



Genetic and environmental correlations between the General Factor of Personality (GFP) and working memory

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ABSTRACT

The present study examines the association between the General Factor of Personality (GFP) and working memory and its etiology with a behavioral genetic approach. The GFP, which explains the common variance among lower-order personality traits, is considered to reflect social effectiveness. Meanwhile, working memory also plays a significant role in social competence. Hence, we expected a substantial association between the GFP and working memory. A total of 253 Japanese twin pairs (124 monozygotic female; 52 monozygotic male; 28 dizygotic female; 17 dizygotic male; and 32 opposite sex twins) were included in the analyses. Phenotypic analyses confirmed a significant positive correlation between the GFP and working memory. Biometric analysis with a bivariate Cholesky decomposition model showed that the phenotypic correlation derived from additive genetic and non-shared environmental correlations. The present findings are in line with social effectiveness account of the GFP.

1. Introduction

In research on the hierarchical nature of personality, scholars are considering the option that it should include a single highest-order factor, which is referred to as the General Factor of Personality (GFP; e.g., Figueredo et al., 2004). The notion of a GFP is based on consistent findings that personality traits systematically covary (e.g., Figueredo et al., 2004; Van der Linden, te Nijenhuis, & Bakker, 2010), such that positively valenced traits are positively correlated. The GFP has been extracted from various personality inventories including those based on the well-known Big Five or the Five-Factor Model, or the 6-factor HEXACO model (Rushton & Irwing, 2011). This body of preceding research on the GFP has been well summarized in a recently published book (Musek, 2017).

One point of discussion regarding the nature of GFP, is whether it reflects a substantive factor or is nothing more than measurement error or a statistical artifact (Anusic et al., 2009; Pettersson et al., 2012). For example, it was suggested that the GFP solely reflects a socially-desirable response bias or a positive self-evaluation (Davies et al., 2015). On the other hand, there are now also many findings suggesting that the GFP reflects a substantive factor that is not confined to self-

reports, but correlates with a range of other-rated and objective outcomes (Musek, 2017; Rushton et al., 2009; Van der Linden et al., 2016). Studies have shown that high-GFP individuals are rated by others as more popular and more likeable (Van der Linden, Scholte, et al., 2010), and obtain higher job performance ratings (Pelt et al., 2017). The association between the GFP based on self-reports and positive personality ratings by others is also seen across cultures. For example, Van der Linden, Dunkel, et al. (2018) found that in a sample of Bolivian forage farmers interviewer ratings of social engagement were strongly correlated with the GFP based upon self-reports. The GFP has also been replicated in studies using Japanese samples (e.g., Rushton et al., 2009). Dunkel et al. (2019) found that interviewer ratings of social responsiveness in the first four years of life predicted the GFP in early adolescence. Based on such findings, one prevailing interpretation of the GFP is that it reflects social effectiveness (Van der Linden et al., 2016). Indeed, high-GFP individuals are rated as being socially effective, even after controlling for measurement error (Dunkel et al., 2016).

Another approach to examine the GFP has been behavioral genetic studies, which have confirmed that the general factor is substantially heritable (e.g., Rushton et al., 2009). In line with the social effectiveness account, a recent meta-analytic review has shown that the GFP is highly

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correlated with emotional intelligence (EI) and that this association is primarily due to shared genetic variance (Van der Linden et al., 2017; Van der Linden, Schermer, et al., 2018).

According to the social effectiveness view, high-GFP people have the motivation and ability to successfully navigate the social world. To do so, regulation of behaviors and emotions, which enable facilitation of interpersonal competence across different social contexts, play an important role (Ronay & von Hippel, 2015). A wide range of studies suggest that working memory plays a significant role in such regulation of behaviors and emotions. Working memory, which is considered to be divided into verbal and spatial (visuospatial) domains (Shah & Miyake, 1996), is a limited multi-component capacity that temporarily stores and actively processes information (Baddeley, 2007). Working memory ability indeed has been associated with behavioral regulation and flexibility (Berezkei, 2015), emotion regulation (McRae et al., 2012; Pe et al., 2013; Schmeichel et al., 2008), emotion recognition (Yim et al., 2013), and communicative perspective-taking (Nilsen & Bacso, 2017). Based on such findings, it can be expected that working memory may also be associated with the GFP. Some scholars have argued that personality and intelligence are independent constructs because they are affected by different selection pressures (Woodley, 2011). In line with this, several studies found no or weak association between the GFP and intelligence (e.g., Dunkel et al., 2014; Loehlin et al., 2015). Other studies, however, reported a relevant GFP-intelligence association (e.g., Dunkel & Cabeza De Baca, 2016). Thus, whether the GFP and intelligence are related still remains an open question. Kretschmar et al. (2018) has suggested that personality-cognitive ability associations may vary at different levels of measurement (i.e., broad versus specific measures), therefore, a useful approach to this topic is to test these associations using measures other than general intelligence. Accordingly, the present study examines the association between the GFP and working memory, which to our knowledge, has not been done before. We will test the phenotypical as well as genetic associations between working memory and the GFP. Phenotypic correlations can only reveal whether associations exist, however, they do not provide information about their etiology, namely, which factors contribute to the associations. Behavioral genetic studies on twin data, on the other hand, enable us to disentangle the genetic and environmental factors contributing to the association between two variables (Plomin et al., 2008). This approach can estimate the relative genetic and environmental contributions to individual difference in an observed phenotype using data from twins who are reared together. In twin studies, the phenotypic variance can be divided into: additive genetic effects (A^2); dominance genetic effects (D^2); shared environment (C^2); and non-shared environment (E^2). In terms of genetic effects, if multiple genes independently influence a trait, genetic variances can be additive. Dominance genetic effects, on the other hand, denote allelic interactions within the same locus. When environmental factors (e.g., parenting style, SES) increase resemblance between co-twins, those effects are considered shared environment. Non-shared environmental effects include factors that make co-twins dissimilar, and also includes measurement error. The classical twin design utilized in this study cannot estimate D^2 and C^2 simultaneously. When the intra-class correlations for MZ twins are more than twice those for DZ twins, D^2 is assumed. Otherwise C^2 is generally estimated. Previous behavioral genetic studies have shown that for the GFP as well as working memory, genetic factors explain approximately 50% of the variance in those constructs (Ando et al., 2001; Figueredo et al., 2004; Rushton et al., 2009). The other 50% of the variances for both variables are due to non-shared environmental factors. As for the GFP, D^2 effects have been often indicated (Rushton et al., 2009; Van der Linden, Schermer, et al., 2018). To investigate the etiology of the GFP-WM relationship we use the behavioral genetic approach with a Japanese twin data from the Keio Twin Study (KTS: Ando et al., 2019).

2. Material and methods

2.1. Participants and procedures

Twin participants ranging from 14 to 30 years old were recruited through the KTS in 1998–2001. Eligible twin participants were those who lived in Tokyo or its neighboring prefectures. In 1998 invitations to participate were sent to all of the eligible twins in the targeted area. Of the approximately 2000 eligible twin pairs, 315 twin pairs (approximately 15%) participated. Among them, 501 individuals ($M = 20.42$ years; $SD = 3.18$; range 16–27; 334 women) underwent the personality and working memory assessment. Zygosity was determined using a standard three-item questionnaire (Ooki et al., 1990) and DNA microsatellite analysis. A total of 124 monozygotic female (MZf), 52 monozygotic male (MZm), 28 dizygotic female (DZf), 17 dizygotic male (DZm), and 32 opposite sex (DZo) twin pairs (253 twin pairs) were included in the present analyses. In addition, one MZf, one MZm, and three DZo single twins did not participate. The implementation of the KTS was approved by the ethics committees of Keio University.

2.2. Measures

2.2.1. Personality traits

Personality was measured with the 240-item Revised NEO Personality Inventory (NEO-PI-R; Costa & McCrae, 1992) that assesses five personality domains, Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness to experience. The answer format is a five-point Likert scale ranging from strongly disagree (0) to strongly agree (4). Internal reliabilities (Cronbach alpha's) of the five scales ranged from 0.84 to 0.91.

2.2.2. Working memory

Working memory was measured with the spatial and verbal working memory tasks, which are revised versions of the working memory span tasks developed by Shah and Miyake (1996). Each task can be further classified into two components, storage and executive functions. Hence, the working memory tasks yield four scores: two modalities by two functions (spatial-storage, spatial-executive, verbal-storage, and verbal-executive). Spatial-storage capacity (Ss) and executive efficacy (Se) were measured by the spatial working memory task. Verbal-storage capacity (Vs) and executive efficacy (Ve) were measured by the verbal working memory task. Detailed procedures of the working memory tasks have been described elsewhere (Ando et al., 2001). Because the Ve scores were skewed in a negative direction ($skew = -5.21$) we performed Box-Cox transformation (Box & Cox, 1964) to make the Ve scores normally distributed ($skew = -0.45$ after the transformation). Detailed descriptive statistics are shown in Supplemental Table S1.

2.3. Statistical analysis

The percentage of missing data was approximately 5% in the present sample. We conducted Little's (1988) MCAR test to examine whether the missing data was completely random. The significant Chi-Square ($\chi^2(51) = 73.70, p = 0.02$) implied non-random missing data. In this case the full information maximum likelihood (FIML) method is preferable to multiple imputation (Shin et al., 2017). Therefore, single twin data were included in the analyses and the parameters were estimated with the FIML method.

Regarding working memory, the four working memory scores were weakly to moderately intercorrelated ($r_s = 0.22$ – 0.46 ; see Supplemental Table S2). Therefore, we abridged the working memory scores by extracting a general factor of working memory (GFWM).

In behavioral genetic analyses, twins are nested within families; the scores of the co-twins are not independent from each other. Thus, we calculated GFWM and GFP scores by using confirmatory factor analysis (CFA) with structural equation modeling method (see Fig. 1). In this

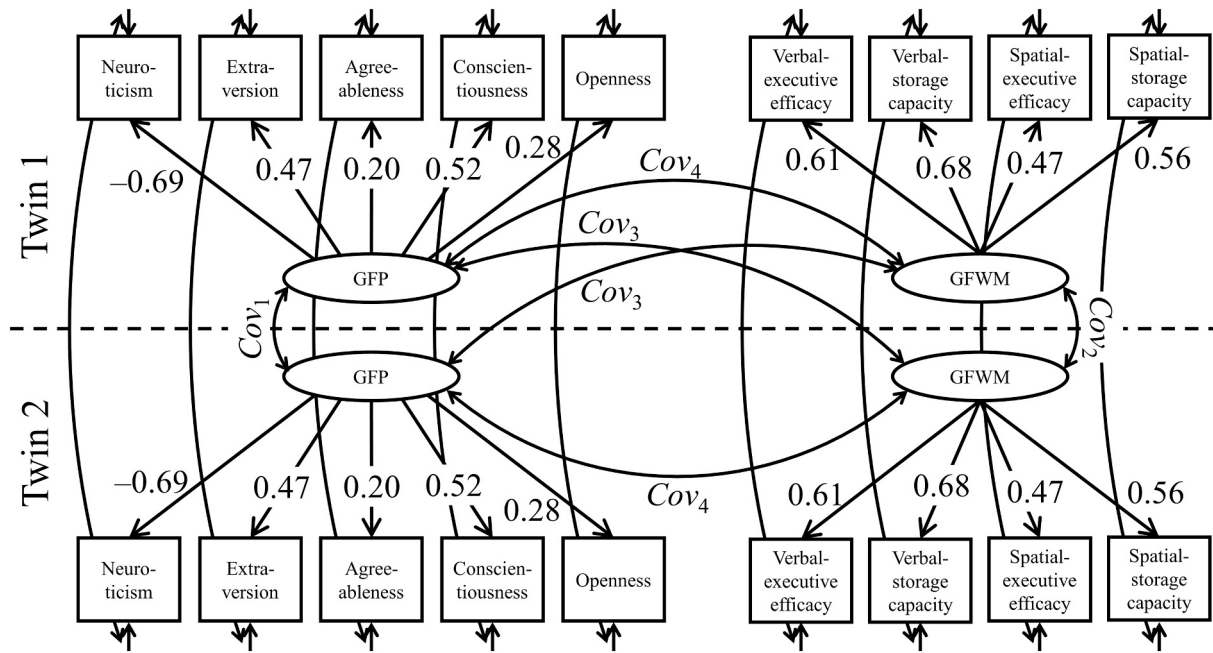


Fig. 1. Confirmatory factor analysis model of the General Factor of Personality (GFP) and the General Factor of Working Memory (GFWM).

model, the mean and residual variance of each observed variable were the same for MZ and DZ twins and for the co-twins. For the latent variables (GFP and GFWM), the univariate covariances (Cov_1 and Cov_2) and cross-trait cross-co-twin covariance (Cov_3) were freely estimated for MZ and DZ twins. The cross-trait covariance within each co-twin (Cov_4) was constrained equal for MZ and DZ twins.

After examining the bivariate phenotypic GFP-GFWM correlations, we proceeded with biometric analyses. To evaluate the origins of the possible GFP-GFWM association, we fitted a Cholesky decomposition model onto the latent factors scores (see Fig. 2). The model fit was assessed using chi-squared tests and root-mean-square error of approximation (RMSEA). Model comparisons were based on the models'

likelihood-ratio chi-squared tests, Bayesian Information Criterion (BIC), and RMSEA. Lower values of BIC and RMSEA suggest a better fit. All data analyses were conducted using Mplus ver.7 (Muthén & Muthén, 2012).

3. Results

3.1. Phenotypic results

As no biased distributions were found (see Supplemental Table S1) the CFA/SEM model (Fig. 1) was used to calculate the GFP and GFWM scores. The model adequately fitted the present data (RMSEA = 0.059,

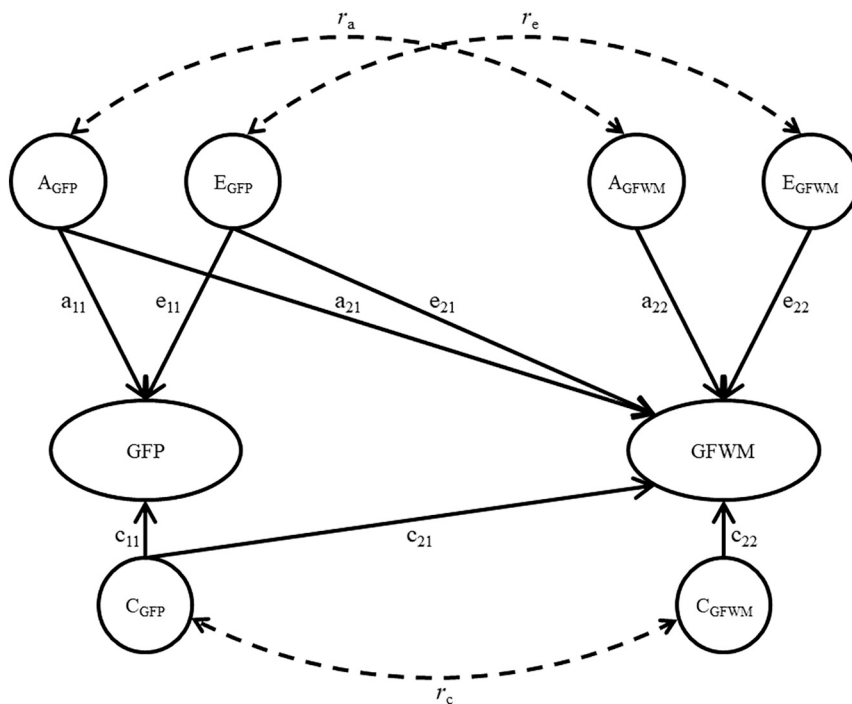


Fig. 2. Path diagram of the Cholesky decomposition model. The variances of the general factor of personality (GFP) and the general factor of working memory (GFWM) are divided into additive genetic (A_{GFP} and A_{GFWM}), shared environmental (C_{GFP} and C_{GFWM}), and non-shared environmental effects (E_{GFP} and E_{GFWM}). a_{11} , c_{11} , and e_{11} are paths representing additive genetic, shared, and non-shared environmental effects to the GFP, respectively; a_{21} , c_{21} , and e_{21} are paths representing additive genetic, shared, and non-shared environmental effects from the GFP to the GFWM, respectively; a_{22} , c_{22} , and e_{22} are paths representing additive genetic, shared, and non-shared environmental contributions unique to the GFWM, respectively. This path diagram represents only one co-twin in a pair (results are identical for the co-twin).

90%CI = [0.046, 0.070]) based on the cut-off criteria (Hu & Bentler, 1998). The standardized factor loadings (of the GFP and GFWM) are shown in Fig. 1, and their confidence intervals and proportion of explained variances are presented in Supplemental Table S3. The GFP loadings on the Big Five were significant and in line with the GFP literature, namely O+, C+, E+, A+ and -N. The latent GFWM loaded significantly and substantially on all four WM domains. The GFP explained approximately 26% of the variance in the Big Five scales, and the GFWM accounted for approximately 37% of the WM score variance.

The phenotypical intra-class correlations between the GFP and the GFWM were rather high for MZ twin pairs ($r = 0.73$, 95%CI = [0.57, 0.88], $p < 0.001$ for the GFP; $r = 0.73$, 95%CI = [0.59, 0.87], $p < 0.001$ for the GFWM). For the DZ twin pairs, the correlations were lower than for the MZ twins ($r = 0.41$, 95%CI = [0.03, 0.79], $p = 0.03$ for the GFP; $r = 0.23$, 95%CI = [-0.08, 0.54], $p = 0.15$ for the GFWM). The phenotypical correlation between the GFP and the GFWM was significant ($r = 0.20$, 95%CI = [0.04, 0.36], $p = 0.01$). Detailed phenotypic correlations are given in Supplemental Table S4. Compared to males, females scored weakly, but significantly higher on the GFP ($r = 0.11$, 95%CI = [0.02, 0.19], $p = 0.01$) but not on the GFWM ($r = -0.04$, 95%CI = [-0.12, 0.05], $p = 0.39$). Participants' age was also significantly and positively associated with the GFP ($r = 0.11$, 95%CI = [0.02, 0.19], $p = 0.01$) but not with the GFWM ($r = 0.00$, 95%CI = [-0.09, 0.09], $p = 0.99$). In the subsequent biometric analyses, we adjusted for the participants' age and sex (McGue & Bouchard, 1984).

3.2. Biometric results

Since the intra-class correlations indicated non-additive effects for the GFWM, we tested the ACE and ADE models at first (Fig. 2). Then we applied the two restricted models, including the AE model, and the CE model, to the bivariate data. Because the ADE model did not converge it was not included in further model comparisons. The chi-square tests and other model-fit indices showed that the AE model, including additive genetic and non-shared environmental factors, was the best fit for the GFP and the GFWM scores. Supplemental Table S5 presents detailed model fit indices.

Heritability estimates of the GFP and the GFWM were relatively high (h^2 s = 0.83). Importantly, their additive genetic and non-shared environmental correlations were statistically significant ($r_a = 0.27$, 95%CI = [0.15, 0.39]; $r_e = 0.25$, 95%CI = [0.11, 0.39]). Table 1 shows detailed parameter estimates in the present AE model.

4. Discussion

In the present study we tested whether the GFP, as a presumed social effectiveness factor, is associated with working memory and examined the etiology of this association. The GFP significantly correlated with the general factor of working memory at the phenotypic level. The magnitude of the association ($r = 0.20$) was within the expected range, of associations between the GFP and general intelligence as reported in previous studies (Dunkel & Cabeza De Baca, 2016). Moreover, behavioral genetic analysis showed that this association was derived from both

additive genetic and non-shared environmental factors or measurement error, whereas there was no direct effect of the shared environment.

Working memory is known to play an important role in social competency (Berezkei, 2015; McRae et al., 2012; Nilsen & Bacso, 2017; Pe et al., 2013; Schmeichel et al., 2008; Yim et al., 2013). Meanwhile, the GFP is closely aligned with trait EI (Van der Linden et al., 2017) and is considered to reflect social effectiveness (Van der Linden et al., 2016). Behaving in a socially effective way often implies that one has to suppresses initial urges to react in a certain way (e.g., get very angry) or to behave to delay gratification (e.g., during courtship). Given the well-established role of WM in the regulation of such behaviors (e.g., Berger, 2011), it makes sense that WM capacity is associated with a person's level of social effectiveness. Therefore, these two factors may partially support the same function, which is in line with their phenotypic correlation.

The behavioral genetic analysis indicated that additive genetic and environmental effects both contribute to the GFP-GFWM association. We also found relatively large heritability in both factors ($h^2 > 0.80$) which may be partly due to the exclusion of measurement errors in the CFA model. High heritability estimates (approximately $h^2 = 0.85$) has also been reported for general intelligence, extracted as a latent factor from intelligence test scores (Panizzon et al., 2014; Shikishima et al., 2009). These findings, including the one we report in the present study, suggest that the narrow-sense heritability of cognitive ability may reach the 0.9 range after correction for unreliability. Additionally, this high heritability may also be due to assortative mating (Plomin & Deary, 2015), which is more prevalent for intelligence than for other psychological traits (Bouchard & McGue, 1981). Overall, the present heritability estimates indicated that there is significant generic variation in the GFP and WM. A positive genetic correlation, especially in the case of pleiotropy, implies directional selection pressure acting simultaneously on traits, assortative mating for both traits, or mutation-selection maintaining substantial genetic variation in two traits (Roff, 1997). However, although mutation-selection balance might play a substantial role in trait variance and covariance among cognitive abilities (Hill et al., 2018), there is some debate about its potential role in personality. For example, Hope et al. (2011) argued that mutation-selection has no relevant role in normal range personality traits. On the other hand, using genome-wide single nucleotide polymorphism (SNP) data from more than 8000 individuals Verweij et al. (2012) found significant effects of rare SNP variants and concluded that "...genetic variation in personality traits having been maintained by mutation-selection balance" (p. 3239).

Assortative mating is known to be much lower for personality than for cognitive ability (Bouchard & McGue, 1981). Thus, this process might not play a strong role. Directional selection, however, which requires us to behave in socially effective manner is also one of the processes that likely played a significant role in the genetic correlation between socially desirable traits (Rushton et al., 2009; Van der Linden et al., 2016) thereby possibly also acting on the GFP and working memory in human evolutionary history.

Meanwhile, the positive environmental correlation we found indicates that the environmental factors enhancing the GFP may also increase working memory ability. From a developmental perspective,

Table 1
Parameter estimates of Cholesky decomposition model.

	A _{GFP}	E _{GFP}	A _{GFWM}	E _{GFWM}	Heritability	r_a	r_e
GFP	0.911*** [0.889, 0.934]	0.412*** [0.362, 0.462]			0.830*** [0.789, 0.871]		
GFWM	0.245*** [0.135, 0.354]	0.103** [0.042, 0.164]	0.875*** [0.839, 0.911]	0.405*** [0.353, 0.457]	0.826*** [0.781, 0.870]	0.270*** [0.150, 0.389]	0.247*** [0.108, 0.385]

Notes. A = additive genetic effect; E = nonshared environmental effect; r_a = additive genetic correlation; r_e = non-shared environmental correlation. 95% confidence intervals are given in parentheses.

** $p < 0.01$.

*** $p < 0.001$.

positive early environments from birth to childhood affect the association. For example, several studies showed that early environmental harshness and unpredictability may have detrimental effects on the GFP as well as working memory (Dunkel et al., 2018). According to adaptive calibration model (Ellis & Del Giudice, 2014), interactions between genes and environments generate variety in the stress response system, which can regulate development of life history strategies including the GFP and working memory. In the future research, it may be useful to directly investigate the gene-environment interactions on the GFP-working memory association.

Although the present study found theoretical meaningful associations between personality and cognitive factors, several limitations should also be noted. Limitations were that personality was only measured by self-report and that the sample size, especially the number of DZ twin pairs, was relatively small. Mono-rater measures of personality traits are easily influenced by random and systematic errors.

Future research may want to examine the GFP-working memory correlation with multiple-method or multiple-rater personality data. Nevertheless, the fact that, the self-reported (GFP) measure of personality was related to the objectively measured working memory already partly deals with the artifact explanation of the GFP. That is, it makes it less likely that the GFP merely arises from answering biases on the personality items. Another factor to take into account is that the present finding is based on a Japanese twin sample, which limits the generalizability. For example, cross-ethnic study showed that the association between the GFP and general intelligence is inflated in several ethnic groups compared to others (Dunkel et al., 2014). Future research may want to replicate the present finding using cross-ethnic twin samples. Additionally, the present study focused on only the general factors of personality and working memory. Kretzschmar et al. (2018) suggested that the associations between personality and cognitive ability are different based on the levels of these hierarchical constructs. For example, recent research has suggested that intelligence associates with a personality profile including intellectual ability, independence, and creativity independently from life history strategies (Dunkel et al., 2021). We may want to extend the present finding by focusing on the domains and facets of personality and more general or different cognitive ability in the future.

All in all, the present findings support the notion that part of the presumed social effectiveness in high-GFP people may be due to enhanced working memory, which would allow them to better regulate their behavior. As such, this study contributes to insight in the nature of a personality factor that is assumed to influence one's score on a wide range of more specific traits.

CRedit authorship contribution statement

Tetsuya Kawamoto: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Dimitri van der Linden:** Writing – review & editing. **Curtis S. Dunkel:** Writing – review & editing. **Juko Ando:** Conceptualization, Investigation, Resources, Data curation, Funding acquisition, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.paid.2021.111125>.

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