Time-of-day effects in implicit associations are probably selection effects, not circadian rhythms

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Abstract

Time-of-day effects in human psychological functioning have been known of since the 1800s. However, outside of research specifically focused on the quantification of circadian rhythms, they have largely been neglected. Moves toward online data collection now mean that psychological investigations take place around the clock, which affords researchers the ability to easily study time-of-day effects. Recent analyses have shown, for instance, that implicit attitudes have time-of-day effects. The plausibility that these effects indicate circadian rhythms rather than selection effects is considered in the current study. There was little evidence that the time-of-day effects in implicit attitudes shifted appropriately with factors known to influence circadian rhythms. Even variables that cannot logically show circadian rhythms demonstrated stronger time-of-day effects than did implicit attitudes. Taken together, these results suggest that time-of-day effects in implicit attitudes are more likely to represent selection effects rather than circadian rhythms, but do not rule out the latter possibility.

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Introduction

Circadian rhythms refer to an approximately 24 hour cycle resulting from the non-linear interactions of the oscillatory processes of the circadian pacemaker and homeostatic sleep pressures (Czeisler et al., 1999; Panda, Hogenesch, & Kay, 2002). These circadian rhythms have been observed via robust time-of-day effects in physiology (Jasper & Hermsdörfer, 2007; Refinetti & Menaker, 1992), behaviour (Yasseri, Sumi, & Kertész, 2012), emotion (Golder & Macy, 2011), and cognition (García, Ramírez, Martínez, & Valdez, 2012). Focussing here on the psychological, time-of-day effects have been observed in cognition since the 1800s (Ebbinghaus, 1885/1964), were shown to occur across a diverse array of tasks (Kleitman, Cooperman, & Mullin, 1933), and later linked to circadian cycles (Wever, 1979). A demonstrable linkage of time-of-day effects to circadian cycles is of critical importance to prevent spurious conclusions about the origins of within-day variation.

The consideration of circadian rhythms has largely been absent from the era of laboratory based psychological experimentation (Schmidt, Collette, Cajochen, & Peigneux, 2007). Indeed, beyond basic cognitive and affective processes, circadian rhythms in psychological processes may be considered largely uncharted territory. With the recent explosion of online data-collection through demonstration websites (Nosek, Banaji, & Greenwald, 2002), analyses of social media (Golder & Macy, 2011), and recruitment via crowd sourcing platforms (Buhrmester, Kwang, & Gosling, 2011), behavioural scientists are now collecting data across all hours of the day. One example where this collection across all hours of the day has been used, was in a test of whether implicit preferences show a circadian rhythm (Zadra & Proffitt, 2014).

Indeed, Zadra and Proffitt (2014) found significant time-of-day effects in implicit preferences that followed a time-course that would be anticipated in circadian rhythms (i.e., morning to evening). The conclusion that implicit preferences have a circadian rhythm is abductively one of two reasonable interpretations of the data. Indeed, it is the one which both Zadra and Proffitt (2014) and I [1] gravitated toward. The second explanation is that in an 'always accessible' study without allocation of participants to a time of participation, that a time-of-day effect is being driven by self-selection. Such a concern can be dealt with in different ways, such as testing to see whether the time-of-day effects differ across groups (Zadra & Proffitt, 2014), or by partialling out effects of groups and analysing the residuals. However, these methods both make the assumption that the groups or dimensions driving selection have been correctly identified, while also assuming that the outcome being modelled is not the factor driving selection.

Three primary endeavours were undertaken in the present paper to investigate the plausibility that time-of-day effects in implicit attitudinal preferences represent circadian processes. First, replication of the findings of time-of-day effects in implicit attitudes was attempted using a different method to that adopted by Zadra and Proffitt (2014) of accounting for variability in participant demographics. Next, the probability of this effect being circadian in nature was examined via analysis of moderation by factors known to influence the timing of circadian rhythms. These factors reliably include age (Paine, Gander, & Travier, 2006; Roenneberg et al., 2004; Van Cauter, Leproult, & Kupfer, 1996), appears to include daylight saving time (DST; Kantermann, Juda, Merrow, & Roenneberg, 2007), and sometimes includes gender (Van Cauter et al., 1996). Finally, it was then examined whether the amount of circadian rhythmicity identified in implicit attitudes exceeded that of other variables that could only be

[1] This was the conclusion independently drawn in the initial pre-print of this manuscript (doi: 10.7287/peerj.preprints.1475v1) prior to becoming aware of Zadra and Proffitt's (2014) paper on the matter.

driven by selection effects (i.e., age and gender). While not necessarily a requirement to exceed this benchmark, it would build confidence in the time-of-day effect being more than selection.

Method

Data

Data from Project Implicit's demonstration Black-White race Implicit Association Test (IAT), was used and is described elsewhere (Xu, Nosek, & Greenwald, 2013). The subset of adults from the US who completed the measure of implicit attitudes and indicated their race (*N* = 1,601,274) were analysed. The observations included vary across analyses as some variables came into or out of the data-collection at different points in time. Completion time was adjusted from server time (US Eastern; F. Xu, personal communication, September 11, 2015) to local time in the respondents' county. In cases where a county sat in two time-zones, it was coded as half-way between the two time-zones. In all regions observing daylight savings, the days in which a transition to or from daylight saving occurred were excluded from analysis.

Americans prefer their own race over other races, and prefer White individuals over Black individuals if they are neither White nor Black (Axt, Ebersole, & Nosek, 2014). To harmonize IAT scores across participant race, a preference for White over Black targets was interpreted as an in-group preference for all participants who were not Black, while a preference for Black over White targets was coded as an in-group preference for Black participants. This recoded score served as the dependent measure. For each categorisation of participant race, this resulted in a significant positive score.

Preparation of the Project Implicit data was conducted in SPSS and analysis performed in STATA, with all code available at https://osf.io/um8g9/?view_only=d66d1a0b1a2a47f8a3a7b6cfc65acbf7.

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Statistical models

Cosinor regression that made use of sine and cosine functions with periodicity 24 hours was employed. Cosinor regression is a highly sensitive method for the detection of circadian rhythms, suitable for analysis of cross-sectional data even when there is a low signal to noise ratio (Refinetti, Cornélissen, & Halberg, 2007). It should be emphasised that this type of analysis only captures a very specific wave-form and periodicity. No covariates were included in any of these cosinor models, instead the association of the covariate/s with the outcome were first regressed out, and the residuals subsequently analysed. These regression models included dummy codes for each level of each demographic predictor and linear and quadratic time effects to detrend the data. The educed circadian rhythm was extracted from these cosinor models using the predicted values from sine and cosine functions. Where interactions were tested the sine and cosine main effects and the main effect of the moderator were fitted along with two interaction terms; one between sine and the moderator and the other between cosine and the moderator. The joint effect of the two interaction terms were then tested.

PART 1: Replication

Results

A significant circadian rhythm was present in the demographics adjusted model, $F(2, 1187494) = 470.87$, $p < .001$. This rhythm was weak, with time-of-day accounting for 0.079% of the variation in implicit preference for the in-group. Despite its weakness, the raw data and the fitted rhythm showed comparable forms (Figure 1A). A significant circadian rhythm was also present in analyses of just the temporally detrended, but otherwise unadjusted, data on the same sample, $F(2, 1187494) = 301.24$, $p < .001$. This rhythm was somewhat weaker than that in the adjusted model, with time-of-day accounting for 0.051% of the variation in implicit preference for the in-group. The two rhythms followed similar time courses, with peak in-group preference at 9:10pm in the adjusted model and at 8:27pm in the unadjusted model (Figure 1B).

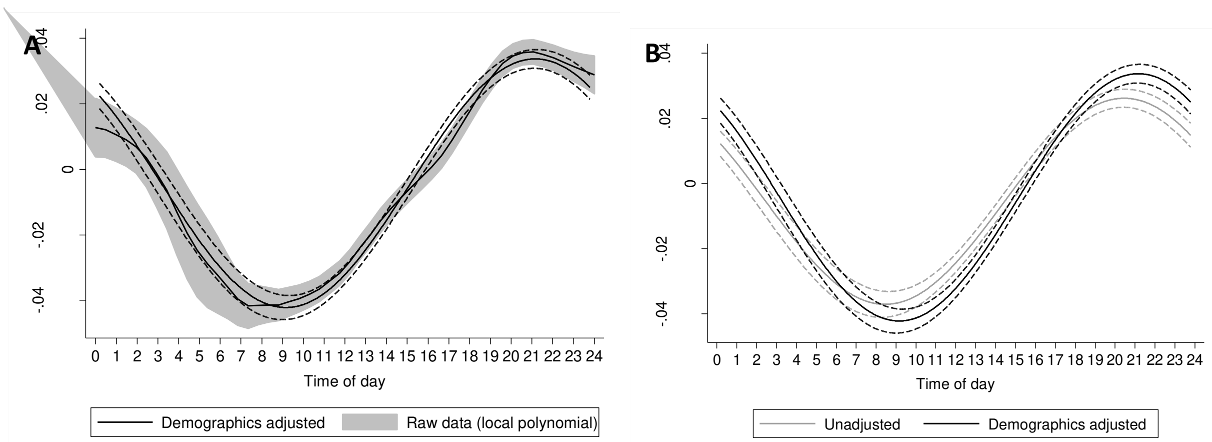

Figure 1. Panel A presents the predicted cosinor function (± 95% CI) superimposed over the local polynomial fit of the raw data (± 95% CI). Note, that where cosinor function takes into account time as if it was circular, the local polynomial does not, which could lead to some distortion at the ends of the function. Panel B comparison of the unadjusted and adjusted cosinor functions.

PART 2: Convergent validity

Despite implicit in-group preferences having robust time-of-day effects, whether or not this is evidence of selection or circadian rhythms is an open question. One way to begin to answer this question is to see if the onset and timing of the time-of-day effect is affected by characteristics known to affect the onset and timing of circadian rhythms. If this rhythm was circadian in origin, it should (a) peak earlier during DST, (b) peak earlier among women than among men, and (c) peak earlier among older adults. These three hypotheses were tested in the adjusted models.

Results

Daylight saving time. Moderation of the circadian rhythm by being in DST time was not observed, $F(2,1187491) = 0.02$, $p = .981$, $r^2 = 0.000\%$. This null pattern replicated if analysis was limited to only those regions which observe DST, $F(2, 1164171) = 0.10$, $p = .902$, $r^2 = 0.000\%$; or if analysis was limited just to time periods in which DST was being observed $F(2, 769931) = 1.76$, $p = .171$, $r^2 = 0.000\%$.

Gender. Moderation of the circadian rhythm by gender was observed, $F(2,1187491) = 22.48$, $p < .001$, $r^2 = 0.004\%$. Consistent with prior work indicating that women have earlier onset circadian rhythms than men, the rhythm observed among women had an average peak (acrophase) occurring 1 hour and 18 minutes before that of the men.

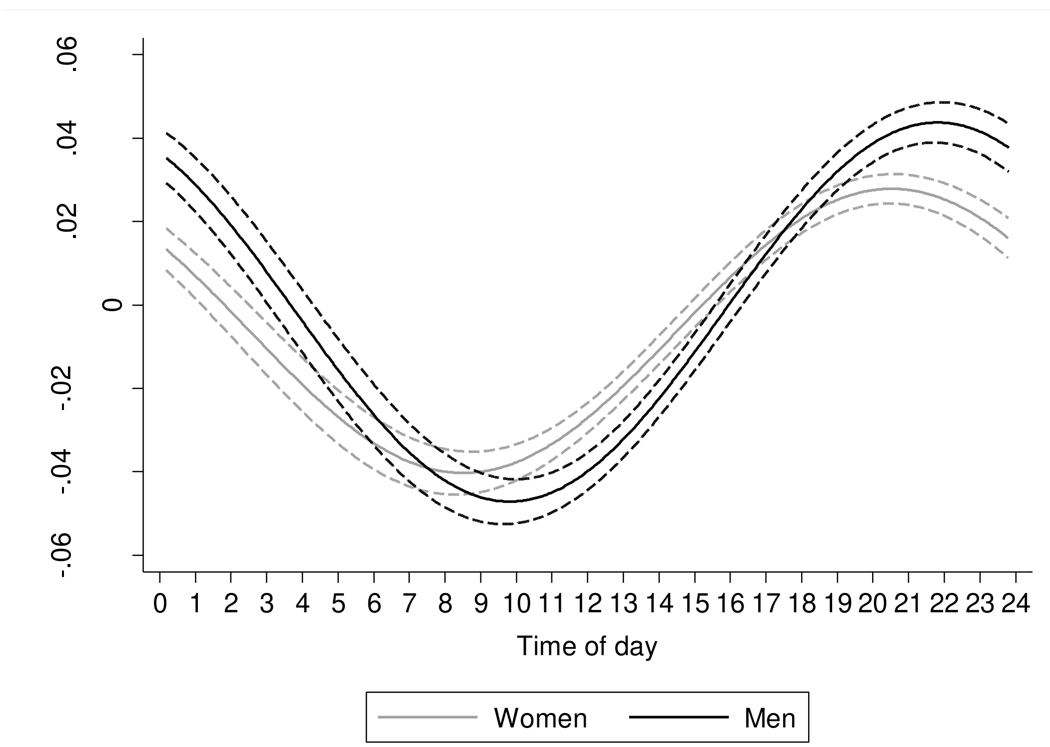

Figure 2. Comparison of the cosinor functions (±95% CI) for women and men. The peak of the function occurs earlier in women than in men.

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Age. To avoid making assumptions about the shape of the relationship between participant age and acrophase, the circadian rhythms were first modelled for each year of age, from 18 to 89, separately. The predicted acrophase of each model was saved, along with the number of contributing observations. Regression of a linear age term on the predicted acrophase, weighted by the number of observations revealed a significant linear effect of age, $F(1,1187495) = 64226.46$, $p < .001$, $r^2 = 5.13\%$ (Figure 3). For reference, about 82% of the data comes from those aged 40 or less, and given that visual inspection suggested the possibility of a discrete relationship for those over 40, this analysis was replicated in those 40 or less. Again, it revealed a significant effect of similar dynamics, $F(1,977994) > 99999$, $p < .001$, $r^2 = 11.66\%$. From this model, the acrophase of an individual aged 18 was predicted to occur 1 hour and 7 minutes before that of a person aged 40. Sensitivity tests were performed, replicating the results of this model, by fitting a continuous age function into the cosinor model for those aged 18 to 40. The moderation by age was significant $F(2,977990) = 5.77$, $p = .003$, $r^2 = 0.001\%$. The predicted acrophase of an individual aged 18 was predicted to occur 1 hour and 12 minutes before that of a person aged 40. However, in both the base tests and sensitivity analyses, this effect runs in the opposite direction to what would be expected based on the literature showing advancement of circadian rhythms with age.

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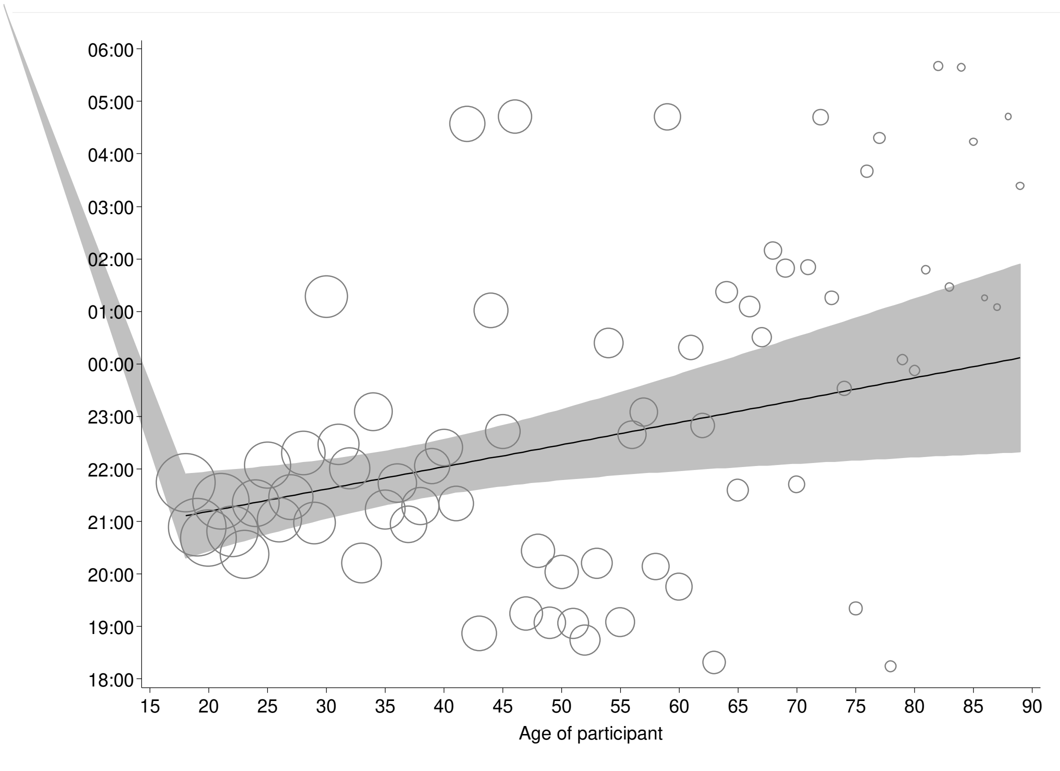

Figure 3. Predicted acrophase of implicit attitudes for participants of each age. Bubble area represents relative differences in the square root of the number of observations contributing to the predicted acrophase. The solid line represents the weighted regression of age on acrophase for the full sample, and the shading the 95% confidence around it.

PART 3: Exceeding selection effects

The magnitude of the cosinor effect size for implicit attitudes was compared to the cosinor effect size for two fixed demographic factors (i.e., age and gender). Neither of these factors vary in a wave pattern across the course of the day and so any time-of-day effect cannot be due to a circadian rhythm. Concretely, a person is not male in the morning, female in the evening, and back to male come the next morning. Similarly, chronological age does not go backwards as would be required in a circadian rhythm. Significant cosinor patterns in these fixed variables would be indicative of time-of-day selection effects rather than circadian rhythms. The magnitude of these selection effects isolated via cosinor regression was set as a benchmark that

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the cosinor effect in implicit attitudes needed to exceed to suggest that something more than selection was taking place.

Results

As outlined in Part 1, the cosinor fit to implicit attitudes explained 0.079% of the variability in IAT scores. This procedure was repeated with residuals from a regression with age fitted as the outcome, and the residuals from a logistic regression with gender fitted as the outcome. The cosinor accounted for 0.547% of the variability in age (acrophase of 8:36pm), and 0.197% of the variability in gender (acrophase of 4:37am). The fit of the cosinor for implicit attitudes accounted for 6.92 times less variance than age despite the similar acrophase, and 2.49 times less variance than gender.

GENERAL DISCUSSION

The finding of time-of-day effects in implicit attitudes by Zadra and Proffitt (2014), was replicated here using an analysis of residuals that factored out discrete effects of socio-demographic factors. Indeed, the high conformity of the modelled cosinor to the raw data gives a degree of confidence that the time-of-day effects are robust and not artefacts of the analytic technique. The primary contribution of this research concerns the interpretation of this effect. There is little evidence that the time-of-day effects are indicative of circadian rhythms. Instead, the time-of-day effects are likely better viewed as selection effects. Only one of three factors known to influence the temporal onset of circadian rhythms had the expected moderating effect, one exerted no influence, and one had an effect in the opposite direction. Moreover, even variables in the data that could only be influenced by selection showed far greater time-of-day effects than those observed for implicit attitudes.

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For a compelling argument to be made that the time-of-day effects in implicit attitudes are circadian in nature, more direct evidence is needed. This could take the form of showing that the onset of the effect varies by participant chronotype (Adan et al., 2012), random allocation to time of participation, or through use of constant routine and forced desynchrony procedures (Blatter & Cajochen, 2007). As it stands, caution must be taken in the analysis of circadian patterns in large online data-sets which have the power to detect even very small effects. An absence of caution may be of little concern when the purpose is to document the time-of-day patterning of behaviour (e.g., Yasseri et al., 2012), but is likely problematic if underlying psychological and circadian processes are of interest (e.g., Zadra & Proffitt, 2014). Large datasets give the ability to study important effects which are statistically small (e.g., Westgate, Riskind, & Nosek, 2015), however, caution is warranted in interpreting time-of-day effects as these may well be driven by selection rather than circadian processes.

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