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Initial cohort characteristics and protocol for SIGMA: An accelerated longitudinal study of environmental factors, inter- and intrapersonal processes, and mental health in adolescence

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Abstract

Background: Over half of all mental health conditions have their onset in adolescence. Large-scale epidemiological studies have identified relevant environmental risk factors for mental health problems. Yet, few have focused on potential mediating inter- and intrapersonal processes in daily life, hampering intervention development.

Objectives: To investigate 1) the impact of environmental risk factors on changes in inter- and intrapersonal processes; 2) the impact of altered inter- and intrapersonal processes on the development of (sub)clinical mental health symptoms in adolescents and; 3) the extent to which changes in inter- and intrapersonal processes mediate the association between environmental risk factors and the mental health outcomes in adolescents.

Methods: ‘SIGMA’ is an accelerated longitudinal study of adolescents aged 12 to 18 from across Flanders, Belgium. Using self-report questionnaires, experience sampling, an experimental task, and wearables, we are investigating the relationship between environmental risk factors (e.g. trauma, parenting), inter- and intrapersonal processes (e.g. real-life social interaction and interpersonal functioning) and mental health outcomes (e.g. psychopathology, self-harm) over time.

Results: N= 1913 adolescents (63% female) aged 11 – 20, from 22 schools, participated. The range of educational trajectories within the sample was broadly representative of the Flemish general adolescent population.

Conclusions: Our findings will enable us to answer fundamental questions about inter- and intrapersonal processes involved in the development and maintenance of poor mental health in adolescence. This includes insights regarding the role of daily-life social and cognitive-affective processes, gained by using experience sampling. The accelerated longitudinal design enables rapid insights into developmental and cohort effects.

Keywords: adolescence; mental health; social interaction; experience sampling method; accelerated longitudinal design; cohort

Over half of all mental health conditions have their onset before 14 years of age¹ and evidence suggests that mental health symptoms in adolescence and young adulthood have a profound, lasting impact on clinical and functional outcomes later in life^{2, 3}. Many large-scale longitudinal cohort studies have identified relevant environmental risk and protective factors for the development and maintenance of mental health problems, also in adolescent populations⁴⁻¹¹. These include, amongst others, childhood trauma^{12, 13}, exposure to bullying^{12, 14-16}, lack of social support^{13, 17, 18}, parenting style^{19, 20}, a family history of mental health problems^{13, 21}, and substance use²²⁻²⁵. Yet, little research has investigated the daily-life intra- and interpersonal processes that may explain the relationship between these environmental risk factors and the development of mental health symptoms^{26, 27}, despite these processes potentially representing critical new early intervention targets. In Figure 1, we posit a conceptual model of the relationship between environmental risk factors and mental health symptoms in adolescence, with (difficulties in) social interaction, interpersonal functioning, cognitive-affective, and identity formation processes as the proposed pathway between environmental risk and psychopathology. This conceptual model underpins the current study.

[INSERT FIGURE 1 ABOUT HERE]

Given the relevance of social risk and protective factors in the development of mental health problems and that most psychiatric problems involve a clear social component, we have focused particularly on inter- and intra-personal processes as mediating factors. All of these processes have been associated with mental health symptoms in previous research²⁸⁻⁴¹, indicating their relevance across a spectrum of mental health problems. Yet, no longitudinal adolescent cohort study to date has investigated such processes as mediating factors between important environmental risk factors and mental health outcomes in daily life. Furthermore,

taking a radical embodied-embedded perspective⁴²⁻⁴⁴, which states that psychiatric phenomena should be construed in terms of dynamic person-environment interactions, we use a novel multi-method approach to examine these inter- and intrapersonal processes. In addition to traditional self-report questionnaires, we employ the Experience Sampling Method (ESM)^{45, 46}, a structured diary technique, which allows us to capture rich, dynamic data regarding inter- and intrapersonal processes in the context of everyday life^{46, 47}, as well as gathering data from wearables and an experimental task. Finally, we use an accelerated longitudinal design⁴⁸ to enable us to investigate how mental health symptoms develop in accordance with changes in these inter- and intrapersonal processes in an expedited way, starting in early adolescence (~12 years old).

The current paper describes the objectives, design, and measures from Wave I of the SIGMA study, a large-scale, longitudinal study of adolescent mental health. With this study, we aim to address fundamental gaps in our knowledge about the inter- and intrapersonal processes involved in the development of mental health problems.

Objectives

The overarching aim of SIGMA is to investigate the inter- and intrapersonal processes involved in the relationship between environmental risk factors and mental health problems over time, in a general population sample of adolescents. Specifically, we aim to investigate 1) the impact of social risk factors on inter- and intrapersonal processes; 2) the impact of altered inter- and intrapersonal processes on the development of (sub)clinical mental health symptoms in adolescents and; 3) the extent to which changes in inter- and intrapersonal processes mediate the association between social risk factors and the development of mental health symptoms in adolescents.

Study design

Setting

The SIGMA study takes place in Flanders, the Dutch-speaking part of Belgium. Wave I began in January 2018 and concluded in May 2019. Data were collected across all five provinces in Flanders, including rural and urban areas. The population of Flanders is approximately 6.6 million people⁴⁹, of which 457,000 are in secondary education⁵⁰. Estimates indicate 14% of individuals in Flanders aged 10-18 experience mental health symptoms⁵¹.

Accelerated longitudinal design

We employed an accelerated longitudinal design, whereby three separate cohorts of different age groups were established in order to investigate developmental and cohort effects over a much shorter period than would be possible with a traditional longitudinal cohort design⁴⁸. The goal of the study is to track the development of adolescents from the ages of 12 – 18 years old, whilst also investigating developmental differences cross-sectionally, across the three age cohorts. We recruited participants aged 12 (cohort 1), 14 (cohort 2), and 16 (cohort 3) years old at baseline (in the first, third and fifth years of secondary school, respectively)¹, with follow-up measurements taking place every two years. This enables us to cover our full developmental age range of interest within a shorter period, whilst also buffering the effects of the dropout from a longer study period. Several other recent developmental studies have also taken this approach⁵²⁻⁵⁵.

¹ Adolescents in Flanders begin secondary education at 11 or 12 years old (depending on their birthday); therefore, some first-year participants were 11 years old. Some participants repeated a year/multiple years of schooling, meaning the Wave I sample also included individuals aged up to 20 years old.

Participants and recruitment

Adolescents were recruited via participating schools. Researchers contacted all secondary schools in Flanders, and when schools agreed to participate, classes were selected for participation (based on representation criteria such as educational trajectory and school year). Researchers then gave a recruitment presentation in the selected classes. Parents of participating adolescents were invited to complete an optional battery of questionnaires online. Inclusion criteria for adolescent participants were: (i) attending the first, third or fifth year of mainstream secondary school, (ii) fluency in Dutch, (iii) being available to complete the 100-minute baseline testing session, and (iv) availability to complete the six-day ESM period.

Ethics and consent

Paper informed consent forms and information letters for both the adolescents and their parents/caregivers were distributed via the school. Towards the end of Wave I data collection, an electronic informed consent system was introduced. Parent/caregiver consent was required for all participants under 18 years of age. Participants and parents/caregivers were required to provide informed consent in advance of the testing day.

In return for taking part, participants were given a €10 shopping voucher. All participating schools were offered a choice of various educational sessions and workshops around the theme of mental health. In addition, schools were able to choose from a range of other activities and resources provided as part of the Te Gek!? - a Flemish mental health non-profit organization – education programme. The study received full ethical approval from the UZ/KU Leuven Medical Ethics Committee (S61395).

Procedure

Data collection took place at schools, during 100 minutes of class time. Participants were tested in groups of 10 - 25 individuals and a maximum of three groups were tested in a single day. When not all students within a class chose to participate, groups of up to 25 students were composed from participating students across multiple classes. Non-participating students remained in a separate classroom and completed normal schoolwork. Baseline testing sessions began with a cognitive task and independent completion of the questionnaire battery using the REDCap application^{56, 57}. Both of these were completed on a tablet. In order to reduce the likelihood of missingness being concentrated at the end of the battery, questionnaires were divided into three blocks. Classes were randomly divided into three groups, each of which began with a different block of questionnaires. Members of the research team were present throughout the baseline testing session for questions. During the completion of the questionnaire battery, four participants from a selection of classes² were randomly chosen to take part in an experimental task, after which they rejoined the main class group and continued with the self-report questionnaires. Participants who completed the full questionnaire battery early were allowed to complete further gamified cognitive tasks on the THINC-it® application⁵⁸. At the end of the testing session, participants were loaned a study smartphone and a researcher instructed small groups of approximately 4 – 5 students about the ESM protocol, the use of the smartphone and the Fitbit Charge 2 (a wearable device), which they were asked to begin wearing immediately and continuously³, until the end of the ESM period. Finally, participants were provided with a support sheet, with contact details for local and regional telephone helplines, as well as sources of face-to-face and online support.

² This was dependent upon the number of participants required for the task within each age group, as well as whether the school could provide an additional separate testing space for the researchers.

³ The participants were asked to remove the device for water-related activities (e.g. swimming, showering).

After the six-day ESM period was completed, equipment was collected and participants received their gift voucher. Payment was not conditional upon number of questionnaires completed. Participants will be followed up every two years, with a minimum of two follow-up measurements. The first of these (Wave II) began in February 2020, but was postponed due to COVID-19. See Figure 2 for procedure diagram.

[INSERT FIGURE 2 ABOUT HERE]

Measures

Here, we provide an overview of the measures used in SIGMA Wave I (see Table 1 for further details). Example items and questionnaire adaptation details are provided in Supplement 1. For all supplementary materials, see: https://osf.io/a9rwp/?view_only=bf9a36c4be4444429c9e47b3d1fb778e. Following the pilot study and discussions with participating schools, an additional response option of ‘I do not wish to answer’ was added to every item. Whilst schools’ request for this was in relation to more ‘sensitive’ questions, e.g. around self-harm, trauma and substance use, to not implicitly single out these questions as especially sensitive, we added the extra response option to all items.

Measures administered in adolescents

Environmental factors

Parenting. Parenting style was assessed using three of the four scales from the General Parenting Style questionnaire, a Dutch-language, aggregated parenting style measure⁵⁹. The questionnaire consists of 22 items, which participants completed about each

parent, resulting in a maximum of 44 items, depending on which parents or caregivers were present within the adolescent's family living situation. The questionnaire assesses psychological control^{59, 60}, responsiveness⁶¹⁻⁶³, and autonomy-support^{64, 65}.

Childhood Trauma. Experiences of childhood trauma were assessed using the Juvenile Victimization Questionnaire – 2nd revision (JVQ-R2⁶⁶), translated into Dutch by the research team. The questionnaire assessed traumatic experiences within four aggregated domains: property crime, physical assault, sexual assault, and general maltreatment. In total 34 items were administered and participants were asked to respond 'yes' or 'no' to each item.

Bullying. A 6-item self-constructed short bullying questionnaire was used, which assessed the frequency of experiences of general bullying, physical bullying, cyberbullying, emotional bullying, bullying perpetration, and the severity of bullying. Response to all items were provided on 5-point Likert-type scales from 0 (never) to 4 (frequently), apart from for the item on bullying severity, where responses options were on a 4-point Likert-type scale from 0 (not at all severe/never experienced) to 3 (severe).

Social support. The 12-item Dutch Social Support List (SSL)⁶⁷ was used to assess presence of support from the participants' broad social network (family, friends, acquaintances, and peers), consisting of three subscales: everyday support, support in case of problems, and appreciation. Participants were asked to indicate how often the situations described in each item occur on a 4-point Likert-type scale from 1 (rarely or never) to 4 (very often).

Substance use. Participants were asked a self-constructed, multiple-choice question - based on items from the CIDI (lifetime version)^{68, 69} - about their lifetime history of using alcohol, cigarettes/nicotine, cannabis/weed, and stimulants, including amphetamines, speed and ADHD medications not prescribed for them. For each substance for which lifetime use was indicated, two follow-up questions were asked regarding the frequency of use and the age at which they first used the substance.

Demographics and living situation. Participants were asked to provide demographic details, including date of birth, height, weight, educational trajectory and school year. They were also asked to provide contact information (personal email address and mobile phone number) to enable us to contact them for future follow-ups. To minimise burden on the adolescents, in Wave I, most other demographic questions regarding, e.g. Belgian/non-Belgian nationality, household members, adoption status, family history of mental health problems etc., were included within the parent/caregiver questionnaires.

Inter- and intrapersonal processes

Social skills. We assessed social skills using the full 36-item version of the Dutch Psychosocial Skills Questionnaire⁷⁰. The scale consists of two major subscales assessing intra- and interpersonal skills. A total score for the scale can also be calculated. Participants are asked to respond to each item on a 5-point Likert scale from 1 (completely disagree) to 5 (completely agree).

Interactive processes in daily life. To assess adolescents' context, behaviour, social interactions, interpersonal functioning, identity formation, and cognitive-affective processes during their everyday life, we used the Experience Sampling Method (ESM)^{45, 46}, a structured real-time and real-world diary technique. Participants received ten notifications at semi-

random moments (in blocks of 90 minutes) between 8:30 AM and 10:30 PM each day for a period of six days via smartphone. The minimum period between consecutive notifications was 15 minutes. As participants also completed ESM during class time, to minimise disruption, all participants within the same class received their notifications simultaneously.⁴ Following the initial notification, participants had 90 seconds to begin the questionnaire, which then timed out if participants took longer than 90 seconds to complete an individual item. ESM questionnaires were completed on a Motorola Moto E4 Android smartphone loaned to participants for the duration of the ESM period. Data were collected using the mobileQ application⁷¹. The smartphone contained no sim card and the mobileQ app was locked to the home screen. Responses to the ESM questionnaires were stored locally on the phone, and then securely downloaded to institutional servers once devices were collected.

For a full description of constructs assessed with ESM, see Table 1. For the full ESM item list, see Supplement 2. All ESM items from the SIGMA study are publicly available within the ESM Item Repository (www.esmitemrepository.com)⁷². The response scale for the majority of items were 7-point Likert-type scales, ranging from 1 (not at all) to 7 (very much so), and others were multiple choice. Each ESM questionnaire contained the same items; a minimum of 42 and a maximum of 46, depending upon responses to conditionally branched items, and no open-ended items. During ESM, participants did not receive any feedback about their responses. For the items assessing self-harm thoughts and behaviours, if participants indicated that they had thought about self-harm, a pop-up was displayed with a supportive message and the details of telephone and online support organisations, including the regional suicide prevention centre (www.zelfmoord1813.be).

⁴ For the first three schools tested, participants within a single class received notifications simultaneously only during school hours, after which notifications were completely random. Due to technical issues, this was changed so that each class received all notifications at the same time.

Basic social interactive capacity. A random sample of $N=208$ participants also completed the Perceptual Crossing Experiment (PCE)⁷³⁻⁷⁵, a minimalistic virtual, dyadic task designed to assess fundamental capacity for social interaction using real-time social dynamics. The PCE task and its feasibility for use with adolescents from the SIGMA study has been described in detail elsewhere⁷⁶.

Attachment. Attachment was assessed using the short 36-item version of the Inventory of Parent and Peer Attachment Revised (IPPA⁷⁷; Dutch translation⁷⁸), which assesses attachment to mother (12 items), father (12 items) and peers (12 items) across three dimensions: communication, trust, and alienation. Responses were provided on a 4-point Likert-type scale from 1 (almost never) to 4 (almost always). First year participants received a shortened version of the IPPA Revised, with seven items in each subscale. An additional vignette-type item from the Attachment Questionnaire for Children (AQ-C)⁷⁹ (Dutch translation⁸⁰) was used to assess close relationships to peers.

Cognitive functioning. All participants completed a “Codebreaker” symbol-coding task in the THINC-it® application⁵⁸ using a tablet computer, in order to measure deviations in cognitive function (processing speed) within our sample.

Emotion regulation. The short version of the Cognitive Emotion Regulation Questionnaire (CERQ-short)⁸¹ is a measure of nine distinct emotion regulation strategies, each framed to refer to what individuals think following a negative experience. The CERQ-short consists of 18 items, assessing 9 strategies each using two items. Each item is rated with a 5-point Likert scale ranging from 1 (almost) never to 5 (almost always).

Identity. Identity was assessed using two questionnaires, the 12-item Erikson Psychosocial Stage Inventory (EPSI)⁸² and the short 11-item version of Dimensionality of Identity Development Scale (DIDS)^{83, 84}, and 4 additional items on sexual and social

identity/orientation. The EPSI consists of two subscales: identity synthesis and confusion. Responses are provided on a 5-point Likert scale from 0 (strongly disagree) to 4 (strongly agree). For the DIDS, responses were provided on a 5-point Likert scale from 0 (completely disagree) to 4 (completely agree).

Threat anticipation. A shortened 10-item version of the Availability Test^{85, 86} including five items on negative self-anticipation and five items on positive self-anticipation was translated into Dutch by the research team and used to assess threat anticipation. Participants were asked to indicate how possible it was that each of the events described in the items would occur in the coming week. Response options were ‘yes’ and ‘no’.

Lifestyle factors. Physical activity, sleep and sedentary behaviour data were collected passively for seven days using the Fitbit Charge 2. Participants were instructed to maintain their normal levels of physical activity and not to go out of their way to be more active during the study period. No feedback on active minutes, sleep duration or sleep quality were provided to participants during the study, but they were aware of the distance they had walked, as this information could not be disabled.

Mental health outcomes

Psychopathology. Our primary outcome is general psychopathology symptoms, assessed using the Dutch version of the 53-item Brief Symptom Inventory (BSI)⁸⁷. A total Global Severity Index (GSI) score (mean) can be calculated to indicate presence and severity of general psychopathology symptoms. The questionnaire contains nine subscales and all response scales range from 0 (not at all) to 4 (extremely).

The Prodromal Questionnaire (PQ-16)⁸⁸ was used to investigate subclinical psychotic symptoms. This consists of 16 statements regarding symptoms, with which participants are

asked to ‘agree’ or ‘disagree’, and agreement leads to a follow-up question regarding the level of burden for that symptom rated on Likert-type scale from 0 (not burdensome) to 3 (very burdensome). This questionnaire was not administered to first-year participants.

The 5-item Diagnostic Interview Schedule for Children (DISC-C)⁸⁹ was administered as a questionnaire to assess psychotic experiences, covering mindreading, delusions of reference and persecution, hearing voices, and bodily changes. All responses were provided on a 3-point Likert-type scale, anchored at 0 (not at all), 1 (yes, maybe), and 2 (yes, definitely).

Lifetime suicidal and non-suicidal self-harm thoughts and behaviours.

Participants’ lifetime history of suicidal and non-suicidal thoughts and behaviours was assessed using six items adapted from the Child and Adolescent Self-harm in Europe survey (CASE)⁹⁰. Response options were ‘no, never’, ‘yes, once’, and ‘yes, more than once’. If participants indicated ‘yes’ to a question, they were presented with a follow-up item asking about the most recent time they had engaged in those thoughts or behaviours, with four answer options: in the last month, in the last 6 months, in the last 12 months, and longer ago.

Attitudes towards physical appearance and problematic eating behaviours. Two items from the Sociocultural Attitudes Towards Appearance Questionnaire-4 (SATAQ-4)⁹¹ were used to assess attitudes towards physical appearance, and were translated into Dutch by the researchers. Participants responded on a 7-point Likert-type scale from 1 (not at all) to 7 (very much). Problematic eating behaviours were assessed using three items adapted from the SCOFF questionnaire⁹², previously translated into Dutch for clinical use, with yes/no response options.

Parent/caregiver questionnaires

Adolescents' parents/caregivers were also invited to complete a battery of online questionnaires regarding their parenting style, their child's social functioning and experience of mental healthcare, familial history of mental health problems, household composition and living situation. Completion was not compulsory. Details of these measures can be found in Supplement 3.

Sample size

The sample size for the SIGMA study was determined based upon an exemplary power calculation conducted for one of the central mechanisms captured by ESM: affective reactivity to the environment. This was operationalised as the relationship between negative affect and the (un)pleasantness of the most important event since the previous momentary questionnaire. Values for the model parameters were determined using the control groups from a merged dataset of 8 previous ESM studies employing a similar protocol. A simulation approach was used to determine the required sample sizes (of the three age groups) in order to have at least 90% power to find a significant three-way interaction (between event (un)pleasantness, age, and some additional risk factor of interest). For this, data were repeatedly simulated, the mixed-effects model was then fitted to each simulated dataset, and the three-way interaction was tested. The proportion of times that the test was significant then indicates the empirical rejection rate (i.e. power). Group sizes of $n = 820$ (Cohort 1), $n = 656$ (Cohort 2), and $n = 525$ (Cohort 3) yields a power of 0.94. We expect approximately 20% attrition at every two-year follow-up.

Open science practices within SIGMA

Within the SIGMA study, we have created an internal data management and “check-out” system⁹³ specifically to facilitate the use of open science practices⁹⁴, including post-registration (a form of pre-registration occurring after data collection, but before data access or analysis)⁹⁵. Open science practices are not routinely used in clinical psychology and psychiatry research⁹⁶⁻⁹⁸. Given the scale of SIGMA and the likelihood that many researchers will use data over time to investigate numerous research questions, we considered this a major opportunity to improve transparency and reproducibility within the field. Data are currently available only for internal use, but external researchers will be able to apply for access to these data in due course.

Results

In total, 22 schools participated in Wave I of SIGMA. The administration of every mainstream secondary school in Flanders (~ 1425 schools) was invited via email to participate in the SIGMA study. Of the schools we contacted directly via email, six responded and four subsequently participated. The remaining 18 schools were recruited through our collaboration with Te Gek!?. From these 22 schools, we recruited N=1960 adolescents, of which N=1913 had useable data (n = 1048 first years ~12 years old; n = 424 third years ~14 years old; and n= 441 fifth years ~16 years old). Within the full sample of N=1913 adolescents, n= 1207 were female, n=695 were male, and n= 7 identified as ‘Other’. Full descriptive characteristics of the SIGMA sample are provided in Table 3.

To our knowledge, there are no standard questions for assessing ethnicity in Belgium and asking about ethnicity and race is not common practice in some European countries, including Belgium, as this is considered a protected characteristic. As a proxy, we asked

adolescents to indicate whether and to what extent they identified with a nationality other than Belgian. From 1446 responses to this question within the full sample of N=1913 participants, n = 544 indicated they identified with a non-Belgian nationality.

Data were collected from adolescents across a range of educational trajectories, e.g. general secondary education (ASO), vocational secondary education (BSO) etc., and the spread of participants across these different educational trajectories was broadly consistent with that of the general adolescent population in Flanders⁵⁰. Parents/caregivers of all 1913 adolescents were invited to complete questionnaires, of which 489 parents/caregivers completed these questionnaires.

Strengths and limitations

To the best of our knowledge, SIGMA is the largest, accelerated longitudinal study to date focusing on the daily-life inter- and intrapersonal processes underpinning adolescent mental health and well-being. Besides from the scale of the study, there are several other notable strengths. SIGMA uses a multi-method approach, combining traditional questionnaires with experience sampling, data from wearables and an experimental task. This means we can gain insights into the dynamic as well as more static psychological processes at play in the development of mental health problems. The accelerated longitudinal design enables us to examine developmental processes and cohort effects within a much shorter period than in a traditional longitudinal study⁴⁸. By placing inter- and intrapersonal processes at the heart of investigating the relationship between well-known social risk factors and mental health symptoms, this may lead to the development of novel early intervention targets for adolescent mental health, and expand our theoretical knowledge of the role of these inter- and intrapersonal processes in mental health problems. Additionally, by using ESM, we collect data with high ecological validity, in the context of adolescents' daily lives, providing

opportunities for improving our understanding of the dynamical person-environment interactions as well as for the development of ecological momentary interventions⁹⁹, which could be delivered in daily life where they are most needed. SIGMA is unique in collecting ESM data during school time, providing us with a richer, broader picture of adolescents' daily lives. Further, the routine use of post-registration⁹⁵ and the data checkout system^{93, 94} embeds open science practices within SIGMA, contributing to transparency and reproducibility in the field of clinical psychology and psychiatry research.

The SIGMA study has a number of strengths, but there are also several limitations to note. Whilst our study demonstrates that conducting ESM research with adolescents at scale is feasible, it is certainly not without challenges. Compliance within SIGMA (41.3%, based on participants who completed at least one ESM questionnaire) was lower than would be expected from previous ESM studies conducted with adults, from both general and clinical populations¹⁰⁰. There may be several reasons for this, including the short (90 second) window in which participants had to respond to a notification, which was a function of the mobileQ app⁷¹ used to collect ESM data. Additionally, notifications were sent during school hours, whereas other studies have collected data only outside of school hours or during breaks. However, we feel this was unlikely to have resulted in reduced compliance, and in fact see school time data collection as a strength of the current study. Additionally, the low uptake of the optional parent questionnaires – only 489 parents completed the questionnaires - means that substantial amounts of demographic, living situation and family history data are missing from Wave I. To address this, some of these items, e.g. nationality, were moved to the adolescent questionnaires during Wave I, and in Wave II, the majority of these questions were moved to the adolescent questionnaires. Finally, the questionnaire battery was lengthy and there was much variation in completion time due to age and educational level, meaning there

is substantial missingness in some questionnaires. Shortening the questionnaire battery and using block randomisation helped resolve this to some extent, but future studies may wish to explore the possibilities for planned missing designs^{101, 102}.

Conclusions

Taking a multi-method, accelerated longitudinal approach, the SIGMA study aims to address critical gaps in our understanding of the inter- and intrapersonal processes underpinning the relationship between environmental risk factors and mental health symptoms, as well as how these processes evolve over the developmental course of adolescence. Further, this is the first accelerated longitudinal study of adolescent mental health to consider the role of daily-life context and social interactive processes in the development of mental health symptoms. Findings from SIGMA can provide new targets for early intervention in adolescent mental health symptoms.

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Conflicts of interest/Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest

Availability of data and materials

SIGMA data are not publicly available. Data are available via an abstract submission process (see description in manuscript). ESM items used in the SIGMA study are available in Supplement 2 on the OSF (https://osf.io/a9rwp/?view_only=bf9a36c4be4444429c9e47b3d1fb778e). These items are also publicly available in the ESM Item Repository (www.esmitemrepository.com; Kirtley et al., 2020; dataset ‘sigma’).

Code availability

No analyses are reported in the current paper, therefore there is no associated code.

Author contributions

Conceptualization: I.M., B.B., C.H., Z.K., M.S., R.v.W., U.R., W.V.; Data curation: O.J.K., N.H. and A.P.H.; Funding acquisition: I.M.; Investigation: O.J.K., R.A., N.H., K.S.F.M.H., A.P.H. and A.L.; Methodology: O.J.K., R.A., N.H., K.S.F.M.H., A.P.H., A.L., B.B., C.H., Z.K., M.S., R.v.W., U.R., W.V. and I.M.; Project administration: O.J.K. and I.M.; Supervision: O.J.K. and I.M.; Writing – original draft: O.J.K.; Writing - review & editing: R.A., N.H., K.S.F.M.H., A.P.H., A.L., B.B., C.H., Z.K., M.S., R.v.W., U.R., W.V. and I.M.

Ethics approval

The study received full ethical approval from the UZ/KU Leuven Medical Ethics Committee (S61395).

Consent to participate

All participants and, where relevant, their parents/caregivers, provided informed consent.

Consent for publication

All authors consented to the publication of this manuscript. During the informed consent procedure, all participants were made aware that the details and results of the SIGMA study would be published in peer-reviewed journals.

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Figure 1. *Conceptual model of the SIGMA study.* SIGMA aims to investigate the inter- and intrapersonal processes that play a role in the relationship between environmental risk and protective factors and mental health outcomes in adolescents within the general population.

Figure 2. *Overview of SIGMA study design and procedure*

Table 1*Overview of self-report measures used in SIGMA Wave I*

<i>Questionnaire measures</i>	<i>Purpose/description</i>	<i>Reliability^a</i>	<i>n for which valid responses^b</i>
General Parenting Style Questionnaire	Three dimensions of parenting styles: psychological control, responsiveness and autonomy support	.94 (responsiveness, father) .94 (responsiveness, mother) .83 (psychological control, father) .87 (psychological control, mother) .85 (autonomy, father) .83 (autonomy, mother)	1572 (responsiveness, father) 1532 (responsiveness, mother) 1576 (psychological control, father) 1528 (psychological control, mother) 1555 (autonomy, father) 1515 (autonomy, mother)
Juvenile Victimization Questionnaire	Childhood trauma experiences	.83 ^{c,d}	1220 ^e

Short bullying questionnaire	Bullying victimisation and perpetration	-	1334
Social Support List	Social support	.87	1793 (general support) 1776 (support problems) 1776 (appreciation)
Alcohol and substance use questionnaire	Lifetime and recent alcohol and drug use	-	1391
Psychosocial skills Questionnaire	Intra- and interpersonal social skills	.91	1484
Inventory of	Attachment to	.93 (father)	654 (father)
Parent and Peer	mother, father, and	.89 (mother)	656 (mother)
Attachment (IPPA)	peers	.88 (peer)	649 (peer)

Attachment Questionnaire for Children (AQ-C)	Attachment to close peers	-	1476
Cognitive Emotion Regulation Questionnaire- Short	Emotion regulation	.57 ^f .57 ^f .45 ^f .56 ^f .69 ^f	1438 (acceptance) 1439 (rumination) 1430 (positive reappraisal) 1376 (self-blame) 1416 (focusing on positives) 1381(catastrophizing) 1350 (blaming others) 1385 (planning) 1378 (perspective- taking)
Erikson Psychosocial Stage Inventory (EPSI)	Identity	.81 (total score) .83 (synthesis subscale)	1373 (total)

		.67 (confusion subscale)	
Dimensions of Identity Development Scale (DIDS)	Identity	.73 ^f (commitment making) .72 ^f (exploration in breadth) .85 (ruminative exploration) .78 ^f (identification with commitment) .52 ^f (exploration in depth)	785 (commitment making) 783 (exploration in breadth) 780 (ruminative exploration) 776 (identification with commitment) 757 (exploration in depth)
Gender and sexual identity questions	Gender and sexual identity	-	1272
Availability Test	Threat anticipation	.79 .75	1636 (positive) 1638 (negative)
Brief Symptom Inventory (BSI)	General psychopathology symptoms	.97	1534

Prodromal	Subclinical	.77 ^c	614
Questionnaire (PQ-16)	psychotic symptoms		
Diagnostic Interview	Psychotic experiences	.61	1193
Schedule for Children (DISC- C)			
Items adapted from the Child and Adolescent Self-harm in Europe (CASE) study and the UK Adult Psychiatry Morbidity Survey (APMS) questionnaires	Lifetime and recent history of suicidal and non-suicidal self-harm thoughts and behaviours	-	1480
Items adapted from the Sociocultural	Attitudes towards physical appearance	0.35 ^f	1401

Attitudes Towards

Physical

Appearance

Questionnaire

Items adapted Weight change and .44^c 1385
from the SCOFF control over food
questionnaire

<i>Experience</i>	Topic/construct	Number of items	Percentage of
<i>Sampling Method</i>	block		completed blocks ^h
Momentary	Positive and	14	98.20
questionnaire	negative affect		
	Identity	3	98.00
	Social context and	9 – 11 ^g	97.52
	experiences		
	Physical context	7	97.28
	Control items	4	97.17
	(tiredness, hunger,		

feeling unwell, and

pain)

Reward anticipation	2	96.93
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Suicidal and non-	1 – 3 ^g	96.85
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suicidal self-harm

thoughts and

behaviours

Substance use	1	96.78
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Disturbance by	1	93.02
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questionnaire

notification

^a Unless otherwise stated, reliability is given as McDonald's coefficient Omega, ω_u , calculated using the R package

'psych'¹⁰³; ^bWe define 'valid' here as the number of participants for which a) a total score, or for measures for which no total score is calculated, b) subscale score(s) could be calculated or, for individual items: c) the number of non-missing responses. NB: Calculating total scores for more participants is possible, using imputation to handle missing data, but we have not imputed data at the dataset (full sample) level, and instead tackle this on a study-by-study basis; ^cCategorical Omega, ω_{u-cat} . Calculated using R package 'misty'¹⁰⁴; ^dCalculated based on the 25 items administered to all participants. For further details of JVQ adaptation see Supplement 1; ^eNumber of valid responses on the 25 items presented to all participants. Valid responses on all JVQ items, $n = 609$; ^fPearson's r (as

questionnaire consisted of two items); ^aSome questions are conditionally branched; ^bCalculated as percentage of completed item blocks as a proportion of the total number of initiated ESM questionnaires.

Table 2.*Descriptive data: SIGMA Wave I participants*

	Cohort			
	Cohort 1	Cohort 2	Cohort 3	Total N= 1913
	First year	Third year	Fifth year	
	(n= 1048)	(n=424)	(n=441)	
Age in years	12.33 (.57)	14.40 (.75)	16.55 (.82)	13.76 (1.86)
<i>M(SD)</i>				
Sex <i>n</i>				
Female	625	285	297	1207
Male	416	136	143	695
Other	3	3	1	7
Educational level <i>n</i>				
ASO	903	205	149	1257
BSO	145	105	142	392
TSO ^a	-	113	132	245
KSO	-	1	18	19
Non-Belgian background	318/862	128/282	98/302	544/1446
<i>n/available responses</i>				

^aFor the first year of secondary school, students can choose from two different study trajectories. From the third grade onwards, students can choose from a broader range of study trajectories: general secondary education (ASO); technical secondary education (TSO); vocational secondary education (BSO); and arts secondary education (KSO).