

Supplemental Information

Changing Activity Durations, Timing, and Travel Among Older Adults in a Fast-Aging Society: The Korean Time Use Survey, 2004–2024

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S1. Data, Sampling, and Analytic Unit

The Korean Time Use Survey (KTUS) is a nationally representative repeated cross-sectional survey conducted by Statistics Korea. Each survey draws a stratified two-stage cluster sample: census enumeration areas are selected first, then households within them (12,435 households in 2019), and all household members aged 10 and over complete time diaries on two designated consecutive days. The diary instrument — one primary activity per 10-minute slot, 144 slots per day — is unchanged across the five surveys used here.

The analytic unit in the harmonized file is a diary, not a unique respondent; respondent and design (stratum/cluster) identifiers are not retained in that file. Statistical tests therefore treat diaries as independent observations, and a conservative variant divides each z statistic by $\sqrt{2}$, which is equivalent to treating each respondent's two diaries as a single observation. Because the two diary days are consecutive, a respondent contributes at most one Sunday (or Saturday) diary, so the variant is strictly conservative for those day types. Between-group subgroup tests are not reported for the same reason.

Survey year	Weekday diaries	Sunday diaries	Saturday diaries
2004	4,688	1,514	1,552
2009	3,240	1,042	1,110
2014	5,464	1,811	1,953
2019	6,904	2,219	2,257
2024	7,886	2,678	2,762

S2. Harmonized Activity Categories and Crosswalk

The common classification contains 18 primary-activity categories, grouped — adapting Ås (1978) — into non-discretionary activities (sleep; meals; personal care; work; school; out-of-school study), maintenance activities (food management; other household chores; childcare; adult care), discretionary activities (volunteering; social interaction; religion; media leisure; culture and tourism; sport; other leisure), and travel. School and out-of-school study are retained in computation but omitted from interpretation because they average no more than 2.6 minutes per day combined among adults aged 65 and older.

KTUS activity classifications were revised between surveys. The crosswalk below maps the raw mid-level codes of each survey year to the 18 analytical categories; only activities identifiable in every survey year are retained. The 2014 survey uses MDIS alphabetic codes. For 2004 and 2009, three-digit sub-codes are reassigned where needed (715 grave visits → religion; 765 sports viewing → culture and tourism; 771 internet → media leisure); the source codes are marked with (–) and the destinations with (+).

Category	Group	2004	2009	2014	2019	2024
1. Sleep	Non-discretionary	11	11	A1	11	11
2. Meals	Non-discretionary	12	12	A2	12	12
3. Personal care	Non-discretionary	13,14,19	13,14,19	A3,A9	13,14	13,14
4. Work	Non-discretionary	21–26,29	21–26,29	B1,B2	21–26	21–26
5. School	Non-discretionary	31	31	C1	31	31
6. Out-of-school study	Non-discretionary	32	32	C2	32	32
7. Food management	Maintenance	41	41	D1	41	41
8. Other household chores	Maintenance	33,42–46,49,78	33,42–46,49,78	D2–D7,D9	42–47,49	42–47,49
9. Childcare	Maintenance	51,52	51,52	E1,E2	51,52	51,52
10. Adult care	Maintenance	53–55	53–55	E3–E7	53,54	53,54
11. Volunteering	Discretionary	61,62	61,62	F1,F2	61–63	61–63
12. Social interaction	Discretionary	71 (–715)	71 (–715)	G1	71	71
13. Religion	Discretionary	74 (+715)	74 (+715)	G3,G6	73,74	73,74
14. Media leisure	Discretionary	73 (+771)	73 (+771)	G2	82	82
15. Culture and tourism	Discretionary	75 (+765)	75 (+765)	G4	81	81
16. Sport	Discretionary	76 (–765)	76 (–765)	G5	83	83
17. Other leisure	Discretionary	77 (–771),79	77 (–771),79	G9	84,85,89	84,85,89
18. Travel	Travel	80–87,89	80–87,89	H1–H5,H7–H9	91–98	91–98
Participation activities (excluded)	—	63,72	63,72	F3	72	72
Survey response and residuals (excluded)	—	91	91	Z1	—	—

Code numbers are era-specific and cannot be compared across columns: code 63 denotes participation activities in 2004–2009 (excluded) but unpaid training within the volunteering division in 2019–2024 (volunteering); code 73 denotes media use in 2004–2009 but religious activity in 2019–2024; and the 9-block is a survey-response residual in 2004–2009 but the travel block in 2019–2024.

Participation activities (last row) are tabulated but excluded from interpretation in every year. The 2019 classification revision moved participation activities out of the volunteering division into a new block (72x: obligatory participation, participation related to children's education, community and social events) and broadened what it captures: among adults 65 and older these codes average 2.1 weekday minutes in 2014 but 14.4 in 2019 and 15.3 in 2024 — a sevenfold jump that occurs exactly at the revision boundary and cannot reflect behavior. No earlier code block is comparable: the 2004–2014 participation

codes (63x/F3) average 0.9–2.1 minutes, and the 2004–2009 72x block held unrelated adult-education codes. All of these codes are therefore pooled into the excluded row, and the volunteering category is limited to volunteering codes in every year. Had the 2019–2024 participation codes instead been pooled into other leisure, other leisure's weekday D would appear as 0.196 with an apparent center shift of +1.74 hours; under the excluded definition it shows $D = 0.080$ and +0.36 hours. All values in the article and this document use the excluded definition.

A second non-comparable block is excluded on the same grounds. In the 2004 and 2009 classifications the 9-block is a survey-response residual whose only sizable code, 919, records filling in the time-use diary itself; 95% of these slots occur at home and mostly after 21:00, with no commuting peak. The numeral 91 denotes genuine travel sub-codes only in 2019–2024, and re-verifying every code against the original codebooks showed that an era-blind reading had carried 919 into travel — 17.3 weekday minutes in 2004 and 21.9 in 2009 among adults 65 and older. These codes, together with the 2014 residual Z1, are excluded in every year. Had 919 been retained, weekday travel would appear to fall by 16.0 minutes with its center moving 46 minutes earlier; the corrected series shows essentially no weekday change (Table 1).

Figure 1 in the article displays these categories in 12 merged groups: household chores combines food management and other household chores; care and volunteering combines childcare, adult care, and volunteering; other leisure includes culture and tourism; the remaining nine activities appear unmerged. The D annotated in each Figure 1 panel is computed from the merged group's normalized 2004 and 2024 curves of that panel's day type, so values for merged groups differ from the activity-level values in Table 1.

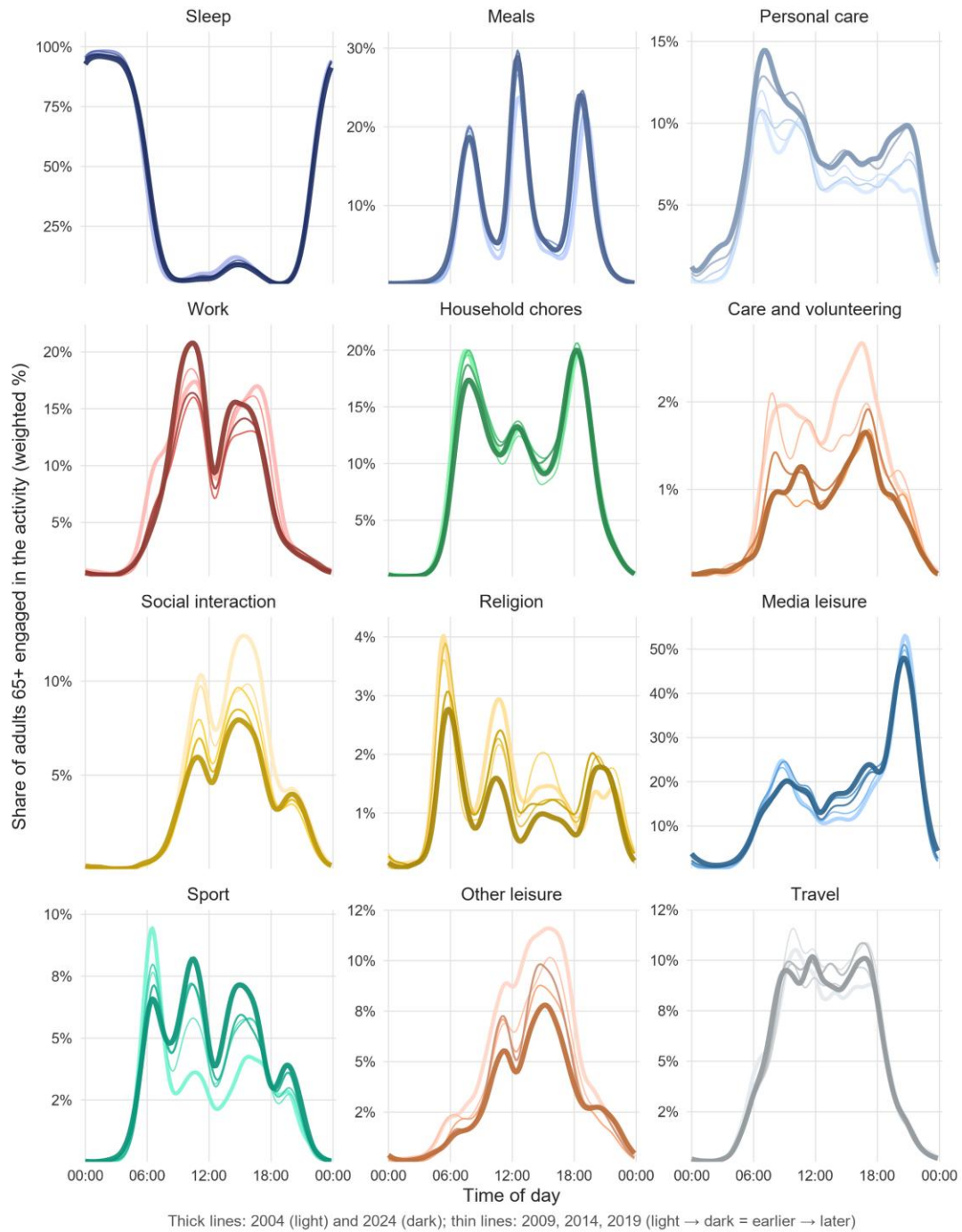


Figure S2. The same 12 activity groups across all five survey years on weekdays, 2004–2024. Thick lines mark the endpoint years 2004 (light) and 2024 (dark); thin lines mark 2009–2019. The V-shaped path of work and the non-monotonic growth of sport are visible in the intermediate years. Y-axis ranges differ across panels.

Figure S2 shows the same 12 groups for all five survey years on weekdays, with the endpoint years emphasized and 2009–2019 as thin context lines. Two findings cited in the article are visible only there:

the V-shaped path of work (2004 and 2024 are similar, 2014 is lower) and the non-monotonic growth of sport.

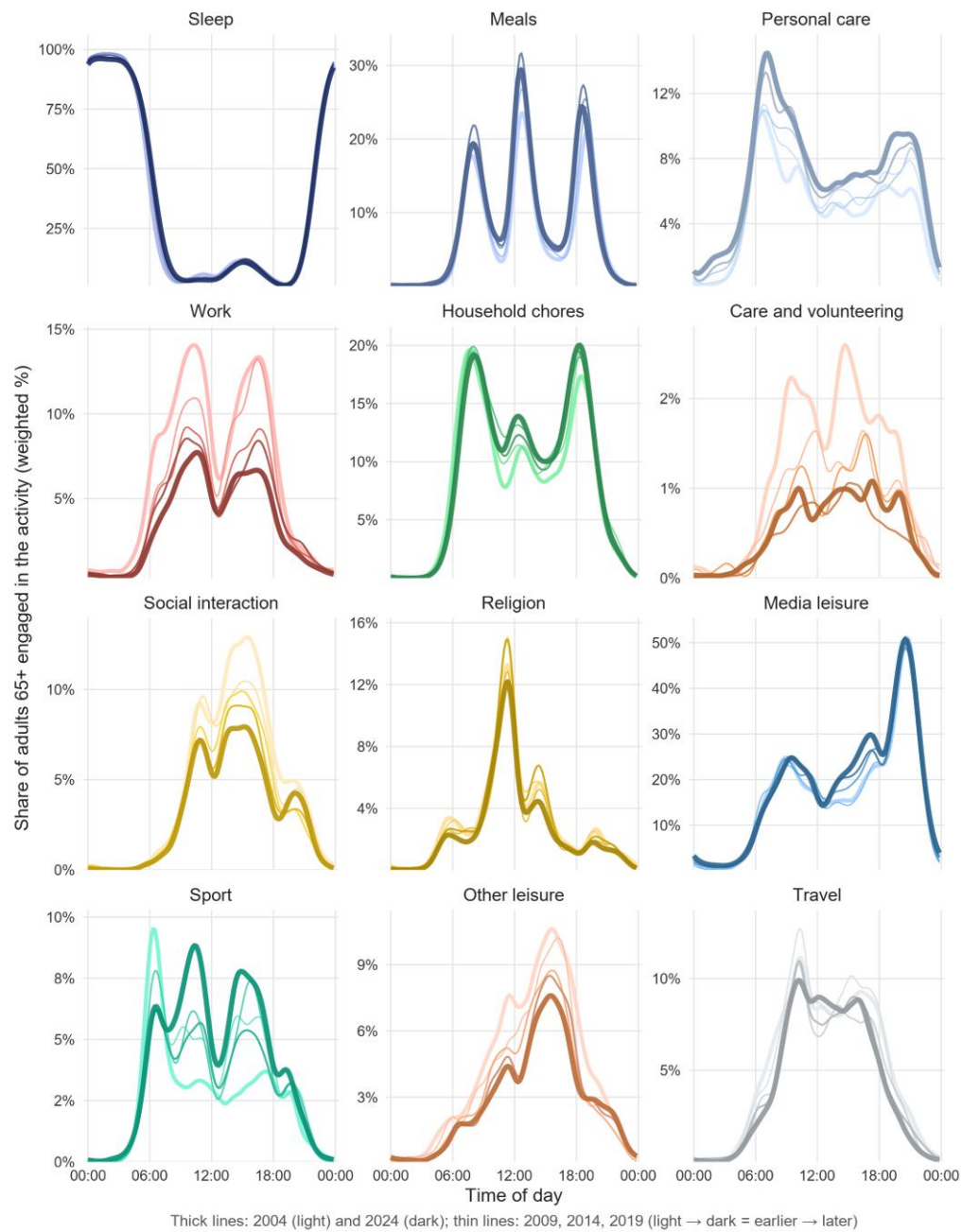


Figure S3. The same 12 activity groups across all five survey years on Sundays, 2004–2024, in the layout of Figure S2. Thick lines mark 2004 (light) and 2024 (dark); thin lines mark 2009–2019. Y-axis ranges differ across panels.

Figure S3 shows the corresponding five-year curves on Sundays, in the same layout.

S3. Measures

For each activity, survey year, and day type, weighted participation rates are calculated for 144 ten-minute slots. Daily minutes equal the sum of these rates multiplied by ten. The Index of Dissimilarity compares the normalized 2004 and 2024 slot distributions:

$$D = \frac{1}{2} \sum_{s=1}^{144} |p_{2024}(s) - p_{2004}(s)|.$$

Normalization ensures that D summarizes redistribution across the day rather than change in total minutes. The participation-weighted timing center is calculated on the linear 24-hour scale using slot start times; the sleep center is reported only descriptively because sleep crosses midnight. Sleep nonetheless enters the duration–timing correlation as one of the 12 non-sparse activities; excluding it leaves both correlations similar (weekday $\rho = -0.39$, Sunday $\rho = -0.12$, versus -0.35 and -0.17 with sleep). Gaussian smoothing with a circular boundary and a three-slot standard deviation is used only in Figures 1, S2, and S3. All tabulated estimates, including the per-panel D in Figure 1, use unsmoothed rates.

How the Index of Dissimilarity (D) isolates timing change

$D = (1/2) \times \text{sum of } |p_{\text{norm},2024}(s) - p_{\text{norm},2004}(s)| \text{ over the 144 ten-minute slots}$

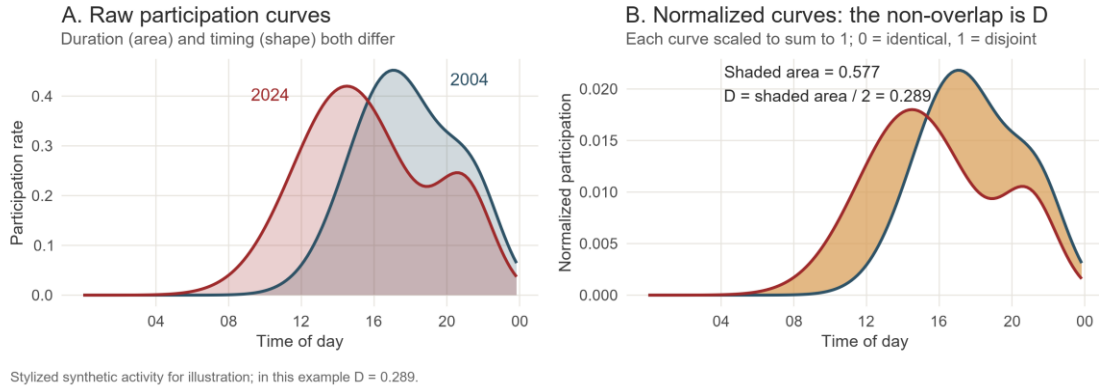


Figure S1. Construction of the Index of Dissimilarity (D) on a stylized activity: raw participation curves that differ in duration and timing (A); normalized curves, whose non-overlapping area (shaded) equals twice D (B).

Figure S1 illustrates the construction on a stylized activity: the raw participation curves, which differ in both duration and timing (panel A), and the normalized curves, whose non-overlapping area equals twice D (panel B).

S4. Statistical Tests

Changes in daily minutes are tested with weighted z-tests, using Hájek-linearized standard errors of the weighted means; reported p-values use the conservative variant defined in S1 (each z divided by $\sqrt{2}$). Because D is a functional of the two aggregate participation curves rather than a mean of diary-level values, no diary-level t-test exists for it; D is instead tested by year-label permutation: year labels are

reassigned at random 999 times, both weighted curves and D are recomputed each time, and the p-value is the share of permuted samples with D at least as large as observed — the null distribution that would arise if year labels were uninformative. Sparse activities with large D are not significant because their permuted D values are just as large, reflecting the small-sample upward bias of dissimilarity indices; this is why the main text treats their D as descriptive. Within each family, p-values are Benjamini–Hochberg adjusted across the 32 activity $\times$ day-type tests (Benjamini & Hochberg, 1995).

Table S1. Weighted z-tests of the 2004→2024 change in daily minutes (conservative variant, adjusted p).

Activity	Weekday Δ	adj. p	Sunday Δ	adj. p
Sleep	−8.9	0.005	5.7	0.326
Meals	18.6	<0.001	20.4	<0.001
Personal care	28.2	<0.001	31.1	<0.001
Work	−8.7	0.155	−42.9	<0.001
Food management	0.0	0.981	6.4	0.122
Other household chores	−5.3	0.014	4.8	0.164
Childcare	−5.2	<0.001	−5.4	0.012
Adult care	−1.6	0.118	−3.5	0.065
Volunteering	−0.2	0.806	0.2	0.859
Social interaction	−20.3	<0.001	−22.0	<0.001
Religion	−5.5	0.004	−7.2	0.161
Media leisure	20.2	<0.001	25.3	0.004
Culture and tourism	−2.3	0.002	0.0	0.981
Sport	15.2	<0.001	18.9	<0.001
Other leisure	−23.6	<0.001	−20.8	<0.001
Travel	1.3	0.620	−11.5	0.009

Table S2. Year-label permutation tests for D (999 permutations, adjusted p).

Activity	Weekday D	perm. p	Sunday D	perm. p
Sleep	0.0311	0.002	0.0398	0.002
Meals	0.1229	0.002	0.1185	0.002
Personal care	0.0869	0.002	0.0952	0.669
Work	0.1212	0.002	0.0653	0.669
Food management	0.0778	0.002	0.1079	0.040
Other household chores	0.1028	0.002	0.1407	0.009
Childcare	0.2558	0.002	0.2477	0.840
Adult care	0.1779	0.775	0.2678	0.669
Volunteering	0.1701	0.766	0.2431	1.000
Social interaction	0.0850	0.002	0.0875	0.419
Religion	0.1582	0.004	0.0703	1.000
Media leisure	0.1004	0.002	0.0746	0.002
Culture and tourism	0.2057	0.579	0.3103	0.994
Sport	0.1898	0.002	0.2290	0.002
Other leisure	0.0799	0.002	0.0829	0.994
Travel	0.0671	0.012	0.1061	0.066

S5. Behavioral Versus Compositional Change (Direct Standardization)

Composition change. The 65+ population itself changed substantially over the study period (weighted weekday diaries):

Year	Share aged 75+	Share female
2004	30.2%	61.0%
2024	40.7%	55.3%

Household size is recorded only from 2019 in the harmonized files; in 2024, 26.6% of weekday diaries were from older adults living alone.

To separate behavioral change from this compositional change, 2024 diaries are reweighted so that the joint age-band (65–69, 70–74, 75–79, 80+) × sex distribution matches the 2004 weighted distribution of the same day type. Δ std compares 2004 with the reweighted 2024, so the gap between raw and standardized change measures the contribution of age–sex composition change within the 65+ population.

Table S3. Raw versus age–sex-standardized change in daily minutes (Δ), 2004→2024.

Activity	Weekday Δ raw	Weekday Δ std	Sunday Δ raw	Sunday Δ std
Sleep	–8.9	–14.7	5.7	1.8
Meals	18.6	18.6	20.4	20.7
Personal care	28.2	27.2	31.1	29.8
Work	–8.7	–1.9	–42.9	–36.7
Food management	0.0	6.3	6.4	9.6
Other household chores	–5.3	–1.4	4.8	8.0
Childcare	–5.2	–4.4	–5.4	–4.8
Adult care	–1.6	–1.4	–3.5	–3.4
Volunteering	–0.2	0.0	0.2	0.2
Social interaction	–20.3	–20.8	–22.0	–22.7
Religion	–5.5	–5.2	–7.2	–6.9
Media leisure	20.2	9.1	25.3	14.4
Culture and tourism	–2.3	–2.3	0.0	0.3
Sport	15.2	14.0	18.9	18.9
Other leisure	–23.6	–25.9	–20.8	–22.8
Travel	1.3	4.8	–11.5	–7.4

Education robustness. Education is recorded in every survey year; adding it to the standardization cells (age band × sex × three education levels, 24 cells) makes the finest cells sparse — one 2004 weekday cell is empty — so the age–sex adjustment is kept as primary. The conclusions hold under the fuller adjustment: personal care and social interaction are similar or larger (weekday Δ +29.1, –19.5; Sunday +31.7, –20.8), weekday travel stays near zero (–0.0) while the Sunday travel decline remains (–9.8), the sport gain attenuates further (weekday +14.0 → +9.6; Sunday +18.9 → +14.3) — rising education, itself part of cohort succession, accounts for part of that gain — and the media-leisure gain stays well below its raw value (weekday +13.1 versus +20.2; Sunday +18.1 versus +25.3), though above the age–sex-standardized value because the education margin runs opposite to the age margin for this activity. Work becomes +0.2 on weekdays and –27.6 on Sundays. Behavioral change here means change

not attributable to the measured composition margins; as in any repeated cross-sectional series, period and cohort influences on behavior itself cannot be separated.

S6. Saturdays and Weekly Averages

Between 2004 and 2024, Korea phased in the five-day workweek (from July 2004 for large establishments, extended in stages through 2011), turning Saturday from a partial workday into a rest day. Saturday changes therefore mix this institutional shift with behavioral change and should be read with that caution; the same caution is stated in the main text.

Table S4. Saturday changes, 2004→2024. Saturday work fell more than on any other day type (−50.1 minutes), while the remaining changes parallel the weekday and Sunday directions. Permutation p-values are unadjusted.

Activity	2004	2024	Δ	D	permutation p
Sleep	499.7	503.5	3.8	0.0460	0.001
Meals	97.2	122.6	25.4	0.1351	0.001
Personal care	78.5	102.6	24.1	0.0951	0.249
Work	116.5	66.4	−50.1	0.0879	0.007
Food management	62.2	72.7	10.5	0.1059	0.014
Other household chores	56.8	62.9	6.1	0.1275	0.005
Childcare	8.1	3.0	−5.1	0.2080	0.919
Adult care	5.9	3.4	−2.5	0.2348	0.993
Volunteering	2.7	3.2	0.5	0.1927	1.000
Social interaction	68.2	48.5	−19.7	0.0743	0.714
Religion	16.2	16.5	0.3	0.1665	0.897
Media leisure	235.4	258.0	22.6	0.0949	0.001
Culture and tourism	3.1	2.4	−0.7	0.1750	1.000
Sport	38.1	52.0	13.9	0.2150	0.001
Other leisure	67.1	39.0	−28.1	0.0743	0.940
Travel	65.9	65.4	−0.5	0.0777	0.949

Table S5. Weekly average daily minutes, (5 × weekday + Saturday + Sunday) / 7. Population-level weekly averages; person-level weekly totals cannot be formed because respondent identifiers are not retained.

Activity	2004	2024	Δ
Sleep	498.7	493.7	−5.0
Meals	97.8	117.6	19.8
Personal care	79.1	107.1	28.0
Work	113.1	93.6	−19.5
Food management	65.9	68.4	2.5
Other household chores	59.9	57.7	−2.2
Childcare	8.3	3.1	−5.2
Adult care	5.6	3.6	−2.0
Volunteering	3.1	3.0	−0.1
Social interaction	65.3	44.9	−20.4
Religion	23.0	18.1	−4.9

Media leisure	224.5	245.7	21.2
Culture and tourism	3.1	1.3	-1.8
Sport	38.2	53.7	15.5
Other leisure	64.6	40.8	-23.8
Travel	70.8	70.0	-0.8