

## Supplementary information for

### *A 4-year longitudinal study investigating the relationship between flexible school starts and grades*

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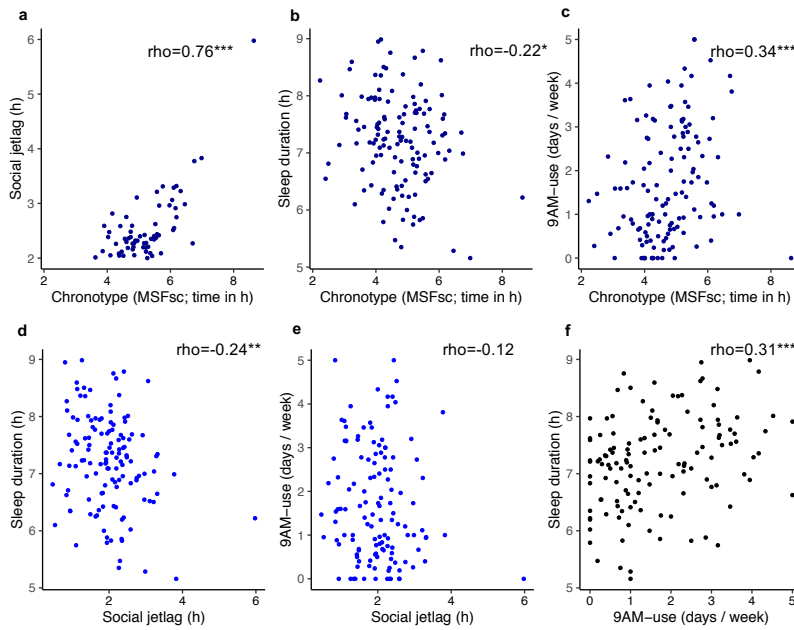
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**Supplementary Figure S1. Correlations between sleep variables.** Spearman rank correlations between the sleep variables social jetlag, chronotype (MSF<sub>sc</sub>), and sleep duration on schooldays, as well as 9AM-use (frequency of  $\geq 9$ AM-starts) (n=129). \*, p<0.05; \*\*, p<0.01; \*\*\*, p<0.001

**Supplementary Table S1. Linear mixed regression models 1 and 2: General and system effects on grades.**

Predicted outcomes are quarterly grades (0%-100%) in 12 academic subjects from students of cohort 1 and 2 (n=157). Abbreviations: b, unstandardized coefficient; se, standard error; beta, standardized coefficient; t, t-statistic; p, p-value;  $\sigma^2$ , variance of residuals of random effects;  $T_{00}$ , variance of ID intercepts of random effects; ICC, intra-class correlation coefficient (describes how much variance is explained by the random effects); N, number of participants; Marginal  $R^2$  describes the amount of variance explained by the fixed effects (predictors); Conditional  $R^2$  describes the amount of variance explained by the full model.

Predictors	Model 1					Model 2				
	b	se	beta	t	p	b	se	beta	t	p
(Intercept)	54.11	1.21		44.74	<b>&lt;0.001</b>	52.79	1.21		43.56	<b>&lt;0.001</b>
System: Flexible system <sup>a</sup>	-0.10	0.42	-0.00	-0.23	0.815	0.64	0.55	0.02	1.16	0.244
Gender: Male <sup>b</sup>	<b>-4.72</b>	2.13	-0.12	-2.21	<b>0.028</b>	-1.43	2.12	-0.03	-0.67	0.501
Grade level: 7 <sup>c</sup>	1.17	0.74	0.02	1.60	0.111	1.23	0.74	0.01	1.66	0.097
Grade level: 8 <sup>c</sup>	<b>3.11</b>	0.49	0.05	6.39	<b>&lt;0.001</b>	<b>3.15</b>	0.49	0.05	6.44	<b>&lt;0.001</b>
Grade level: 9 <sup>c</sup>	<b>2.59</b>	0.34	0.06	7.53	<b>&lt;0.001</b>	<b>2.62</b>	0.35	0.06	7.58	<b>&lt;0.001</b>
Grade level: 11 <sup>c</sup>	0.50	0.35	0.01	1.42	0.155	0.48	0.36	0.01	1.34	0.180
Grade level: 12 <sup>c</sup>	<b>3.44</b>	0.55	0.05	6.21	<b>&lt;0.001</b>	<b>3.37</b>	0.56	0.05	6.05	<b>&lt;0.001</b>
Quarter: 2 <sup>d</sup>	<b>0.82</b>	0.32	0.02	2.59	<b>0.010</b>	<b>0.82</b>	0.32	0.02	2.58	<b>0.010</b>
Quarter: 3 <sup>d</sup>	0.30	0.34	0.01	0.88	0.378	0.25	0.34	0.01	0.75	0.451
Quarter: 4 <sup>d</sup>	<b>2.34</b>	0.33	0.05	7.15	<b>&lt;0.001</b>	<b>2.30</b>	0.33	0.05	7.00	<b>&lt;0.001</b>
Discipline: Sciences <sup>e</sup>	<b>3.40</b>	0.30	0.09	11.36	<b>&lt;0.001</b>	<b>5.22</b>	0.30	0.14	17.30	<b>&lt;0.001</b>
Discipline: Social Sciences <sup>e</sup>	<b>3.87</b>	0.36	0.08	10.69	<b>&lt;0.001</b>	<b>7.25</b>	0.37	0.16	19.33	<b>&lt;0.001</b>
Male*Sciences	<b>4.74</b>	0.54	0.08	8.83	<b>&lt;0.001</b>					
Male*Social Sciences	<b>8.03</b>	0.65	0.11	12.44	<b>&lt;0.001</b>					
Flexible system*Sciences						<b>-1.23</b>	0.54	-0.02	-2.29	<b>0.022</b>
Flexible system*Social Sciences						<b>-2.56</b>	0.63	-0.04	-4.05	<b>&lt;0.001</b>
Flexible system*Male						<b>1.32</b>	0.52	0.02	2.53	<b>0.011</b>
<b>Random Effects</b>										
$\sigma^2$	200.29					202.07				
$T_{00}$	146.38 <sub>ID</sub>					146.37 <sub>ID</sub>				
ICC	0.42					0.42				
N	157 <sub>ID</sub>					157 <sub>ID</sub>				
Observations	16724					16724				
Marginal $R^2$ / Conditional $R^2$	0.033 / 0.441					0.028 / 0.436				

<sup>a</sup>Reference is conventional system.

<sup>b</sup>Reference is female.

<sup>c</sup>Reference is grade level 10.

<sup>d</sup>Reference is quarter 1.

<sup>e</sup>Reference is Languages.

**Supplementary Table S2. Post hoc results of mixed models 1 and 2.** Results are presented as marginal estimated means of quarterly grades scaled 0-100% (standard error), degrees of freedom. Simple contrast results are presented as estimated difference of academic grades (standard error), p-value. Degrees of freedom method: Kenward-Rogers. Results are averaged over the levels of system or gender, grade level, and quarter. Tukey method for comparison of 3 estimates.

<b>Model 1</b>				
<b>Gender</b>	<b>Languages</b>	<b>Sciences</b>	<b>Social Sciences</b>	<b>Simple contrasts</b>
<b>female</b>	<b>56.7</b> (1.19) 166	<b>60.1</b> (1.19) 166	<b>60.6</b> (1.21) 176	Languages-Sciences: <b>-3.41</b> (0.30), <b>p&lt;.0001</b> Languages-Social Sciences: <b>-3.87</b> (0.36), <b>p&lt;.0001</b> Sciences-Social Sciences: <b>-0.47</b> (0.36), p=0.3895
<b>male</b>	<b>52.0</b> (1.79) 164	<b>60.2</b> (1.78) 163	<b>63.9</b> (1.80) 172	Languages-Sciences: <b>-8.15</b> (0.45), <b>p&lt;.0001</b> Languages-Social Sciences: <b>-11.90</b> (0.54), <b>p&lt;.0001</b> Sciences-Social Sciences: <b>-3.76</b> (0.52), <b>p&lt;.0001</b>
<b>Simple contrasts</b>	<b>4.72</b> (2.13) p=0.0284	<b>-0.00</b> (2.13) p=0.9915	<b>-3.31</b> (2.16) p=0.1269	
<b>Model 2</b>				
<b>System</b>	<b>Languages</b>	<b>Sciences</b>	<b>Social Sciences</b>	<b>Simple contrasts</b>
<b>conventional</b>	54.7 (1.08) 168	59.9 (1.08) 167	62.0 (1.10) 182	Languages-Sciences: <b>-5.22</b> (0.30), <b>p&lt;.0001</b> Languages-Social Sciences: <b>-7.25</b> (0.38), <b>p&lt;.0001</b> Sciences-Social Sciences: <b>-2.03</b> (0.37), <b>p&lt;.0001</b>
<b>flexible</b>	56.0 (1.14) 212	60.0 (1.13) 206	60.7 (1.16) 227	Languages-Sciences: <b>-3.99</b> (0.45), <b>p&lt;.0001</b> Languages-Social Sciences: <b>-4.69</b> (0.51), <b>p&lt;.0001</b> Sciences-Social Sciences: <b>-0.69</b> (0.49), p=0.3355
<b>Simple contrasts</b>	<b>-1.30</b> (0.54) <b>p=0.0168</b>	<b>-0.07</b> (0.61) p=0.8849	<b>1.26</b> (0.61) <b>p=0.0384</b>	
<b>System</b>	<b>Female</b>	<b>Male</b>		<b>Simple contrasts</b>
<b>conventional</b>	<b>59.6</b> (1.18) 160	<b>58.2</b> (1.77) 158		female-male: 1.43 (2.12), p=0.5010
<b>flexible</b>	<b>59.0</b> (1.22) 186	<b>58.9</b> (1.81) 173		female-male: 0.11 (2.14), p=0.9580
<b>Simple contrasts</b>	0.62 (0.45) p=0.1726	0.7 (0.56) p=0.2106		

**Supplementary Table S3. Linear mixed regression models 3a-d: Effect of changes in sleep and of  $\geq 9$ AM-use on grade improvements from the conventional to the flexible system.** Predicted outcomes are quarterly grades (0%-100%) in 12 academic subjects from students of cohort 1 (n=63) over 4 years. "Change" refers to the absolute difference of the respective sleep variable between the conventional and the flexible system (t1-t0). Positive numbers mean later chronotype, longer sleep and more social jetlag in the flexible system (t1). 9AM-use is the frequency of  $\geq 9$ AM-starts at t1 (no baseline data for calculation of change available). Abbreviations: Flex, Flexible system; b, unstandardized coefficient; se, standard error; beta, standardized coefficient; p, p value;  $\sigma^2$ , variance of residuals of random effects;  $T_{00}$ , variance of ID intercepts of random effects; ICC, intra-class correlation coefficient (describes how much variance is explained by the random effects); N, number of participants; Marginal R<sup>2</sup> describes the amount of variance explained by the fixed effects (predictors); Conditional R<sup>2</sup> describes the amount of variance explained by the full model.

Predictors	Model3a: Chronotype change				Model3b: Sleep duration change				Model3c: Social jetlag change				Model3d: 9AM-use			
	b	se	beta	p	b	se	beta	p	b	se	beta	p	b	se	beta	p
(Intercept)	53.26	1.97		<b>&lt;0.001</b>	53.30	1.94		<b>&lt;0.001</b>	53.29	1.95		<b>&lt;0.001</b>	53.35	1.86		<b>&lt;0.001</b>
System: Flexible system	-0.01	0.68	0.00	0.983	0.00	0.68	0.00	0.998	0.04	0.68	0.00	0.953	0.02	0.68	0.00	0.977
Gender: Male <sup>a</sup>	-2.56	3.24	-0.07	0.432	-2.64	3.11	-0.07	0.399	-2.64	3.15	-0.07	0.405	-2.80	2.98	-0.07	0.352
Grade level: 7 <sup>b</sup>	5.96	3.33	0.02	0.074	6.31	3.35	0.02	0.060	6.46	3.34	0.02	0.053	5.89	3.33	0.02	0.077
Grade level: 8 <sup>b</sup>	2.52	0.77	<b>0.04</b>	<b>0.001</b>	2.49	0.77	<b>0.04</b>	<b>0.001</b>	2.49	0.77	<b>0.04</b>	<b>0.001</b>	2.50	0.76	<b>0.04</b>	<b>0.001</b>
Grade level: 9 <sup>b</sup>	2.14	0.57	<b>0.05</b>	<b>&lt;0.001</b>	2.13	0.57	<b>0.05</b>	<b>&lt;0.001</b>	2.11	0.57	<b>0.05</b>	<b>&lt;0.001</b>	2.08	0.57	<b>0.05</b>	<b>&lt;0.001</b>
Grade level: 11 <sup>b</sup>	1.07	0.53	<b>0.03</b>	<b>0.045</b>	1.08	0.53	<b>0.03</b>	<b>0.042</b>	1.11	0.53	<b>0.03</b>	<b>0.039</b>	1.11	0.53	<b>0.03</b>	<b>0.038</b>
Grade level: 12 <sup>b</sup>	3.42	0.82	<b>0.06</b>	<b>&lt;0.001</b>	3.38	0.82	<b>0.06</b>	<b>&lt;0.001</b>	3.37	0.82	<b>0.06</b>	<b>&lt;0.001</b>	3.46	0.82	<b>0.06</b>	<b>&lt;0.001</b>
Quarter: 2 <sup>c</sup>	0.71	0.50	0.02	0.157	0.70	0.50	0.02	0.160	0.71	0.50	0.02	0.155	0.71	0.50	0.02	0.154
Quarter: 3 <sup>c</sup>	0.47	0.54	0.01	0.386	0.46	0.54	0.01	0.392	0.47	0.54	0.01	0.380	0.48	0.54	0.01	0.367
Quarter: 4 <sup>c</sup>	2.31	0.52	<b>0.05</b>	<b>&lt;0.001</b>	2.30	0.52	<b>0.05</b>	<b>&lt;0.001</b>	2.30	0.52	<b>0.05</b>	<b>&lt;0.001</b>	2.31	0.52	<b>0.05</b>	<b>&lt;0.001</b>
Discipline: Sciences <sup>d</sup>	6.22	0.40	<b>0.16</b>	<b>&lt;0.001</b>	6.22	0.40	<b>0.16</b>	<b>&lt;0.001</b>	6.22	0.40	<b>0.16</b>	<b>&lt;0.001</b>	6.22	0.40	<b>0.16</b>	<b>&lt;0.001</b>
Discipline: Social Sciences <sup>d</sup>	7.63	0.48	<b>0.17</b>	<b>&lt;0.001</b>	7.63	0.48	<b>0.17</b>	<b>&lt;0.001</b>	7.64	0.48	<b>0.17</b>	<b>&lt;0.001</b>	7.64	0.48	<b>0.17</b>	<b>&lt;0.001</b>
Chronotype change (MSF <sub>sc</sub> ; h)	0.40	2.18	0.02	0.855												
Flex* Chronotype change	0.10	0.53	0.00	0.845												
Sleep duration change (h)					2.32	2.94	0.06	0.434								
Flex* Sleep duration change					-0.77	0.83	-0.01	0.352								
Social jetlag change (h)									0.11	2.11	0.00	0.958				
Flex* Social jetlag change									1.28	0.58	<b>0.03</b>	<b>0.027</b>				
9AM-use ( schooldays/week)													-3.04	1.21	<b>-0.19</b>	<b>0.015</b>
Flex*9AM-use													0.59	0.36	0.02	0.101
<b>Random effects</b>																
$\sigma^2$	205.07				205.05				204.92				204.99			
$T_{00}$	140.27 <sub>ID</sub>				139.10 <sub>ID</sub>				140.24 <sub>ID</sub>				128.08 <sub>ID</sub>			
ICC	0.41				0.40				0.41				0.28			
N	63 <sub>ID</sub>				63 <sub>ID</sub>				63 <sub>ID</sub>				63 <sub>ID</sub>			
Observations	6683				6683				6683				6683			
Marginal R <sup>2</sup> / Conditional R <sup>2</sup>	0.040 / 0.430				0.043 / 0.430				0.041 / 0.430				0.071 / 0.428			

<sup>a</sup>Reference is female.

<sup>b</sup>Reference is grade level 10.

<sup>c</sup>Reference is quarter 1.

<sup>d</sup>Reference is Languages.

**Supplementary Table S4. Linear mixed regression models 4a-e: Effect of absolute sleep characteristics in the flexible system on grades.** Predicted outcomes are quarterly grades (0%-100%) in 12 academic subjects from students of cohorts 1 and 2 (n=129) over 1.5 years in the flexible system. 9AM-use is the frequency of ≥9AM-starts in the flexible system. Abbreviations: b, unstandardized coefficient; se, standard error; beta, standardized coefficient; p, p value;  $\sigma^2$ , variance of residuals of random effects;  $\tau_{00}$ , variance of ID intercepts of random effects; ICC, intra-class correlation coefficient (describes how much variance is explained by the random effects); N, number of participants; Marginal R<sup>2</sup> describes the amount of variance explained by the fixed effects (predictors); Conditional R<sup>2</sup> describes the amount of variance explained by the full model.

	Model 4a: Chronotype				Model 4b: Sleep duration				Model 4c: Social jetlag				Model 4d: 9AM-use				Model 4e: All			
Predictors	b	se	beta	p	b	se	beta	p	b	se	beta	p	b	se	beta	p	b	se	beta	p
(Intercept)	59.50	5.81		<0.001	65.13	10.70		<0.001	53.68	3.40		<0.001	60.50	2.19		<0.001	64.77	14.51		<0.001
Gender: Male <sup>a</sup>	-0.31	2.61	-0.01	0.907	-0.61	2.54	-0.01	0.810	-0.83	2.54	-0.02	0.744	-0.72	2.49	-0.02	0.773	-0.15	2.63	0.00	0.956
Grade level: 9 <sup>b</sup>	3.35	0.82	<b>0.05</b>	<0.001	3.35	0.82	<b>0.05</b>	<0.001	3.36	0.82	<b>0.05</b>	<0.001	3.27	0.82	<b>0.05</b>	<0.001	3.27	0.82	<b>0.05</b>	<0.001
Grade level: 11 <sup>b</sup>	0.47	0.62	0.01	0.450	0.46	0.62	0.01	0.451	0.45	0.62	0.01	0.469	0.58	0.62	0.01	0.350	0.57	0.62	0.01	0.355
Grade level: 12 <sup>b</sup>	0.02	1.00	0.00	0.984	0.02	0.99	0.00	0.984	-0.02	0.99	0.00	0.983	0.27	1.00	0.01	0.790	0.26	1.00	0.01	0.794
Quarter: 2 <sup>c</sup>	0.38	0.65	0.01	0.559	0.38	0.65	0.01	0.559	0.38	0.65	0.01	0.559	0.38	0.65	0.01	0.562	0.38	0.65	0.01	0.561
Quarter: 3 <sup>c</sup>	-0.05	0.65	-0.00	0.933	-0.06	0.65	-0.00	0.932	-0.07	0.65	0.00	0.917	0.02	0.65	0.00	0.980	0.02	0.65	0.00	0.979
Quarter: 4 <sup>c</sup>	1.69	0.61	<b>0.04</b>	<b>0.005</b>	1.69	0.61	<b>0.04</b>	<b>0.005</b>	1.68	0.61	<b>0.04</b>	<b>0.006</b>	1.76	0.61	<b>0.05</b>	<b>0.004</b>	1.76	0.61	<b>0.05</b>	<b>0.004</b>
Discipline: Sciences <sup>d</sup>	4.27	0.43	<b>0.11</b>	<0.001	4.28	0.43	<b>0.11</b>	<0.001	4.27	0.43	<b>0.11</b>	<0.001	4.27	0.43	<b>0.11</b>	<0.001	4.28	0.43	<b>0.11</b>	<0.001
Discipline: Social Sciences <sup>d</sup>	4.65	0.49	<b>0.10</b>	<0.001	4.65	0.49	<b>0.10</b>	<0.001	4.65	0.49	<b>0.10</b>	<0.001	4.65	0.49	<b>0.10</b>	<0.001	4.65	0.49	<b>0.10</b>	<0.001
Chronotype (local time in h)	-0.53	1.23	-0.03	0.665													-2.37	2.35	-0.12	0.315
Sleep duration (h)					-1.12	1.47	-0.05	0.448									-0.27	1.61	-0.01	0.865
Social jetlag (h)									1.76	1.54	0.07	0.256					3.70	2.78	0.14	0.186
≥9AM-use (schooldays/week)													-2.12	0.91		<b>0.022</b>	-1.32	1.20	-0.08	0.272
<b>Random Effects</b>																				
$\sigma^2$	168.88				168.87				168.87				168.87				168.87			
$\tau_{00}$	174.27 <sub>ID</sub>				173.89 <sub>ID</sub>				172.93 <sub>ID</sub>				167.17 <sub>ID</sub>				168.81 <sub>ID</sub>			
ICC	0.51				0.51				0.51				0.50				0.50			
N	129 <sub>ID</sub>				129 <sub>ID</sub>				129 <sub>ID</sub>				129 <sub>ID</sub>				129 <sub>ID</sub>			
Observations	5111				5111				5111				5111				5111			
Marginal R <sup>2</sup> / Conditional R <sup>2</sup>	0.018 / 0.517				0.019 / 0.517				0.022 / 0.517				0.037 / 0.516				0.042 / 0.521			

<sup>a</sup>Reference is female.

<sup>b</sup>Reference is grade level 10.

<sup>c</sup>Reference is quarter 1.

<sup>d</sup>Reference is Languages.