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RESEARCH REPORT

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Drinking motives, personality traits and life stressors—identifying pathways to harmful alcohol use in adolescence using a panel network approach

René Freichel[1] | Janine Pfirrmann[1] | Janna Cousjin[2] | Peter de Jong[3] | Ingmar Franken[2] | Tobias Banaschewski[4] | Arun L. W. Bokde[5] | Sylvane Desrivières[6] | Herta Flor[7,8] | Antoine Grigis[9] | Hugh Garavan[10] | Andreas Heinz[11] | Jean-Luc Martinot[12] | Marie-Laure Paillère Martinot[12,13] | Eric Artiges[12,14] | Frauke Nees[15] | Dimitri Papadopoulos Orfanos[9] | Luise Poustka[16] | Sarah Hohmann[4] | Juliane H. Fröhner[17] | Michael N. Smolka[17] | Nilakshi Vaidya[18] | Robert Whelan[19] | Gunter Schumann[18,20] | Henrik Walter[11] | Ilya M. Veer[1] | Reinout W. Wiers[1,21] | IMAGEN Consortium

Correspondence
René Freichel, Addiction Development and Psychopathology (ADAPT)-lab, Department of Psychology, University of Amsterdam, Amsterdam, The Netherlands.
Email: r.freichel@uva.nl

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Abstract

Background and aims: Models of alcohol use risk suggest that drinking motives represent the most proximal risk factors on which more distal factors converge. However, little is known about how distinct risk factors influence each other and alcohol use on different temporal scales (within a given moment versus over time). We aimed to estimate the dynamic associations of distal (personality and life stressors) and proximal (drinking motives) risk factors, and their relationship to alcohol use in adolescence and early adulthood using a novel graphical vector autoregressive (GVAR) panel network approach.

Design, setting and cases: We estimated panel networks on data from the IMAGEN study, a longitudinal European cohort study following adolescents across three waves (aged 16, 19 and 22 years). Our sample consisted of 1829 adolescents (51% females) who reported alcohol use on at least one assessment wave.

Measurements: Risk factors included personality traits (NEO-FFI: neuroticism, extraversion, openness, agreeableness and conscientiousness; SURPS: impulsivity and sensation-seeking), stressful life events (LEQ: sum scores of stressful life events), and drinking motives [drinking motives questionnaire (DMQ): social, enhancement, conformity, coping anxiety and coping depression]. We assessed alcohol use [alcohol use disorders

René Freichel and Janine Pfirrmann contributed equally.

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identification test (AUDIT): quantity and frequency] and alcohol-related problems (AUDIT: related problems).

Findings: Within a given moment, social [partial correlation (pcor) = 0.17] and enhancement motives (pcor = 0.15) co-occurred most strongly with drinking quantity and frequency, while coping depression motives (pcor = 0.13), openness (pcor = 0.05) and impulsivity (pcor = 0.09) were related to alcohol-related problems. The temporal network showed no predictive associations between distal risk factors and drinking motives. Social motives (beta = 0.21), previous alcohol use (beta = 0.11) and openness (beta = 0.10) predicted alcohol-related problems over time (all $P < 0.01$).

Conclusions: Heavy and frequent alcohol use, along with social drinking motives, appear to be key targets for preventing the development of alcohol-related problems throughout late adolescence. We found no evidence for personality traits and life stressors predisposing towards distinct drinking motives over time.

KEYWORDS
Adolescence, alcohol use, alcohol-related problems, panel network, risk factors, drinking motives

INTRODUCTION

Substance use disorders, including alcohol use disorders, present severe psychiatric conditions that have been linked to all-cause mortality and cardiovascular disease [1], thereby causing a substantial health and economic burden [2]. The transition from adolescence to emerging adulthood is characterized by rapidly increasing rates of alcohol use, as well as significant biological, cognitive and social changes [3, 4]. Harmful alcohol use during this important developmental period may interfere with the normative course of development, and consequently increase the risk of future alcohol-related problems and dependence [5–7]. Identifying pathways towards harmful alcohol use in late adolescence could therefore help to develop more effective prevention and early intervention strategies.

Several risk-factor domains for the initial onset and maintenance of harmful alcohol use during adolescence and early adulthood have been identified. Among those, early onset of drinking, personality traits, environmental life stressors and drinking motives received particular empirical support [8]. There is consistent evidence linking personality traits, such as impulsivity and sensation-seeking to adolescent binge drinking (i.e. consumption of high quantities of alcohol in short time-periods) [9–11]. With respect to the 'big five' classification of personality traits, a recent meta-analysis [12] showed that higher levels of extraversion and lower levels of conscientiousness were most consistently associated with binge drinking among a predominantly young adult sample. Both longitudinal and cross-sectional research has implicated stressful life events as a major risk factor for the onset and degree of alcohol use throughout adolescence and early adulthood [13–18]. A recent study of a community sample of adolescents demonstrated that high or repeated exposure to early life stressors (before the age of 17 years) was associated with an increased risk for alcohol-related problems in late adolescence and early adulthood [16].

In addition to personality and life stressors, a growing body of evidence highlights the role of drinking motives in adolescent alcohol consumption. According to Cooper's four-factor model [19], four distinct motivations to drink emerge from the valence (i.e. to reduce negative affect or increase positive affect), as well as the source (i.e. internal or external) of the expected reinforcement of alcohol consumption. The four resulting drinking motives are social (positive, external) motives, enhancement (positive, internal) motives, conformity (negative, external) motives and coping (negative, internal) motives. Grant and colleagues [20] extended the four-factor model and further distinguished between motives of coping with anxiety and with depression. It has been suggested that drinking motives constitute the most proximal predictors of alcohol consumption on which more distal factors converge [21]. That is, distal risk factors (e.g. personality traits, life stressors) may give rise to distinct drinking motives which, in turn, influence alcohol use behavior as proximal risk factors. Indeed, ample research has supported drinking motives to be a mediator in the relationship between personality traits and alcohol consumption [22–27]. Although research examining the relationship between life stress, drinking motives and alcohol use is largely restricted to adulthood, some studies have also provided support for the mediator role of drinking motives in adolescents and young adults [28–30].

Despite a substantial body of literature highlighting the role of personality traits, life stressors and drinking motives for adolescent alcohol consumption, research has primarily examined specific risk factor domains (e.g. personality traits) in isolation [22, 26, 30]. As a consequence, potentially complex associations between different personality traits, life stressors and drinking motives remain poorly understood, both with respect to their co-occurrence and potential temporal dynamics. Moreover, existing studies that focused upon the interplay of distal and proximal risk factors of alcohol use are primarily of cross-sectional nature, and thus cannot discern within- and between-person effects. However, understanding such within-person (change within individuals) and between-person (individual differences) effects is crucial [31], given that interventions targeting specific risk factors will lead to within-person change.

In the current study, we therefore applied a novel methodological approach, a panel graphical multi-level network model [32], to longitudinal data from the IMAGEN cohort, a large-scale (n > 1800) study assessing alcohol use and associated risk factors (personality, life events and drinking motives) throughout adolescence and early adulthood (16–22 years). A longitudinal network approach allowed us to (a) investigate complex (inter-)relations among alcohol risk factor domains, (b) discern undirected contemporaneous from directed temporal effects and (c) separate within- and between-person effects [33, 34].

The current study aimed to identify normative developmental pathways to harmful alcohol use in late adolescence and early adulthood using a novel panel data network approach. Our approach was guided by two main research questions: (1) how are multiple personality traits and life stressors related to each other and different drinking motives and (2) how are these relations linked to late adolescent alcohol use and related problems (over time)? Drawing upon previous literature [21, 22, 24, 26, 35], we predicted that different patterns of personality traits and life stressors would give rise to distinct drinking motives over time, and that drinking motives would present the most proximal predictors of alcohol use in adolescence and early adulthood. We also hypothesized that positive drinking motives (social, enhancement) would predict alcohol use, while negative coping motives would be predictive of alcohol-related problems.

METHOD

Data source

We acquired data from the IMAGEN project, a large-scale, longitudinal, multi-center cohort study of adolescents [36]. The IMAGEN cohort included a large group of adolescents who were recruited across eight European research centers, including sites in Germany (Berlin, Dresden, Hamburg and Mannheim), the United Kingdom (London and Nottingham), Ireland (Dublin) and France (Paris). Personality, stressful life events, drinking motives and alcohol consumption were assessed at ages 16 (wave 2), 19 (wave 3) and 22 (wave 4) years. The study was approved by all local ethics committees in accordance with the Declaration of Helsinki. Written informed consent was obtained by the legal guardian of the adolescent participant prior to the age of 18, and by the participant thereafter. A more detailed description of the sample composition and study design is provided elsewhere [36]. All network analyses were based on data acquired at waves 2, 3 and 4 and restricted to adolescents who reported consuming alcohol on at least one of the three assessment waves (n = 1829).

Measures

Alcohol use and related problems

Adolescent alcohol use and related problems were assessed using the alcohol use disorders identification test (AUDIT) [37]. The AUDIT is a self-report based 10-item screening instrument for hazardous and harmful alcohol consumption. We used sum scores of the two AUDIT subscales [38] in our network analysis: quantity and frequency of alcohol use (items 1–3; possible subscale scores: 0–12) and alcohol-related problems (items 4–10; possible subscale scores: 0–28). Both AUDIT subscales were simultaneously included in the model. An overview of all Cronbach's alpha estimates can be found in the Supporting information (see Supporting information, Table S3).

Drinking motives

A modified version of the drinking motives questionnaire—revised (DMQ-R) [19] was used to assess motives for alcohol use. The questionnaire comprises 28 items (see Supporting information, Tables S1 and S2) that measure five distinct drinking motives [20]: enhancement (five items), social (five items), conformity (five items), coping anxiety (four items) and coping depression (nine items). Each item on the DMQ-R questionnaire asks participants to rate on how many occasions a specific reason motivated them to use alcohol in the past 12 months on a five-point Likert scale [1 = (almost) never, 2 = seldom, 3 = sometimes, 4 = often and 5 = always]. We calculated subscale scores for each motive as the mean of relevant item scores.

Personality measures

Personality traits were assessed by means of two self-report questionnaires: the neuroticism-extraversion–openness five factor inventory (NEO-FFI) [39, 40] and the substance use risk profile scale (SURPS) [41]. The NEO-FFI contains 60 items that measure the five-factor personality dimensions: neuroticism, extraversion, openness, agreeableness and conscientiousness. Each item on the NEO-FFI presents a self-descriptive statement to which participants must indicate their agreement on a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). We computed total scores for each personality dimension as the sum of 12 item scores in accordance with the inventory's five-factor structure (score range = 12–60). The SURPS is a brief, 23-item self-report scale that assesses four personality risk dimensions for specific patterns of substance use: hopelessness, anxiety sensitivity, impulsivity and sensation-seeking. Participants must rate their agreement with each of the 23 items on a four-point Likert scale from 1 (strongly disagree) to 4 (strongly agree). We included sum scores of the SURPS subscales impulsivity (five items, score range = 5–20) and sensation-seeking (six items, score range = 6–24) in our network analysis, as those have been most consistently related to adolescent binge drinking [9, 11].

Stressful life events

The life events questionnaire (LEQ) [42] is a 39-item scale that assesses the perceived desirability and life-time occurrence of

stressful life events across seven life domains: parents/family, accident/illness, sexuality, autonomy, deviance, relocation and distress. Perceived desirability is assessed by asking participants how happy or unhappy each item would make them feel on a five-point Likert scale (−2 = very unhappy, −1 = unhappy, 0 = neutral, 1 = happy, 2 = very happy). To ensure that the experience of life stressors was perceived as negative, we first categorized each item based on its rated desirability as negative (desirability < 0), neutral (desirability = 0) or positive (desirability > 0) [42]. We then selected all negative valence items (desirability < 0) for each participant separately and computed the sum score of their life-time occurrence (0 = no, 1 = yes; score range = 0–39) at each wave.

Statistical analysis and modeling

We used a panel graphical vector autoregression (GVAR) model [32] for network estimation. The panel GVAR is a multi-level lag-1 GVAR model [43] that is structurally similar to a random intercept cross-lagged panel data model to fit data from independent subjects assessed on a few measurement occasions. The VAR part of the model predicts each variable as a combined function of the variable's own, and all other variables' cross-lagged values (lag-1), thereby accounting for the temporal dependencies of repeated intra-individual assessments. The graphical part subsequently estimates a Gaussian graphical model (GGM) on the residual (co)variances of the VAR to uncover the relation between variables within a specific measurement occasion [43]. As such, the panel GVAR allows for the estimation of temporal effects (i.e. directed partial correlations derived from standardized regression coefficients), contemporaneous effects (i.e. partial contemporaneous correlations) and between-subjects effects (i.e. partial between-subjects correlations). The directed temporal network describes how variables predict each other across waves, while the undirected contemporaneous network describes symmetric bidirectional associations within the same measurement period. Importantly, the estimated temporal and contemporaneous parameters in the panel GVAR encode fixed effects—that is, within-person effects of an average person in the population [32]. Before estimating the panel networks, we detrended the data for possible linear and non-linear effects of time and standardized assessment scores across waves. This approach is considered appropriate in panel network analytical approaches, in which the focus of interest is on the correlational and not the mean structure [44]. We first estimated a saturated model structure (i.e. all edges included), and used a full information maximum likelihood (FIML) estimator to account for missing data. Following initial model estimation, we applied standard pruning procedures to remove non-significant edges and performed a step-up model search along modification indices that is common practice in the network analytical literature [45]. The pruning process removes all non-significant edges (using alpha = 0.05) and then re-estimates the model with all non-significant edges fixed to zero. This ensures that all estimates in the final model are based on a pruned model that excludes non-significant edges.

Model fit was evaluated based on the root mean squared error (RMSEA), comparative fit index (CFI) and the Tucker–Lewis index (TLI), according to standard criteria (RMSEA < 0.05, CFI > 0.95, TLI > 0.95) [46, 47]. We used the *psychonetrics* package [48] for modeling and the *qgraph* package [49] for network visualization. To assess the stability of the final network, we employed a bootstrapping procedure (n = 1000). Strength centrality measures were computed to quantify the relative node importance in the network. For the temporal network, we calculated each node's in-strength (i.e. sum of all ingoing absolute edge weights) and out-strength (i.e. sum of all outgoing absolute edge weights). For the contemporaneous networks, we estimated the node strength, which is defined as the sum of all absolute edge weights that are connected to a given node [50]. All analyses were carried out using the software R version 4.1.2 [51]. This study was not pre-registered, and our results should be considered exploratory.

RESULTS

The sample included 1829 participants that were recruited among eight European research sites: Berlin (n = 206), Dresden (n = 234), Hamburg (n = 231), Mannheim (n = 218), London (n = 234), Nottingham (n = 299), Dublin (n = 187) and Paris (n = 220). Our sample consisted of 51% (n = 929) female, 46% (n = 850) male and 3% (n = 50) without available or consistent data on sex. Among the 1829 eligible participants (i.e. alcohol use on at least one of the three assessment waves), 1630 (89.12%) provided data at wave 2, 1471 (80.43%) at wave 3 and 1333 (72.89%) at wave 4. Participants showed an average increase in alcohol use and related problems throughout the assessment period, with moderate levels of drinking [AUDIT quantity and frequency: mean = 4.25, standard deviation (SD) = 2.19; AUDIT-related problems: mean = 2.00, SD = 3.01) at the last wave. A detailed description of sample characteristics and missing values for each measure is provided in the Supporting information (see Supporting information, Tables S4 and S5).

The saturated panel network model provided an excellent fit to the data (BIC = 151280.89, RMSEA = 0.03, CFI = 0.97, TLI = 0.95). We applied standard pruning procedures (alpha = 0.05) to make the networks robust against false positive findings and facilitate interpretation. The pruned model showed a similarly good fit (BIC = 149843.30, RMSEA = 0.03, CFI = 0.95, TLI = 0.95).

The contemporaneous network shown in Figure 1 depicts undirected partial correlations between variables within a given moment, after accounting for their temporal dependencies. Overall, the network revealed associations between all five drinking motives, personality traits and different facets of alcohol use. There was a strong association between alcohol use quantity and frequency and alcohol-related problems. Alcohol use quantity and frequency further showed positive associations with the social, enhancement and, to a lesser extent, coping depression motives, as well as negative associations with conformity, conscientiousness, agreeableness and neuroticism. The enhancement motive was additionally associated with the social drinking motive, extraversion, sensation-seeking and the two coping

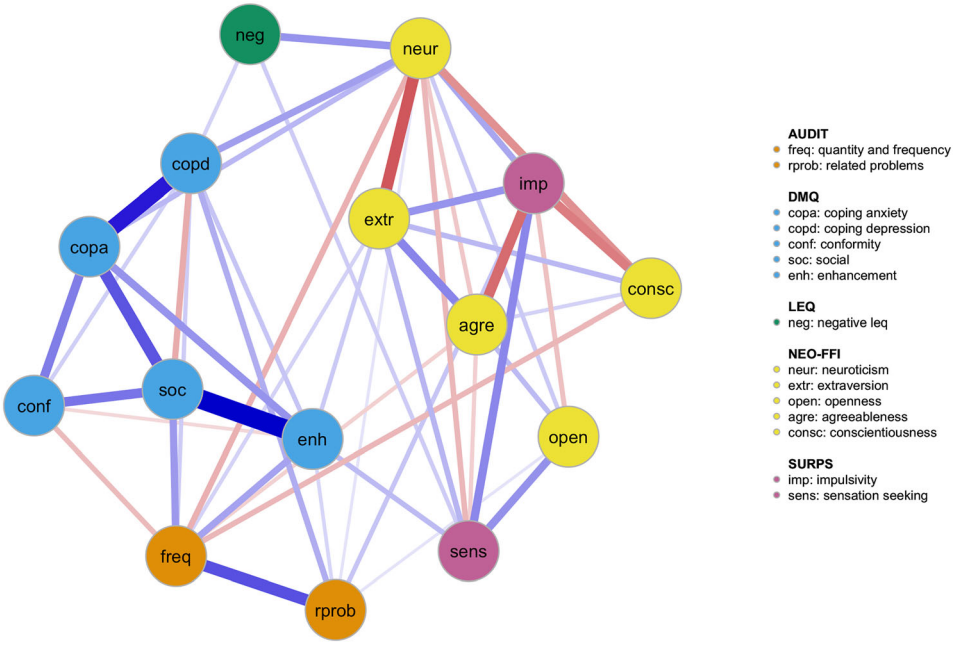

FIGURE 1 Fixed-effect contemporaneous associations within the same time window. The thickness and color (blue = positive, red = negative) of the edges represent the strength and direction of the associations, respectively.

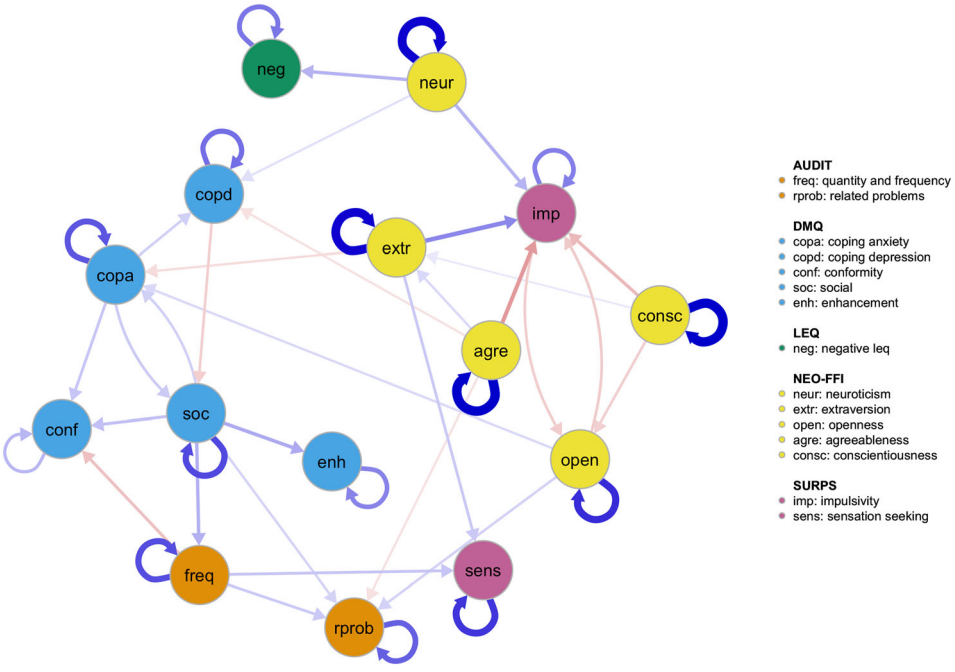

FIGURE 2 Fixed-effect directed temporal associations.

motives (anxiety and depression). Alcohol-related problems were associated with the coping depression motive and impulsivity and, to a lesser extent, with neuroticism and openness. Stressful life events showed positive associations with neuroticism, the coping depression motive and sensation-seeking. Node strength centrality analysis (see Supporting information, Figure S1) revealed that among all personality traits included, neuroticism showed the highest relative importance in the network. Among the five drinking motives, the social motive was identified as the most central, although closely followed by enhancement and coping (anxiety and depression) motives.

The temporal network depicts directed predictive relationships between drinking motives, personality domains, negative life events and alcohol use (see Figure 2). Overall, directed temporal associations revealed a complex pattern of unidirectional, bidirectional (i.e. feedback loops) and autoregressive effects, in which four pathways towards alcohol use and related problems emerged. First, previous alcohol use and related problems predicted future drinking and related problems, respectively (autocorrelations). Secondly, alcohol use quantity and frequency predicted alcohol-related problems at the next time-point. Thirdly, the social drinking motive directly predicted alcohol use quantity and frequency, as well as alcohol-related problems over time. Fourthly, higher levels of openness predicted more alcohol-related problems.

Our node centrality analysis (see Figure 3) revealed that impulsivity had the highest in-strength, while social drinking motives showed

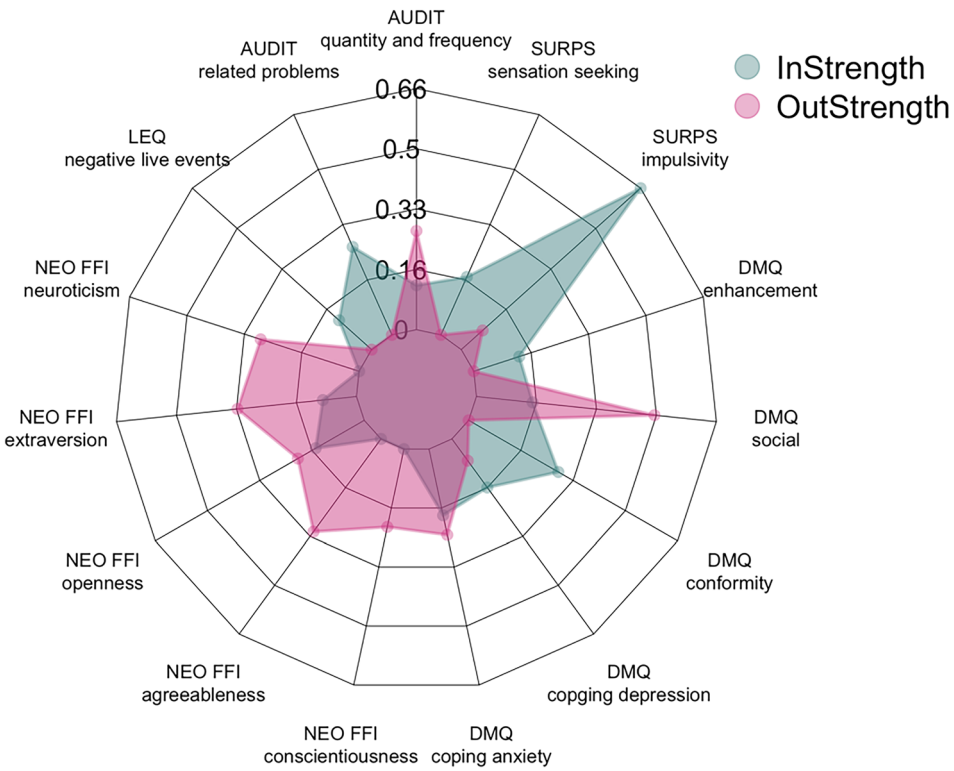

FIGURE 3 Outgoing and incoming strength of all nodes. The radar chart visualizes the degree (*y*-axis) to which variables in the temporal network influence other variables (out-strength) and are being influenced by other variables (in-strength) over time.

the highest out-strength. In other words, impulsivity was strongly predicted by most NEO-FFI factors; namely, higher levels of extraversion and neuroticism, as well as lower levels of conscientiousness, agreeableness and openness. Conversely, social drinking motives positively predicted alcohol use, alcohol-related problems and a range of other drinking motives (enhancement, conformity and coping anxiety) at the next measurement occasion.

All associations central to the interpretation of the networks are sufficiently stable, as indicated by our bootstrapping analysis (Supporting information, Figs S3 and S4). Contemporaneous and temporal edge weights are provided in the Supporting information, Tables S6 and S7.

DISCUSSION

The aim of our study was to explore the complex inter-relationships between distal (personality risk profiles, stressful life events) and proximal (drinking motives) risk factors of late adolescent alcohol use and problems using a novel panel network methodology. Applying panel GVAR models to data of a large-scale cohort study, we disentangled within- from between-person relations, and modeled the contemporaneous and temporal interrelations between distinct risk factor domains and adolescent alcohol use. Our findings describe normative developmental patterns in the general population. Overall, the panel GVAR model suggested that the various domains of risk factors were dynamically related and associated with alcohol use and related problems throughout adolescence and early adulthood. The resulting contemporaneous and temporal networks revealed both overlapping and distinct structures, thus highlighting the importance of understanding risk factors for alcohol use in the context of different temporal scales.

At the contemporaneous level, we identified two main patterns of associations that evolved around the expected valence of drinking (i.e. to increase positive affect versus to decrease negative affect) [19]. The first pattern involved a strong relation between the two positive valence motives: drinking for social reasons and drinking to enhance positive mood or wellbeing. Importantly, the two positive valence motives (social and enhancement) showed the strongest associations with drinking frequency but were unrelated to alcohol use-related problems. These findings are well aligned with existing literature in which social and enhancement motives have been most consistently related to frequent and heavy alcohol use [21, 26, 52]. Within the positive reinforcement pattern of associations, we also observed positive relations between extraversion, sensation-seeking and the enhancement motive. Supporting evidence for these associations comes from previous studies reporting that more extraverted and sensation-seeking adolescents are more likely to drink for enhancement motives [23, 26, 41, 53, 54].

Within the second pattern of associations, the negative valence pattern, the role of neuroticism, coping depression, stressful life events and alcohol-related problems warrants a more detailed inspection. Neuroticism was positively associated with stressful life events, the two coping motives, impulsivity and alcohol-related problems, but negatively with alcohol use frequency. These findings are consistent with research on this topic suggesting that more neurotic adolescents and young adults tend to show a higher reactivity to stressful situations [55, 56], more impulsive behavior [57] and higher tendencies to

use drinking as a coping mechanism for anxiety or depression [22]. Importantly, among the neuroticism-centered associations, only the coping depression motive also covaried with stressful life events and alcohol-related problems, thereby further supporting the importance of contextual factors, and potentially separate motivational processes (coping anxiety versus coping depression) in neuroticism-associated drinking patterns [41].

Among the various personality traits, impulsivity showed the strongest association with alcohol-related problems, which fits the general characterization of impulsivity as an inability to control behavior when facing immediate reinforcers (such as alcohol) [41]. Surprisingly, impulsivity did not co-occur with any of the five drinking motives. This finding diverges from previous work showing a non-specific pattern of associations between impulsivity and drinking motives [27, 53]. One potential explanation for this inconsistency might arise from the application of different analysis methods across studies. That is, whereas studies reporting a relationship between impulsivity and drinking motives primarily relied upon zero-order correlations [10, 27, 53], the use of partial correlations has failed to reveal such associations [41]. In the current study we replicated that pattern, finding significant Pearson's correlations (r = 0.16–0.29, all $P < 0.05$) between mean scores of impulsivity and all five drinking motives (see Figure S2) on a cross-sectional level, but not in our contemporaneous network representing partial correlations after accounting for temporal dependencies. Although to a lesser extent than impulsivity, openness to experience covaried with alcohol-related problems, which is in contrast to previous research reporting no association between openness and alcohol-related problems and dependence [58].

The temporal network revealed dynamic associations among personality traits, stressful life events, drinking motives and alcohol use. Overall, associations were predominantly, but not exclusively, restricted within risk factor domains, which is in contrast to our hypothesis that personality traits and stressful life events might predispose towards specific drinking motives over time [21, 26]. Our findings highlight three key pathways to alcohol use and related problems throughout adolescence and early adulthood. First, social drinking motives emerged as the node with the highest out-strength centrality, predicting (a) the quantity and frequency of alcohol use, (b) alcohol-related problems (directly and indirectly through alcohol use frequency and quantity) and (c) various other drinking motives. These findings indicate that the external social reinforcement effects of alcohol use might have more far-reaching implications than typically assumed [20]. That is, higher levels of social motives for drinking may increase alcohol use and related problems (directly and indirectly) which, in turn, drives the development of alcohol dependence at a later stage. These findings are in line with a previous cross-lagged panel study in young adult men showing that social motives predicted heavy alcohol use and related consequences 15 months later [59]. Moreover, initial alcohol use for social motives may heighten the acceptability of drinking, thereby risking transcendence to other motives driving alcohol use and related problems on a contemporaneous level. Secondly, previous alcohol use quantity and frequency predicted future alcohol use quantity and frequency, as well as alcohol-related problems. In combination with the first pathway, these findings do not support the importance of a range of coping motives for the development of alcohol-related problems (cf. [19]) but, rather, suggest that alcohol use, possibly harmful use [60], during adolescence is the driving force in developing future alcohol-related problems [5, 61]. Thirdly, higher levels of openness predicted more alcohol-related problems over time. This finding is somewhat surprising, given the mixed evidence from cross-sectional studies. That is, while most studies reported no relation between openness and alcohol use and related problems [12, 62], others suggested that openness may even attenuate the risk of heavy alcohol consumption [63], but also reduce the probability of abstinence [64]. Lastly, impulsivity emerged as the node with the highest in-strength centrality, indicating that impulsivity was the risk factor being most influenced by other factors in the network. While impulsivity was associated with alcohol-related problems at the contemporaneous level, it was not influenced by any of the alcohol use measures at the previous measurement, nor did it predict alcohol use quantity and frequency or related problems at the next time-point. These findings are in contrast with prior research consistently reporting a bidirectional temporal relationship between impulsivity and the development of alcohol use disorders over time [65, 66]. Several factors may contribute to the observed discrepancy, including the use of a predominantly healthy sample recruited in non-clinical settings, as well as our ability to control for a range of other risk factors (e.g. the level of previous alcohol use) in the temporal network.

The current findings should be interpreted in light of several limitations. First, the personality trait impulsivity was assessed as a single construct on the SURPS questionnaire in the current study [41]. However, according to the UPPS-P model of impulsivity [67, 68], impulsivity presents a multi-dimensional construct with different facets of impulsivity (i.e. negative urgency, positive urgency, lack of premeditation, lack of perseverance and sensation-seeking) relating to different aspects of alcohol involvement [69, 70]. As the SURPS's impulsivity scale seems to relate most strongly to the positive and negative urgency facets [71], future studies might benefit from the inclusion of all impulsivity-related facets in the model. Secondly, we used an adapted version of the DMQ that included subtle changes to the original item wordings for the social, enhancement and conformity subscales. Despite the high levels of internal consistencies found for all subscales, future studies should validate our findings using the original measure [20]. Thirdly, the use of self-report measures for the assessment of stressful life events and alcohol use may be subject to biases common in retrospective recall. Fourthly, the current study did not account for potential sex, gender or cultural (i.e. recruitment centers) differences in the contemporaneous and temporal panel networks. However, mounting evidence points to the existence of sex-specific risk profiles for adolescent alcohol use and alcohol-related problems [15, 72]. Future studies might thus benefit from the estimation of separate sex- or gender-specific networks. Fifthly, it should be

emphasized that while the within-person temporal associations found in the panel GVAR model describe temporally ordered relations between variables that fulfill the criteria of Granger causality [73], associations may not necessarily reflect causal effects [74]. Moreover, existing GVAR panel models assume liner lag-1 relationships in an approximately stationary time-series. With a linear lag of 3 years in the IMAGEN cohort, the estimated temporal network might not capture relations that operate on more granular or longer time-scales. Future studies could thus benefit from the use of different time-scales, especially in the context of trait–motive convergence. Lastly, our findings were based on a group of largely healthy adolescents who were first assessed at age 16 years, a time when the majority had already started using alcohol. It is possible that stronger temporal connections between coping motives and alcohol-related problems might emerge in subclinical samples.

To conclude, our resulting panel networks revealed a complex pattern of associations among different distal (personality traits, life stressors) and proximal (drinking motives) alcohol use risk factors throughout adolescence and early adulthood. The contemporaneous and temporal networks showed structural differences, highlighting the importance of examining the interplay of alcohol risk factor domains at different temporal scales. In the context of temporal predictions, the prior quantity and frequency of alcohol use, openness and social motives emerged as the most important predictors of future alcohol use and alcohol-related problems. In contrast to our expectations, distal risk factors (personality traits and stressful life events) did not converge on different drinking motives over time. After controlling for temporal dependencies, drinking to increase positive affect (social and enhancement motives) uniquely covaried with drinking quantity and frequency, while drinking to cope with negative affect (coping depression motives) also co-occurred with alcohol use problems. In this context, impulsivity emerged as the distal factor that co-occurred most strongly with alcohol-related problems within a given moment. Our findings outline specific risk factor patterns that may offer ground for time-sensitive intervention and prevention efforts aimed at targeting harmful alcohol use and alcohol-related problems. In particular, interventions targeting heavy and frequent drinking, and social motives in late adolescence may prove to be effective in preventing a negative spiral of alcohol-related problems from arising in the future.

AUTHOR CONTRIBUTIONS

René Freichel: Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); visualization (equal); writing—original draft (equal); writing—review and editing (equal). **Janine Pfirmann:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); visualization (equal); writing—original draft (equal); writing—review and editing (equal). **Janna Cousijn:** Supervision (equal); writing—review and editing (equal). **Peter de Jong:** Supervision (equal); writing—review and editing (equal). **Ingmar H.A. Franken:** Supervision (equal); writing—review and editing (equal). **Tobias Banaschewski:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Arun Bokde:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Sylvane Desrivières:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Herta Flor:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Antoine Grigis:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Hugh Garavan:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Andreas Heinz:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Jean-Luc Martinot:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Marie-Laure Paillère Martinot:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Eric Artiges:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Frauke Nees:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Dimitri Papadopoulos:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Luise Poustka:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Sarah Hohmann:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Juliane H. Fröhner:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Michael N Smolka:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Nilakshi Vaidya:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Robert Whelan:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Gunter Schumann:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Henrik Walter:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal). **Ilya Veer:** Conceptualization (equal); investigation (equal); methodology (equal); writing—review and editing (equal). **Reinout Wiers:** Conceptualization (equal); funding acquisition (equal); investigation (equal); methodology (equal); supervision (equal); writing—review and editing (equal). **IMAGEN Consortium:** Funding acquisition (equal); investigation (equal); project administration (equal); resources (equal).

AFFILIATIONS

[1]Addiction Development and Psychopathology (ADAPT)-lab, Department of Psychology, University of Amsterdam, Amsterdam, The Netherlands
[2]Center for Substance Use and Addiction Research. (CESAR), Department of Psychology, Education and Child Studies, Erasmus University Rotterdam, Rotterdam, The Netherlands
[3]Department of Clinical Psychology and Experimental Psychopathology, University of Groningen, Groningen, The Netherlands
[4]Department of Child and Adolescent Psychiatry and Psychotherapy, Central Institute of Mental Health, Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany

[5]Discipline of Psychiatry, School of Medicine and Trinity College Institute of Neuroscience, Trinity College Dublin, Dublin, Ireland
[6]Centre for Population Neuroscience and Precision Medicine (PONS), Institute of Psychiatry, Psychology and Neuroscience, SGDP Centre, King's College London, UK
[7]Institute of Cognitive and Clinical Neuroscience, Central Institute of Mental Health, Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany
[8]Department of Psychology, School of Social Sciences, University of Mannheim, Mannheim, Germany
[9]NeuroSpin, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[10]Departments of Psychiatry and Psychology, University of Vermont, Burlington, VT, USA
[11]Department of Psychiatry and Psychotherapy CCM, Charité – Universitätsmedizin Berlin, corporate member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Berlin, Germany
[12]Institut National de la Santé et de la Recherche Médicale, INSERM U A10 'Trajectoires développementales en psychiatrie', Université Paris-Saclay, Ecole Normale supérieure Paris-Saclay, CNRS, Centre Borelli, Gif-sur-Yvette, France
[13]AP-HP, Sorbonne Université, Department of Child and Adolescent Psychiatry, Pitié-Salpêtrière Hospital, Paris, France
[14]Psychiatry Department, EPS Barthélémy Durand, Etampes, France
[15]Institute of Medical Psychology and Medical Sociology, Kiel University, Kiel, Germany
[16]Department of Child and Adolescent Psychiatry and Psychotherapy, University Medical Centre Göttingen, Göttingen, Germany
[17]Department of Psychiatry and Neuroimaging Center, Technische Universität Dresden, Dresden, Germany
[18]Centre for Population Neuroscience and Stratified Medicine (PONS), Department of Psychiatry and Neuroscience, Charité Universitätsmedizin Berlin, Germany
[19]School of Psychology and Global Brain Health Institute, Trinity College Dublin, Dublin, Ireland
[20]Centre for Population Neuroscience and Precision Medicine (PONS), Institute for Science and Technology of Brain-inspired Intelligence (ISTBI), Fudan University, Shanghai, China
[21]Center for Urban Mental Health, University of Amsterdam, Amsterdam, The Netherlands

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DECLARATION OF INTERESTS

T.B. served in an advisory or consultancy role for Lundbeck, Medice, Neurim Pharmaceuticals, Oberberg GmbH and Shire. He received conference support or speaker's fee from Lilly, Medice, Novartis and Shire. He has been involved in clinical trials conducted by Shire and Viforpharma. He has received royalties from Hogrefe, Kohlhammer, CIP Medien and Oxford University Press. The present work is unrelated to the above grants and relationships. L.P. served in an advisory or consultancy role for Roche and Viforpharm and received speaker's fee from Shire. She received royalties from Hogrefe, Kohlhammer and

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the IMAGEN study. Restrictions apply to the availability of these data, which were used under license for this study.

ORCID

René Freichel https://orcid.org/0000-0002-9478-0575
Janine Pfirrmann https://orcid.org/0000-0001-7282-3899
Ingmar Franken https://orcid.org/0000-0002-7853-2694
Michael N. Smolka https://orcid.org/0000-0001-5398-5569
Robert Whelan https://orcid.org/0000-0002-2790-7281
Reinout W. Wiers https://orcid.org/0000-0002-4312-9766

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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