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Using the time-varying autoregressive model to study dynamic changes in situation perceptions and emotional reactions

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Abstract

Objective: Assuming personality to be a system of intra-individual processes emerging over time in interaction with the environment, we propose an idiographic approach to investigate potential changes of intra-individual dynamics in the perception of situations and emotions of individuals varying in personality traits. We compared the semiparametric time-varying autoregressive model (TV-AR) that takes into account the non-stationarity of psychological processes at the individual level, with the standard AR model.

Method: We conducted analyses of individual time series to assess intra-individual changes in mean levels and inertia on data from two adolescents who completed measures of personality and indicated their situation perceptions and emotions five times a day for 19 days.

Results: For the less honest, emotional, extraverted, and more agreeable adolescent, the TV-AR model detected reliable changes in the intra-individual dynamics of situation perceptions and emotions whereas, for the other individual, the standard AR model was more preferred, given the lack of changes in the intra-individual dynamics.

Conclusions: Psychological processes dynamics in situation perception and emotions may vary from person to person depending on their personality. This work constitutes a first step in demonstrating that an idiographic approach has advantages in identifying changes in individuals' perceptions and reactions to situations.

KEYWORDS

dynamic modeling, idiographic, non-stationarity, time-varying autoregressive model

1 | INTRODUCTION

Understanding why people do what they do is a central issue in personality psychology. With this aim, psychologists have looked at situations as potential individuals' drivers of behaviors along with personality (Baumert et al., 2017; Funder, 2016; Mischel & Shoda, 1995). Personality shapes how situations influence behavior, and situations shape how a person's attributes impact behavior (e.g., Donnellan, Lucas, & Fleeson, 2009; Fleeson & Furr, 2016; Funder, 2001; Furr & Funder, 2004, 2018; Kenrick & Funder, 1988;

Mischel, 1968). As a consequence, there is a renewed interest in how to describe and measure situational information (Rauthmann, Sherman, & Funder, 2015), resulting for example in the Situational Eight DIAMONDS taxonomy (Rauthmann et al., 2014) that encompasses eight dimensions of perceived situation characteristics (i.e., Duty, Intellect, Adversity, Mating, positivity, Negativity, Deception, and Sociality). With this instrument, for example, one can examine the person $\times$ situation interaction by testing whether personality influences the relations between situation characteristics and behavior.

Traditionally, research in personality has been driven by a nomothetic perspective in which researchers aimed at making general predictions about the population based on variations observed at an inter-individual level of analysis. However, because of its reliance on average effects across subjects, this approach cannot be sufficient to provide information about specific individuals and thus about intra-individual dynamics (Beck & Jackson, 2019; Cervone, 2005; Fleenor & Nofle, 2012; Molenaar, 2004). As an alternative, the idiographic perspective that has been present since the early days of personality research (e.g., Cattell, 1957), emphasizes the centrality of the individual as the essential focus for understanding personality (e.g., Fischer & Bidell, 2006; Molenaar, 2004, 2013; Smith & Thelen, 2003; Van Geert & Van Dijk, 2002). According to this approach, personality reflects an integrated dynamic system of intra-individual processes that arise over time in response to and in interaction with the environment (Hofmans, De Clercq, Kuppens, Verbeke, & Widiger, 2019). Within this perspective, research on personality focuses on an intra-individual level of analysis based on time-dependent differences along a single subject's daily life trajectory (Beck & Jackson, 2018). This approach potentially allowed to investigate the interplay between personality and situation (e.g., Cervone, 2005; Fournier, Moskowitz, & Zuroff, 2008; Mischel & Shoda, 1995; Wright & Mischel, 1987). In this context, research can investigate whether personality influences how individuals act or feel from a temporal perspective, that is, across situations that are represented as data points.

The interest in this approach has been renewed with the development of recent technological and analytical tools, particularly the emergence of ambulatory assessment (e.g., ecological momentary assessment, experience sampling methodology, ambulatory psychophysiology, daily diaries; Csikszentmihalyi & Larson, 2014; Trull & Ebner-Priemer, 2014; Wright & Zimmermann, 2019). Ambulatory assessment is specifically designed to collect multiple observations per individual, and the resulting intensive longitudinal data or time-series data can then be used, among others, for hypothesis testing at the level of the single individual (Conner, Tennen, Fleenor, & Barrett, 2009; Wright & Zimmermann, 2019).

In general, the more data points, and the more extended the assessment period, the more the intra-individual processes will unfold themselves (Schoorman, Houtveen, & Hamaker, 2015). However, note that the number of data points and the assessment period might depend on the process one wants to investigate (e.g., frequent changes over short periods vs. rare changes over long periods) (see Haynes, O'Brien, & Kaholokula, 2011 for a discussion).

These methods allow examining the intra-individual temporal dynamics through the assessment of specific constructs such as variability, instability, covariation of situation and behavior, and inertia. For example, Rauthmann, Jones, and

Sherman (2016) conducted an ambulatory assessment study on a sample of undergraduate students and found situations characteristics and personality states showed only modest stability across time. In this contribution, we focused on inertia that can be defined as the resistance to change. Inertia is formalized as the degree to which a person's state can be predicted by his or her previous state (with high predictability reflecting high inertia). High inertia means that a person's state is likely to persist from one moment to the next. Low inertia means that a person's state is more susceptible to change. Here, we conceptualize and operationalize inertia as the influence of a situation, defined as how one feels and perceives it at a point in time, on the situation as one feels and perceives it at the successive time point. Considering that some personality traits have been shown to correlate with emotional inertia (e.g., Neuroticism, Suls, Green, & Hillis, 1998), studying inertia seems consequently important to a better understanding of the interplay between personality and situation.

One of the most popular approaches to estimating inertia is the autoregressive modeling (AR model), a family of statistical models that estimate lagged influences among variables over time via autoregressive coefficients. The latter indicates how each variable predicts itself at the next time point. However, even if these models aimed at providing information about intra-individual processes, they focus primarily on the population instead of the individual. For example, most of the models are based on the assumption that the parameters for the sample are informative for each individual of this sample. In other words, people are meant to be similar to each other and obey the same dynamic model (e.g., Multilevel Dynamic Structural Equation Modeling, Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018).

Another critical drawback of these models is the assumption of stationarity. This assumption implies that the statistical characteristics of a process are time-invariant (without trends or cycles; Chatfield, 2003; Molenaar, 2013). Take, for instance, a shy adolescent. According to the stationarity assumption, his or her levels of shyness should remain constant over time, from childhood to adolescence, regardless of the situations encountered during his life. Similarly, he or she should experience carry-over effects (inertia) in feeling anxious across situations (i.e., data points) in a stable way over time. Stationarity, however, seems unrealistic for most, if not all, personality processes. This assumption is violated with developmental processes, which are characterized by increases and declines alternating over time. Furthermore, intra-individual processes can change over time due to both internal (e.g., personality) and external (e.g., situation) factors. Such changes could occur within short periods (e.g., changes in the levels of the adolescent's shyness after the experience of rejection at the party), but also over years or months (e.g., changes in the levels of the adolescent's shyness

depending on the different life events encountered; de Haan-Rietdijk, Gottman, Bergeman, & Hamaker, 2016).

Several sources can give rise to a non-stationary process. In psychological research, the focus has mainly been on detecting a specific type of non-stationarity: a gradual change in the mean of a process, which is visible as a trend in the data. Two common approaches to dealing with a trend consist of either detrending or modeling the trend (e.g., Tschacher & Ramseyer, 2009). Although different, a drawback of both methods is that they require specifying the functional form of the trend (e.g., linear) to make the time-series data trend stationary (Hamaker & Dolan, 2009). Furthermore, trends in the data could also be due to a change in the autoregressive parameter. However, in current models, this is often not taken into account.

To account for both sources of non-stationarity, Bringmann et al. (2017) and Bringmann, Ferrer, Hamaker, Borsboom, and Tuerlinckx (2018) have recently introduced a model, which allows dealing with non-stationarity, the semiparametric time-varying autoregressive model (TV-AR) model. The TV-AR is an extension of the AR model and is based on semiparametric statistical modeling using a readily applicable generalized additive modeling framework (GAM, Hastie & Tibshirani, 1990; McKeown & Sneddon, 2014; Sullivan, Shadish, & Steiner, 2015; Wood, 2006). The defining feature of the TV-AR model is that the coefficients of the model are allowed to vary over time, following an unspecified function of time (Dahlhaus, 1997; Giraitis, Kapetanios, & Yates, 2014; Härdle, Lütkepohl, & Chen, 1997). There are at least two reasons why the TV-AR model is useful for dealing with non-stationarity. First, different from detrending or other methods for modeling the trend, the TV-AR can detect trends in a data-driven way, and thus no pre-specifications are needed to account for a trend in the data (Bringmann et al., 2017). Second, the TV-AR allows detecting and modeling change both in the intercept and autoregression parameter simultaneously.

There are other time-varying models than the TV-AR in psychology (for a review see Piccirillo & Rodebaugh, 2019; Wright & Zimmermann, 2019). For example, some, such as dynamic linear models, are based on the state-space modeling framework (e.g., Chow, Zu, Shifren, & Zhang, 2011; Molenaar, 1987; Molenaar, Sinclair, Rovine, Ram, & Corneal, 2009). However, state-space models require the specification of the way parameters of the time-varying model vary over time (Belsley & Kuh, 1973; for an exception see Molenaar et al., 2009), whereas most psychological theories give only limited information about the nature of the change of a process (Tan, Shiyko, Li, Li, & Dierker, 2012).

A univariate TV-AR model is defined as:

$$y_t = \beta_{0,t} + \beta_{1,t} y_{t-1} + \varepsilon_t.$$

As in the standard AR model, the $\beta_{0,t}$ coefficient represents the intercept, whereas the coefficient $\beta_{1,t}$ captures the strength and direction of the autoregressive effect. However, as the t indicates, the intercept and the direction and strength of the autoregressive effect can now take different values over time. On the contrary, the innovation term (i.e., dynamical error), defined as what cannot be predicted by the previous observation (Chatfield, 2003), still forms a white noise process so that the values of ε_t are independently and identically distributed, which implies that their variance is constant over time.

The TV-AR model requires two assumptions. First, although the functional form of $\beta_{0,t}$ and $\beta_{1,t}$ can be any function, changes in the parameter values are restricted to be gradual. Any change in the temporal dynamics of intra-individual processes is thus assumed to be smooth. Smoothness entails the parameter values at time points close to a given time point to be very similar. This assumption implies that the TV-AR is not appropriate to model abrupt changes in the data (e.g., a sudden change in the emotional experience). Second, although the TV-AR model is designed for handling the non-stationary process, the process still needs to be bounded to get interpretable results. Statistically, in the univariate case, this comes down to local stationarity, which results in $-1 < \beta_{1,t} < 1$, for all t (Bringmann et al., 2017; Dahlhaus, 1997). Even if the TV-AR model is at an early stage of test, it has already been shown to be useful for understanding changes over time in emotion dynamics in couples (Bringmann et al., 2018) and in individual affective trajectories in people suffering from major depressive disorder (Slofstra et al., 2018).

1.1 | Aims of the contribution

We aimed at investigating whether changes can occur in intra-individual temporal dynamics regarding situation perception and emotion and whether these changes are related to personality traits. We wish to study whether personality traits are related to the stability or instability over time of the influence of one situation (i.e., how one feels or perceives it) onto the next. To do so, we assess whether the intra-individual temporal dynamics perception of situations and emotional states over time can be described better by a time-varying (TV-AR model) or a time-invariant (AR model) statistical model. In terms of dynamic constructs, we focused particularly on inertia to determine whether an individual's emotion and situation perception at time t can be predicted by emotion and situation perception at $t - 1$ and whether this inertia is stable over time. Although inertia is a concept that could provide a better understanding of the interplay between personality and situation, inertia has been studied only regarding emotional dynamics in clinical and personality psychology (Koval et al., 2015; Kuppens, Allen, & Sheeber, 2010; Wang,

Hamaker, & Bergeman, 2012). Moreover, in these studies, inertia has also been assumed to be time-invariant, without taking into account the possibility that it may vary over time (for an exception see Koval & Kuppens, 2012).

Moreover, we hypothesized that dynamic constructs could change over time for some people and not for others. Depending on the personality profile, inertia in emotions and situation perception could be stable (i.e., time-invariant process) and thus the AR model would provide a better fit or could be unstable over time (i.e., time-varying process), and thus the TV-AR model would provide a better fit.

As a first demonstration of the usefulness of the idiographic approach based on a non-stationarity assumption in the study of the temporal dynamics of situation perceptions and emotional reactions for different personality profiles, we focused on adolescents. Adolescence is a critical period of individual development, characterized by several changes in personality (Blos, 1968; Erikson, 1968; Steinberg & Morris, 2001). In comparison to adults, adolescents more frequently experience high-intensity positive and negative emotions, greater emotional intensity, and greater instability (e.g., Csikszentmihalyi & Larson, 1984). However, a recent review (Bailen, Green, & Thompson, 2019) showed that emotional experience across adolescence is quite dynamic and that there is no typical pattern.

Instead, intra- and inter-individual factors help clarify how and when emotional experiences vary among adolescents. Each adolescent's subjective experience and unique perception of the world might shape his/her development of personality, adaptation, and psychopathology (Shiner & Caspi, 2003). However, no extant studies have focused on adolescents to investigate the temporal dynamics of emotion and situation perception. Because the TV-AR model allows analyzing data from one individual at the time, for the sake of brevity and illustration of the method, we decided to focus only on two adolescents, who were significantly different regarding personality traits. Thus, we expected that their differences in traits would also reflect in different temporal dynamics of psychological situation perception and emotional reactions.

2 | METHOD

2.1 | Procedure

A sample of adolescents ($N = 198$; age range comprised between 14 and 19 years; $M_{\text{age}} = 16.05$; $SD = 1.11$) was recruited from several high schools. The study consisted of two sessions. During the first session, participants were asked to fill in measures of personality. In the current work, we focused specifically on the HEXACO-60 (Ashton & Lee, 2009). The second session was conducted using an experience sampling

methodology. Adolescents installed on their smartphone an App, Time2Rate, developed by iMoobyte for the Department of Psychology of the University of Milano-Bicocca. Using a fixed-interval measurement schedule, this App prompted participants five times a day (2:00, 4:00, 6:00, 8:00, and 10:00 p.m.) for 19 days. At each assessment, participants had to think about a social situation they were in within the last hour and describe it using the ultra-brief version of the Situational Eight DIAMONDS (S8-III, Rauthmann & Sherman, 2016). They also had to indicate their emotional and behavioral states experienced in the described situation. Participants had to complete each assessment within a 30-min window (e.g., 2:00–2:30 p.m.) during which, if they did not complete the survey at the time of the first prompt, they received two reminders after 10 and 20 min, respectively. Both parental consent forms and adolescents assent forms were completed, and the Ethics Committee of the University has approved this research.

2.2 | Measures

2.2.1 | HEXACO Personality Inventory

The HEXACO-60 (Ashton & Lee, 2009) consists of 10 items assessing each of the six personality dimensions: Honesty-Humility (e.g., *I want people to know that I am an important person of high status*), Emotionality (e.g., *I would feel afraid if I had to travel in bad weather conditions*), Extraversion (e.g., *I rarely express my opinions in group meetings*), Agreeableness (e.g., *Most people tend to get angry more quickly than I do*), Conscientiousness (e.g., *When working, I sometimes have difficulties due to being disorganized*), and Openness to Experience (e.g., *I like people who have unconventional views*). Participants respond with 5-point Likert scales from 1 (*strongly disagree*) to 5 (*strongly agree*). Cronbach's alpha from the whole sample ranged from .65 to .79.

2.2.2 | Ultra-brief Situational Eight DIAMONDS (S8-III, Rauthmann & Sherman, 2016)

This questionnaire assesses situation perception with eight situational characteristics with one item each: Duty (*Should something be done?*), Intellect (*Is deep cognitive processing necessary?*), Adversity (*Is someone threatened?*), Mating (*Is there an opportunity to attract someone?*), Positivity (*Is the situation nice?*), Negativity (*Can negative feelings arise?*), Deception (*Is mistrust an issue?*), and Sociality (*Is social interaction possible, desire, or necessary?*). Participants indicated on a scale from 1 (not at all) to 7 (completely) how

much each item applied to the social situation they experienced in the last hour.

2.2.3 | Emotions (adapted from Buckley, Winkel, & Leary, 2004)

Participants indicated how rejected, lonely, anxious, sad, hurt, happy, and shameful they felt in the social situation they described on 7-point scales ranging from 1 (*not at all*) to 7 (*very much*). In the present contribution, we focused only on the five emotions examined in the rejection literature (i.e., Anxiety, Sadness, Anger, Hurt, and Happiness) (e.g., Leary, 2016; Leary, Twenge, & Quinlivan, 2006).

2.3 | Selection of the two participants

The criteria for choosing those two particular adolescents were twofold. The first criterion was statistical. Ideally, to detect time-varying processes in terms of small changes, such as a small linear increase over time, one needs approximately 100 data points. However, 60 data points are enough for detecting larger changes over time (Bringmann et al., 2017). Our design led to a maximum of 95 data points, and only five individuals showed more than 80. The second criterion was theoretical. We were interested in studying adolescents who differ in personality traits to detect whether such a difference might also be present in the dynamics of the emotions and perceptions of the situation. To establish whether the two adolescents diverged in personality traits, we applied the Standard Error of difference method (e.g., Levin, Fox, & Forde, 1998) that allows assessing whether any difference between the HEXACO scores of the two participants is real or due to measurement error. For each HEXACO dimension, we first computed an individual score for each adolescent. Then, we calculated the Standard Error of difference¹ for each HEXACO dimension. To do so, we used the reliability indexes (Cronbach's alpha, ranging from .70 to .76) and the Standard Deviations of the HEXACO-60 from another study with a relatively large Italian adolescent sample

($N = 750$) (Baiocco et al., 2017; see Appendix) to obtain more generalizable and reliable results than if we had used our sample ($N = 198$). If the difference observed between two participants' scores is equal or greater than the SE difference, then the difference is considered as true. Only two adolescents (two males, aged 17 and 18, classmates of the fourth year of high school) were significantly different in their level of Honesty/Humility, Emotionality, Extraversion, and Agreeableness (Table 1). More specifically, Participant 2 described himself as more honest, emotional, and extroverted and less agreeable than Participant 1.

3 | DATA ANALYSES

There were 94 data points for Participant 1 and 84 for Participant 2. Participant 1 completed the five entries per day except for the last day for which he did not complete the last data entry, and Participant 2 ended the study 2 days before Participant 1. Descriptive statistics for both situation characteristics and emotions of the two adolescents are reported in Table 2. Considering skewness and kurtosis, Deception for both participants and Hurt and Anger for Participant 2 violated the normality assumption. Moreover, there was no variability in the ratings of Adversity for both participants and Sadness for Participant 2. Therefore, we did not run the analyses on these variables.

3.1 | Time-varying autoregressive analyses

To detect whether the temporal dynamics underlying the situation perceptions and emotions of the two participants were time-varying, we applied the standard AR and the TV-AR models.

In the standard AR model, both the intercept and the autoregressive parameter are time-invariant; as a result, the mean² is also fixed. The inertia and the mean of the process thus remain the same over time.

$$\text{Situation Characteristic}_t = \beta_0 + \beta_1 \text{Situation Characteristic}_{t-1} + \varepsilon_t. \quad (1)$$

	Participant 1	Participant 2	SE difference
Honesty/humility	3.0	4.1	0.52
Emotionality	2.9	3.5	0.49
Extraversion	2.7	3.7	0.46
Agreeableness	3.9	2.9	0.41
Conscientiousness	3.9	3.6	0.46
Openness to Experience	2.7	2.8	0.51

Note: In boldface are indicated the dimensions on which the two participants differed (mean difference $\geq$ SE difference).

TABLE 1 Mean score and Standard Error of difference of the HEXACO-60 dimensions of the two participants

TABLE 2 Descriptive statistics of the Situational Eight DIAMONDS dimension and emotion ratings for the two participants

	Participant 1						Participant 2					
	<i>M</i>	<i>SD</i>	<i>SE</i>	Median	Skewness	Kurtosis	<i>M</i>	<i>SD</i>	<i>SE</i>	Median	Skewness	Kurtosis
Situation												
Duty	3.27	0.8	0.11	3.00	0.33	0.69	4.08	2.88	0.31	5.00	−0.07	−1.95
Intellect	1.82	0.95	0.10	2.00	1.03	0.43	3.62	2.55	0.28	3.00	0.14	−1.79
Adversity	1.00	0.00	0.00	1.00	–	–	1.00	0.00	0.00	1.00	–	–
Mating	1.50	0.88	0.09	1.00	1.51	1.43	1.24	0.53	0.06	1.00	2.59	8.10
Positivity	2.98	1.62	0.17	3.5	−0.09	−1.52	4.65	1.73	0.19	5.00	−0.58	−0.87
Negativity	2.37	1.23	0.13	2.00	0.45	−0.90	2.93	2.05	0.22	2.00	0.53	−1.26
Deception	1.01	0.10	0.01	1.00	9.39	87.06	1.04	0.33	0.04	1.00	8.84	77.07
Sociality	1.67	1.13	0.12	1.00	1.37	0.49	3.05	2.52	0.27	1.00	0.53	−1.58
Emotion												
Sadness	4.36	1.94	0.20	3.00	0.47	−1.56	1.00	0.00	0.00	1.00	–	–
Anger	4.14	2.18	0.23	3.00	0.36	−1.62	1.17	0.82	0.09	1.00	5.41	31.36
Anxiety	4.17	0.76	0.08	4.00	−0.88	1.63	4.79	1.63	0.08	5.00	−0.57	0.18
Hurt	2.43	1.96	0.20	1.00	0.66	−1.49	1.05	0.44	0.05	1.00	8.84	77.07
Happiness	3.22	1.67	0.17	4.00	−0.27	−1.43	5.14	1.52	0.17	5.00	−0.60	−0.43

Note: Statistics were calculated on 94 data points for Participant 1 and 84 for Participant 2.

According to Equation 1, situation characteristic at a time t (*Situation Characteristic_t*) can be estimated from a time-invariant intercept $\beta_{0,t}$, and a time-invariant autoregressive parameter ($\beta_{1,t}$; the effect of Situation Characteristic at $t - 1$).

In the TV-AR, both the intercept and the autoregressive parameter are allowed to vary over time. The TV-AR parameter implies that inertia changes over time. The mean level is dependent on both the intercept and the autoregressive parameter.³ Therefore, changes over time, both in the intercept and in the autoregressive parameter, may result in changes in the mean:

$$\text{Situation Characteristic}_t = \beta_{0,t} + \beta_{1,t} \text{Situation Characteristic}_{t-1} + \epsilon_t. \quad (2)$$

Equation 2 shows that situation characteristic at a time t (*Situation Characteristic_t*) can be estimated from a time-varying intercept $\beta_{0,t}$, and a TV-AR parameter ($\beta_{1,t}$; the effect of Situation Characteristic at $t - 1$).

In both models, the residuals (ϵ_t) are mutually independent and assumed to come from a normal distribution with constant variance. For the TV-AR, we used the GAM framework (see Bringmann et al., 2017 for a thorough discussion of the GAM approach), to allow both the intercept and the autoregressive parameter to vary over time. There are various ways to fit GAMs. We adopted the method proposed by Wood (2006), based on a penalized maximum likelihood approach using regression splines. In this approach, the time-varying $\beta_{0,t}$ and $\beta_{1,t}$ coefficients of the TV-AR model are replaced with non-parametric (smooth) basis functions. The analysis

reported here were based on the default settings of the GAM software (i.e., *mgcv* package in R; Wood, 2006): A number of 10 basis functions and the thin plate spline regression basis, and a time-lag of 1. To estimate the GAM-based TV-AR, we used the *tvvarGAM* package in R (Haslbeck, Bringmann, & Waldorp, 2017), a wrapper around the *mgcv* package (Wood, 2006).⁴

Following Bringmann et al.'s (2017) guidelines, we considered the following three indices to detect changes in situation perception and emotion over time:

(1) The Bayesian information criterion (BIC) model fit (the BIC function indicates whether a standard time-invariant model or a time-varying model fits the data better. The lowest fit index indicates the best model fit, following the parsimony rule. For example, when the intercept and autoregressive parameter are allowed to change over time, and the model fit improves (i.e., $\text{BIC}_{\text{AR}} > \text{BIC}_{\text{TV-AR}}$), we can infer that the TV-AR model is better than the standard AR model. On the contrary, when the intercept and autoregressive parameter are allowed to change over time, but the model fit does not improve (i.e., $\text{BIC}_{\text{TV-AR}} > \text{BIC}_{\text{AR}}$), we can infer that the standard AR model is better than the TV-AR.

(2) A significant⁵ time-varying intercept (the smooth parameter for the intercept). A significant time-varying intercept could be interpreted as a significant change in the intercept over time. Because the TV-AR model automatically includes a time-invariant intercept, the significance implies that (another) time-varying intercept is needed to estimate better the data.

(3) A significant TV-AR function (the smooth parameter for the autoregressive function). In this case, the parameter may represent not only a significant change in inertia over time but also a significant time-invariant autoregressive parameter. Therefore, this index was indicative of a time-varying process only if the effective degrees of freedom was larger than 1 (*edf*; an indication of a linear process; Shadish, Zuur, & Sullivan, 2014).

Sometimes indices presented conflicting results. For instance, the model-fit index, BIC, could be indicative of a time-invariant process, while both the time-varying intercept and the TV-AR parameter could be significant. Following the parsimony rule, we decided to adopt a sequential process. If the BIC indicated a time-invariant process (i.e., standard AR better than TV-AR), we did not consider the other criteria (i.e., the significance of the intercept and autoregressive parameter). If the BIC indicated a time-varying process, we then examined the significance of the intercept and autoregressive parameter. However, even in this case, when the intercept and the autoregressive parameter were not significant, we concluded for a time-invariant process. In sum, we were very conservative in considering results as indicating a time-varying process (for a less conservative approach see Bringmann et al., 2017).

Also, the *tvvarGAM* package generates plots for every individual time series accompanied by the plotted smooth curves of the intercept and the autoregressive parameter, and the plotted inferred mean (a function of the intercept and autoregressive parameter). These were visually inspected to detect problems with lagged missingness, fluctuations, outliers, and sudden changes. Moreover, the plotted smooth curves of the intercept and the autoregressive parameter, and the plotted inferred mean were visually inspected for the direction of change. If the smooth curves or inferred mean exceeded the 95% credible intervals plotted around them, the plots were described as indicative of change. On this basis, the presence and direction of change and inertia in both situation characteristics and emotions were derived from the model selection as follows.

Varying or stable mean: If one or more of the time-varying indices (i.e., intercept and autoregressive parameter) was significant, the plotted inferred mean was inspected to assess the presence and direction of change. Based on the inferred mean at the beginning and the end of each's time series, the intra-individual change was estimated to describe the time-varying process. We did not consider intra-individual changes in mean scores of less than 5 data points ($\leq 5\%$ of the total 95) as relevant. If the time series were invariant or if no (relevant) change in the plotted mean was detected, the overall mean score was used to summarize the invariant processes.

Varying or stable inertia: If the autoregressive parameter was time-varying, then the directionality of change was described using the initial value, and the end value of the

smooth curve of the autoregressive parameter for each time series. If the autoregressive parameter was invariant, the stable inertia was estimated.

4 | RESULTS

4.1 | Time-varying autoregressive analyses

A summary of the results of the TV-AR analyses for the two adolescents on situation characteristics and emotions are reported in Tables 3 (Participant 1)⁶ and 4 (Participant 2). For illustration purposes, we present in details the results for one of the dimensions of the situation perception (i.e., positivity) and one emotion (i.e., Anxiety) for both participants with the graphical support of the plots (Figures 1 and 2). Then, we summarize the results for the other dimensions and emotions, detailing the results and including the plots only when a process was indicated as time-varying.

4.2 | Detailed results for positivity and Anxiety

Focusing on positivity, for Participant 1, the first criterion indicated that the underlying process was varying over time and thus non-stationary (i.e., $BIC_{AR} > BIC_{TV-AR}$, Table 3). The intercept was time-varying, while the autoregressive parameter was not. The trend underlying the perception of situational positivity is thus due only to a time-varying intercept. The visual inspection of Figure 1 (left panels) confirmed these results. Both the plotted smooth curve of the intercept (upper panel) and the plotted inferred mean varied over time at least until the 16th day (80th data point), while the smooth curve of the autoregressive parameter (middle panel) did not go up or down at any point in time. In this specific case, the mean was equal to the intercept as the autoregressive parameter equaled zero. Participant 1 perceived the situations as less positive over time during the 19 days, as represented by the changing intercept and mean. The TV-AR thus seems to be the best model for describing the intra-individual temporal dynamics of the subjective positivity of the situation for Participant 1.

For participant 2, in contrast, all three criteria indicated a time-invariant process, that is, stationary (Table 4). The model fit did not improve ($BIC_{AR} < BIC_{TV-AR}$), and neither the time-varying intercept nor the autoregressive functions indicated any time-varying process. Consistently, the visual inspection of Figure 1 (right panels) indicated that neither the plotted smooth curve of both the intercept and the autoregressive parameter (upper and middle panel), nor the plotted inferred mean showed a clear change over time when taking their CI into account (Figure 1, lower panel). In sum, for

TABLE 3 Time series model fit (BIC), *F* tests of the smooth functions of the intercept and autoregressive parameter, and mean range for Participant 1

	AR			TV-AR					Mean range
	BIC	Intercept	Autoregressive	BIC	Intercept		Autoregressive		
					F	edf	F	edf	
Situation									
Duty	281.85	6.40***	3.52***	287.42	0.40	1.00	3.52**	5.58	3.4–3.1
Intellect	268.97	6.36***	2.94**	265.96	2.10	4.55	1.30	2.97	2.7–1.9
Mating	250.72	10.19***	−1.99*	250.06	3.27*	3.41	6.21**	2.00	1.5–1.4
Positivity	247.92	17.66***	1.26	236.63	5.66***	7.85	1.16	2.00	4.5–1.0
Negativity	315.99	18.59***	1.34	264.87	1.06	1.00	6.95***	8.22	4.8–1.1
Sociability	297.30	10.05***	−2.26*	298.28	2.25	2.99	6.39**	2.00	2.8–1.4
Emotion									
Sadness	224.97	1.81	22.99***	229.69	1.97	7.78	7.33**	2.59	3.0–6.8
Anger	220.07	1.68	27.05***	210.24	1.36	1.00	18.74***	9.60	1.8–6.8
Anxiety	199.25	5.45***	5.63***	197.12	7.84**	1.00	7.04***	4.10	4.0–4.0
Happiness	211.44	1.49	20.94***	213.78	3.89***	7.90	7.25**	2.00	4.8–1.6

Note: All variables that did not meet criteria (no variability, normality assumption violated) are not included in the table. Mean range = first to last value in the 19 days interval.

Bold values indicate which model shows the best fit.

p* < .01; *p* < .001.

TABLE 4 Time series BIC (Model fit), *F* tests of the smooth functions of the intercept and autoregressive parameter, and mean range for Participant 2

	AR			TV-AR					
	BIC	Intercept	Autoregressive	BIC	Intercept		Autoregressive		Mean range
					<i>F</i>	<i>edf</i>	<i>F</i>	<i>edf</i>	
Situation									
Duty	428.14	7.99***	−0.68	443.54	0.99	2.68	1.88	4.43	4.1–4.1
Intellect	407.17	13.02***	−1.03	416.67	2.24	4.50	2.40	3.54	4.1–4.3
Mating	407.17	7.57***	0.88	416.67	2.48	8.51	2.69	3.07	1.4–2.0
Positivity	342.38	7.84***	0.74	359.27	1.34	2.38	1.61	8.37	4.2–5.3
Negativity	369.75	6.59***	1.09	374.59	3.06	1.00	1.87	2.00	2.8–3.0
Sociability	405.71	7.05***	−0.14	412.95	0.89	1.00	0.08	2.00	3.5–2.6
Emotion									
Anxiety	315.50	5.19***	4.30***	323.85	1.86	1.52	3.57***	9.21	4.0–2.5
Happiness	250.79	3.25**	10.37	254.05	4.48***	8.64	2.53	2.00	4.5–5.5

Note: All variables that did not meet criteria (no variability, normality assumption violated) are not included in the table. Mean range = first to last value in the 19 days interval.

Bold values indicate which model shows the best fit.

p* < .01; *p* < .001.

Participant 2, we concluded that both the inertia of positivity and the mean remained constant over time (i.e., stationary). Thus, the standard AR model represents the best model for detecting such a temporal dynamic.

Regarding Anxiety, for Participant 1, the three criteria supported a time-varying process. Both the time-varying intercept and the TV-AR parameter were significantly

different from zero. All indicators (i.e., significance and *edf*) were in favor of time-varying inertia. Also, the visual inspection of Figure 2 (left panels) indicates that the autoregressive function (middle panel) changed over time, and so did both the intercept function (upper panel). However, as the mean is a function of the intercept and autocorrelation (for the formula, see the endnote 3), a time-varying

Positivity

FIGURE 1 The plotted time series of the perception of the situation in terms of Positivity for Participant 1 (left panels) and Participant 2 (right panels), including the plotted smooth curve of the intercept (upper panel), smooth curve of the autoregressive parameter (middle panel), and inferred mean with 95% Credible Intervals (lower panel)

intercept and autocorrelation can also cancel each other out, resulting in a time-invariant mean. Over the 19 days interval, Participant 1 thus experienced mainly inconstant carry-over effects for Anxiety, but his level of Anxiety was stable.

For Participant 2, the BIC indicated that the AR showed the best fit, suggesting that the temporal dynamics of Anxiety was time-invariant. The standard AR showed that the autoregressive parameter was significant. We thus conclude that participant 2 experienced stable carry-over effects in Anxiety over the 19 days of social interactions.

4.3 | Results regarding other situations and emotions

When considering the other DIAMONDS dimensions and emotions (Tables 3 and 4), Participant 2 showed a pattern similar than to the one described above. Results indicated he was stable over time in the other situation characteristics (i.e., Duty, Intellect, Mating, Negativity, and Sociability) and emotions (i.e., Anger) (Table 4).

As for Participant 1, on the one hand, he showed stability in the perception of situations as dutiful, sociable, and requiring intellect as well as in feeling sad and happy (Table 3) indicating that the AR seems the best model for detecting the temporal dynamics of these constructs. On the other hand, Participant 1 exhibited instability in the perception of Mating and Negativity. More specifically, focusing on Mating, the BIC showed that the underlying process was time-varying. The time-varying intercept and autoregressive parameter were significantly different from zero. Despite its significance, the *edf* of the autoregressive parameter was just above 1, introducing the possibility that the underlying process was linear instead of varying. The plotted smooth curve of the autoregressive parameter (Figure 3, middle panel) was time-invariant. On the contrary, both the plotted smooth curve of the intercept (upper panel) and the plotted inferred mean (lower panel) varied over time. In sum, for Mating, inertia was time-invariant, while the intercept changed over time.

Regarding Negativity, the BIC was indicative of a time-varying process. While the TV-AR parameter was significant, the intercept was not. All indicators (i.e., significance

FIGURE 2 The plotted time series of Anxiety felt for Participant 1 (left panels) and Participant 2 (right panels), including the plotted smooth curve of the intercept (upper panel), smooth curve of the autoregressive parameter (middle panel), and inferred mean with 95% Credible Intervals (lower panel)

and *edf*) supported for time-varying inertia. While the plotted smooth curve of the intercept did not change over time (Figure 4, upper panel), the plotted smooth curve of the autoregressive parameter varied over time. Consistently, the plotted inferred mean changed over time (lower panel).

Finally, focusing on Anger, the BIC indicated that the process was time-varying. The TV-AR parameter was different from zero, indicating that inertia was not stable over time ($p < .001$; *edf* > 1). The function of the autoregressive parameter (Figure 5, middle panel) and the plotted inferred mean (lower panel) were time-varying. On the contrary, the function of the intercept was time-invariant. In conclusion, the TV-AR seems the best model for detecting the temporal dynamics underlying the perception of Mating, Negativity, and the emotion of Anger.

5 | DISCUSSION

In this contribution, we adopted an idiographic approach to investigate potential changes in intra-individual dynamics in the perception of situations and emotional reactions of two

adolescents varying in personality traits, focusing specifically on inertia. Assuming that people do not systematically change equally over time (Baumert et al., 2017; Molenaar, 2013), we applied a new statistical model, labeled TV-AR (Bringmann et al., 2018, 2017) that allows for intra-individual processes to be time-variant (i.e., non-stationarity assumption) and a standard AR model. We examined whether the intra-individual temporal dynamics of situations perception and emotional states could be described better by a time-varying or a time-invariant model for two adolescents differing in their personality profile.

The two participants differed in Honesty, Emotionality, Extraversion, and Agreeableness. Moreover, they showed differences in terms of the stability of their temporal dynamics throughout the assessment period. In general, while Participant 2 showed stability in both the perception of situation characteristics and his emotional reactions in social interactions reported five times a day during 19 days, Participant 1 showed stability only in two emotions and three situation characteristics. Going more into details, both participants showed stable mean levels and inertia of Happiness and Sadness over time. Only Participant 1 exhibited unstable

Mating

FIGURE 3 The plotted time series of Mating felt for Participant 1 (left panels) and Participant 2 (right panels), including the plotted smooth curve of the intercept (upper panel), smooth curve of the autoregressive parameter (middle panel), and inferred mean with 95% Credible Intervals (lower panel)

inertia of Anger and Anxiety, indicating that their carry-over effects changed over time. The difference in stability between the two participants regarding Anger and Anxiety might mirror their differences in Extraversion. Because those two emotions imply more an interpersonal context than Sadness or Happiness, and because Participant 1 is lower in Extraversion than Participant 2, the impact of the different social situations encountered might be more important for him and result in unstable carry-over effects. It thus seems that the differences in personality could be related to differences in stability regarding the influence of one context (i.e., how one perceives the situation or how one feels) on the successive context.

Both participants showed stable dynamics in perceiving situations as dutiful and requiring intellect, probably explained by their everyday environment (i.e., school) that implied duties and thinking. Moreover, for Participant 1, whereas inertia in Positivity was time-invariant, the inertia of Negativity was time-varying. The pattern of data regarding Negativity provides a good example of how the TV-AR model can be useful to capture individuals' temporal dynamics. When Negativity was modeled using the standard AR, the autoregressive parameter was not significant, showing no inertia. On the contrary, the TV-AR showed that inertia was present but unstable

over time. Hence, the TV-AR could reveal information that remained silent when using the standard AR, drawing more accurate conclusions on individuals. In other words, it seems to be important to stress the value of considering inertia as something that varies over time to obtain a more thorough description of individuals. This might be especially relevant when studying adolescents. Adolescence is known as a “storm and stress” period, characterized by a greater instability mostly in emotions. The fact that inertia is linked to maladjustment among adolescents (e.g., Kuppens et al., 2012; Mancini & Luebbe, 2016; Neumann, Van Lier, Frijns, Meeus, & Koot, 2011) highlights the importance of studying the conditions under which it varies over time, to provide information that is useful for preventing the psychopathology onset.

Several limitations ought to be taken into account and pointed toward future research. First, the TV-AR model assumes the change to be gradual so that abrupt changes cannot be identified. However, abrupt changes can be characteristic of specific psychological functioning, such as those characterized by impulsivity and personality disorder, or of reactions to particular situations (e.g., sudden stress), which would be interesting to assess to obtain a deep and exhaustive understanding of individuals and their interaction with

FIGURE 4 The plotted time series of Negativity felt for Participant 1 (left panels) and Participant 2 (right panels), including the plotted smooth curve of the intercept (upper panel), smooth curve of the autoregressive parameter (middle panel), and inferred mean with 95% Credible Intervals (lower panel)

the environment. Another limitation is related to the number of time points (95), which were at the limit of acceptability. Although 60 data points can be enough for detecting important changes over time (Bringmann et al., 2017), the TV-AR model usually requires many time points (around 100) to get reliable estimates (Bringmann et al., 2018, 2017), especially when looking at small changes such as the ones we observed in our data. Third, we assessed situation perception and emotions using standard measures (i.e., DIAMONDS and emotions) for all individuals, considering all the items. Considering the exploratory nature of the work, this approach was adequate. However, the results showed that neither Deception nor Adversity varied over time for both participants in terms of variations. Nor were Sadness, Hurt, and Anger. In line with Haynes, Mumma, and Pinson (2009), to push further the idiographic approach, a first step could consist in the selection of a set of relevant variables for each participant, to maximize the possibility of detecting changes in temporal dynamics.

While the nomothetic approach, focusing on the group level, facilitates generalization of results, the idiographic approach, focusing on the intra-individual level, assesses the heterogeneity of the data. As noted by Beck and Jackson

(2019, p. 3): “Idiographic data are inherently temporal, given that they require multiple responses from a single individual.” As a result, idiographic models can examine better the effects of context and time, providing a more nuanced picture of the dynamical processes involved in one's everyday life. This is particularly true for the TV-AR that provides personalized models of individuals' processes over time. For example, both participants showed inertia in Anxiety. However, for Participant 2, this inertia was stable over time whereas for Participant 1, it was not. By not assuming stationarity, the TV-AR goes beyond AR models because it purports to capture potential nonlinear temporal dynamics. In other words, the TV-AR can reveal information that is not available when using the standard AR, drawing more accurate conclusions on individuals, thus allowing to reach a deeper understanding of personality, behaviors, and emotions. Our work is in line with others that consider personality in terms of intra- rather than inter-individual differences to examine temporal dynamics (Beck & Jackson, 2019).

This contribution investigated the person $\times$ situation interaction adopting a temporal perspective that allows examining whether different personality profiles vary in stability regarding how one situation, defined as how one feels at a

Anger

FIGURE 5 The plotted time series of Anger felt for Participant 1(left panels) and Participant 2 (right panels): the plotted smooth curve of the intercept (upper panel), the smooth curve of the autoregressive parameter (middle panel), and the inferred mean with 95% Credible Intervals (lower panel). *Note:* It is important to note that Anger in Participant 2 is not easily interpretable (especially the autocorrelation, thus cannot be estimated)

certain point in time, influences how one feels at the successive time. Future research is needed to examine the interplay between person and situation a step further by assessing the temporal dynamics underlying the interaction between situation and behavior over time (i.e., cross-lagged effects) using a time-varying vector autoregressive model (TV-AR, Bringmann et al., 2018) in relation to personality traits. To go further, we strongly believe that it is necessary to bring the idiographic and nomothetic approaches together. Future research should explore new ways of going beyond a single individual and to connect results obtained from single individuals to those from the total sample (Bringmann et al., 2013; de Haan-Rietdijk et al., 2016; Schuurman, Ferrer, de Boer-Sonnenschein, & Hamaker, 2016) in order to establish stronger links between personality profiles and specific intra-individual dynamics.

To summarize, we applied a model that considers the non-stationary dynamic of intra-individual processes in examining one indicator of non-stationarity, that is, inertia in situation perception. The TV-AR supports the idea that temporal dynamics of behavior are important to understand personality (Beck & Jackson, 2019; Cattell, 1957). By investigating whether individuals show inertia in the way they feel or perceive situations in different contexts

and whether this inertia is stable over time, the TV-AR applied to EMA data allows to test for the periodicity of emotions or perceptions. Moreover, by examining whether these periodicities vary for two individuals with different personality profiles, we provide more information on these specific profiles. Even if the TV-AR model is only at its early stages, it may hold particular promise for personality science. The TV-AR model allows considering all influences on a person, including the temporal nature of behavior and how it changes regarding the context and in response to others. It can also be used with many different data (e.g., behavioral, emotional, physiological time series data), to create person-specific maps identifying contemporaneous and lagged directed relations of each considered variables. The maps provide insight into the heterogeneity within each people and the time courses underlying their functioning. Thus, the TV-AR model appears to be an optimal tool for providing a more complete picture of the periodicity of behaviors, cognitions, and emotions and thus of personality.

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CONFLICT OF INTERESTS

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ENDNOTES

¹When both scores are from the same test, the formula for the calculation of the SE difference is:

$$\text{SE difference} = 1.414 \times \text{SEm where SEm} = SD \times (1 - \alpha)$$

²According to Giraitis et al. (2014) to derive the model-implied mean of a standard AR model, we can write:

$$\mu_t \approx \frac{\beta_0}{1 - \beta_1}$$

³According to Giraitis et al. (2014) to derive the model-implied mean of a TV-AR model, we can write:

$$\mu_t \approx \frac{\beta_{0,t}}{1 - \beta_{1,t}}$$

⁴Data and R code of the analyses are available at the following link: <https://drive.google.com/drive/folders/1RbdI8SOvUATs2GMGQ4GqIAIcTNMwqdlu?usp=sharing>.

⁵For each participant, each model was applied to 5 emotions (2 for Participant 2) and 6 situation characteristics, we thus set the level of significance at $p < .01$ for indices 2 and 3.

⁶We excluded Hurt. Even though the time-varying indices (i.e., intercept and autoregressive parameters) were significant, the plots were uninterpretable. This might be due to a nongradual change over time.

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APPENDIX

TABLE A1 Mean and standard deviation and Cronbach's alpha of the HEXACO-60 from Baiocco et al. (2017)

HEXACO-60 scores	Mean	SD	Cronbach's alpha
Honesty/humility	3.48	0.68	0.71
Emotionality	3.31	0.65	0.72
Extraversion	3.25	0.67	0.76
Agreeableness	2.92	0.57	0.74
Conscientiousness	3.51	0.61	0.71
Openness to Experience	3.31	0.66	0.70