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Daily Fluctuations in Positive Affect Positively Co-Vary with Working Memory Performance

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Abstract

Positive affect is related to cognitive performance in multiple ways. It is associated with motivational aspects of performance, affective states capture attention, and information processing modes are a function of affect. In this study, we examined whether these links are relevant within individuals across time when they experience minor ups and downs of positive affect and work on cognitive tasks in the laboratory on a day-to-day basis. Using a micro-longitudinal design, 101 younger adults (20–31 years) worked on three working memory tasks on about 100 occasions. Every day, they also reported on their momentary affect and their motivation to work on the tasks. In two of the three tasks, performance was enhanced on days when positive affect was above average. This performance enhancement was also associated with more motivation. Importantly, increases in task performance on days with above-average positive affect were mainly unrelated to variations in negative affect. This study's results are in line with between-person findings suggesting that high levels of well-being are associated with successful outcomes. They imply that success on cognitively demanding tasks is more likely on days when feeling happier.

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Cognitive performance levels are not merely stable attributes of individuals (Rabbitt, Osman, Moore, & Stollery, 2001; Schmiedek, Lövdén, & Lindenberger, in press), but also vary within individuals, and co-vary with motivation, stress, negative affect (NA), and affect regulation (Brose, Schmiedek, Lövdén, & Lindenberger, 2012; Riediger, Wrzus, Schmiedek, Wagner, & Lindenberger, 2011; Sliwinski, Smyth, Hofer, & Stawski, 2006). Understanding the reasons for within-person variations in performance is, among other things, important for being able to control performance levels (e.g., performing optimally in exams). This is particularly true for basic components of information processing such as working memory (WM), which is crucial for higher-order cognitive operations (e.g., reasoning; Engle, Tuholski, Laughlin, & Andrew, 1999).

A variable that may relate to WM performance at the within-person level is positive affect[1] (PA). To date, insights on how PA and cognition are related have primarily been gained via experimental manipulations of emotions or by means of cross-sectional observations. Findings point in two directions, to a positive and negative PA–WM relationship. On the one hand, PA is related to increased feelings of energy, approach behaviors paralleling success (e.g., higher engagement in activities), and a greater sense of control (Lyubomirsky, King, & Diener; see also Cacioppo, Gardner, & Berntson, 1999). Believing in one's impact on outcomes is likely to increase effort (Bandura, 1977), and increased energy provides resources in the form of persistence and volitional control of off-task thoughts (Kuhl, 1987). This would suggest an enhancing effect of PA on WM performance via a motivational route. Empirical findings support these considerations. For example, studies on well-being and performance indicators in work contexts report positive associations (for review, see Lyubomirsky et al., 2005) and PA positively relates to task engagement (Salanova, Llorens, & Schaufeli, 2011).

Neuropsychological evidence also suggests a positive PA–WM association. Working memory has two major components, maintenance and updating, which are related to dopamine activity (DA) of the prefrontal cortex and the striatum, respectively (Cools & D'Esposito, 2011). As experiencing positive feelings alters DA levels, PA may thereby affect WM (Ashby, Isen, & Turken, 1999). The DA–WM relationships follow an inverted U-shape, however (Cools & D'Esposito, 2011), implying that only moderate but not extreme increases in PA should result in better performance.

Conversely, experimental studies often report negative associations between WM and PA (Mitchell & Phillips, 2007). One explanation for this is that affective states consume cognitive resources if they elicit regulation or draw attention to threatening or joyful events (Ellis & Ashbrook, 1988). Given limited cognitive resources, the allocation of resources to affect results in performance impairments on tasks that are resource-intensive (Mitchel & Phillips, 2007). This challenges the assumption that daily PA positively co-varies with WM. Furthermore, experiencing high levels of PA may result in a heuristic processing mode that is not beneficial for WM performance. PA signals the absence of threats and results in non-rigorous problem-solving and a broadened repertoire of thoughts, which, for example, facilitates creative problem solving (Isen, 1999; Schwarz & Bless, 1991). To the contrary, task requirements of *WM tasks* (e.g., narrowed attention and low distractibility) may *not* be met when processing is heuristic (Dreisbach & Goschke, 2004). Relevant refinements to these ideas are that (a) only PA low in motivational intensity (i.e., amusement) results in heuristic processing (Gable & Harmon-Jones, 2010), and (b) although PA often induces heuristic processing, this can be counteracted by motivation (Bodenhausen, Kramer, & Susser, 1994). For example, the evaluation of a performance situation may be positively biased by PA and this may increase task engagement (Martin, Ward, Achee, & Wyer, 1993).

This study examines these opposing views at the within-person level of functioning using a micro-longitudinal design with 100 laboratory assessments. It investigates whether PA is associated with enhanced or attenuated WM performance within individuals as their PA varies more naturally[2]. We tentatively hypothesize a positive relationship between PA and WM because subtle day-to-day variations in PA differ from induced emotions in experimental studies. The former are often object-less and less intense then the latter, which typically have an object and elicit regulation (Ekman, 1994). Therefore, the resource account may be less relevant in the context of this study. Moreover, it seems likely that volitional components are relevant for WM performance variations when measured within individuals on a day-to-day level, and these are closely related to PA (see above).

Additionally, this study investigates whether within-person variations in PA simply have the opposite effect on WM than NA variations. Experimental and micro-longitudinal approaches revealed that NA is associated with *decreased* initiative and WM performance (Brose et al., 2012; Hertel, 2000). However, PA and NA are not opposite ends of a single dimension—their within-person correlation is only moderate (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000). It is therefore possible that the relationships between performance and PA and NA, respectively, are (partly) independent. We explored these possibilities and thereby followed up on earlier findings (Brose et al., 2012).

Method

This investigation is part of the COGITO study, a study in which participants completed

120 days of assessments of cognitive performance and daily life experiences (10 pretest and posttest sessions, 100 daily sessions; for details, see Schmiedek, Lövdén, & Lindenberger, 2009). This investigation reports data from the 100 daily sessions and includes 101 younger participants (51.5% women, age: 20–31, *M*=25.6). On average, participants had 12.5 years of school education. The sessions (87–107, *M*=101, 1–1.5 hours each) were scheduled on an individual basis (from Monday to Saturday, 8 a.m. to 7.30 p.m). Participants worked individually on 12 computerized cognitive tasks (3 WM, 3 episodic memory, and 6 perceptual speed tasks) in rooms with 3 to 6 computers. Sessions began and ended with self-reports.

Measures

Self-report. *Positive affect* was assessed prior to the cognitive tasks with the *Positive and Negative Affect Schedule* (PANAS; Watson, Clark, & Tellegen, 1988). Ten items measuring high arousal PA (e.g., *enthusiastic*) were presented each day. Individuals rated how well these adjectives described their current mood. *Motivation* was conceptualized as participants' experience related to a target activity, as suggested by self-determination theory. It was administered after task performance with two items from the Effort subscale of the Intrinsic Motivation Inventory (e.g., *I tried to do well on this activity today;* Deci & Ryan, n.d.). Both measures had 8-point answering scales (0: does not apply at all, 7: applies very well); aggregates across items were used in the analyses. We also included the NA subscale that we used previously (an aggregate across the items *distressed*, *upset*, *irritable*, *nervous*, and *jittery*; Brose et al., 2012).

Cognitive Performance. In this investigation, we focused on the three WM tasks, the spatial 3-back task, the verbal alpha span task, and the numerical updating task (see Schmiedek et al., 2013, for details). Each session included (A) four blocks of the 3-back task (39 trials each) in which dots appeared in varying locations in a 4x4 grind and participants had to respond to each dot as to whether it was in the same position as the dot three steps earlier in the sequence; (B) eight blocks of the alpha span task (10 items each) in which ten uppercase consonants were presented sequentially, with a number located below each letter. For each letter, participants had to decide whether the number corresponded to the alphabetic position of the letter within the set of letters presented up to this step; (C) eight blocks of the updating task in which participants had to memorize and update one digit numbers. In each block, four numbers were presented in a row, followed by eight updating operations (additions, subtractions) presented in a row below, with the original digit number no longer present. This sequence was followed by a row with empty cells where results had to be entered. On the tasks, the average performance across blocks (accuracy and RT) was used for analyses. RT information was not relevant for the updating task because speed of responding was not instructed to be a criterion for task performance. As task difficulty was individually adjusted according to pretest performance the mean level of WM performance was not investigated further.

Statistical Analyses

The statistical procedures are similar to those extensively described in Brose et al. (2012). A mixed model approach was used to account for the hierarchical structure of the data (i.e., occasions were nested in individuals). The same model served to address all research questions:

$$\text{Performance}_{ji} = \beta_{0i} + \beta_{01}(\text{DailyVar}_i) + \beta_{1i}(\text{Days}_{ji}) + \beta_{2i}(\text{Affect}_{ji}) + \beta_{21}(\text{Affect}_{ji}\times\text{DailyVar}_i) + u_{0i} + u_{1i} + u_{2i} + r_{ij}$$

Here, Performance_{ji} is thought to change across study time (predictor Days_{ji}) and to co-vary with affect across days (predictor Affect_{ji}). Random effects are expressed by u_{0i}, u_{1i}, and u_{2i} (individual differences in mean performance, change, and the affect–performance coupling). R_{ij}

represents the residual variance. DailyVar_i is a Level-2 moderator of the intercept (β_{01}) and, importantly, of the strength of the affect–performance coupling (β_{21}). DailyVar_i is a variable that indicates how participants' performance varied systematically from day to day (Schmiedek et al., 2013). It was derived by means of variance decomposition with trials nested in days within individuals (i.e., unconditional 2-level models were fitted for each individual) and the equation $\text{DailyVar}_i=\sigma^2_{\text{days}}/(\sigma^2_{\text{days}} +[\sigma^2_{\text{trials}}/n_{\text{trials}}])$. DailyVar_i characterizes individual differences in the systematicity of daily variation. It was included as a moderator of the affect–performance association because meaningful associations between PA and WM should only be observable if the daily within-person variation in WM is systematic[3].

The analyses to test associations between performance and affect were conducted using SAS PROC GLIMMIX (Ruppert, Wand, & Carroll, 2003). This multilevel procedure allows the modeling of complex changes in performance across study time (e.g., learning curves with transitory performance decreases) by means of penalized radial spline smoothing functions.

Results

Descriptive information on study variables is provided in Table 1. Firstly, we tested whether WM performance was better or worse on days when individuals experienced relatively high levels of PA. In the following, we will focus on the interaction term Affect×DailyVar because PA–WM associations can only occur if individuals' WM fluctuates systematically from day to day, which is captured by the moderator DailyVar. On days with enhanced PA, individuals' spatial and verbal WM performance was more accurate. Numerical WM performance was not significantly related to PA, but the coefficient's estimate is in the same directions as in the other tasks (Table 2, Column 1). Performance on the spatial WM task was also faster on these days (Column 2), which means that performance can even be called more efficient here. On the verbal task, performance was not related to RT on these days, ruling out a speed-accuracy trade-off.

Secondly, we tested whether there was any evidence for a quadratic within-person relationship between PA and WM (e.g., whether particularly high levels of PA are not optimal for performance because the PA-related neurotransmitter dopamine only enhances performance at moderate increases; see above). To do so, we added quadratic affect terms (Table 2, Column 3). These additional predictors were not significant in any of the three tasks, thus failing to lend support for the notion that extreme levels of daily PA relate to below-average WM performance.

Thirdly, we tested whether PA shares predictive variance with motivation in the spatial and verbal WM task (this question is obsolete in the numerical task given the absence of a PA–WM relationship). Once motivational variation was taken into account, PA was no longer significantly associated with spatial and verbal WM performance (Table 2, Column 4; note that motivation is also a significant predictor of numerical WM performance). Motivation remained the only significant predictor. An analysis of the amount of performance variance uniquely explained by PA revealed that the majority was shared with motivation's predictive variance (Table 2, bottom rows belonging to each task). These findings, albeit correlational, may indicate that PA increases performance because of increased initiative.

Finally, we tested whether PA and NA explain the same portion of variance in WM performance or whether their effects are (partially) additive, suggesting independent prediction. The results speak for the latter. NA and PA are both significant and mainly independent predictors of spatial WM performance, estimate PA×DailyVar = 0.17, *SE* = 0.07; estimate NA×DailyVar = -0.10, *SE* = 0.05. Independent prediction can be inferred from the variance explained by PA and NA when modeled in separate analyses (4.9% and 1.7%, respectively) and when modeled simultaneously (6.4%). Thus, with regard to spatial WM performance variation, PA and NA are not two sides of the same coin. Verbal WM performance is not related to NA, estimate = -0.01, *SE* = 0.02. Together, given the absence of a NA relationship with performance in the verbal WM task and the absence of a PA relationship with the numerical WM task, the present results provide no evidence of shared predictive variance among PA and NA.

Discussion

Daily variations in PA showed a positive, linear relationship with spatial and verbal WM performance. As days with above-average PA and enhanced WM performance were also days with above-average motivation in these tasks, increased initiative or persistence may play a role in the association between PA and WM performance. This finding differs from the conclusion in a major review of experimental studies that PA and WM performance are negatively related potentially because of capacity limitations or a heuristic processing mode (Mitchell & Phillips, 2007). Our interpretation of this disparity is that variations in task performance across days are more strongly related to affect-related *volitional* components of performance than to more implicit mechanisms such as resource allocation and shifts in processing modes. Individuals' motivation may have outweighed or prevented decrements due to capacity limits and processing modes (see also Bodenhausen et al., 1994). Alternatively, the subtle affect variations in this study may not have occupied attentional resources in the first place. Instead, PA may have functioned as information in the laboratory, indicating liking of the situation and thereby increasing compliance, effort, or initiative (cf. Martin et al., 1993).

Associations between PA and WM were mainly independent of NA in this study. Thus, in the context of WM performance, high levels of PA do not simply mean the same as low levels of NA. This finding is consistent with neuropsychological views according to which the effects of PA and NA on executive functions are mediated differently in the brain (i.e., through different neurotransmitter systems: the dopaminergic [serotonergic, respectively] system is mainly relevant for PA [NA, respectively]; Mitchell & Phillips, 2007). This finding is furthermore interesting because PA and NA share their respective predictive variances almost completely with motivation (see also Brose et al., 2012). In other words, increased motivation on days with heightened PA is important for performance benefits, and so is increased motivation on days with reduced NA. However, these links must differ in nature. The relative absence of NA might signal that effort is currently not needed elsewhere and can therefore be invested in the task, whereas heightened PA might mainly increase competence beliefs and compliance.

The findings of this study were not completely consistent across the three tasks. Positive affect was not related to the numerical WM task, which made two follow-up questions (on associations with motivation and NA) obsolete. We attribute this to the relatively low within-person reliability of the day-to-day variation in this task (i.e., a small amount of systematic day-to-day variation) that was revealed by Schmiedek and colleagues (2013), who carried out detailed analyses on how systematic performance variation was across days and blocks in the COGITO study. Because of the small contribution of systematic day-to-day fluctuations, it is more difficult to detect systematic co-variation with other variables.

It has to be noted that the findings presented in this study are only correlational in nature and do not allow any causal conclusions. While feeling better than usual may improve the motivation to perform well, motivation may equally make one feel better, or efficient performance may raise both PA and motivation. Furthermore, a yet disregarded variable may underlie these associations. For example, high levels of energy may boost PA and motivation, which, in turn, would increase performance. To complicate matters even more, the causal link between PA and cognition may be person-specific. One person may become more self-confident when PA is increased while another may become more compliant. Person-specific analyses are required to gain a better understanding of individual within-person dynamics between affect and cognition (Molenaar, 2004). Present findings did not suggest a quadratic PA–WM relationship, which speaks against the assumption that extreme levels of PA have detrimental effects on WM performance (Cools & D'Esposito, 2011). Perhaps the intensity variation of PA in the laboratory, albeit related to aspects of daily life (e.g., Wolff, Schmiedek, Brose, & Lindenberger, in press), was still too limited to cause pronounced changes in DA that would result in subpar WM performance. Thus, the present study should be followed up with ambulatory assessments to capture the whole range of affective experiences in daily life.

To conclude, this study is in line with between-person findings suggesting that high levels of well-being are associated with behaviors paralleling success and successful outcomes (Lyubomirsky et al., 2005). They also imply that success on cognitively demanding tasks is more likely on days when feeling happier.

Footnotes

[1]With affect, we mean object-less, longer-term states as opposed to emotion.

[2]In theoretical accounts, PA is often described as causing effects on cognition; please note that our correlational analyses do not suffice to test causal effects.

[3]Such a procedure is not necessary in between-person analyses where systematic variation is typically well-established.

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Table 1.

Descriptive Statistics

Self-report measures	i*M* (*M*)	i*M* (*SD*)	i*SD* (*M*)	iSD (*SD*)
Positive affect	3.09	1.03	0.57	0.21
Motivation	3.79	1.16	0.79	0.34
Negative affect	1.32	0.94	0.71	0.31

WM tasks: Amount of daily variability	i*SD* (*M*)	i*SD* (*SD*)
3-back, accuracy	4.30	3.10
3-back, RT	29.14	24.96
Alpha span, accuracy	6.10	1.14
Alpha span, RT	48.18	34.15
Numerical updating, accuracy	8.00	1.61

WM tasks: Reliability of daily variability (DailyVar)	*M*	*SD*
3-back, accuracy	0.36	0.28
3-back, RT	0.68	0.15
Alpha span, accuracy	0.23	0.19
Alpha span, RT	0.48	0.22
Numerical updating, accuracy	0.15	0.16

Note. WM = working memory, RT = reaction time, i*M* = intraindividual mean, i*SD* = intraindividual standard deviation. Affect and performance were assessed on all occasions. Thus, each individual has a mean (i*M*) and a standard deviation (i*SD*), on each variable. Table 1 reports the means and standard deviations of the resulting distributions of the intraindividual coefficients. Because presentation times of the WM task were individually adjusted before participants started the 100-day phase, means across study time cannot be interpreted straightforwardly (e.g., mean levels of 80% accurate are not directly comparable for different individuals if their presentation times differ). Therefore, Table 1 provides information on individuals' performance variations (i.e., the i*SD*), but not on performance means.

Table 2.

Couplings Between Positive Affect (PA), Motivation, and WM Performance, Fixed Effects

	Outcome is: Accuracy		Outcome is RT		Outcome is Accuracy, Predictor 2 is: PA squared		Motivation	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Spatial WM task								
Intercept	2.27*	0.18	0.31	0.05	2.28	0.18	2.29*	0.19
DailyVar	-0.74*	0.34	0.02	0.07	-0.74*	0.34	-0.66	0.34
PA	-0.01	0.03	0.01	0.01	-0.02	0.03	0.01	0.02
PA × DailyVar	0.17*	0.07	-0.02*	0.01	0.18*	0.07	-0.01	0.05
Predictor 2					-0.03	0.02	0.01	0.03
Predictor 2 × DailyVar					0.01	0.04	0.34*	0.05
Pseudo-R2 (Level-1)	4.9%		2.2%		5.40%		25.4%	
Unique R2 PA							1.1%	
R2 Predictor 2[1]							24.2%	
Verbal WM task								
Intercept	0.50*	0.1	0.84	0.05	0.50*	0.10	0.51*	0.1
DailyVar	-0.72*	0.3	-0.28	0.09	-0.70*	0.30	-0.71*	0.3
PA	-0.01	0.01	0.01	0.01	-0.01	0.01	-0.01	0.01
PA × DailyVar	0.07*	0.03	-0.001	0.01	0.06*	0.03	0.02	0.03
Predictor 2					0.00	0.01	0.01	0.01
Predictor 2 × DailyVar					-0.02	0.02	0.11*	0.02
Pseudo-R2 (Level-1)	1%		1.8%		1%		3.3%	
Unique R2 PA							0.1%	
R2 Predictor 2[1]							3.2%	
Numerical WM task								
Intercept	0.43*	0.11			0.43	<.0001	0.43*	0.11
DailyVar	0.55	0.44			0.55	0.21	0.56	0.44
PA	0.01	0.01			0.01	0.61	-0.01	0.01
PA × DailyVar	0.06	0.05			0.07	0.13	0.01	0.04
Predictor 2					0.00	0.87	0.03	0.01
Predictor 2 × DailyVar					-0.03	0.63	0.15*	0.04
Pseudo-R2 (Level-1)	0%				1%		2.2%	
Unique R2 PA							0%	
R2 Predictor 2[1]							2.2%	

Note. * $p < .05$; fixed effect not listed: session; random effects not listed: intercept, slope variances, residual; [1]within-person variance explained by univariate model with Predictor 2.