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The Implications of Daylight Saving Time: A Field Experiment on Cognitive Performance and Risk Taking

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The Implications of Daylight Saving Time: A Field Experiment on Cognitive Performance and Risk Taking

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ABSTRACT

To explore the effects of daylights saving time (DST) transition on cognitive performance and risk-taking behaviour immediately before and one week after the shift to DST, this study examines two Australian populations living in similar geographic surroundings who experience either no DST transition (Queensland) or a one-hour DST desynchronization (New South Wales). This exogenous variation creates natural control (QLD) and treatment (NSW) groups that enable isolation and identification of the DST transition’s effect on the two outcome variables. Proximity to the border ensures similar socio-demographic and socio-economic conditions and thus permits comparison of the cognitive performance and risk-taking behaviour of affected versus unaffected individuals. The results suggest that exposure to the DST transition has no significant impact on either cognitive performance or risk-taking behaviour.

JEL Codes: D81, C93, C21, I1

Keywords: Daylight Saving Time, Risk-Taking Behaviour, Cognitive Performance, Field Experiment

1. Introduction

The debate over the efficacy of daylight savings time (DST) has continued from the last century to this, with rural residents being more reluctant than urban residents to sacrifice early morning sunlight in summer (Patrick, 1919; Harrison, 2013). DST was first introduced by Germany in 1916 to reduce artificial lighting in order to save fuel for the World War I war efforts[1]. Key arguments against DST cite potential adverse effects on health and cognitive performance (Gaski and Sagarin, 2011; Kantermann et al., 2007). The shortcomings of available studies are often due to the lack of a good control group to measure the effect of DST and the lack of information about the dynamics over time. We use a field experiment thanks to the difference in DST policy of two neighbouring Australian states – New South Wales uses DST while Queensland does not. We invited participants living close to the border of both states to participate in online incentivized tests of cognitive performance and measures of risk attitudes at three intervals: before, immediately after the DST change and one week later to observe the effect DST has on these measures. We do not find a significant impact of the DST transition.

Today, more than 1.6 billion men and women (Kotchen and Grant, 2011) in around 79 countries and territories (as of 2012, http://www.timeanddate.com/time/dst/2012.html), most in higher latitudes (Harrison, 2013), must move their clocks forward in the spring and backward in the autumn, usually by an hour. A key argument against DST is its implications for behaviour and physiology (Gaski and Sagarin, 2011), especially as they relate to human performance. By directly disrupting the sleep cycle, the DST transition leads to abrupt and acute discrepancies between biological and social time that may throw the body into a condition of internal desynchronisation with potentially adverse effects on health (Kantermann et al., 2007). Not

[1] http://www.timeanddate.com/time/dst/history.html.

only does fatigue negatively affect cognitive functioning (Noy et al., 2011), even minor sleep deprivation can seriously compromise attention, alertness, and cognitive ability and induce errors of judgment (Kamstra et al., 2000). Aviation history is replete with accidents caused by sleep-deprived pilot error (e.g., the crash of American Airlines Flight 1420), and sleepiness is estimated to be involved in at least 15–20% of road crashes (Connor et al., 2002; Horne and Reyner, 1999; National Transportation Safety Board, 1999). Such tragedies as the explosions of the space shuttle Challenger and the Chernobyl nuclear power plant, as well as the Exxon Valdez oil spill, can also be traced to human error caused by disruption of the sleep cycle (Coren, 1996a, as cited in Kamstra et al., 2000: 1005).

Other concerns relate to adverse environmental effects or safety on the road and in the workplace. Research suggests that even a small decrease in sleep duration can increase the likelihood of accidents (Coren, 1998). The evidence for automobile crashes, however, is mixed: whereas several U.S. studies (Hicks et al., 1983; Coren, 1996b, 1998; Varughese and Allen, 2001) and one British study (Monk, 1980) report a significant increase in crash counts immediately following the shift to DST, other studies from Canada (Vincent, 1998) and Sweden (Lambe and Cummings, 2000) find no significant immediate impact. On the other hand, Barnes and Wagner (2009) provide clear evidence that both the frequency and severity of workplace injuries increase on the Monday following the DST switch in which one hour of sleep is lost.

Methodologically, these studies are problematic in that they are mostly observational, making it hard to distinguish whether the accidents resulted from cognitive impairment related to sleep cycle asynchrony or such confounding factors as darker, colder, or even icier early morning conditions during the weeks following the springtime leap forward (Harrison, 2013). More recently researchers have focused on empirical study of the physiological effects of transition to DST (Gaski and Sagarin, 2011), which evaluates the effects of sleep deprivation using three primary measures: cognitive performance, motor performance, and mood. According to the evidence, which is heavily focussed on basic attentional and complex processes (Lim and Dinges, 2010), sleep deprivation increases perceptual and cognitive distortions and negatively affects vigilance (Krueger, 1989). However, because it is difficult to incentivize sleeplessness in a natural environment for a large number of individuals, most studies on sleep deprivation rely on artificial misalignment of the sleep-wake rhythm under controlled laboratory conditions (Baron and Reid, 2014). As a result, relatively little is known about the impact of misalignment on real-world individual decision making. The research findings do however suggest that the discordance between biological and social time induced by the DST transition can disrupt the duration and quality of sleep, which for many adults, causes a sleep deficit during the work week that has serious neurobehavioral and physiological consequences (Spaeth et al., 2012). In addition to decreasing sleep efficiency, the switch to DST can also reduce sleep duration (Lahti et al., 2006a): it takes several days for the chronic partial sleep deprivation to readjust to its chronobiologic rhythm (Kanterman et al., 2007; Lahti et al., 2006a).

The transition to DST thus offers an ideal opportunity to conduct a large scale study of the effect of internal desynchronization on human decision making. Being endogenous, human circadian rhythms do not instantaneously adjust to the sudden schedule change imposed by DST and may need a week to readapt when routines are broken (Monk, 1980; Monk and Aplin, 1980). To overcome the methodological difficulty of controlling for potentially confounding factors, this analysis exploits the geographic variation in two Australian populations, one in Queensland (QLD), which undergoes no DST shift, and a neighbouring population in New South Wales (NSW) that experiences a one hour DST desynchronization (circadian misalignment). Specifically, using a carefully designed field experiment, the study identifies the effect of internal desynchronisation on individual cognitive functioning and risk-taking, a topic on which very little research exists. One review by Harrison and Horne (2000) does suggest that a one-night sleep loss adversely affects performance in simple, repetitive, and unimaginative tasks but not in complex, rule-based tasks (similar to cognitive tests). It further shows that complex real-world decisions that are not rule-based (e.g., lateral or innovative thinking, inferring the effects of actions or events) are susceptible to sleep loss through compromised efficiency in the prefrontal cortex of human brain.

Despite recent advances in understanding of the effects of sleep-loss on risk taking behaviour (RTB), the implications of sleep deprivation for risk-taking propensity and judgment are still understudied (Killgore et al., 2011) and the precise cognitive process between sleep deprivation and risk taking is little understood (McKenna et al., 2007). There is, however, evidence that sleep deprived subjects are less risk averse when faced with gains but less risk seeking in the face of losses (McKenna et al., 2007). Risk decisions are a result of various cognitive processes (Frings, 2012). According to Womack et al. (2013), 18 out of 23 studies on sleep loss and RTB demonstrate a clear association between higher levels of sleepiness and higher levels of risk-taking behaviour. Womack et al. (2013) provide an excellent overview of studies on the relation between sleep loss and RTB looking at the prefrontal cortex (e.g., adverse effects, decrease in glucose metabolism or increased activity during RTB tasks). These studies, however, suffer from the usual drawbacks of using self-reported measures of RTB and sleep loss and so can at best show only correlation (not causality) between the two measures, which is in fact the most common finding in the literature (Womack et al., 2013). In laboratory studies, sleep deprivation is usually experimentally manipulated through strong incentives, such as requiring treatment group participants to go without sleep for at least 24 hours under controlled conditions. Such constraints limit both the number of treatment group participants and the study's external validity.

This current study, in contrast, is able to infer a *causal* role of sleep loss on cognitive functioning and RTB because of a novel experimental design that relies neither on self-reported RTB nor on artificially induced states of wakefulness. Rather, the simple field experiment elicits RTB in randomly selected participants through risk-tasks that are well-established in experimental economics (Hey and Orme, 1994). The study's novelty lies in its sleep loss treatment, which exploits the sleep loss experienced immediately following the DST switch experienced by the NSW but not the QLD sample. The springtime transition to DST in NSW thus acts as an exogenous treatment effect that permits causal inference of whether the internal desynchronization from the one-hour post-DST transition sleep loss adversely affects human cognitive performance and RTB. Given the lack of behavioural studies around DST transitions (Kantermann et al., 2007) – except perhaps for Monk and Folkard's (1976) early analysis of the waking time of 65 subjects 6 days before and 11 days after the DST change – the study examines individual behaviour both the day of the DST shift (directly after) and a week later to enable the observation of an adjustment process.

2. Method

2.1. Experimental design

The key component of our experimental design is the regional variation in Australia's daylight saving policy (see Fig. 1), which results in two adjacent states – for example, Queensland (QLD) and New South Wales (NSW) – having contrary practices. As a result, from the first Sunday in April to the first Saturday in October, the two states share Australian Eastern Standard Time (AEST), but then NSW springs forward by one hour at 2:00 AM on the first Sunday in October, while QLD maintains AEST. As a result, individuals living in very similar geographic surroundings experience either a one-hour internal desynchronization or none at all (see Fig. 1). This exogenous variation naturally creates a control (QLD) and a treatment (NSW) group with which to identify the DST transition's effect on the outcome variables.

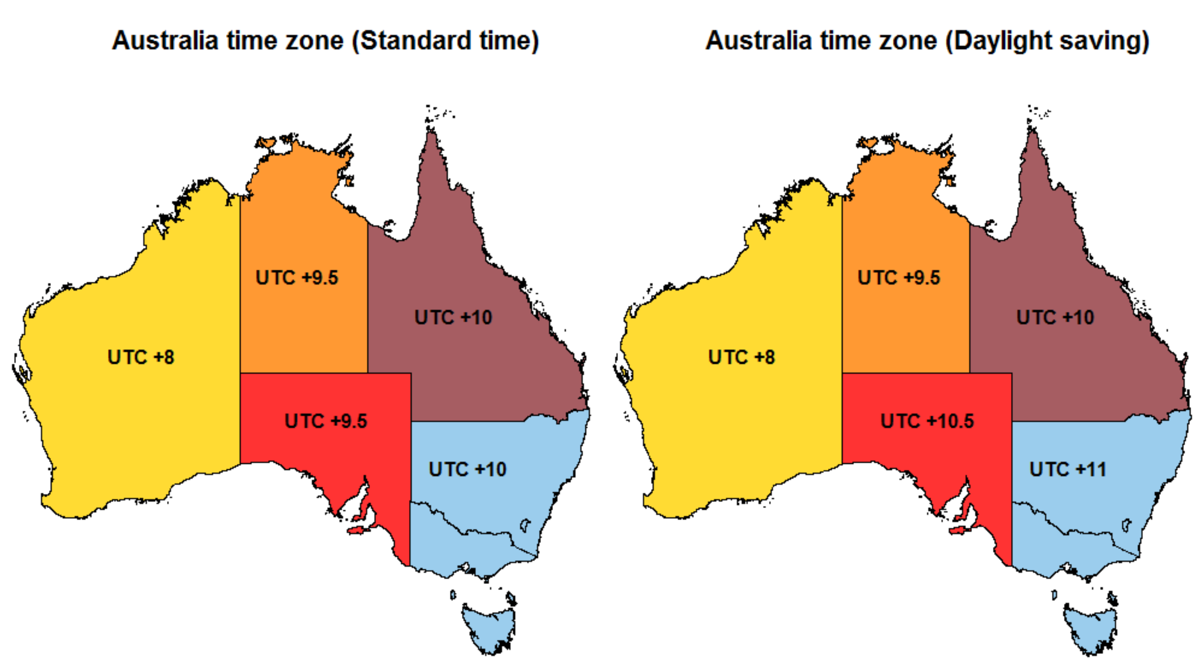

Fig. 1. Time zones in Australia under standard and daylight saving time. Queensland, the Northern Territory and Western Australia are the states that do not observe daylight saving. The figure has been generated with the statistical software Stata 13 with the help of data from the Australian Bureau of Statistics (2011). The color represent the each state in Australia: Queensland (maroon), New South Wales\Victoria\Tasmania (sky blue), Northern Territory (ochre), South Australia (red) and Western Australia (gold).

Participants were recruited from both sides of the state border (see Fig. 2) as one critical identification assumption is that the both population (QLD and NSW) are comparable on both sides of the border. Because of the low population density in northern NSW, the control group is larger than the treatment group (see Fig. 2 and Fig. A1 in the Appendix). A total of 91 participants from QLD and 47 from NSW participated in all three experimental waves: one week prior to the transition (wave 1); October 6, 2013, the transitional day in NSW[2] (wave 2);

[2] The change occurred at 2:00 AM on the Sunday.

and one week after the DST switch (wave 3). Participation decreased by 38.1% from wave 1 to 2 and 27.4% from wave 2 to 3, with 307, 190, and 138 participants, respectively. Nevertheless, the differences in individual characteristics for both those who left early and those who remained are not statistically significant (see Appendix Table A1). The incentive for participation in the study was $8 for each wave. For participants that completed all three waves one of the three attention tasks and one of the 30 lotteries was randomly selected. They then received 33 cents per correct answer for the Stroop task in addition to the nominal values provided by the lottery (on average $16.40). In each stage, the participants completed certain tasks and a short post-experimental questionnaire, both administered online. On average, the activity took 6.2 minutes to complete.

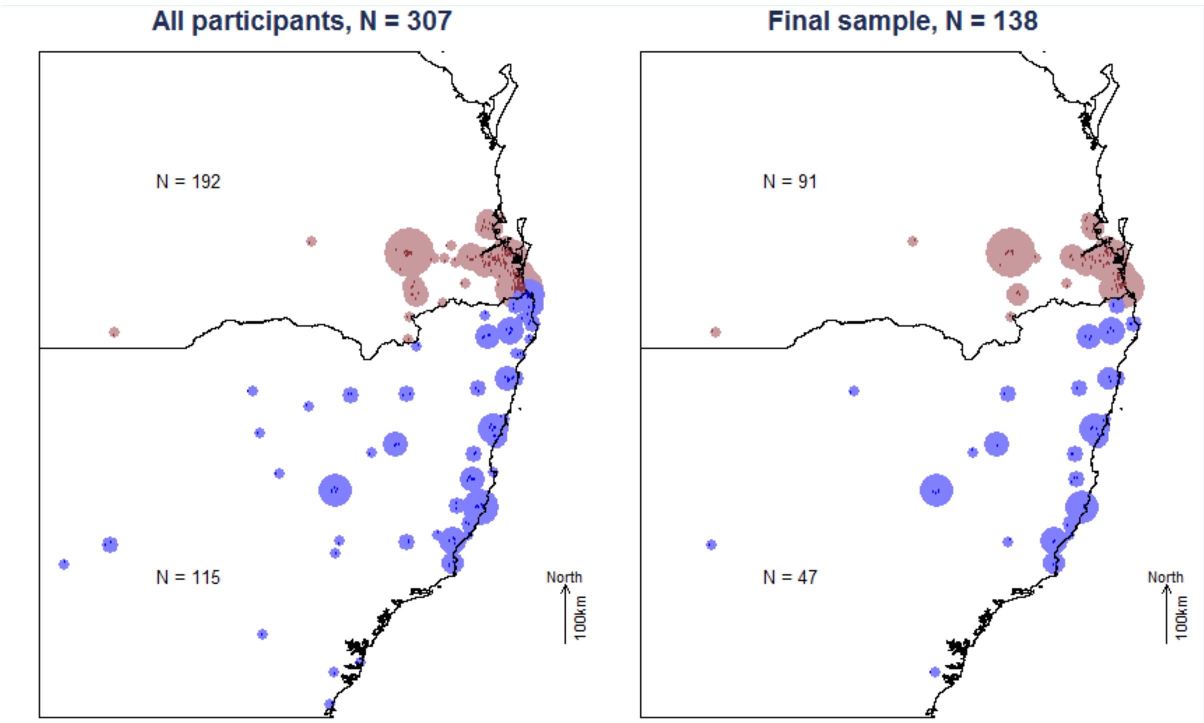

Fig.2: Regional distribution of the observations. Red part: Queensland; Blue one: New South Wales. Left hand-side depicts all participants who conducted the first wave, while the right-hand side shows the final set of observations used in the analysis (those who participated in all three waves).

The tasks were designed to elicit information on two aspects of human faculty: cognitive functioning (attention/alertness), as measured by performance on a Stroop

Interference Test (SIT), and risk-taking behaviour, elicited through a lottery choice task (LCT). The SIT (Stroop, 1935) is a selective attention test with inhibition of an automatic cognitive response that targets complex attention (versus simple attention tests, which focus only on visual or auditory detection of a single class of stimuli; Lim and Dinges, 2010). This task type is important in that the extant empirical evidence identifies simple attention as the cognitive domain most strongly linked with short-term sleep deprivation (Lim and Dinges, 2010). The SIT is a popular tool among sleep researchers for eliciting cognitive performance (see, e.g., MacLeod, 1991, Cain et al., 2011), which varies with type of task (Pilcher and Huffcut, 1996). That is, incongruent stimuli typically require more processing time because the association between idea and word has been so frequent as to become automatic, whereas in the case of colours and pictures, the brain must make a voluntary effort to identify the font colour by overriding its first reaction (Cattell, 1886). Assuming that the participants in the control and treatment groups share a similar internal biological clock, any post-DST transition change in cognitive performance or risk-taking among the treatment group should be attributable to the effect of DST-generated circadian misalignment, which would predict inferior performance in the DST-treated group.

The SIT tool used in the experiment was the computerized version in which the participants' computer screens display a series of colour words (Black, Blue, Yellow, Green, and Red), sometimes in the same font colour as the word (congruence) and sometimes in a different font colour (incongruence). The participants had to choose the most accurate font colour from among five clickable options independently of the colour names. The task was limited to 30 trials due to the length of the entire experiment, and the inherent risk that too many repetitions would have increased the number of unfinished surveys. Furthermore, we conducted the experiments three times within a period of two weeks. Risk preference was then assessed using an LCT standard in experimental economics (Hey and Orme, 1994) in which participants are presented with 10 sets of simple lottery choices involving a binary decision (lottery A vs. lottery B) with identical expected monetary values (see Fig. 2). The expectation was that treatment group participants would be more risk averse and choose the certain outcome more often.

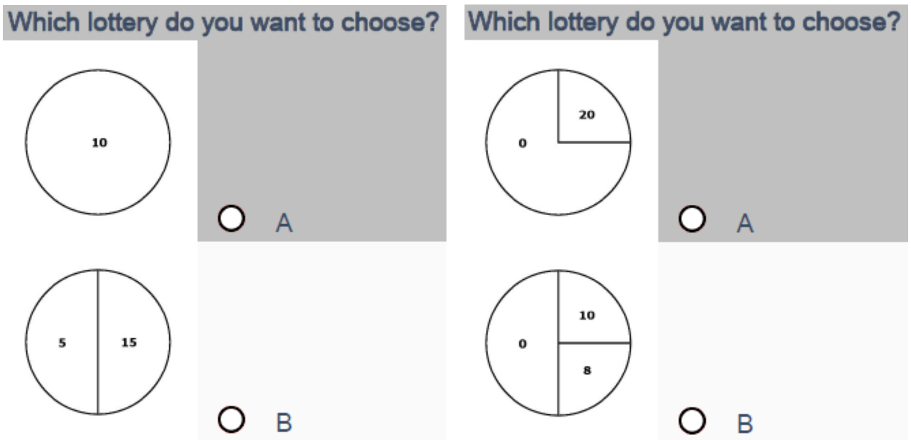

Fig. 2. Example of the lottery choice task. It displays a pair of lotteries for the lotter choice task modelled after Hey and Orme (1994). Participants were confronted with 10 different pairs of lotteries in each round and had to choose one or the other with a chance of 1/30 that this lottery then would be played out for them. Lotteries had similar expected values, but exhibited differences in the distribution of payoffs. In the first example we can see that both lottery A and B have an equal expected value of $10 but of course lottery A would be classified as much safer option since it offers a fixed payment. In the second example lottery B has actually a slightly lower expected value ($4.5) than lottery A ($5), but would still be considered the saver option as the probability to get any payout is 50% compared to the 25% probability to get the $20 in lottery A.

To reduce any additional unobserved pressure factors such as time constraints, individual sleep preferences, or the rest-activity cycle (whose fragmentation can be reduced or increased by the DST transition; Lahti et al., 2006b), participants were allowed to choose when during the day they would complete the experiment. Applying a two-sample Kolmogorov-Smirnov equality-of-distributions test to the distribution of experimental start times in both regions (see Fig. A1) reveals no statistically significant differences between the QLD and NSW groups (for the distribution in all three waves, see Table 1).

Table 1
Mean difference in time of experiment between NSW and QLD.

Wave	N	Mean difference (in min.)	*P*-value
Total	414	-0.634 (QLD starts later)	0.98
1st	138	12.17 (NSW starts later)	0.72
2nd	138	-15.17 (QLD starts later)	0.70
3rd	138	1.096 (NSW starts later)	0.97

Based on a two-sample Kolmogorov-Smirnov equality-of-distributions test.

2.2. Identification assumption

To check the validity of the assumption that the characteristics of individuals on both sides of the QLD-NSW border are not systematically dissimilar, the questionnaire also probed for differences in such variables as age, marital status, income, number of children in the household, and distance to the border. Tests for equality of means for each single factor point to no significant differences except for distance from the border, which is driven by the lower population density in northern NSW, and people in households without children (Table 2). This result supports the assumption that the control and treatment groups do not differ systematically in their characteristics, enabling valid determination of the DST transition's effect on cognitive performance and risk-taking behaviour.

Table 2
Test of pre-existing differences between the control (QLD) and treatment group (NSW).

Variable	NSW mean	Sd.	Min	Max	N	QLD Mean	Sd.	Min	Max	N	t-test p-value
Risk Aversion one week before	5.94	2.56	0	10	47	5.88	2.71	0	10	91	0.905
SIT one week before	29.17	1.98	22	30	47	29.18	1.87	20	30	91	0.987
Male	0.40		0	1	47	0.51		0	1	91	0.262
Age Group=18 - 24	0.02		0	1	47	0.02		0	1	91	0.979
Age Group=25 - 34	0.06		0	1	47	0.07		0	1	91	0.963
Age Group=35 - 44	0.09		0	1	47	0.12		0	1	91	0.526
Age Group=45 - 54	0.17		0	1	47	0.12		0	1	91	0.429
Age Group=55 - 64	0.34		0	1	47	0.22		0	1	91	0.128
Age Group=65 or Older	0.32		0	1	47	0.43		0	1	91	0.215
Marital Status=Divorced	0.19		0	1	47	0.13		0	1	91	0.359
Marital Status=Married	0.47		0	1	47	0.59		0	1	91	0.163
Marital Status=Other	0.09		0	1	47	0.02		0	1	91	0.086*
Marital Status=Separated						0.03		0	1	91	

Marital Status=Single	0.19		0	1	47	0.16		0	1	91	0.698
Income Group=$35,000 to Under	0.26		0	1	47	0.14		0	1	91	0.106
Income Group=$50,000 to Under	0.17		0	1	47	0.19		0	1	91	0.812
Income Group=$75,000 to Under						0.13		0	1	91	
Income Group=$100,000 or More	0.11		0	1	47	0.11		0	1	91	0.95
Household Children=2	0.06		0	1	47	0.07		0	1	91	0.963
Household Children=3 or More						0.04		0	1	91	
Household Children=None	0.91		0	1	47	0.78		0	1	91	0.048**
Distance from Border (latitude)	1.95	1.38	-0.13	5.55	47	0.71	0.30	-0.28	1.42	91	0.000***

Degrees latitude are obtained by computing the central latitude of the postcode given as home. The distance from the border is then measured as absolute distance of the postcode latitude to the 28.5 degree latitude line, which is a crude approximation of the QLD and NSW border (see Appendix Fig. A1). The values can become slightly negative for postcodes that lie on opposing side of this line. For three variables, no observations were available for NSW. Similar to a summary table we also report values of variables where there is no observation in NSW. *, **, *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

2.3. Estimation strategy

The effect of the DST transition on cognitive performance and risk aversion behaviour is estimated using a difference-in-difference strategy in which Q is the control group (QLD), N the treatment group (NSW), and y the outcome of interest (measure of cognitive performance, higher values implying better performance; or risk aversion, number of safe options). The regression framework is as follows:

$$y_{it} = \beta_1 + \beta_2 T_t + \beta_3 D_i + \beta_4 T_t \times D_i + \varepsilon_{it}, \quad i = Q, N; t = 0, 1, 2 \qquad (1)$$

Here, the dummy D_i captures possible differences between the treatment and control groups prior to the DST switch. The dummies T_t denotes the wave aggregate factors that would cause changes in y even in the absence of a DST-induced time difference between the two groups. The coefficient of interest is β_4, the difference-in-differences. Because the outcome variables are not expected to differ systematically between the treatment and control groups, inferences are based on standard OLS regressions presenting estimations with and without control variables.

3. Results

No statistically significant effects of DST are observable on either individual cognitive performance or risk aversion. As Fig. 4 shows, in the Stroop test, the cognitive performance of the treatment group seems to peak on the day of the DST transition, which is indicative of more alertness than the control group. The reason for this superior performance is not immediately clear: in wave 3 (the week following the DST switch), the treatment group seems to perform only slightly worse than the control group (i.e., the difference is not statistically significant). On the other hand, relative to the wave 2 peak, the treatment group's performance falls while the control group's performance rises.

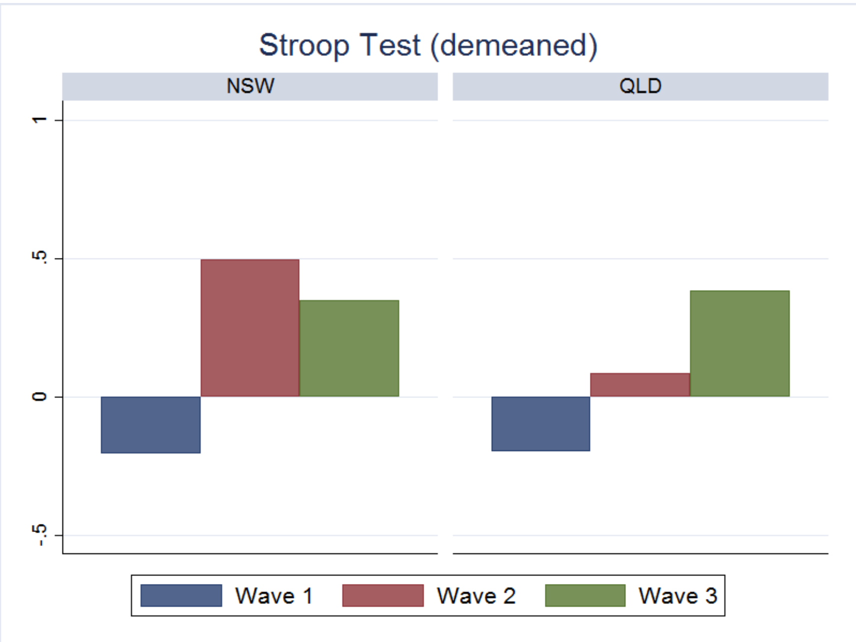

Fig. 4. Stroop test results.

As regards risk taking, measured by the choice between two lotteries of dissimilar risk but identical expected gain, the participants in both groups became increasingly risk averse over time (see Fig. 5). Nevertheless, the statistical tests reveal no statistically significant differences between the treatment and control groups across the waves in terms of lottery choice. Overall, therefore, our results suggest that the DST transition has no statistically significant effects on cognitive functioning and risk taking behaviour, which may indicate that individuals adjust their internal biological rhythms fairly efficiently when the clock is moved ahead in springtime.

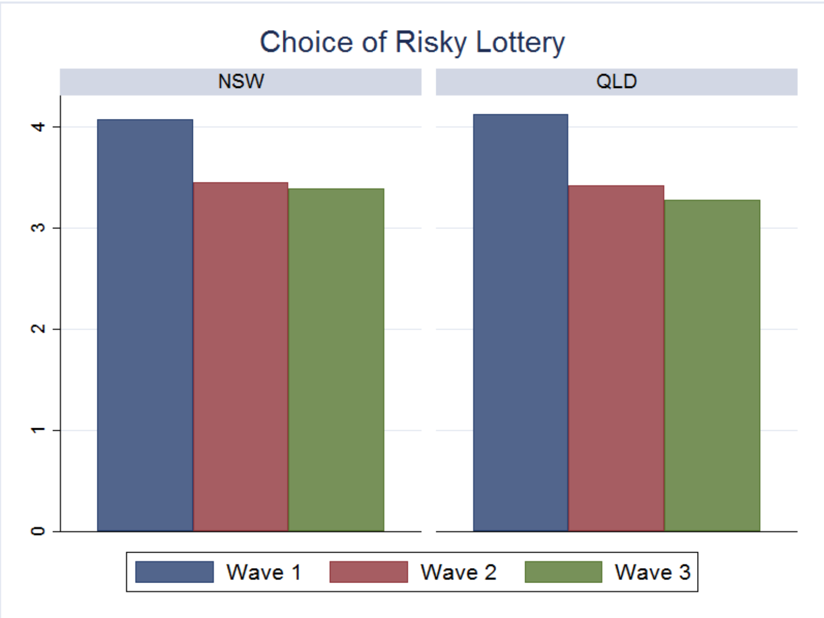

Fig. 5. Risk lottery results.

Specific individual characteristics are controlled for to tests for such variations as individual heterogeneity in the ability to cope and performance under sleep deprivation (Killgore, 2010). As part of this analysis, a multivariate analysis using OLS reports standardized coefficients for these individual factors. For each dependent variable, seven specifications are developed. Difference in difference results with and without additional controls are presented. Income was added sequentially to make up for missing values (see specifications 4 and 7 (Table 3) and 11 and 14 (Table 4)). A dummy variable for the category don't know/prefer not to answer is introduced in four specifications (3, 6, 10, and 13). Six more specifications divide with dummies the sample into different time periods based on the experimental start time (see specifications 5 to 7 and 12 to 14) although controlling for this latter using a time of the experiment variable initially produced no statistically significant coefficients. The day is divided into 4 sections, namely early morning (00:00 to 05:59), morning (06:00 to 11:59), afternoon (12:00 to 17:59), and evening (18:00 to 23:59).

For the interaction effects, all specifications confirm that NSW participants did not behave differently due to the DST change. Interestingly, the QLD participants behaved differently in the week after the DST change (wave 3). Not only did Queenslanders perform better and showed more risk aversion than before the DST change, but in line with previous literature (Eckel and Grossman, 2008), the males were more risk seeking than the females. On the cognitive test, however, no significant gender differences emerged. Although risk aversion is positively correlated with both number of children and being divorced, there is substantial heterogeneity and non-linearity among the income groups for both dependent variables. The oldest age group exhibits the lowest performance, compared to the reference group (aged 18–24). The middle-aged people (aged 25-44) seem to be somewhat more risk loving compared to the reference group. In terms of income, which reflects socio-economic status, people in the income group under $15,000 are seen to exhibit significantly more appetite for risk, whereas the individuals in the income range $35,000 – $50,000 are most risk averse compared to the reference income range of $15,000 – $35,000. Surprisingly, people are more risk averse in the early morning compared to the reference group (morning).

Table 3

Difference-in-differences estimations with and without further controls using Stroop test performance as a dependent variable

Dep. Var.: Stroop Test Performance	(1)	(2)	(3)	(4)	(5)	(6)	(7)
NSW	*-0.002*	*-0.033*	*-0.024*	*-0.014*	*-0.040*	*-0.030*	*-0.015*
	-0.006	-0.099	-0.0723	-0.041	-0.117	-0.090	-0.043
	(-0.02)	(-0.27)	(-0.21)	(-0.11)	(-0.33)	(-0.26)	(-0.12)
Wave 1	ref.	ref.	ref.	ref.	ref.	ref.	ref.
Wave 2	*0.096*	*0.097*	*0.100*	*0.124*	*0.098*	*0.099*	*0.130**
	0.286	0.290	0.300	0.359	0.292	0.296	0.376

	(1.16)	(1.24)	(1.29)	(1.62)	(1.23)	(1.25)	(1.68)
Wave 3	_0.195***_	_0.197***_	_0.202***_	_0.201**_	_0.195***_	_0.198***_	_0.207***_
	0.582	0.588	0.602	0.581	0.583	0.590	0.599
	(2.71)	(2.73)	(2.77)	(2.56)	(2.79)	(2.80)	(2.74)
NSW*wave 2		_0.094_	_0.094_	_0.068_	_0.096_	_0.096_	_0.069_
	0.416	0.417	0.418	0.288	0.427	0.426	0.296
	(1.09)	(1.15)	(1.15)	(0.78)	(1.18)	(1.18)	(0.81)
NSW*wave 3		_-0.007_	_-0.006_	_-0.020_	_0.0003_	_-0.0004_	_-0.017_
	-0.0292	-0.0290	-0.0284	-0.0847	0.0017	-0.00211	-0.071
	(-0.08)	(-0.08)	(-0.08)	(-0.22)	(0.00)	(-0.01)	(-0.18)
Gender							
Male		_-0.060_	_-0.074_	_-0.053_	_-0.062_	_-0.075_	_-0.055_
		-0.170	-0.209	-0.146	-0.173	-0.211	-0.149
		(-1.33)	(-1.40)	(-1.00)	(-1.33)	(-1.39)	(-1.00)
Age group							
13 - 17		_-0.286**_	_-0.332***_	_-0.348***_	_-0.289**_	_-0.335***_	_-0.352***_
		-3.370	-3.914	-3.768	-3.406	-3.942	-3.804
		(-2.53)	(-2.87)	(-2.66)	(-2.52)	(-2.85)	(-2.64)
18 - 24		ref.	ref.	ref.	ref.	ref.	ref.
25 - 34		_-0.070_	_-0.089_	_-0.105_	_-0.070_	_-0.088_	_-0.108_
		-0.400	-0.507	-0.583	-0.399	-0.499	-0.600
		(-1.39)	(-1.52)	(-1.32)	(-1.32)	(-1.44)	(-1.32)
35 - 44		_-0.022_	_-0.034_	_-0.038_	_-0.023_	_-0.035_	_-0.041_
		-0.0996	-0.153	-0.170	-0.106	-0.156	-0.182
		(-0.37)	(-0.55)	(-0.42)	(-0.38)	(-0.54)	(-0.45)
45 - 54		_-0.097_	_-0.117_	_-0.123_	_-0.100_	_-0.119_	_-0.130_
		-0.397	-0.479	-0.474	-0.408	-0.486	-0.504
		(-1.29)	(-1.52)	(-1.16)	(-1.29)	(-1.52)	(-1.20)
55 - 64		_-0.040_	_-0.067_	_-0.068_	_-0.040_	_-0.066_	_-0.070_
		-0.129	-0.214	-0.211	-0.129	-0.211	-0.219
		(-0.49)	(-0.80)	(-0.58)	(-0.48)	(-0.77)	(-0.59)
65 or older		_-0.244**_	_-0.272***_	_-0.281**_	_-0.244**_	_-0.271***_	_-0.285**_
		-0.703	-0.784	-0.782	-0.702	-0.780	-0.796
		(-2.59)	(-2.80)	(-2.08)	(-2.54)	(-2.76)	(-2.09)
Marital status							
Single		ref.	ref.	ref.	ref.	ref.	ref.
De facto		-0.118*	-0.108	-0.134*	-0.119*	-0.109	-0.133*
		_-0.709_	_-0.650_	_-0.852_	_-0.716_	_-0.659_	_-0.848_
		(-1.74)	(-1.53)	(-1.67)	(-1.74)	(-1.54)	(-1.66)
Divorced		0.035	0.026	0.002	0.037	0.030	0.006
		_0.135_	_0.104_	_0.00728_	_0.146_	_0.116_	_0.0212_
		(0.61)	(0.46)	(0.03)	(0.65)	(0.51)	(0.10)
Married		-0.035	-0.035	-0.087	-0.031	-0.030	-0.082
		_-0.0990_	_-0.0999_	_-0.239_	_-0.0874_	_-0.0854_	_-0.226_
		(-0.60)	(-0.57)	(-1.37)	(-0.53)	(-0.48)	(-1.28)
Other		0.016	0.011	-0.001	0.015	0.011	-0.001
		_0.109_	_0.0725_	_-0.00476_	_0.107_	_0.0739_	_-0.00349_
		(0.57)	(0.37)	(-0.03)	(0.56)	(0.37)	(-0.02)
Separated		_0.010_	_0.017_	_-0.003_	_0.009_	_0.016_	_-0.003_
		0.0978	0.163	-0.0319	0.0836	0.150	-0.0374
		(0.48)	(0.70)	(-0.11)	(0.40)	(0.64)	(-0.13)
Number of children in the household							
One		ref.	ref.	ref.	ref.	ref.	ref.
Two		_-0.080_	_-0.085_	_-0.082_	_-0.073_	_-0.079_	_-0.077_
		-0.457	-0.487	-0.455	-0.418	-0.449	-0.425
		(-1.54)	(-1.61)	(-1.35)	(-1.43)	(-1.50)	(-1.26)
Three or more		_-0.004_	_-0.018_	_-0.004_	_-0.006_	_-0.018_	_-0.005_
		-0.0335	-0.150	-0.0315	-0.0471	-0.155	-0.0371
		(-0.12)	(-0.50)	(-0.10)	(-0.17)	(-0.50)	(-0.12)
None		_-0.053_	_-0.059_	_-0.028_	_-0.055_	_-0.061_	_-0.029_
		-0.196	-0.219	-0.103	-0.206	-0.228	-0.105
		(-1.12)	(-1.12)	(-0.42)	(-1.14)	(-1.12)	(-0.40)
Income group							
Under $15,000			_0.049*_	_0.043_		_0.049*_	_0.045_
			0.408	0.335		0.408	0.346
			(1.68)	(1.35)		(1.78)	(1.46)

$15,000 to under $35,000			ref.	ref.		ref.	ref.
$35,000 to under $50,000			*-0.036*	*-0.037*		*-0.034*	*-0.034*
			-0.132	-0.125		-0.124	-0.114
			(-0.65)	(-0.62)		(-0.60)	(-0.56)
$50,000 to under $75,000			*0.004*	*0.014*		*0.004*	*0.016*
			0.0129	0.0470		0.0164	0.0527
			(0.05)	(0.19)		(0.07)	(0.21)
$75,000 to under $100,000			*0.035*	*0.047*		*0.031*	*0.045*
			0.174	0.216		0.155	0.209
			(0.81)	(1.00)		(0.71)	(0.96)
$100,000 or more			*-0.005*	*0.015*		*-0.007*	*0.015*
			-0.0228	0.0639		-0.0300	0.0640
			(-0.07)	(0.19)		(-0.09)	(0.19)
Don't Know/Prefer not to answer			*-0.076*			*-0.072*	
			-0.354			-0.336	
			(-1.14)			(-1.09)	
Time of experiment		*0.004*	*0.012*	*0.031*			
		3.79e-10	1.24e-09	3.14e-09			
		(0.06)	(0.19)	(0.50)			
Period of day							
Early morning					*0.014*	*0.011*	*0.015*
					0.405	0.326	0.392
					(1.19)	(0.76)	(0.87)
Morning					ref.	ref.	ref.
Afternoon					*0.031*	*0.030*	*0.053*
					0.0861	0.0852	0.146
					(0.65)	(0.63)	(1.05)
Evening					*-0.040*	*-0.031*	*0.010*
					-0.185	-0.145	0.0452
					(-0.54)	(-0.44)	(0.15)
Distance from border		*-0.022*	*-0.023*	*-0.047*	*-0.026*	*-0.027*	*-0.051*
		-0.0305	-0.0323	-0.0616	-0.0356	-0.0369	-0.0660
		(-0.36)	(-0.37)	(-0.69)	(-0.42)	(-0.42)	(-0.74)
N	414	414	414	372	414	414	372
R-squared	0.036	0.140	0.149	0.151	0.143	0.151	0.153
Prob. > F	0.001	0.015	0.056	0.161	0.143	0.151	0.153

Notes: Standardized beta coefficients in italics. *t*-statistics in parentheses. The symbols *, **, *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. Reference categories: QLD, wave 1, age group = 18 to 24, marital status = single, number of children = one, income group = $15,000 to under $35,000, period of day = morning.

Table 4

Difference-in-differences estimations with and without further controls using risk aversion as a dependent variable.

Dep. Var. : Risk aversion	(8)	(9)	(10)	(11)	(12)	(13)	(14)
NSW	*0.010*	*0.018*	*0.008*	*-0.037*	*0.033*	*0.021*	*-0.025*
	0.0570	0.100	0.0445	-0.205	0.187	0.118	-0.134
	(0.12)	(0.19)	(0.08)	(-0.35)	(0.35)	(0.21)	(-0.23)
Wave 1	ref.	ref.	ref.	ref.	ref.	ref.	ref.
Wave 2	*0.125**	*0.129*	*0.122*	*0.117*	*0.139**	*0.134**	*0.130*
	0.703	0.728	0.684	0.646	0.784	0.753	0.718
	(1.70)	(1.63)	(1.60)	(1.48)	(1.76)	(1.76)	(1.62)
Wave 3	*0.150***	*0.157**	*0.146**	*0.135**	*0.170***	*0.163***	*0.151**
	0.846	0.882	0.819	0.746	0.958	0.918	0.832
	(2.06)	(1.92)	(1.90)	(1.65)	(2.09)	(2.12)	(1.82)
NSW*wave 2	*-0.010*	*-0.010*	*-0.011*	*-0.007*	*-0.018*	*-0.017*	*-0.014*

	-0.0863	-0.0826	-0.0890	-0.0548	-0.149	-0.140	-0.118
	(-0.13)	(-0.12)	(-0.14)	(-0.08)	(-0.22)	(-0.21)	(-0.17)
NSW*wave 3	*-0.020*	*-0.020*	*-0.020*	*0.005*	*-0.033*	*-0.031*	*-0.003*
	-0.165	-0.164	-0.166	0.0433	-0.272	-0.260	-0.0283
	(-0.26)	(-0.26)	(-0.26)	(0.06)	(-0.42)	(-0.40)	(-0.04)
Gender							
Male		*-0.140****	*-0.185****	*-0.158****	*-0.135****	*-0.180****	*-0.153****
		-0.742	-0.981	-0.823	-0.718	-0.958	-0.795
		(-2.72)	(-3.36)	(-2.83)	(-2.63)	(-3.28)	(-2.71)
Age group							
13 to 17		*-0.044*	*0.107*	*0.204***	*-0.036*	*0.112*	*0.217***
		-0.979	2.366	4.224	-0.797	2.490	4.489
		(-0.71)	(1.15)	(2.04)	(-0.56)	(1.19)	(2.15)
18 to 24		ref.	ref.	ref.	ref.	ref.	ref.
25 to 34		*-0.206***	*-0.146*	*0.004*	*-0.209***	*-0.150*	*0.013*
		-2.212	-1.572	0.0450	-2.250	-1.613	0.138
35 to 44		(-2.14)	(-1.40)	(0.05)	(-2.11)	(-1.39)	(0.15)
		-0.157	*-0.091*	*0.097*	*-0.161*	*-0.095*	*0.104*
		-1.340	-0.773	0.826	-1.376	-0.810	0.886
45 to 54		(-1.38)	(-0.70)	(0.88)	(-1.38)	(-0.71)	(0.96)
		*-0.200**	*-0.176*	*0.083*	*-0.213**	*-0.188*	*0.084*
		-1.538	-1.354	0.614	-1.643	-1.447	0.620
55 to 64		(-1.65)	(-1.30)	(0.78)	(-1.71)	(-1.35)	(0.81)
		-0.244	*-0.154*	*0.164*	*-0.254*	*-0.164*	*0.171*
		-1.472	-0.933	0.976	-1.533	-0.992	1.019
65 or older		(-1.56)	(-0.90)	(1.16)	(-1.58)	(-0.92)	(1.23)
		-0.191	*-0.089*	*0.200*	*-0.204*	*-0.101*	*0.209*
		-1.038	-0.482	1.065	-1.111	-0.551	1.113
		(-1.14)	(-0.47)	(1.32)	(-1.18)	(-0.52)	(1.40)
Marital status							
Single		ref.	ref.	ref.	ref.	ref.	ref.
De facto		*-0.073*	*-0.085*	*-0.089*	*-0.066*	*-0.079*	*-0.082*
		-0.825	-0.970	-1.080	-0.749	-0.891	-0.989
		(-1.39)	(-1.52)	(-1.47)	(-1.25)	(-1.37)	(-1.32)
Divorced		*-0.036*	*-0.011*	*-0.017*	*-0.032*	*-0.010*	*-0.015*
		-0.264	-0.0780	-0.116	-0.239	-0.0763	-0.108
		(-0.50)	(-0.15)	(-0.22)	(-0.45)	(-0.15)	(-0.21)
Married		*0.045*	*0.004*	*0.004*	*0.053*	*0.008*	*0.011*
		0.242	0.0205	0.0230	0.281	0.0415	0.0571
		(0.58)	(0.05)	(0.05)	(0.67)	(0.10)	(0.13)
Other		*-0.048*	*-0.052*	*-0.052*	*-0.044*	*-0.049*	*-0.049*
		-0.623	-0.671	-0.630	-0.574	-0.643	-0.601
		(-0.80)	(-0.91)	(-0.86)	(-0.72)	(-0.86)	(-0.81)
Separated		*0.086***	*0.058*	*0.023*	*0.094***	*0.065**	*0.031*
		1.561	1.053	0.477	1.712	1.181	0.647
		(2.37)	(1.50)	(0.75)	(2.55)	(1.67)	(0.97)
Number of children in the household							
One		ref.	ref.	ref.	ref.	ref.	ref.
Two		*0.165****	*0.169****	*0.153***	*0.168****	*0.168****	*0.159***
		1.778	1.813	1.620	1.807	1.806	1.683
		(2.65)	(2.72)	(2.35)	(2.74)	(2.74)	(2.44)
Three or more		*0.064*	*0.075*	*0.083*	*0.072*	*0.081*	*0.092*
		1.016	1.183	1.221	1.145	1.273	1.350
		(1.23)	(1.45)	(1.44)	(1.36)	(1.53)	(1.55)
None		*0.215***	*0.200***	*0.208***	*0.239****	*0.218****	*0.232****
		1.507	1.398	1.445	1.670	1.525	1.611
		(2.50)	(2.51)	(2.48)	(2.74)	(2.69)	(2.66)
Income group							
Under $15,000			*-0.184***	*-0.205**		*-0.183**	*-0.204**
			-2.910	-3.027		-2.888	-3.007
			(-1.98)	(-1.93)		(-1.97)	(-1.92)
$15,000 to under $35,000			ref.	ref.		ref.	ref.
$35,000 to under $50,000			*0.190****	*0.202****		*0.188****	*0.200****
			1.310	1.310		1.295	1.299
			(3.29)	(3.28)		(3.24)	(3.25)

$50,000 to under $75,000			*0.126**	*0.142**		*0.118**	*0.134**
			0.865	0.920		0.810	0.873
			(1.88)	(1.95)		(1.75)	(1.83)
$75,000 to under $100,000			*0.092**	*0.094**		*0.095**	*0.095**
			0.865	0.824		0.897	0.839
			(1.88)	(1.79)		(1.93)	(1.80)
$100,000 or more			*-0.077*	*-0.075*		*-0.076*	*-0.074*
			-0.659	-0.599		-0.646	-0.593
			(-1.19)	(-1.04)		(-1.16)	(-1.03)
Don't Know/Prefer not to answer			*0.017*			*0.012*	
			0.147			0.103	
			(0.27)			(0.19)	
Start time of experiment		*0.011*	*-0.009*	*-0.014*			
		2.25e-09	-1.68e-09	-2.75e-09			
		(0.18)	(-0.14)	(-0.22)			
Period of day							
Early morning					*0.051****	*0.041***	*0.038**
					2.761	2.200	1.892
					(2.98)	(2.39)	(1.91)
Morning					ref.	ref.	ref.
Afternoon					*-0.014*	*-0.021*	*-0.021*
					-0.0769	-0.113	-0.110
					(-0.24)	(-0.37)	(-0.34)
Evening					*0.065*	*0.053*	*0.034*
					0.561	0.459	0.300
					(1.04)	(0.87)	(0.53)
Distance from border		*-0.020*	*-0.009*	*-0.014*	*-0.017*	*-0.004*	*-0.012*
		-0.0518	-0.0232	-0.0355	-0.0429	-0.0116	-0.0294
		(-0.34)	(-0.14)	(-0.21)	(-0.28)	(-0.07)	(-0.18)
N	414	414	414	372	414	414	372
R-squared	0.017	0.076	0.145	0.148	0.083	0.150	0.151
Prob. > F	0.207	0.006	0.000	0.000	0.083	0.150	0.151

Notes: Standardized beta coefficients in italics. *t*-statistics in parentheses. The symbols *, **, *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. Reference categories: QLD, wave 1, age group = 18 to 24, marital status = single, number of children = one, income group = $15,000 to under $35,000, period of day = morning.

4. Discussion

Contrary to the findings of some earlier studies, the current study does not find any significant impact of the DST transition on cognitive performance or risk-taking behaviour. Although the exact mechanism is yet to be understood, the findings tend to support the argument in favour of human adaptability to internal sleep-asynchrony due to a one hour transition to DST. The study makes several methodological contributions. First, unlike artificially controlled laboratory experiments or field studies using aggregated data (e.g., accident rates), which ignore unobserved factors capable of influencing the results, the field experiment employs a control (QLD) and a treatment (NSW) group naturally created by exogenous geographic variation. These naturally created groups enable isolation of the DST transition's effect on the two outcome variables: cognitive performance and risk taking among both affected and unaffected individuals. In addition, because of their geographic proximity, all study participants are socio-demographically and socio-economically similar, which fulfils a critical identification assumption of the research. The study design also begins to remedy the lack of longitudinal studies in this area by exploring differences before, immediately after, and one week following the DST shift.

The analysis does, however, suffer from certain limitations, several of which suggest avenues for future research. First, the low magnitude of the standard deviation in performance on the Stroop test suggests that a more challenging task might increase the variability in cognitive functioning. It could also indicate that the number of trials should be higher. As pointed out above, using a large sample of voluntary participants in an experiment that is repeated three times over a period of two weeks limits the ability to use a more extensive test. Similarly, because different cognitive functions require different processes (e.g., stimulus detection, information encoding, working memory; Jackson et al., 2013), future investigations might throw more light on DST's cognitive implications by employing a similar setting but exploring each underlying cognitive process in detail. The novelty of the task could also be problematic given evidence that although simple repetitive tasks are sensitive to sleep loss, complex rule-based tasks are not (Harrison and Horne, 2000). Thus, the fact that only one out of six RTB studies using the Balloon Analogue Risk Task (BART) shows a positive relation between sleep loss and risk-taking behaviour may result from BART being a more physically demanding task than other RTB measures (Womack et al., 2013: 353). More evidence is thus needed using different tasks and instruments.

Another possible improvement would be the collection of more background information to capture such additional participant variables as how well rested the individuals were at the time of task performance, which could be relevant to individual heterogeneity. More important, performance might differ between Sunday and Monday (or the next working day[3]), with individuals being more sleep deprived on returning to their daily routine. In sum, even though in this case the field study design revealed no statistically significant effects between the treated and untreated group and over time, it does have the potential to provide important additional insights on the effects of the DST transition in particular or of fatigue and sleep deprivation in general on human behaviour and performance.

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[3] Monday following the DST switch was (as usual) Labour Day.

Appendix

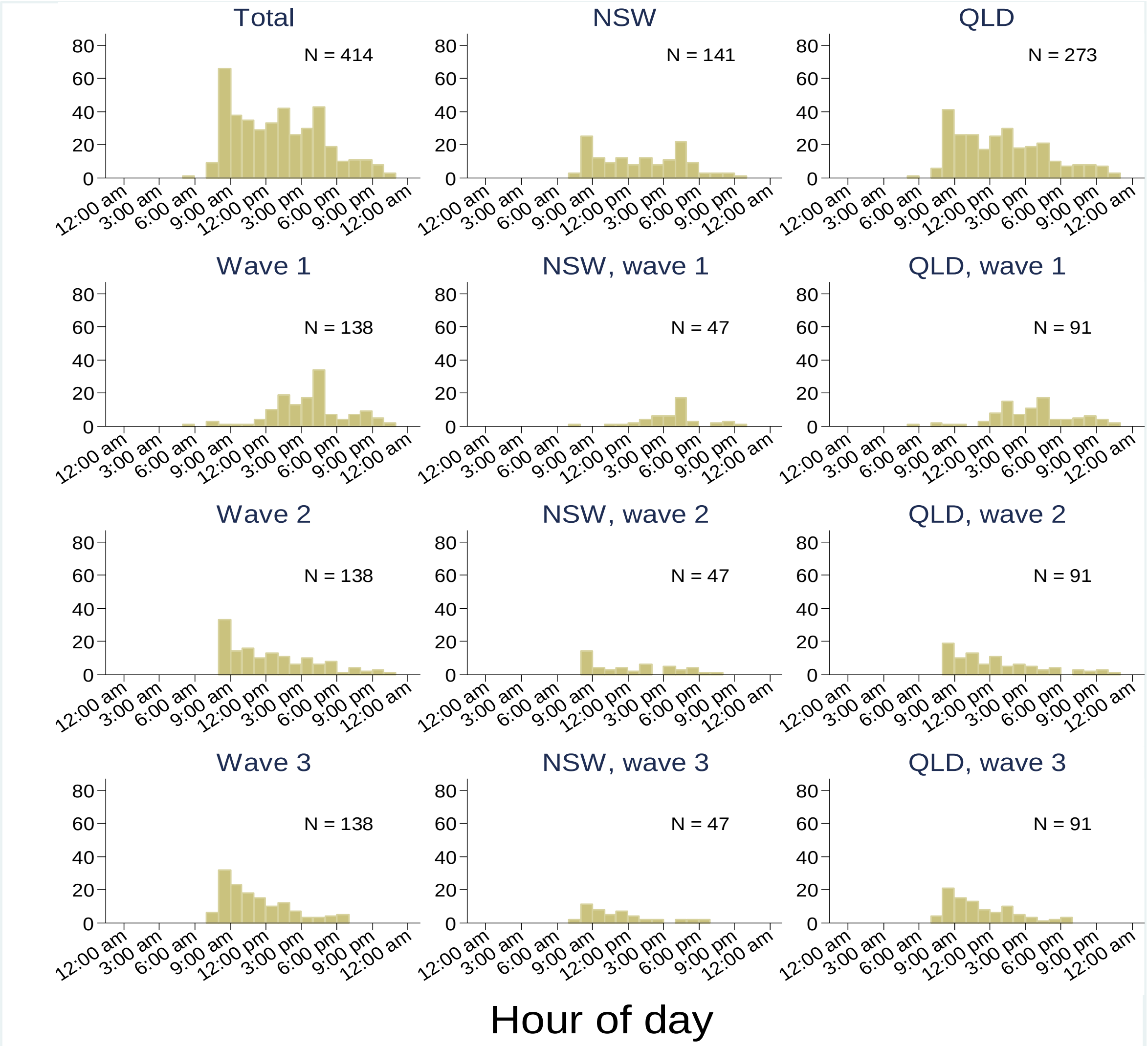

Fig. A1. Distribution of experiment time by states and waves, with each bin representing 1 hour. Wave 1: one week prior to the DST change (September 29); wave 2: the day of the change in NSW (October 6, 2013); wave 3: one week after the DST change (October 13, 2013).

Table A1

Distribution comparison between drop outs and non-drop outs – wave 1

Variables	Kolmogorov-Smirnov p-value	Pearson's χ^2	p-value
Risk aversion	0.608		
Stroop test	1.000		
Distance from border	0.981		
Male		0.798	0.372
Age group		6.356	0.499
Marital status		5.465	0.362
Number of children in the household		0.201	0.977
Income group		3.882	0.693
Period of day		4.663	0.198

Note: Continuous variables were tested using the two-sample Kolmogorov-Smirnov test and categorical one with a Pearson's χ^2 test. Age groups: 13 – 17, 18 – 24, 25 – 34, 35 – 44, 45 – 54, 55 – 64 and 65 or older; marital status: single, de facto, divorced, married, other and separated; number of children in the household: one, two, three or more and none; income group: under $15,000, $15,000 to under $35,000, $35,000 to under $50,000, $50,000 to under $75,000, $75,000 to under $100,000, $100,000 or more, and don't know/prefer not to answer; period of day: early morning, morning, afternoon and evening.

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