Associations of Resting Heart Rate and Intelligence With General and Specific Psychopathology: A Prospective Population Study of 899,398 Swedish Men

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Abstract
We examined longitudinal associations of resting heart rate (RHR) and general intelligence (IQ) with two psychopathology models (correlated factors and general factor model). RHR and IQ were measured during conscription (mean age = 18.23 years; N = 899,398 Swedish males). A correlated factors model of register-based outcomes (including 10 psychiatric diagnoses, criminal convictions, and prescription of anxiolytic medications; mean age at follow-up = 43.09 years) identified internalizing, externalizing, and psychotic dimensions; the general factor model additionally identified a general dimension. All correlated factors were inversely associated with IQ; however, the general factor model showed that several of these associations were attributable to general variance rather than specific variance. In both psychopathology models, RHR weakly but significantly predicted higher internalizing but lower externalizing problems. Intelligence might be a transdiagnostic risk factor for any form of psychopathology, and the internalizing and externalizing spectra might be differentiated by psychobiological processes related to sensitivity to punishment.

Keywords
general factor of psychopathology, resting heart rate, intelligence

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In recent years, it has been hypothesized that a general factor and several specific factors influence mental health problems (Caspí & Moffitt, 2018; Lahey, Krueger, Rathouz, Waldman, & Zald, 2017). Although this model is useful because it can account for comorbidity among mental health problems, it is still unclear what the general and specific factors actually measure (Bonifay, Lane, & Reise, 2017; Caspi & Moffitt, 2018; Snyder & Hankin, 2017; van Bork, Epskamp, Rhemtulla, Borsboom, & van der Maas, 2017; Widiger & Oltmanns, 2017). There is growing evidence, however, that the general factor of psychopathology is associated with lower intelligence and greater negative emotionality, impulsivity, and atypical thinking (Carver, Johnson, & Timpano, 2017; Caspi & Moffitt, 2018; Lahey et al., 2017; Tackett et al., 2013). Much less is known about the nature of the specific latent factors of psychopathology identified in general factor models. For example, it is unclear what psychobiological processes are associated with specific internalizing problems, such as depression and anxiety, independently of general distress and impairment.

The first of three goals of this study was to test the prediction that individual differences in intelligence is one of the transdiagnostic factors that nonspecifically increases risk for any form of psychopathology (Caspí
findings with those based on a correlated factors model. Of the general and specific factors by comparing the partly reflect insensitivity to threats and punishment and that the externalizing spectrum might partly reflect an elevated sensitivity toward threats and punishment. One speculation is that the internalizing spectrum might be associated with subsequent higher risk of being diagnosed with obsessive compulsive disorder, schizophrenia, and anxiety disorders but lower risk of substance use disorders and criminal convictions. In contrast, adolescents and adults displaying antisocial behavior have lower RHR (Lorber, Kemp et al., 2014). Earlier studies have reported that RHR is elevated in patients with major depression, generalized anxiety disorder, and psychotic disorders (Clamor et al., 2014; Kemp et al., 2014). The mean age at conscription was 18.23 years. As part of the conscription evaluation, RHR was measured after 5 to 10 min of rest in the supine position with an appropriate cuff at heart level. We excluded RHR values below 35 and above 145 beats per minute \( n = 172 \) as outliers or potential data entry errors (Latvala et al., 2016). IQ was assessed during the conscription evaluation using the Swedish Enlistment Battery (SEB). Three different versions of the SEB were used during the study period: SEB67 during 1969 to 1979 (reliability \( \omega = .81 \); Carlstedt & Mårdberg, 1993; Mårdberg & Carlstedt, 1998). We standardized \( M = 0, SD = 1 \) RHR and IQ to facilitate effect size comparisons (for unstandardized means and standard deviations, see Table S1 in the Supplemental Material available online).
Outcomes: later psychiatric disorders, crimes, and anxiolytic prescriptions

The mean age of the sample at end of follow-up (2013) was 43.09 years (range = 21–63); thus, the average follow-up time after conscription was 24.86 years (range = 3–44). We linked the males to several national registers that record contact with the mental health and judicial systems. Information about all psychiatric inpatient admissions since 1973 and outpatient diagnoses since 2001 were available from the National Patient Register until the end of 2013. To access inpatient or outpatient care, individuals must receive a referral from a primary care physician, present (and be admitted) at a psychiatric emergency clinic, or be forcibly admitted against their will. Diagnoses were assigned by the attending psychiatrist according to Swedish translations of the International Classification of Diseases (ICD 8, 9, and 10) in a nonhierarchical fashion. We included 10 psychiatric disorders (Table 1; ICD codes are available in Table S2 in the Supplemental Material). We also included violent (e.g., unlawful threats, assault, and homicide) and property (e.g., theft and burglary) criminal convictions from the Swedish Crime Register as indicators of antisocial behavior. As a measure of potentially less severe internalizing problems, we included prescription of anxiolytics (sedatives, Anatomical Therapeutic Chemical [ATC] N05C; anxiolytics, ATC N05B; and antidepressants, ATC N06A), which can be prescribed without contact with inpatient or outpatient care (i.e., they can be prescribed by primary care physicians and private mental health practitioners). All outcomes were treated as binary variables, that is, we examined only whether they had occurred. Descriptive statistics are displayed in Table S1 in the Supplemental Material.

Covariates

We adjusted the analyses for several potential confounders, similar to our earlier studies based on the same sample (Latvala et al., 2016). To control for possible associations with body size, we adjusted for height and weight, which were measured during the conscription evaluation. We also adjusted for physical fitness, which was assessed during the conscription evaluation via an exercise test with a bicycle ergometer, generating a measure of maximal workload (expressed in watts). This measure was divided by weight to take into account body size. Family socioeconomic status in childhood was derived from the occupation of the head of the household and coded into three classes: low, medium, and high. Finally, we included year of birth to adjust for potential cohort and period effects.
Statistical analyses

First, we conducted an EFA of the 13 adverse outcomes. We used an exploratory analysis rather than confirmatory analysis because the outcomes seemed unlikely to have simple structure. That is, in contrast to paper-and-pencil instruments, which allow test developers to iteratively delete or amend interstitial factor markers until simple structure is achieved, we analyzed adverse outcomes recorded in national registers. It seemed unreasonable to assume that these outcomes would align perfectly along only a single specific dimension in the multivariate space (i.e., load at zero on all but one specific factor). We used the scree plot, which pits the number of extracted components against their explained variance, to decide how many factors to extract (Cattell, 1966).

We rotated the factor solution in two ways. First, to isolate a general factor, we rotated the solution toward one general factor and several uncorrelated specific factors using a direct Schmid-Leiman transformation (Waller, 2018). Second, we rotated the solution toward a correlated factors model using the oblique Geomin rotation. Using exploratory structural equation modeling (Asparouhov & Muthen, 2009), we then regressed each of these two rotations onto RHR, IQ, and the covariates. To examine the linearity of the associations, we divided RHR and IQ into sextiles and examined latent factor means, as well as prevalence of the 13 observed outcomes, in each sextile.

We derived the factor rotation matrices with the package GPArotation (Bernards & Jennrich, 2005) for the R software environment (Version 3.5.1; R Core Team, 2018). All analyses were carried out in Mplus (Muthén & Muthén, 2012). We treated the binary outcomes as ordered categorical variables and used the mean- and variance-adjusted weighted least square estimator. Because we captured a large proportion of all Swedish males, some of the participants were siblings, so we might have underestimated the standard errors. Therefore, we clustered on the mother to estimate unbiased standard errors.

Sensitivity analyses

First, because the age span was wide, we divided the sample into four cohorts: men who were conscripted between 1969 and 1980, between 1980 and 1990, between 1990 and 2000, and between 2000 and 2010. We then examined the similarity of the factor structure and standardized regression coefficients (βs) across these four cohorts. Second, because we lumped together three versions of the SEB IQ test, we examined the βs separately for the three tests. Third, we reran the regressions excluding either IQ or RHR to examine whether their covariance influenced the βs. Fourth, we regressed both the latent general and specific factors, and the observed outcomes, onto the exposures simultaneously to examine the proportion of the variance in each outcome that could be attributed to indirect effects (via the latent factors) or direct effects.

Results

Exploratory factor analysis

The first five eigenvalues of the 13 outcomes were 6.91, 1.63, 1.33, 0.78, and 0.62. Consequently, we extracted three exploratory factors that fit the data well (root mean square error of approximation [RMSEA] = 0.011, 90% confidence interval [CI] = [0.011, 0.011]; confirmatory fit index, CFI = .995; Tucker-Lewis index [TLI] = .990; χ² (42) = 8,168.602, p < .001).

We rotated this solution toward a general factor model and toward a correlated factors model. Table 1 displays the factor loadings and correlations. In the general factor model, all outcomes loaded positively on the general factor (mean loading = 0.56; range = 0.41–0.68). The first specific factor captured internalizing problems (depression loading = 0.62; anxiety loading = 0.57). The second specific factor captured externalizing problems (drug abuse loading = 0.48; violent crimes loading = 0.55). The third specific factor captured psychotic problems (schizophrenia loading = 0.45; schizoaffective disorder loading = 0.66). In the correlated factors model, the factors mimicked the specific factors, albeit with stronger loadings (Table 1).

Exploratory factors regressed onto resting heart rate and intelligence

First, we regressed the general factor model onto RHR, IQ, and the covariates (RMSEA = 0.008, 90% CI = [0.007, 0.008]; CFI = .994; TLI = .993; χ² (148) = 13,063.714, p < .001). The results are displayed in Table 1. RHR had a small but significant effect on the general factor (β = −0.010, 95% CI = [−0.014, −0.006]). Furthermore, RHR significantly predicted higher specific internalizing problems (β = 0.040, 95% CI = [0.034, 0.046]) and higher specific psychotic problems (β = 0.025, 95% CI = [0.017, 0.033]) but lower specific externalizing problems (β = −0.074, 95% CI = [−0.078, −0.070]). In contrast, IQ was a significant and negative predictor of the general factor (β = −0.181, 95% CI = [−0.183, −0.179]). Furthermore, IQ was negatively associated with the specific externalizing factors (β = −0.221, 95% CI = [−0.225, −0.217]) and specific psychotic factors (β = −0.015, 95% CI = [−0.021, −0.009]) and positively
associated with the specific internalizing factor (β = 0.054, 95% CI = [0.050, 0.058]). The associations with the four latent factors (Fig. 1) and the 13 adverse outcomes (see Table S3 in the Supplemental Material) appeared largely linear.

Second, we regressed the correlated factors model onto RHR and IQ (Table 1). RHR significantly predicted higher internalizing problems (β = 0.017, 95% CI = [0.013, 0.022]) and higher psychotic problems (β = 0.028, 95% CI = [0.021, 0.035]) but lower externalizing problems (β = −0.075, 95% CI = [−0.079, −0.070]). IQ was negatively associated with the externalizing factor (β = −0.288, 95% CI = [−0.291, −0.284]), the psychotic factor (β = −0.087, 95% CI = [−0.092, −0.082]), and the internalizing factor (β = −0.094, 95% CI = [−0.098, −0.091]).

Because the association between RHR and the factors remained similar in the general and the correlated factors model, it implies that RHR is primarily associated with specific rather than general variance. In contrast, the correlated factors rotation appeared to mask that a substantial part of the associations between IQ and the factors could be attributed to general rather than specific variance.

**Sensitivity analysis**

First, both the factor structures and the βs were similar across four conscription cohorts, indicating that the results generalized across a wide age span (sensitivity analysis; see Table S4 in the Supplemental Material). Second, the βs were similar across the three versions of the SEB, supporting our lumping of the IQ tests (see Table S4 in the Supplemental Material). Third, the βs remained very similar after excluding either IQ or RHR (see Table S4 in the Supplemental Material), indicating that their covariance did not influence the results. Fourth, on average, 87% of the variance explained in each outcome could be attributed to indirect effects via the latent factor model (see Fig. S1 in the Supplemental Material). This further suggests that the exposures influenced the underlying risk toward broader forms of psychopathology rather than each of the observed outcomes independently.

**Discussion**

Although a general factor model is useful in that it can account for comorbidity among mental health problems, it presents interpretive challenges. We showed that lower intelligence at age 18 years was a transdiagnostic predictor for every form of psychopathology in middle adulthood via the general psychopathology factor. In contrast, RHR distinguished between internalizing and externalizing problems.

One speculation is that RHR might index an underlying psychobiological process akin to sensitivity to threat and punishment (Raine, 2015). Insensitivity to threats was central to the original conceptualization of the psychopathy construct (Cleckley, 1955). Indeed, people with psychopathic traits tend to display damped psychobiological arousal in response to impending punishments (Hare, 1965; Lykken, 1957), are slower to recognize faces with fearful expressions (Sylvers, Brennan, & Lilienfeld, 2011), and self-report as less suicidal, anxious, and depressed after suppression effects are isolated (Blonigen et al., 2010; Douglas et al., 2008; Hicks & Patrick, 2006). Thus, independently of general distress and impairment, a high sensitivity to threats and punishment might predispose people toward internalizing problems, whereas a low sensitivity to threats and punishment might predispose people toward externalizing problems.

In contrast to RHR, the association between IQ and psychopathology appeared to be substantially attributable to general variance, replicating past studies (Casp et al., 2014; Castellanos-Ryan et al., 2016; Grotzinger et al., 2019; Huang-Pollock et al., 2017; Lahey et al., 2015; Nigg et al., 2017). This association could arise because lower cognitive ability increases exposure to adverse environments that in turn increase general mental health problems or because lower cognitive ability reduces the tendency to seek mental health treatment (Casp et al., 2018). However, because the diagnoses in this study were assigned after individuals sought treatment and because the association between IQ and general psychopathology appears to emerge before the age of 6 (Casp & Moffitt, 2018; Grotzinger et al., 2019), adverse environments or lack of treatment-seeking behavior might not account for the entire association. One speculation is that part of the association might be attributable to executive functioning, which is phenotypically and genetically associated with both general psychopathology and intelligence (Harden et al., 2020; Martel et al., 2017).

Lower IQ also predicted higher scores on the specific externalizing factor, replicating past research (Huang-Pollock et al., 2017; Nigg et al., 2017). This might represent a direct effect, perhaps mediated via education, because even after adjusting for potential family-level confounds (including genetics), low IQ and academic achievement remain associated with externalizing problems (Frisell, Pawitan, & Langstrom, 2012; Kendler et al., 2018).

**Implications**

The results presented herein have several implications. First, it might be useful to examine whether executive functions partly drive the associations between lower intelligence and general psychopathology and specific
Fig. 1. Standardized factor means by sextiles of resting heart rate and general intelligence (IQ). Displays standardized factor means by sextiles of predictors, and the fourth sextile was the reference group. Bars represent 95% confidence intervals.
externalizing problems (Harden et al., 2020; Martel et al., 2017). Second, in a recent review, RHR was the only endophenotype out of 40 candidates that displayed reliable associations with molecular genetic variants (Iacono, Malone, & Vrieze, 2017). Thus, one possibility is that RHR might help shed light on the genetic architecture underlying internalizing and externalizing problems. Third, whereas the current RDoC perspective highlights the biological underpinnings of anxiety and fear (Cuthbert & Insel, 2013), it does not appear to consider the opposite extreme of fear (i.e., fearlessness) as equally maladaptive. These results imply that both extremes of the fear continuum might predispose people toward opposite types of adverse outcomes (Rojas & Widiger, 2018).

**Limitations**

These results should be interpreted in light of the strengths and limitations of the study. Study strengths include that we relied on a large sample of males followed up for an average of 25 years and that the outcomes were retrieved from population registers and the judicial system. Study limitations include first, that because only 95% of the men born in Sweden were mandated to participate in the conscription evaluation, it remains uncertain whether our results generalize to the remaining 5% of Swedish males who did not undergo conscription, females, and people born in other countries. Second, although we speculate that RHR might be an indicator of an underlying trait dimension, it is unknown whether the associations are driven by constant differences in RHR or by differences in response to a potentially stressful evaluation. If the latter, RHR would be predictive of only future outcomes if assessed during an equally stressful situation. Third, it is possible that when the loadings on the general factor are based on register data, they might be overestimated because of collider bias, given that people with several disorders might be more prone to end up in the mental health system (also called Berkson’s bias); however, the magnitude of the loadings on the general factor in this register-based study appeared similar to that of survey studies, in which one might expect collider bias to lead to underestimation of general factor loadings because individuals with several mental health problems might be less prone to participate in such surveys (Caspi et al., 2014; Lahey et al., 2015).

**Conclusion**

Lower IQ was a transdiagnostic predictor of future mental health problems via the general factor of psychopathology. In contrast, RHR was associated in opposite directions with the specific internalizing and specific externalizing factors, which suggests that these latent factors of psychopathology might partly reflect elevated sensitivity versus insensitivity toward threats and punishment, respectively.

**Transparency**

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**Author Contributions**

E. Pettersson, A. Latvala, P. Lichtenstein, and B. B. Lahey developed the study concept. All of the authors contributed to the study design. Data extraction was performed by E. Pettersson and A. Latvala. E. Pettersson conducted the analyses and drafted the manuscript. All of the authors provided critical revisions and approved the final manuscript for submission.

**Declaration of Conflicting Interests**

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

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**Supplemental Material**

Additional supporting information can be found at http://journals.sagepub.com/doi/suppl/10.1177/2167702616657069

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