leisure

REML criterion at convergence: 2304.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.92479	-0.57623	0.06721	0.61024	2.45052

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
id	(Intercept)	1.057	1.0283	
	shiftQR	0.510	0.7142	-0.17
	Residual	2.427	1.5579	

Number of obs: 579, groups: id, 90

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	5.21362	0.20713	226.73541	25.171	< 2e-16 ***
shiftQR	0.35754	0.16457	104.84680	2.173	0.0321 *
tid19	-0.16567	0.16334	443.58219	-1.014	0.3110
tid22	1.13348	0.17304	456.74377	6.550	1.55e-10 ***
order	0.05864	0.06822	325.84751	0.860	0.3907

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

```
(Intr) shftQR tid19 tid22
shiftQR -0.467
tid19 -0.473 0.010
tid22 -0.438 0.004 0.571
order -0.482 0.305 -0.012 -0.042
```

Sensitivity analysis, unpaired t-test

Welch Two Sample t-test

```
data: qr and dd
t = 0.49484, df = 57.908, p-value = 0.6226
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.5548357 0.9192232
sample estimates:
mean of x mean of y
5.829630 5.647436
```

The estimated difference of the unpaired t-test (diff = 0.18) is half the size of the estimated effect of shift in the mlm-model ($\beta = 0.36$). The result indicates that there may be confounding due to the order of shift.

Sleepiness - interaction model

Original model output

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: KSS_work ~ shift:tid + order + shift + tid + (shift | id)
##           Data: d_H5agg
##
## REML criterion at convergence: 2374.4
##
## Scaled residuals:
##           Min           1Q   Median    3Q           Max
## -2.77473 -0.58053 -0.06905  0.56451  3.00882
##
## Random effects:
## Groups  Name              Variance Std.Dev. Corr
## id      (Intercept)  1.3954   1.1813
##          shiftQR      0.7047   0.8394  -0.43
## Residual              1.2865   1.1342
## Number of obs: 685, groups: id, 90
##
## Fixed effects:
##           Estimate Std. Error      df t value Pr(>|t|)
## (Intercept)      4.60001      0.31389 198.61467 14.655 < 2e-16 ***
## order            0.08860      0.07300 135.55923  1.214 0.226995
## shiftQR          0.46516      0.20685 376.02132  2.249 0.025101 *
## tid10           -0.86003      0.17799 506.79656 -4.832 1.8e-06 ***
## tid13           -0.66025      0.17791 513.32699 -3.711 0.000229 ***
## tid16            0.22441      0.17795 509.88478  1.261 0.207847
## shiftQR:tid10    -0.18780      0.24714 505.93654 -0.760 0.447690
## shiftQR:tid13    0.07169      0.24703 509.67449  0.290 0.771777
```

```
## shiftQR:tid16 0.18499 0.25057 510.15429 0.738 0.460675
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##      (Intr) order shftQR tid10 tid13 tid16 sQR:10 sQR:13
## order      -0.820
## shiftQR     -0.549 0.266
## tid10       -0.300 0.004 0.451
## tid13       -0.308 0.010 0.458 0.523
## tid16       -0.305 0.008 0.454 0.521 0.528
## shftQR:tid10 0.216 -0.004 -0.620 -0.720 -0.376 -0.375
## shftQR:tid13 0.222 -0.008 -0.625 -0.377 -0.720 -0.380 0.518
## shftQR:tid16 0.214 -0.003 -0.614 -0.370 -0.375 -0.710 0.511 0.514
```

Fragmentation index

Original model output:

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: fragmentation_index ~ shift + order + (shift | id)
Data: d_wide
```

REML criterion at convergence: 1710.6

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.90113	-0.49427	-0.01652	0.47316	2.66403

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
id	(Intercept)	34.86	5.904	
	shiftQR	26.32	5.130	-0.19
	Residual	40.08	6.331	

Number of obs: 242, groups: id, 87

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	23.9484	1.7298	200.1436	13.845	<2e-16 ***
shiftQR	1.7213	1.0539	95.1611	1.633	0.106
order	-1.0743	0.4288	203.4932	-2.505	0.013 *

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr) shftQR
shiftQR	-0.477
order	-0.866 0.288

Sensitivity analysis, unpaired t-test

Welch Two Sample t-test

```
data: qr and dd
t = -0.84092, df = 52.357, p-value = 0.4042
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-6.905903 2.826655
sample estimates:
mean of x mean of y
21.84884 23.88846
```

The estimated difference from the sensitivity analysis is in the opposite direction to that of the mlm-model (diff = -2.04 vs. $\beta = 1.72$).

Sensitivity analysis, paired t-test

Paired t-test

```
data: qr_FI and dd_FI
t = 2.304, df = 86, p-value = 0.02364
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
0.3150389 4.2784477
sample estimates:
mean of the differences
2.296743
```

The paired t-test results in a significant difference of 2.3 percentage points more fragmented sleep during quick returns compared to day-day transitions ($p = 0.024$). This estimate does not, however, control for the confounding effect of order. The mlm-model (presented above) indicates that when order is inserted into the model, the effect of shift is no longer significant. As you can see in the model output, there is also a correlation between the parameters shift and order, which indicates that we cannot fully discern the effect of shift from that of order and vice versa. Thus, the data is inconclusive but more than not indicates that the difference we see here is due to the number of consecutive workdays (=order) rather than an effect of shift.

KSD-SQI

Original model output:

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
```

Formula: KSD_SQI ~ shift + order + (shift | id)

Data: d_wide

REML criterion at convergence: 593.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.7398	-0.5441	0.1204	0.6321	1.7429

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
id	(Intercept)	0.1057	0.3250	
	shiftQR	0.2492	0.4992	-0.05
Residual		0.4286	0.6547	

Number of obs: 250, groups: id, 90

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(> t)
(Intercept)	4.20498	0.15409	195.20574	27.289	< 2e-16 ***
shiftQR	-0.49145	0.10400	99.38662	-4.725	7.57e-06 ***
order	-0.01577	0.03960	217.20390	-0.398	0.691

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr) shftQR
shiftQR	-0.468
order	-0.897 0.271

Sensitivity analysis, unpaired t-test

Welch Two Sample t-test

data: qr and dd

t = -2.6436, df = 57.708, p-value = 0.01055

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

-0.8514592 -0.1176044

sample estimates:

mean of x mean of y

3.717391 4.201923

The estimated difference of the unpaired t-test (diff = -0.48) is essentially equal to the estimated effect of shift in the mlm-model ($\beta = -0.49$).

Sensitivity analysis, paired t-test

Paired t-test

data: qr_ksd and dd_ksd

t = -4.8087, df = 88, p-value = 6.228e-06

```
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.6576735 -0.2730382
sample estimates:
mean of the differences
-0.4653558
```

The paired t-test (diff = -0.47) and the mlm model ($\beta = -0.49$) results in an essentially equal estimated difference in sleep quality between conditions.

Sleep length

Results from original model (paired t-test)

```
Paired t-test

data: qr_sleep and dd_sleep
t = -9.6864, df = 86, p-value = 1.972e-15
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-1.2304338 -0.8113925
sample estimates:
mean of the differences
-1.020913
```

Sensitivity analysis, unpaired t-test

```
Welch Two Sample t-test

data: qr and dd
t = -6.2532, df = 43.612, p-value = 1.481e-07
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-1.6665295 -0.8539833
sample estimates:
mean of x mean of y
6.000000 7.260256
```

The unpaired t-test results in an observed difference in sleep length (diff = -1.26) of the same order (slightly larger) of the paired t-test (diff = -1.02).

Secondary outcomes

Sleep efficiency (%)

Results from original model (paired t-test)

Paired t-test

```
data: qr_perc and dd_perc
t = -2.3051, df = 86, p-value = 0.02357
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-1.443540 -0.106652
sample estimates:
mean of the differences
-0.7750958
```

Sensitivity test (unpaired t-test)

Welch Two Sample t-test

```
data: qr and dd
t = 1.2274, df = 45.638, p-value = 0.226
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.8086302 3.3345693
sample estimates:
mean of x mean of y
89.68605 88.42308
```

The unpaired t-test gives an estimate in the opposite direction (diff = 1.26 percentage points) of that of the paired t-test (diff = -0.78 percentage points). Both estimates are small, and the effect observed in the main analysis may be due to chance.

Anxious at bedtime

Results from original model (paired t-test)

Paired t-test

```
data: qr_anx_bed and dd_anx_bed
t = -2.4736, df = 89, p-value = 0.01527
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.68791758 -0.07504538
sample estimates:
mean of the differences
-0.3814815
```

Sensitivity test (unpaired t-test)

Welch Two Sample t-test

```
data: qr and dd
t = -1.512, df = 55.961, p-value = 0.1362
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-1.0380480 0.1450714
sample estimates:
mean of x mean of y
3.630435 4.076923
```

The observed difference in the unpaired t-test (diff = -0.45) is close to that of the paired t-test in the main analysis (diff = -0.38).

Feeling rested

Results from original model (paired t-test)

Paired t-test

```
data: qr_rested and dd_rested
t = -4.5996, df = 89, p-value = 1.395e-05
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.7716814 -0.3060963
sample estimates:
mean of the differences
-0.5388889
```

Sensitivity test (unpaired t-test)

Welch Two Sample t-test

```
data: qr and dd
t = -3.2266, df = 40.818, p-value = 0.002471
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-1.2616418 -0.2901977
sample estimates:
mean of x mean of y
2.108696 2.884615
```

The observed difference in the unpaired t-test in the sensitivity analysis (diff = -0.78) is 50 % larger compared to the observed difference in the paired t-test of the main analysis (diff = -0.54). In the main analysis, we have not controlled for order effects. It

could be that some of the difference in feeling rested is masked by the number of consecutive work days (day-day transitions usually follow after quick returns).

Feeling tense during the day

Results from original model (paired t-test)

Paired t-test

```
data: qr_tense and dd_tense
t = 0.11478, df = 89, p-value = 0.9089
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.2718567 0.3051901
sample estimates:
mean of the differences
0.01666667
```

Sensitivity test (unpaired t-test)

Welch Two Sample t-test

```
data: qr and dd
t = 1.6007, df = 58.197, p-value = 0.1149
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.1155965 1.0386735
sample estimates:
mean of x mean of y
2.500000 2.038462
```

Whereas the paired t-test of the main analysis indicates no difference between conditions (diff = 0.02), the unpaired t-test does so (diff = 0.46) although not significant. The results are inconclusive.

Ability to turn off work - during the first day of either transition (evening-day // day-day)

Results from paired t-test

```
##
## Paired t-test
##
## data: qr_detach_lagged and dd_detach_lagged
## t = 1.5385, df = 89, p-value = 0.1275
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
```

```
## -0.0631554 0.4964887
## sample estimates:
## mean of the differences
##      0.2166667
```

Sensitivity test (unpaired t-test)

```
##
## Welch Two Sample t-test
##
## data: qr and dd
## t = 1.1757, df = 49.748, p-value = 0.2453
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
## -0.2808501 1.0734922
## sample estimates:
## mean of x mean of y
## 2.434783 2.038462
```

The observed difference in the unpaired t-test in the sensitivity analysis (diff = 0.4) is more than twice the size compared to the observed difference in the paired t-test of the main analysis (diff = 0.22). Both are non-significant, but it could be that the difference in psychological detachment is masked by the order in which shifts appear.

Ability to turn off work - during the second day of either transition (evening-day // day-day)

Results from original model (paired t-test)

Paired t-test

```
data: qr_detach and dd_detach
t = 1.5709, df = 89, p-value = 0.1198
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.05543139 0.47394991
sample estimates:
mean of the differences
0.2092593
```

Sensitivity test (unpaired t-test)

Welch Two Sample t-test

```
data: qr and dd
t = 1.6231, df = 59.859, p-value = 0.1098
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-0.1180365 1.1336886
```

```
sample estimates:  
mean of x mean of y  
2.347826 1.840000
```

Again, the observed difference in the unpaired t-test in the sensitivity analysis (diff = 0.51) is more than twice the size compared to the observed difference in the paired t-test of the main analysis (diff = 0.21). Both are non-significant, but it could be that the difference in psychological detachment is masked by the order in which shifts appear.