Investigating the Mutualism Theory of Intelligence within the Domain of General Knowledge in Adolescence and Young Adulthood

Graafland-Baaij, Rosanne

Psychologie
Faculteit der Sociale Wetenschappen

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Rosanne Graafland-Baaij

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Student number: s2345153
Supervisor: Ivan Simpson-Kent
Second reader: Nina Komrij

Abstract

Cognitive abilities such as problem solving, logic reasoning and general knowledge have traditionally been theorized and studied as factor models, whereby latent unobserved variables such as general intelligence (*g*-factor), or crystallized (*gc*) and fluid intelligence (*gf*) pose as the underlying mechanisms for performance on cognitive tests. However, the mutualism theory of intelligence conceptualizes general cognitive ability and its components as a network, in which individual cognitive abilities (e.g., reasoning and vocabulary) influence and facilitate each other's development. Studies into the use of mutualism theory have supported the theory as an explanation of the development between different cognitive constructs. Studies into development within a singular construct, however, remains sparse. Our study aimed to fill this gap in the literature.

Using this network psychometrics we researched the construct general knowledge (*gkn*) using a data set of answers to a multiple-choice general knowledge test, obtained from the Open-Source Psychometrics Project database. Grouping the participants based on age (13-18, 19-24 and 25-35 years old) we found that overall, the partial correlations are weaker for the youngest group and strongest for the older groups. This suggests that general knowledge is not as strongly developed in the youngest group compared to the older groups. We also found that the youngest group had the most positive partial correlations overall, suggesting that mutualism is most active in this age range. Concurrently, we found that the middle group had the highest of both total amount of partial correlations, and total amount of positive partial correlations. The oldest group had the widest range in partial correlations, and the smallest number of partial correlations compared to the total amount of partial correlations recorded, suggesting that the development of general knowledge strengthens with age from younger to older adolescence and that this development levels off in (early) adulthood. These findings support the theory of mutualism and opens up avenues for further research into the use of mutualism theory to investigate the development of (constructs of) intelligence and related factors.

Layman's Abstract

Intelligence is widely described and commonly understood as an unobserved mechanism, responsible for the performance of cognitive skills. A novel but complementary theory of intelligence is the mutualism theory. Mutualism theory states that intelligence and its' constructs (such as general knowledge, vocabulary, or logic reasoning) are analogous to a network. The development of intelligence can be explained by the positive influence that the different constructs of intelligence have on each other's development. As an individual grows and develops, so do their cognitive skills, and mutualism states that the different cognitive skills help each other grow by positively influencing each other.

Studies into the use of mutualism theory explaining the development between different cognitive constructs have shown evidence in support of this theory. However, little to no research in the development within one singular construct of intelligence has been performed. We aimed to use the theory of mutualism to investigate the development within one singular cognitive construct: general knowledge. To this end, individuals who had previously filled out an online general knowledge test were grouped based on age (13-18 years, 19-24 years, and 25-35 years) and the connections between their scores on each answer were analyzed.

Overall, we found that this group had the highest rate of positive connections, however these connections were weakest compared to the older groups. We found that the middle group had both the most connections overall, and the most positive connection. The oldest group had both the largest range of connections and the smallest number of connections overall. These findings suggest that the general knowledge of the youngest group is not as strongly developed as that of the older groups. Upon these findings, we drew the conclusion that mutualism is most active in the youngest group. As age increases, so does the strength of the initially weak connections within the construct of general knowledge. Between older adolescence and (early) adulthood we conclude that the strength of the connections within the construct of general knowledge stops developing.

Introduction

The modern study of human intelligence began at the start of the 20th century when, in 1904, English psychologist Charles Spearman observed what is referred to as the 'positive manifold of cognitive abilities' (Spearman, 1904). The positive manifold of cognitive abilities refers to the phenomenon where individuals who perform well on one cognitive test are likely to perform well on other cognitive tests, regardless of the domain. From this observation, Spearman formulated the general cognitive ability 'general intelligence' (or *g*) as the main underlying mechanism responsible for the positive manifold. This theoretical framework posits general intelligence as a single underlying and unobserved factor that gives rise to individual differences in different cognitive abilities. The g-factor model of intelligence has to be a robust finding across cultures including non-Western cultures (Warne & Burningham, 2019).

Crystallized Intelligence and General Knowledge

A commonly used competing model to the g-factor is Cattell's fluid and crystallized intelligence (Cattell, 1963). Fluid intelligence, or *gf*, refers to the ability to solve novel problems without prior task-specific knowledge. Crystallized intelligence, or *gc*, refers to the ability to perform well on tests and/or tasks such as arithmetic and vocabulary that require the use of prior knowledge, skills, and experience (e.g., those acquired through education). A related construct within crystallized intelligence is the construct of general knowledge (*gkn*, Buades-Sitjar & Duñabeitia, 2022; Flanagan & Dixon, 2014). General knowledge refers to one's ability to store and retrieve facts and knowledge regarding a wide range of different subjects accumulated during a lifetime (Buades-Sitjar et al., 2021; Buades-Sitjar & Duñabeitia, 2022). Since the acquisition of general knowledge takes place over a lifetime, school quality, socioeconomic status, and culture play an important role in the development and enhancement of general knowledge. Earlier research into the attainment of general knowledge by Buades-Sitjar et al. (2021) showed that age is a strong predictor of the amount of general knowledge up until the age of 50 years, after which it deteriorates.

Intelligence as a Network: Mutualism Theory

Traditionally intelligence has been theorized and researched as factor models (e.g., the *g*-factor), posing latent, unobserved variables such as general, crystallized and fluid intelligence as the driving forces underlying cognitive performance (Spearman, 1904). However, while factor models of intelligence have found numerous support in the literature,

interpreting abstract latent factors has proven difficult and controversial (see Borsboom et al, 2003).

An alternative approach to understanding and modeling intelligence and its development is mutualism theory, put forth by van der Maas et al (2006). Taking inspiration from the Lotka-Volterra predator-prey model (May, 1973 and Murray, 2002, as cited in Van der Maas et al, 2006), mutualism assumes that intelligence is the result of positive interactions between individual cognitive abilities over time (van der Maas et al., 2006). This contrasts with factor models, which, if interpreted causally, assume that unobserved, latent variables give rise to cognitive performance. Instead, mutualism theory states that cognitive abilities (e.g., reasoning and vocabulary) positively reinforce each other during development, the net result of which is the emergence of the positive manifold that Spearman discovered in the early 20th century (cite Spearman, 1904). For example, according to mutualism theory, a child's vocabulary might increase their reasoning abilities and vice versa, strengthening the initially weak correlations between these abilities as the child ages.

Mutualism has found empirical support in both cross-sectional and longitudinal studies in diverse cognitive abilities including reasoning, vocabulary, science and working memory (Kievit et al., 2017; Hofman et al., 2018; Kan et al., 2019; Peng & Kievit, 2020; Griffiths et al., 2022; Neubeck et al., 2022; Zhang & Peng, 2023). Mutualism can be interpreted as a network theory of intelligence, whereby individual cognitive abilities represent nodes while their correlations represent edges. The study of mutualism so far has been focused on the mutualism between constructs of intelligence, e.g., vocabulary and reasoning (Kievit et al., 2017) or vocabulary and non-verbal reasoning (Griffiths et al., 2022). However, not much research has been done on the concept of mutualism within a single construct such as general intelligence. Research within a single construct is performed by Hofman et al., (2018) investigating the co-development of simple and advanced math ability across one school year. The results of this research support the theory of mutualism.

Research aim and hypothesis

Mutualism states that cognitive abilities are initially weakly related, but influence and facilitate each other's development in a positive manner, causing the correlations between the abilities to become stronger over time. Though the concept of mutualism as a theory of intelligence is relatively new, research into the development of intelligence and related cognitive abilities has shown support for the theory of mutualism, demonstrating mutualism between constructs cognitive abilities. Within a single construct of cognitive ability, research

and prospective evidence remain sparse. This study aims to fill this gap in the literature and hopes to find support for the theory of mutualism in the development within a single construct of cognitive ability. The construct we aim to investigate is the construct of general knowledge (*gkn*).

In this study, we used general knowledge test data from the Open-Source Psychometrics Project (https://openpsychometrics.org/) to investigate the development of general knowledge from young adolescence to early adulthood (ages 13-35 years old) in the light of the Mutualism Theory of intelligence, using network psychometrics (Epskamp et al., 2017). From this our hypothesis is as follows: We hypothesize that, across different age groups (13-18, 19-24, and 25-35 years), the positive correlations between the nodes from the general knowledge (*gkn*) test will increase in strength. In doing so, we hope to gain insight into the age-related differences that occur within the general knowledge construct.

Methods

Participants

We obtained the current study's data from the Open-Source Psychometrics Project's website (https://openpsychometrics.org/_rawdata/). This website hosts a collection of personality tests and the raw data accumulated from these tests. Users of this website are notified that their answers to these tests are added to the datasets. The users are asked if their data is accurate and can be used for research purposes upon completing the test. If the users indicate their answers are not accurate and not suited for research purposes, their raw data is removed from the datasets. The sample consists of 19,218 anonymous participants. The participants range in gender (male, female or other) and in age (13 years and older). Some participants chose not to fill out their gender. For the entire dataset, 49,7% identified as male, 47,6% identified as female, 2,3% identified as other, and 0,48% did not input gender. As some participants filled out an impossible age (e.g., 67998 years), and because the study concerned specific age groups (adolescence and early adulthood), the data were filtered to include participants aged between 13 (youngest age included in the original dataset) and 35 years old. The data then consisted of 15126 participants, with a mean age for this subset of 22.25 years, and a standard deviation of 5.44 years. For this subset, 48.7% identified as male, 48.3% identified as female, 2.7% identified as other, and 0.3% did not input gender. After creating this subset, the participants were grouped into three separate groups and labelled according to their age range, ages 13-18, 'Younger Adolescent' (n = 4580), 19-24 'Older Adolescent' (n = 5934), and 25-35 'Young Adult' (n = 4612). Labels assigned to individuals in these age groups

can vary based on for example social roles, cultural background, and biological aspects. The UN Convention on the Rights of a Child defines a child as any individual up until the age of 18 (Sawyer et al., 2018). The distinction between the groups 'Younger Adolescent' (ages 13 to 18) and 'Older Adolescent' (ages 19 to 24) is made based on this definition. Adolescence is developmental process that starts around the age of 10-13 and encompasses the transition from childhood to adulthood (Arain et al., 2013). The end of adolescence is traditionally marked by completion of brain maturation around the age of 24 (Arain et al., 2013; Sawyer et al., 2018), hence the distinction between 'Older Adolescent' (ages 19 to 24) and 'Adult' (ages 25 to 35). As we are interested in the developmental aspects of general knowledge, we decided to have the maximum age at 35 years.

Cognitive Assessment: The Multifactor General Knowledge Test

For our *gkn* measure, participants filled out an online Multifactor General Knowledge Test (MFGK (Form A v0.8)). The test consists of 32 open questions, with ten possible answers for each question. Examples of questions are 'Which of these drugs are painkillers?,' and 'Who of these are famous poets?'. Five of the ten possible answers are correct. Selecting a correct answer awards the participant 1 point, selecting an incorrect answer deducts 1.25 points from the participant's score, encouraging the participant to select only those answers they think are right. Participants are hereby discouraged from guessing answers, as guessing can result in a lower score. The scores obtained on the test have a mean score of 500, with a standard deviation of 100. The scores obtained on the test are divided into two domains (Domain A and Domain B), each with two scales, creating a total of four scales. According to the test, each domain has 2 separate constructs: domain A1 and A2, and domain B1 and B2. Although examples of which questions correspond to which (sub)domain are given, the exact division remains unclear, and detailed information was not provided by the creators of the questionnaire or the moderators of the page. To give insight into the (sub)domains we show the examples for the domains provided. For domain A1: 'Who of these were famous poets?', 'Which of these are Broadway musicals?', 'Which of these are religious holidays?', for domain A2: 'Which of these drugs are painkillers?', 'Which of these diseases are sexually transmitted?', 'Which of these are brands of cigarettes?', for domain B1: 'Which of these were ever colonies of France?', 'Which of these countries produce a lot of oil?', 'Which of these countries possess nuclear weapons?', and domain B2: 'Which of these file types are video?', 'Which of these are web browsers?', 'Which of these are versions of the Linux operating system?' (*Multifactor General Knowledge Test results, n.d.)*. Domain A1 appears to be more centered around fashion/leisure/holidays, domain

A2 appears to be centered around health/drugs knowledge, domain B1 shows a tendency towards geopolitical and topological knowledge, whereas domain B2 appears to be related to the internet. The correlation between the two domains is near-0.

Before a participant is allowed to start the test, they must fill out a separate questionnaire about the instructions, only being allowed to start the test if the instructions are correctly understood, and the participant obtains 0 mistakes on the questionnaire. One can fill out the questionnaire as often as they want to obtain 0 mistakes. After the test, a participant is asked to select their age, gender, whether English is their native language, if they filled out the test in a serious manner, and if their results can be stored for research purposes. Should an individual indicate their answers are not accurate and are unsuited for research purposes, the results will be discarded from the data set.

The data downloaded from the Open-Source Psychometrics Project data page (Open psychology data: Raw data from online personality tests (openpsychometrics.org)) consisted of the 32 questions, all the possible answers to these questions, the answers given by the participant and the total score of that answer (total score for the right answers minus the total score of the wrong answers). The total scores (Q1s, Q2s, Q3s, etc.) were used as nodes within the network models for this study's analyses. See 'Codebook' in Appendix A for a detailed description of all data.

Statistical Analyses

All analyses were performed using the R programming language (R Core Team, 2023) and RStudio (R version 4.3.1 (2023-06-16 ucrt) -- "Beagle Scouts"). We hypothesized that, across the age groups, the positive (partial) correlations between nodes increase in strength within the network model. We tested this hypothesis using the network psychometrics framework (Borsboom et al., 2021). For each network model, the nodes consisted of the total score of each of the 32 questions of the test. These components are referred to as QxS, with x = the number of the question (e.g., Q1s, Q2s, Q3s etc.). As there are 32 questions in total, the network consists of 32 nodes. For the full sample as well as each age group (Younger adolescent: age 13-18 years; Older Adolescent: age 19-24 years, and Young Adult: age 25-35 years), we estimated a network model and used partial correlations (i.e., the strength between two variables while controlling for other variables) as the edge weights between nodes. A partial correlation is the correlation that remains between for example question 1 ('Which of these are famous poets?') and question 2 ('Which of these are Broadway Musicals?'), after controlling for any and all correlations with any of the other 30 questions. Controlling for other

(partial) correlations within the networks leads to overall smaller partial correlations between questions/edge weights between nodes. Throughout the remainder of this thesis, we will refer to the edge weights/partial correlations as partial correlations, or PC.

The networks were estimated through applying Gaussian Graphical Models (Pearson correlations) using regularization (graphical lasso, see Friedman et al. 2008). To account for missingness and to reduce the occurrence of false positives, pairwise deletion and a threshold tuning parameter of 0.5, were used, respectively, in the network estimations. These methods generate sparser networks (fewer number of edges) with simpler visualization and interpretation of the conditional dependencies (partial correlations) between nodes of the network. This is accomplished by penalizing for more complex models and is a widely used approach in network psychometrics (for further details, see Epskamp and Fried 2018).

In line with our hypothesis, we expect to find weaker partial correlations in the youngest age group (Younger adolescent) compared to the older groups (Older Adolescent and Young Adult). If we find that the strength of the correlations is consistently higher for the older groups (compared to the younger group), it will confirm our hypothesis. If the correlations for the younger group are consistently higher, or, if there is no substantial difference between any of the groups it will reject our hypothesis. All network models were estimated using the bootnet (version 1.5.6) and qgraph (version 1.9.5) R-packages.

The mean, median, range, the sum total amount of positive partial correlations, the total amount (non-zero) partial correlations and the total amount of negative partial correlations for each network were inspected, giving insight into the descriptives of the partial correlations. Furthermore, we investigated both all positive edges that were consistent across all age groups, and all positive correlations above 0.1, we deemed as ‘strong’ given the graphical lasso approach we used with its threshold. To investigate the consistent positive edges across the age groups, we compare all the correlation matrices, and set any value lower than 0 to -1. This leaves us with only the positive correlations across all three networks. To investigate the stronger positive edges, we set any value lower than 0.1 to -1, leaving us with only the correlations of 0.1 or higher across all three networks. To promote visual analysis of the networks, an average layout was used, keeping all nodes in the same place for each iteration. The R-script written and used for this research can be found on https://osf.io/bn9a4/

Stability analysis

The networks were assessed for robustness using stability analysis of the networks (Epskamp, 2018). A CS-coefficient of 0.5 or higher is preferred, and should not be lower than

0.25 (Epskamp, 2018). A correlation stability analysis was performed by bootstrapping 2000 samples for each of the networks.

Ethics

The study has been approved by the Leiden University's Psychology Research Ethics Committee on November 23rd , 2023 (approval number 2023-11-10-I.L. Simpson-Kent-V1-5080).

Results

Similarities between partial correlation networks across age groups

The networks revealed a consistent pattern of partial correlations across age groups (Figure 1). Most partial correlations (PC) between nodes were positive (90% for the Young Adolescent and 84 % for both the Older Adolescent and Young Adult groups). Noticeably, two separate groups of highly correlated nodes (compared to the rest of the network) formed in each age group: the first group consisting of Q9s ('Which of these were ever colonies of France?'), Q10s ('Which of these countries still have a monarchy (may only be ceremonial)?'), Q11s ('Which of these countries produce a lot of oil?') and Q12s ('Which of these countries possess nuclear weapons?') in the top right corner of each network (PC range: 0,13-0,23), and the second group that included Q5s ('Which of these drugs are painkillers'), Q6s ('Which of these diseases are sexually transmitted?'), and Q31s ('Which of these are types of cancer?') on the left side of the network (PC range: 0,13-0,20). We also found throughout all networks a strong positive relationship between Q15s ('Which of these are versions of the Linux operating system?') and Q30s ('Which of these are types of computer cables?'), with partial correlations of 0.18 (young adolescent), 0.26 (older adolescent) and 0.22 (young adult). Consistently positive and strong partial correlations are also found between Q17s ('Which of these are garments (pieces of clothing)?') and Q32s ('Which of these are fabric patterns?), specifically 0.22 for Young Adolescent, 0.23 for Older Adolescent, 0.26 for Young Adult).

Next, the mean, median and range of the partial correlations were inspected (see table 1). The means for all networks were relatively similar. The Younger Adolescent group, the Older Adolescent and the Young Adult group all have a mean of 0.027 (rounded up to three decimals) and the Full Sample has a mean of 0.028. The standard deviation for the Younger Adolescent group is 0.043, for the Older Adolescent group it is 0.048, for the Young Adult group it is 0.05, and for the Full Sample it is 0.049. The median for the Younger Adolescent

group and the Older Adolescent group is 0.005 (rounded up to three decimals), whereas the median for the Young Adult group is 0, and 0.01 for the Full Sample.

Performing the stability analysis yielded a CS-coefficient of 0.75 for all networks after bootstrapping 2000 samples for each network.

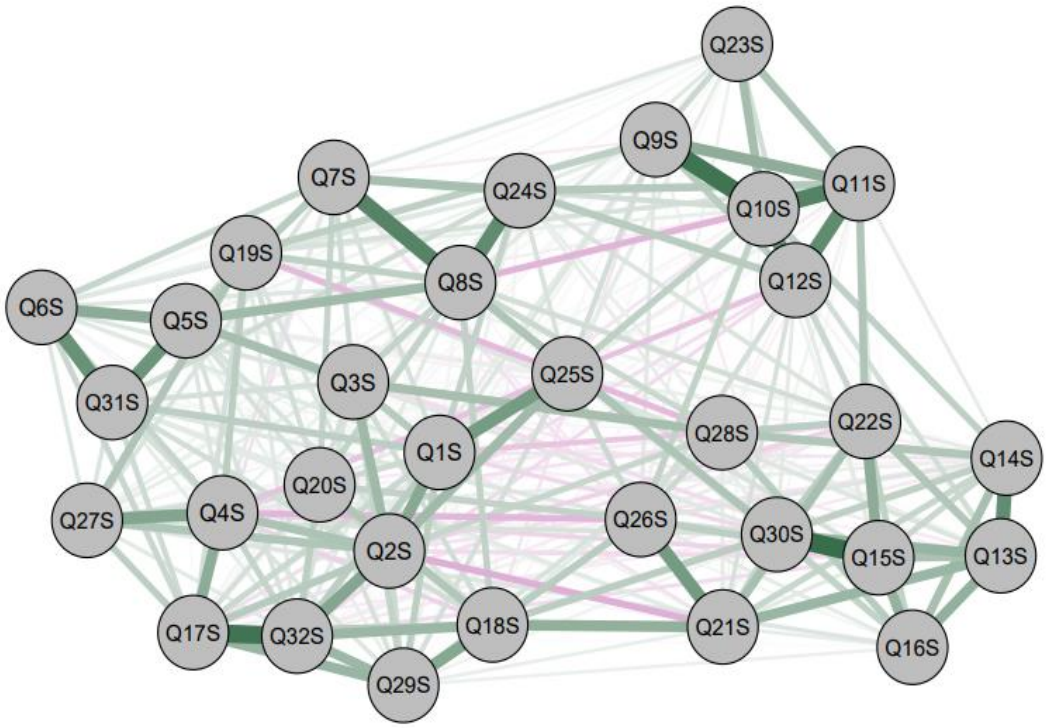
Differences between partial correlation networks across age groups

The networks also showed differences when compared to each other. For example, the weak but positive partial correlation between Q7s (‘Which of these are brands of cigarettes?’) and Q23s (‘Which of these countries contain many ancient pyramids?’) equals 0.031 for the Younger Adolescent group, increases for the Older Adolescent group (PC = 0.058), but does not exist for the young adult group (0). Between Q8s (‘Which of these are slang terms for marijuana?’) and Q10s (‘Which of these countries still have a monarchy (may only be ceremonial)?’) negative partial correlations are observed for both the older adolescent group (PC = -0.09) and young adult group (PC = -0.09), but does not exist for the younger adolescent group (PC = 0). Between Q8s and Q14s the partial correlations equal 0 for both the younger adolescent and the older adolescent group but equals -0.08 for the young adult group. Another difference is the amount of negative partial correlations, which is smallest for the younger adolescent group. The network for this group shows fewer lines in the top half of the network indicating negative relationships, compared to the other age groups and the full sample.

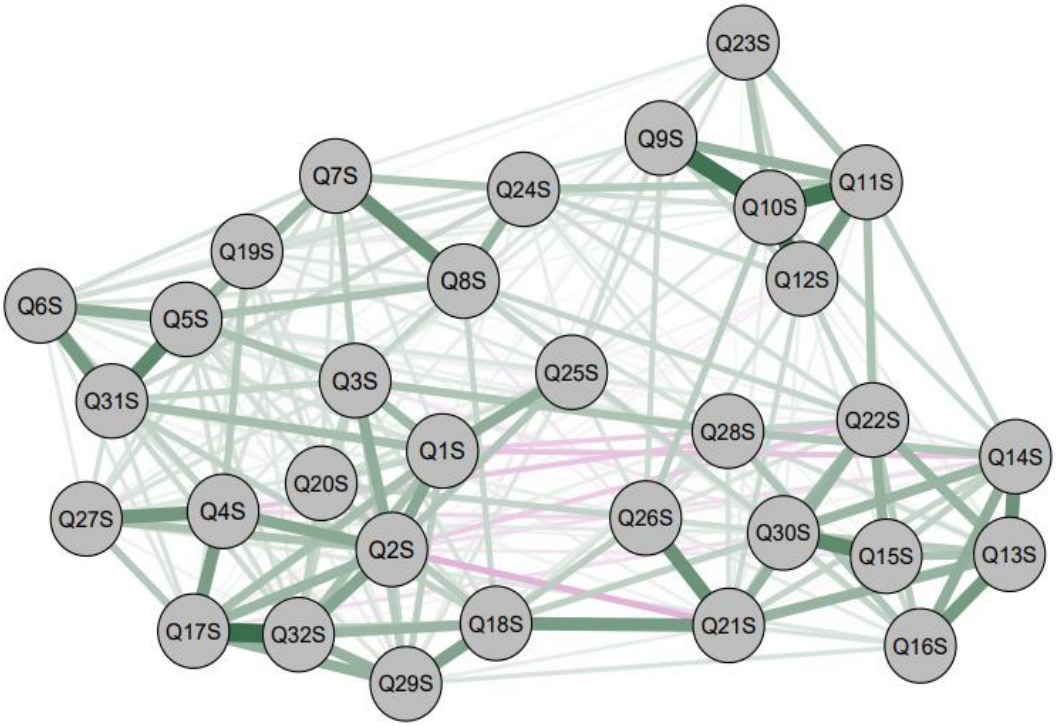
Figure 1

Networks for full sample and age groups (younger adolescent, older adolescent, and young adult)

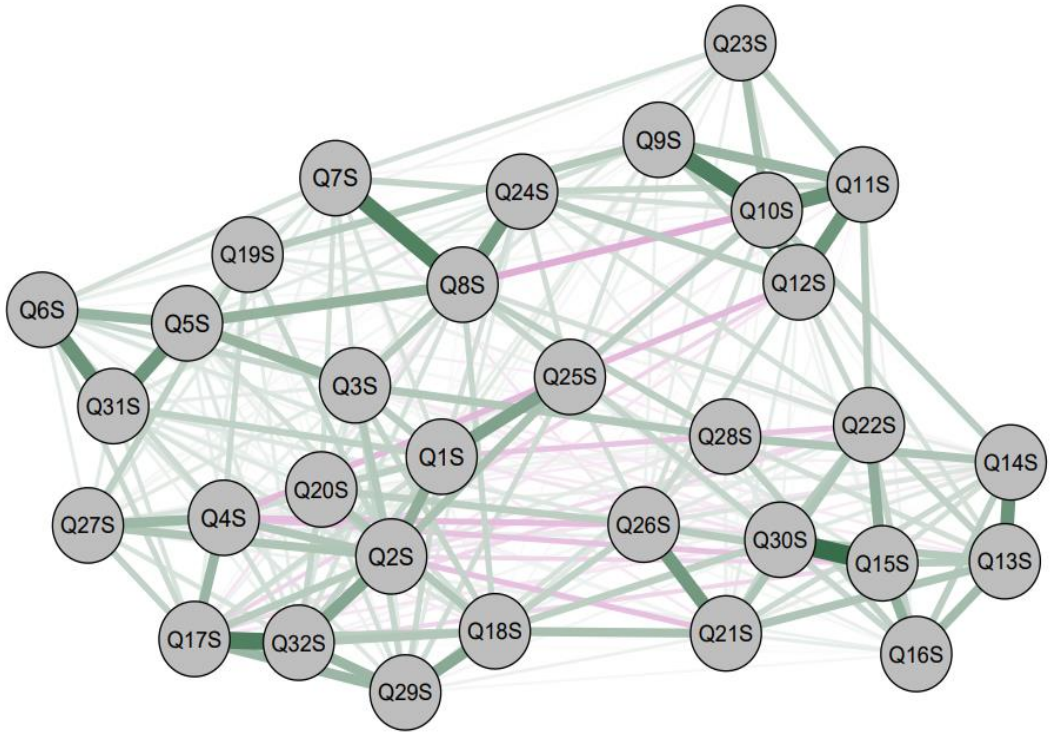
Full sample



Younger adolescent



Older adolescent



Young adult

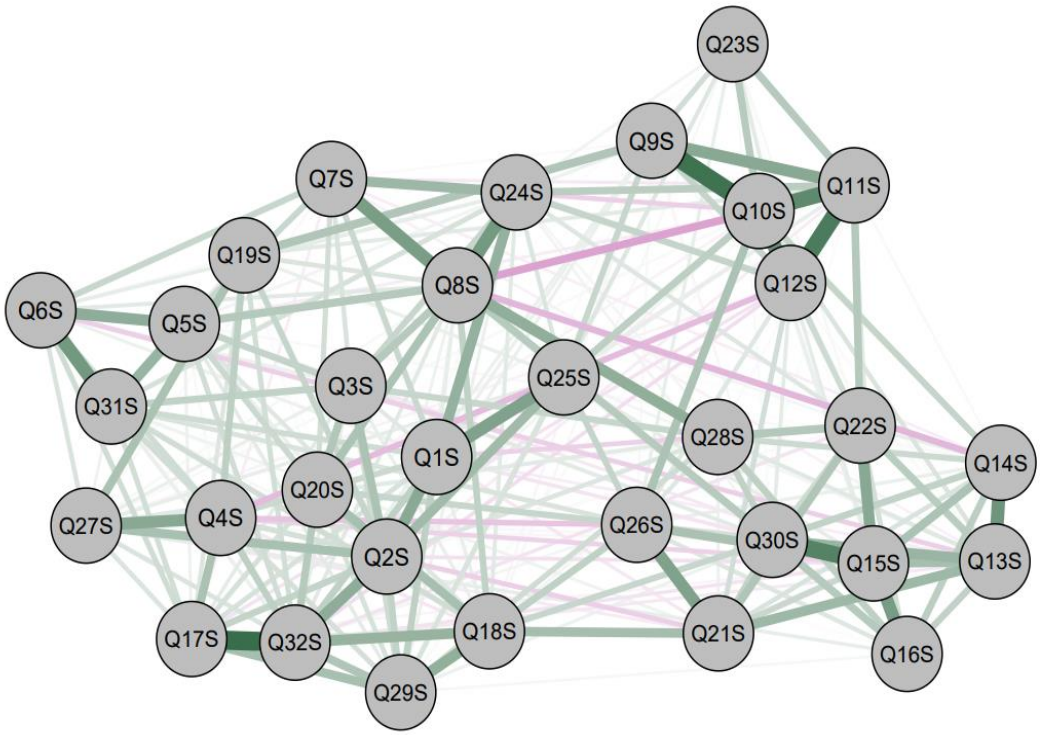


Table 1

Descriptive Statistics of Estimated Networks

	Younger adolescent	Older adolescent	Young adult	Full sample
Mean	0.0266	0.0273	0.0272	0.0280
Median	0.0045	0.0049	0	0.0097
St. Dev.	0.0431	0.0483	0.0495	0.0487
Range	-0.0649 - 0.2211	-0.0850 - 0.2638	-0.0944 - 0.2623	-0.0764 - 0.2444

Descriptives of Partial Correlation Networks

The total amount of nonzero partial correlations follows this same, fluctuating, pattern; the older adolescent group has the largest number of edges overall (323) whereas the young adult group had the lowest number of edges overall (291), and the young adolescent group has 297. Inspecting the descriptives for the partial correlation matrices (see table 2), we see an increase in total positive partial correlations between the ages 13-18 (268) and 19-24 years (271), followed by a decrease for the oldest age group (243). When compared to the total

amount of nonzero partial correlations, the total amount of positive partial correlations shows a decrease from the young adolescent group (0.90) to the older adolescent group (0.84) and remains the same for the older adolescent and young adult group (0.84). The total amount of negative partial correlations is smallest for the young adolescent group (29) and increases for the older adolescent group (52), and then decreases somewhat for the young adult group (48).

As age progresses, the both the negative and the positive partial correlations strengthen. For the Young adolescent group, the lowest correlation is between Q2s ('Which of these are Broadway musicals?') and Q21s ('Which of these are components that may be found in an electrical circuit?') (PC = - 0.07), and the highest correlation is between Q17s ('Which of these are garments (pieces of clothing)?') and Q32s ('Which of these are fabric patterns?') (PC = 0.22). For the Older adolescent group, the lowest correlation is represented by Q8s ('Which of these are slang terms for marijuana?') and Q10s ('Which of these countries still have a monarchy (may only be ceremonial)?') (PC = -0.09), whereas the highest correlation is represented by Q15s ('Which of these are versions of the Linux operating system?') and Q30s ('Which of these are types of computer cables?') (0.26). For the Young adult group, the lowest correlation was also between Q8s ('Which of these are slang terms for marijuana?') and Q10s ('Which of these countries still have a monarchy (may only be ceremonial)?') (PC = -0.09), and the highest correlation was between Q17s ('Which of these are garments (pieces of clothing)?') and Q32s ('Which of these are fabric patterns?') (PC = 0.26). The range of the full sample was most similar to that of the younger adolescent group, with the lowest partial correlation = -0.08, and the strongest partial correlation = 0.24. The total amount of partial correlations that remain positive for all age groups is 204.

Table 2

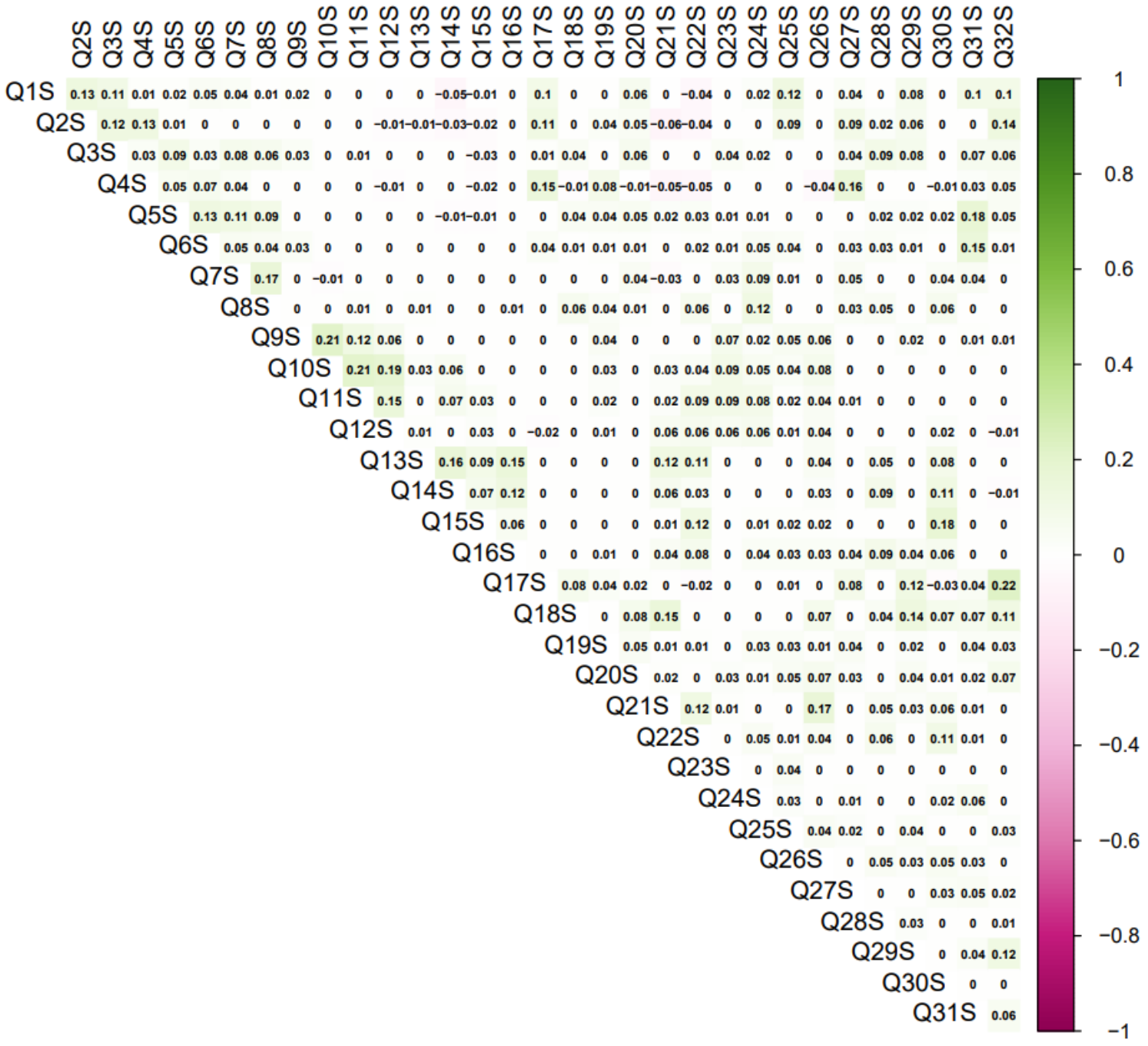
Partial correlation network descriptives

	Younger adolescent	Older adolescent	Young adult
Total (Nonzero)			
PC	297	323	291
Positive PC	268	271	243
Negative PC	29	52	48
Ratio positive to nonzero			
PC	0.90	0.84	0.84

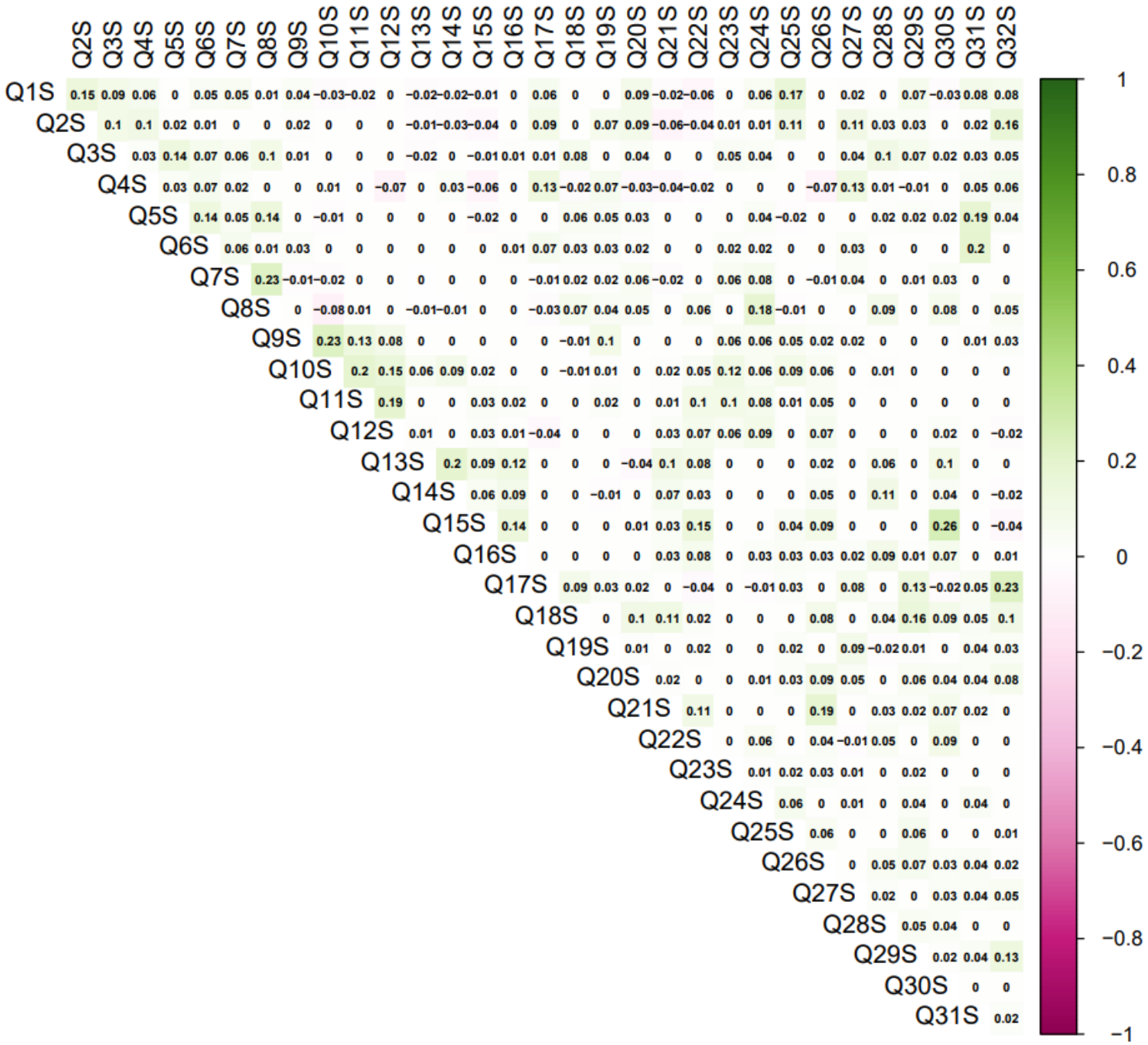
Figure 2

Correlation matrices

Younger adolescent



Older adolescent



Young adult

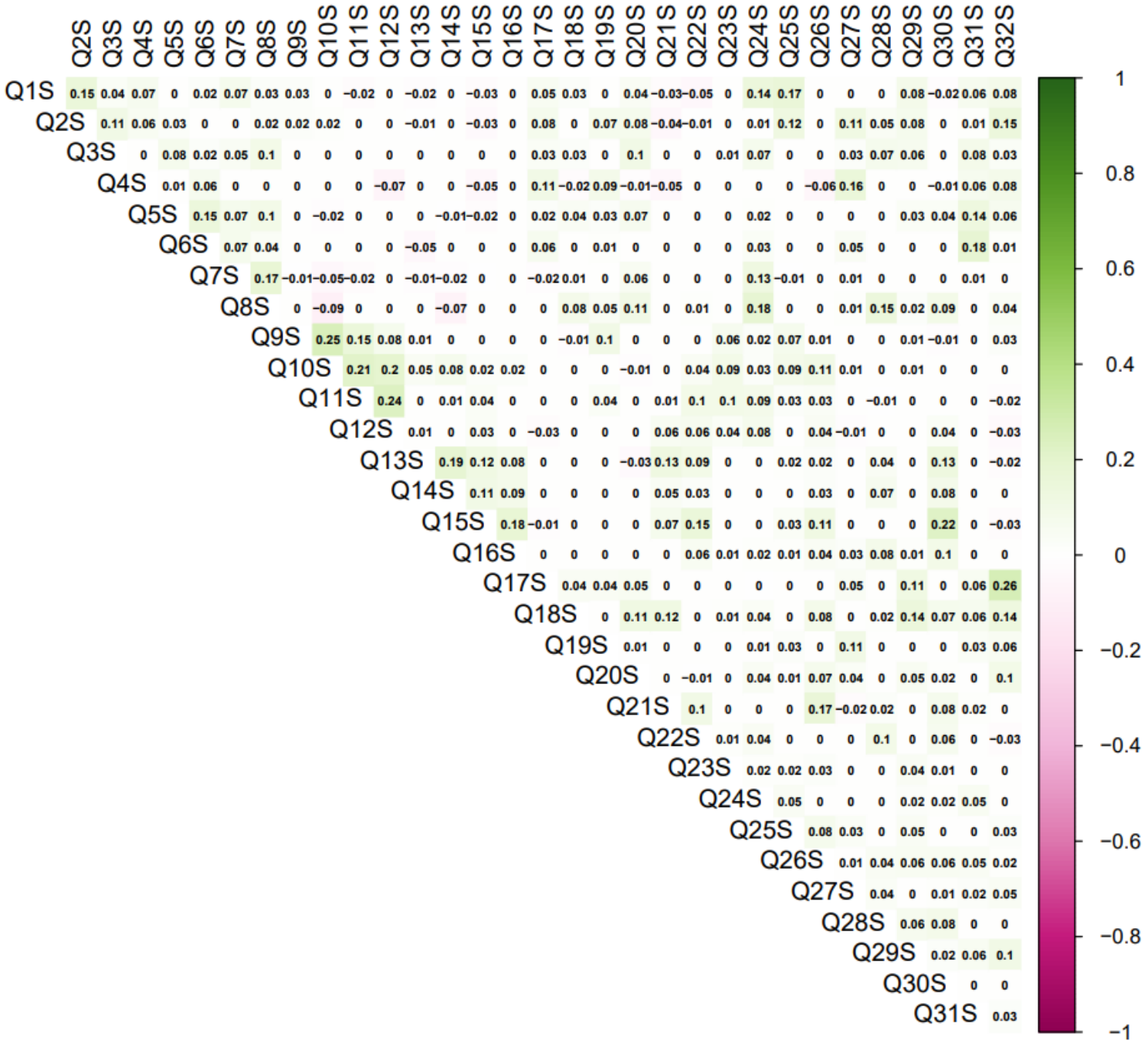
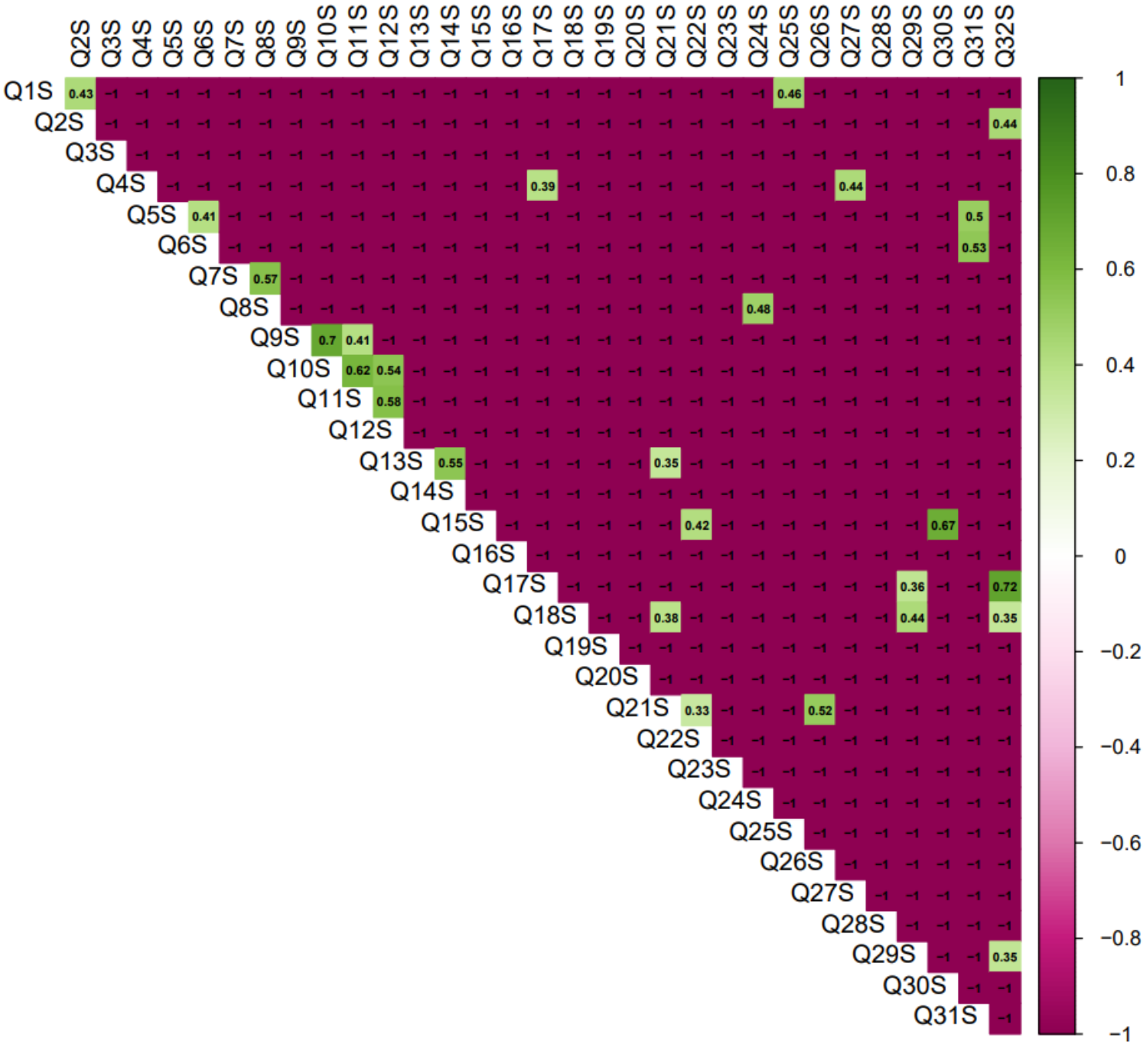

Q2S Q3S Q4S Q5S Q6S Q7S Q8S Q9S Q10S Q11S Q12S Q13S Q14S Q15S Q16S Q17S Q18S Q19S Q20S Q21S Q22S Q23S Q24S Q25S Q26S Q27S Q28S Q29S Q30S Q31S Q32S
Q1S 0.15 0.04 0.07 0 0.02 0.07 0.03 0.03 0 −0.02 0 −0.02 0 −0.03 0 0.05 0.03 0 0.04 −0.03 −0.05 0 0.14 0.17 0 0 0 0.08 −0.02 0.06 0.08
Q2S 0.11 0.06 0.03 0 0 0.02 0.02 0.02 0 0 −0.01 0 −0.03 0 0.08 0 0.07 0.08 −0.04 −0.01 0 0.01 0.12 0 0.11 0.05 0.08 0 0.01 0.15
Q3S 0 0.08 0.02 0.05 0.1 0 0 0 0 0 0 0 0 0 0.03 0.03 0 0.1 0 0 0.01 0.07 0 0 0.03 0.07 0.06 0 0.08 0.03
Q4S 0.01 0.06 0 0 0 0 0 −0.07 0 0 −0.05 0 0.11 −0.02 0.09 −0.01 −0.05 0 0 0 0 −0.06 0.16 0 0 −0.01 0.06 0.08
Q5S 0.15 0.07 0.1 0 −0.02 0 0 0 −0.01 −0.02 0 0.02 0.04 0.03 0.07 0 0 0 0.02 0 0 0 0 0.03 0.04 0.14 0.06
Q6S 0.07 0.04 0 0 0 0 −0.05 0 0 0 0.06 0 0.01 0 0 0 0 0.03 0 0 0.05 0 0 0 0.18 0.01
Q7S 0.17 −0.01 −0.05 −0.02 0 −0.01 −0.02 0 0 −0.02 0.01 0 0.06 0 0 0 0.13 −0.01 0 0.01 0 0 0 0.01 0
Q8S 0 −0.09 0 0 0 −0.07 0 0 0 0.08 0.05 0.11 0 0.01 0 0.18 0 0 0.01 0.15 0.02 0.09 0 0.04
Q9S 0.25 0.15 0.08 0.01 0 0 0 0 −0.01 0.1 0 0 0 0.06 0.02 0.07 0.01 0 0 0.01 −0.01 0 0.03
Q10S 0.21 0.2 0.05 0.08 0.02 0.02 0 0 0 −0.01 0 0.04 0.09 0.03 0.09 0.11 0.01 0 0.01 0 0 0
Q11S 0.24 0 0.01 0.04 0 0 0 0.04 0 0.01 0.1 0.1 0.09 0.03 0.03 0 −0.01 0 0 0 −0.02
Q12S 0.01 0 0.03 0 −0.03 0 0 0 0.06 0.06 0.04 0.08 0 0.04 −0.01 0 0 0.04 0 −0.03
Q13S 0.19 0.12 0.08 0 0 0 −0.03 0.13 0.09 0 0 0.02 0.02 0 0.04 0 0.13 0 −0.02
Q14S 0.11 0.09 0 0 0 0 0.05 0.03 0 0 0 0.03 0 0.07 0 0.08 0 0
Q15S 0.18 −0.01 0 0 0 0.07 0.15 0 0 0.03 0.11 0 0 0 0.22 0 −0.03
Q16S 0 0 0 0 0 0.06 0.01 0.02 0.01 0.04 0.03 0.08 0.01 0.1 0 0
Q17S 0.04 0.04 0.05 0 0 0 0 0 0 0.05 0 0.11 0 0.06 0.26
Q18S 0 0.11 0.12 0 0.01 0.04 0 0.08 0 0.02 0.14 0.07 0.06 0.14
Q19S 0.01 0 0 0 0.01 0.03 0 0.11 0 0 0 0.03 0.06
Q20S 0 −0.01 0 0.04 0.01 0.07 0.04 0 0.05 0.02 0 0.1
Q21S 0.1 0 0 0 0.17 −0.02 0.02 0 0.08 0.02 0
Q22S 0.01 0.04 0 0 0 0.1 0 0.06 0 −0.03
Q23S 0.02 0.02 0.03 0 0 0.04 0.01 0 0
Q24S 0.05 0 0 0 0.02 0.02 0.05 0
Q25S 0.08 0.03 0 0.05 0 0 0.03
Q26S 0.01 0.04 0.06 0.06 0.05 0.02
Q27S 0.04 0 0.01 0.02 0.05
Q28S 0.06 0.08 0 0
Q29S 0.02 0.06 0.1
Q30S 0 0
Q31S 0.03
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1

Figure 3

Positive partial correlations across ages



Strongest partial correlations

The strongest partial correlations (defined here as those > 0.1) that stay positive for all networks (younger adolescent, older adolescent, and young adult) gives a total of 27 partial correlations (see table 3 and figure 4). The partial correlations follow different patterns, increasing, decreasing, or fluctuating across age groups. Of note are the partial correlations between questions 9 and 10, with partial correlations for the younger adolescent group PC = 0.21, the older adolescent group PC = 0.23, and the young adult group PC = 0.25, as they show relatively high partial correlations which increase across all age groups. The partial correlations between questions 2 and 32 show a pattern that increases between the younger adolescent group (PC = 0.14) and the older adolescent group (PC = 0.16), after which it slightly decreases for the young adult group (PC = 0.15). The partial correlation between questions 18 and 21 show are strongest for the younger adolescent group (PC = 0.15), decreasing for the older adolescent group (PC = 0.11) and then slightly increasing for the young adult group (PC = 0.12). All the partial correlations between the questions for each age groups, as well as the corresponding question content can be found in table 3.

When inspecting the questions, there are some that show a considerable content overlap, e.g. question 1: 'who of these are famous poets?' and question 2: 'Which of these are Broadway musicals?', question 5 'Which of these drugs are painkillers?' and question 31: 'Which of these are types of cancer?', question 7: 'Which of these are brands of cigarettes?' and question 8: 'Which of these are slang terms for marijuana?', and question 15: 'Which of these are versions of the Linux operating system?' and question 30: 'Which of these are types of computer cables?'. The first example, the overlap between questions 1 and 2, were 2 examples mentioned for domain A1, explaining the strong correlation between the two questions.

Of the 27 partial correlations above .10, 11 were strongest for the young adult group, 7 of which showed an increase across age groups: questions 1 and 2, questions 5 and 6, questions 9 and 10 and 9 and 11, questions 11 and 12, questions 15 and 22, and questions 17 and 32. 4 partial correlations where strongest for the younger adolescent group, namely between questions 4 and 17 and 4 and 27, and between questions 21 and 18, and 21 and 22. The remaining 12 partial correlations showed the strongest value for the older adolescent group, following a fluctuating pattern.

Table 3

Questions for each age group with partial correlations > 0.10

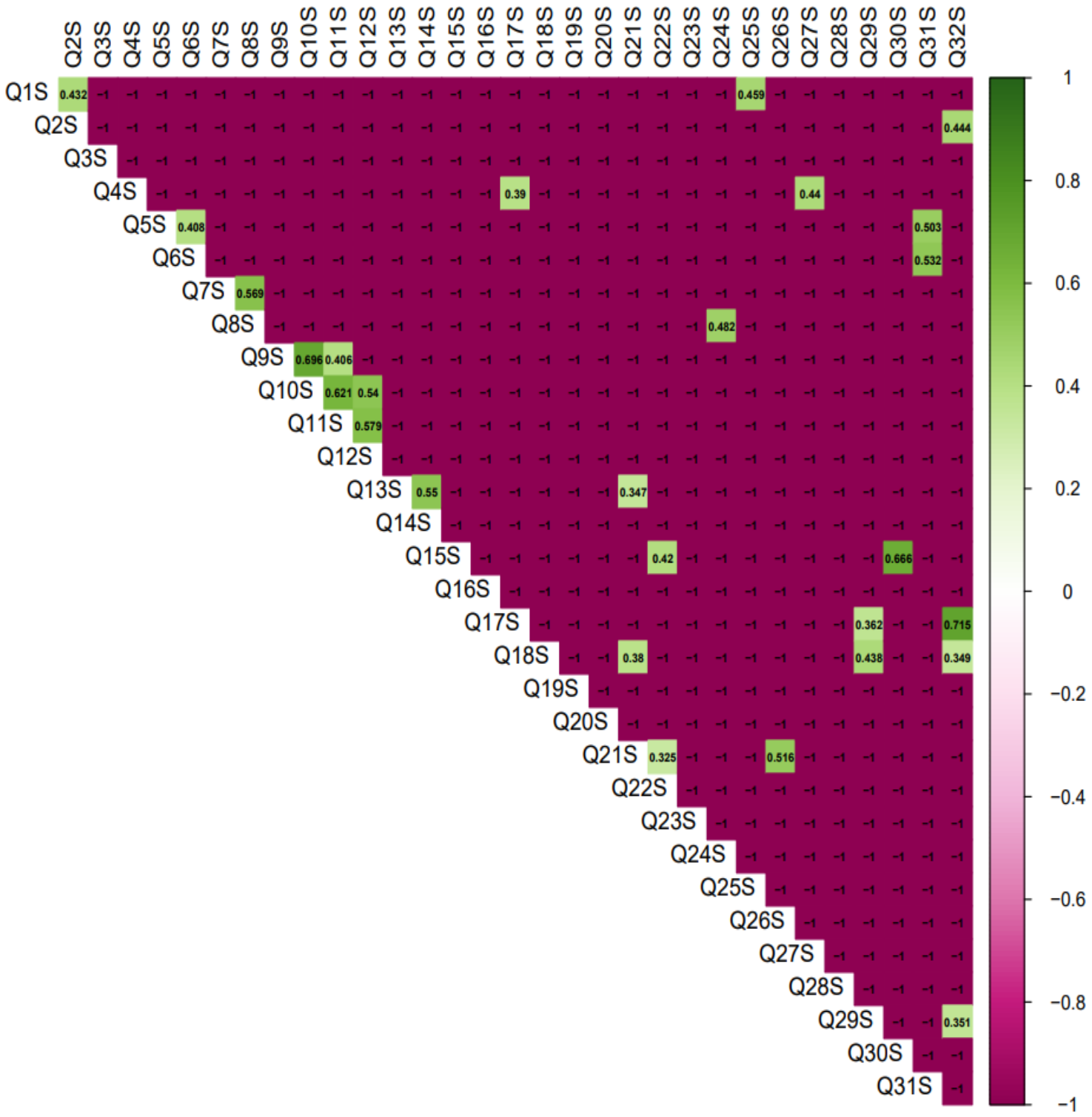
Edge		Partial Correlations			Question
		Younger adolescent	Older adolescent	Young adult	
Q1					Who of these are famous poets?
	Q2	0.13	0.15	0.15	Which of these are Broadway musicals?
	Q25	0.12	0.17	0.17	Which of these books have more than 1,000 pages?
Q2					Which of these are Broadway musicals?
	Q32	0.14	0.16	0.15	Which of these are fabric patterns?’
Q4					Which of these are brands of make-up?
	Q17	0.15	0.13	0.11	Which of these are garments (pieces of clothing)?
	Q27	0.16	0.13	0.16	Which of these are exercise programs?
Q5					Which of these drugs are painkillers?
	Q6	0.13	0.14	0.15	Which of these diseases are sexually transmitted?
	Q31	0.18	0.19	0.14	Which of these are types of cancer?
Q6					Which of these diseases are sexually transmitted?
	Q31	0.15	0.20	0.18	Which of these are types of cancer?
Q8					Which of these are slang terms for marijuana?
	Q7	0.17	0.23	0.17	Which of these are brands of cigarettes?
	Q24	0.12	0.18	0.18	Who of these are famous criminals?
Q9					Which of these were ever colonies of France?
	Q10	0.21	0.23	0.25	Which of these countries still have a monarchy (may only be ceremonial)?
	Q11	0.12	0.13	0.15	Which of these countries produce a lot of oil?

Q10				Which of these countries still have a monarchy (may only be ceremonial)?
	Q11	0.21	0.20	0.21	Which of these countries produce a lot of oil?
	Q12	0.19	0.15	0.20	Which of these countries posses nuclear weapons?
Q11					Which of these countries produce a lot of oil?
	Q12	0.15	0.19	0.24	Which of these countries posses nuclear weapons?
Q13					Which of these file types are videos?
	Q14	0.16	0.20	0.19	Which of these are web browsers?
	Q21	0.12	0.10	0.13	Which of these are electronic components that might be found in an electrical circuit?
Q15					Which of these are versions of the Linux operating system?
	Q22	0.12	0.15	0.15	Which of these are cryptocurrencies?
	Q30	0.18	0.26	0.22	Which of these are types of computer cables?
Q17					Which of these are garments (pieces of clothing)?
	Q29	0.12	0.13	0.11	Which of these words have similar meaning to the word ‘fancy’?
	Q32	0.22	0.23	0.26	Which of these are fabric patterns?
Q18					Which of these are craftsman’s tools?
	Q21	0.15	0.11	0.12	Which of these are electronic components that might be found in an electrical circuit?
	Q29	0.14	0.16	0.14	Which of these words have similar meaning to the word ‘fancy’?
	Q32	0.11	0.10	0.14	Which of these are fabric patterns?

Q21					Which of these are electronic components that might be found in an electrical circuit?
	Q22	0.12	0.11	0.10	Which of these are cryptocurrencies?
	Q26	0.17	0.19	0.17	Which of these are units of distance?
Q29					Which of these words have similar meaning to the word ‘fancy’?
	Q32	0.12	0.13	0.10	Which of these are fabric patterns?

Figure 4

Positive correlations >0.10 across ages



Discussion

In the following paragraphs we will discuss the specific findings for each age group, formulate interpretations of these findings and connect these to existing literature. Then, we will formulate implications, both practical and theoretical, and suggestions for further research.

Similarities between partial correlation networks

Consistent patterns of partial correlations were found across age groups. Two groups (Q9s ('Which of these were ever colonies of France?'), Q10s ('Which of these countries still have a monarchy (may only be ceremonial)?'), Q11s ('Which of these countries produce a lot of oil?') and Q12s ('Which of these countries possess nuclear weapons?'), and Q5s ('Which of these drugs are painkillers'), Q6s ('Which of these diseases are sexually transmitted?'), and Q31s ('Which of these are types of cancer?') were highly positively correlated, compared to the other partial correlations within each network, across all age groups. The first group encompasses questions that relate to geopolitical/topological knowledge. The questions 9 ('Which of these were ever colonies of France?') 11 ('Which of these countries produce a lot of oil?') and 12 ('Which of these countries possess nuclear weapons?') are provided examples of Domain B1 (*Multifactor General Knowledge Test results, n.d.).* As question 10 also relates to geopolitical knowledge and considering the strength of the partial correlation to the other questions from Domain B1, it can be assumed that this question belongs to Domain B1 as well. Regarding the second group, the questions are all examples provided for Domain A2 (*Multifactor General Knowledge Test results, n.d.)* which we assumed consists of health and drug related knowledge. Both groups contain questions that are strongest across ages (here defined as edge weight/partial correlations >.10), except for the edge weight/partial correlation between questions 9 and 12, which are still positively correlated, albeit not above .10 (0.063, 0.083, 0.075). This positive and consistent pattern across age groups implies that, regardless of age, the score obtained on one of the questions within these groups positively influences the scores obtained on the other questions within each group.

Differences

Differences between different iterations of the network were also observed. The weak but positive relationship between questions 7 ('Which of these are brands of cigarettes?') and 23 ('Which of these countries contain many pyramids?') for the younger adolescent and older adolescent group (0.031 and 0.058 respectively), completely disappears of the young adult group (0). The content of question 7 is seemingly related to Domain A2 (health related

information and facts), whereas question 23 is seemingly related to Domain B1 (geopolitical and topological information and facts). For the two younger groups, knowledge about assorted brands of cigarettes is positively related to knowledge about countries with pyramids whereas for young adults, knowledge about different brands of cigarettes has no effect on the knowledge about countries with pyramids (in this particular questionnaire).

Descriptives

Though the average strength of the partial correlations did not vary strongly, more variance (standard deviation) in the strength of the partial correlations/partial correlations was observed. Moreover, the range of the partial correlations also increased. Inspecting the content of the questions related to the range shows that the strongest partial correlations were found between questions that show significant content overlap. The strongest correlations were found between questions 17 (‘Which of these are garments (pieces of clothing)?’) and 32 (‘Which of these are fabric patterns?’) for both the younger adolescent group and the young adult group, and questions 15 (‘Which of these are versions of the Linux operating system?’) and 30 (‘Which of these are computer cables?’) for the older adolescent group. However, the partial correlations between questions 17 and 32 remained strong for the older adolescent group: 0.232. The correlation between questions 15 and 30 are strong for the younger adolescent and young adult group (0.179 and 0.223 respectively). This finding suggests that, regardless of age, correctly answering these questions is positively related. The edge weight/partial correlation between question 15 and 30 for the older adolescent group is the highest correlation recorded across all networks (0.264), perhaps due to this group being more technologically inclined.

The partial correlation between questions 2 (‘Which of these are Broadway musicals?’) and 21 (‘Which of these are components that may be found in an electrical circuit?’) was the lowest partial correlation recorded for the younger adolescent group (-0.065). The partial correlations between questions 8 (‘Which of these are slang terms for marijuana?’) and 10 (‘Which of these countries still have a monarchy (may only be ceremonial)?’) were lowest for both the older adolescent and young adult group (-0.085 and -0.094 respectively). Noticeably, the negative partial correlation between questions 8 and 10 does not exist for the younger adolescent group (0), suggesting that factual knowledge about marijuana and related slang terms has no influence on knowing which countries have monarchies in this age group. The median partial correlations for all age groups were all around or slightly above 0, indicating that a partial correlation of (slightly above) 0 is the midpoint of all age groups, regardless of the increasing range. For the full sample however, the median was higher, around 0.01. The

midpoint of the full sample is slightly lower than a (relatively) strong partial correlation (PC <0.01).

Mutualism

In line with our hypothesis, within the descriptive statistics of all the partial correlation matrices (table 2) we found that the mean of all partial correlations increased with age or fluctuate (increased and then decreased with age). As age progressed, we observed that both the negative and positive partial correlations strengthened in magnitude. Overall, the older adolescent group network contained the most partial correlations, both positive and negative. We also found that the range of the partial correlations increases. While the older adolescent group contained the most positive edges, and the most edges overall, the younger adolescent group contains the highest ratio of positive edges to total edges compared to the older adolescent and young adult groups. This finding leads us to conclude that mutualism is widespread and active in adolescence, where 90% of different components/subjects of general knowledge positively influence and facilitate each other. The increasing of the range suggests that, with age, the partial correlations increase in strength, suggesting the reciprocal nature of intelligence posed by mutualism.

The younger adolescent group ranged in age between 13 and 18 years, which is the period most younger adolescents attend high school or vocational studies. During this time, adolescents are acquiring and storing a wide variety of factual and academic. Therefore, this finding supports the notion that mutualism is more active during this adolescent period. Between the ages of 19 and 24 years, we see that older adolescents start their first jobs and/or attend university or college, some get married and may start families. They might start travelling, on their own or with others, exploring new cultures, taking up adult tasks and caring for others, whilst still being independent (Bonnie et al., 2015). When focusing on the young adult group, we notice that they have the largest range in partial correlations. We also see that the total amount of partial correlations is lowest for this age. These findings underscore that mutualism, at least using this test of general knowledge, is most present in younger ages.

Positive and strongest network edges across ages

Across ages we found 204 partial correlations that remained positive, and 27 partial correlations/partial correlations we considered to be strong (PC <0.10). Examining question content, we found the strongest correlations between questions with considerable content overlap. Questions regarding knowledge of computers and internet-based factual knowledge

showed higher partial correlations between them than questions between for example the domain of geopolitical and topological knowledge and the domain of fashion/leisure/holidays. 12 of the partial correlations followed the fluctuating pattern seen in the amount of non-zero partial correlations and the mean, where the partial correlation was strongest for the older adolescent group. 11 were strongest for the young adult group and 4 were strongest for the younger adolescent group. As only the content of the questions was made available to us, as well as some examples of the division amongst domains, it is impossible to properly formulate implications based on question content or overarching themes.

Strengths and limitations

Performing the stability analysis showed that, for all networks, 75% of the sample could be dropped whilst still maintaining a correlation of 0.70 with the original sample. This shows that all networks are stable, and that the findings for each networks are robust to a considerable number of observations being dropped out.

Another strength of this study is, though the study is cross-sectional, the study had a large sample size. Studies using a mutualistic approach to intelligence has been done before, however these studies were concerned with between-constructs effects of mutualism. This study focused on using mutualism within a single construct of intelligence, making this a novel study. As such little evidence and literature can be found to relate to and integrate, which is a limitation of this study. At the same time, this allows room for a lot of avenues to pursue in regards these topics, which is a strength.

Another limitation is the fact that this is an online study, and very few information was provided by the creators of the questionnaire from the Open-Source Psychometrics Project. Attempts were made to obtain more information about the questionnaire, but no response was received. This means that we had little to no information on the division of the questions amongst the domains or the bases of the division. We are only able to draw conclusions based on the content of the questions, not on the overarching themes of the questions.

Practical and theoretical implications

Intelligence is a strong predictor of health, academic success, general wellbeing and much more (Simpson-Kent et al., 2021). Its' role in daily life, and therefore as topic within the scientific community, cannot be understated. At the same time, intelligence seems to be undefined, and based on who you ask, you will get different answers to the question 'what is

intelligence?' (Richardson, 2022). As network analysis of intelligence is still a novel concept so it is difficult to formulate any practical implications at this stage.

Future research directions

This research has focused on the extent to which network analysis of a single construct within intelligence (general knowledge) helps us better understand age related differences in general knowledge. Though we can tentatively interpret the findings to suggest that mutualism is present and active in younger age groups and slows down as age progresses, a deeper understanding of the development of general knowledge still evades us. Longitudinal studies following individuals' accumulation of general knowledge over time are required.

Future studies should also investigate the possible role of age-related specialization and differentiation/dedifferentiation. As performance on cognitive tests change over time (Deary et al., 1996; Craik & Bialystok, 2006; Tucker-Drob, 2009), it has been observed that intelligence develops showing a strong increase over time which then levels off around the end of adolescence; intelligence does not keep developing endlessly (van der Maas et al., 2006). One explanation offered for these developmental changes is the theory of (de)differentiation (Hartung et al., 2018). The differentiation hypothesis states that relations between cognitive abilities increase over time, potentially due to greater cognitive specialization with age. In contrast, in factor models differentiation is often assessed as decrease in relations (covariances) between cognitive abilities during childhood (differentiation), and an increase in relations between cognitive abilities during adulthood (dedifferentiation). Evidence for differentiation and dedifferentiation have been inconclusive, possibly due to neither process being solely responsible for age-related changes in cognitive abilities but rather both together influence the development of intelligence (Hartung et al., 2018; Breit et al, 2021; Craik et al, 2006). Specialization and (de)differentiation are both theoretical constructs that have been researched extensively, however evidence is often inconclusive because neither one is solely responsible for age related/developmental differences (Hartung et al., 2018; Breit et al, 2021; Craik et al, 2006). To our knowledge, network analysis has not yet been used to study specialization/(de)differentiation. Therefore, future research should aim to fill this gap in light of the mutualism (network) theory of intelligence.

A study which focusses on individuals' socio-economic status, cultural background and academic history, and the role these factors play into the acquisition and development of general knowledge, as well as the role this construct plays between constructs of intelligence, is recommended. Research into these constructs have demonstrated the larger role these factors

play in the acquisition of knowledge (Schroeders et al., 2021), but also for example in vocabulary acquisition (Buades-Sitjar et al., 2021).

Conclusion

Crystalized intelligence surmises the knowledge and skills acquired in a lifetime. Generally speaking, a very young person's amount of general knowledge may not be as extensive as that of an older person, as the general intelligence takes some time to develop (van der Maas et al., 2006; Buades-Sitjar et al., 2021) and is a result of learning, education and acculturation (Schroeders et al., 2021). At the same time, intelligence does not keep developing boundlessly, at some point in time the development levels off (van der Maas et al., 2006). Conventionally, intelligence and components of intelligence have been researched as factor models. The aim of this research was to investigate a different, but complementary, approach to analyzing and understanding the age-related differences within a specific construct of intelligence, general knowledge, drawing inspiration from the mutualism theory of intelligence. Mutualism states that components of intelligence positively reinforce each other during development (van der Maas et al., 2006).

To investigate this approach, we estimated a network model on three different age groups (13-18, 19-24 and 25-35 years). It was hypothesized that the strength of the correlations between the nodes of the network would increase with age. Our analyses showed overall positive correlations between the nodes of the networks, for all iterations, with some negative and near-0 correlations. These findings suggested that mutualism is most active in younger adolescence, between the ages of 13 and 18. We surmised that this is because adolescents these ages are going to high school or follow vocational studies, and are acquiring and storing factual knowledge from varied (and often new) sources of information. Future research should be focused on the role of (de)differentiation within the development of (constructs within) intelligence, longitudinal research into the development of the construct general knowledge (and related factors such as socio-economic status) and intelligence as a whole using mutualism theory.

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Appendix A: Codebook

This data was collected through an on-line general knowledge test. Data collection took place 2017-2018. Users were motivated to take the test to obtain personalized results.

This test used a unique question format, where each question was of a type that could have multiple correct answers. In each question, 10 answers were displayed to the respondent and they were told that 5 were correct and to select as many as they knew but not to guess.

The test consisted of 32 questions. They were shown to each subject in a random order. There were four values stored for each question:

QXS The number of right answers selected for this question minus the number of wrong answers.
QXA The exact answers selected for this question.
QXE The time spend on this question is miliseconds.
QXI The position this question in the survey.

(X=question ID number)

The questions asked are in the data structure below:
{
'Q1' : {'Q': 1, 'text': 'Who of these were famous poets?', 'A1': 'Robert Frost', 'A0': 'Emily Dickinson', 'A3': 'Maya Angelou', 'A2': 'Sylvia Plath', 'A5': 'Elizabeth Cady Stanton', 'A4': 'Langston Hughes', 'A7': 'Marcel Cordoba', 'A6': 'Abigail Adams', 'A9': 'Trent Moseson', 'A8': 'Sun Tzu'},
'Q2' : {'Q': 2, 'text': 'Which of these are Broadway musicals?', 'A1': 'The Lion King', 'A0': 'Cats', 'A3': 'Wicked', 'A2': 'Hamilton', 'A5': 'Casablanca', 'A4': 'Kinky Boots', 'A7': 'Blue Swede Shoes', 'A6': 'The Tin Man', 'A9': 'Amandine', 'A8': 'Common Projects'},
'Q3' : {'Q': 3, 'text': 'Which of these are religious holidays?', 'A1': 'Christmas', 'A0': 'Kwanzaa', 'A3': 'Yom Kippur', 'A2': 'Ramadan', 'A5': 'Mirch Masala', 'A4': 'Hanukkah', 'A7': 'Amadar', 'A6': 'Reconciliation', 'A9': 'Viveza', 'A8': 'Durest'},

'Q4' : {'Q': 4, 'text': 'Which of these are brands of makeup?', 'A1': 'Sephora', 'A0': 'CoverGirl', 'A3': 'Dior', 'A2': 'Maybelline', 'A5': 'ThriftyGal', 'A4': 'Shiseido', 'A7': 'Reis', 'A6': 'Allenda', 'A9': 'Aejeong', 'A8': 'NewBeautyTruth'},
'Q5' : {'Q': 5, 'text': 'Which of these drugs are painkillers?', 'A1': 'Ibuprofen', 'A0': 'Oxycodone', 'A3': 'Morphine', 'A2': 'Codeine', 'A5': 'Modafinil', 'A4': 'Asprin', 'A7': 'Alemtuzumab', 'A6': 'Creatine', 'A9': 'Carboplatin', 'A8': 'Semtex'},
'Q6' : {'Q': 6, 'text': 'Which of these diseases are sexually transmitted?', 'A1': 'Herpes', 'A0': 'AIDS', 'A3': 'Human Papillomavirus', 'A2': 'Chlamydia', 'A5': 'Botulism', 'A4': 'Trichomoniasis', 'A7': 'Pneumonia', 'A6': 'Shingles', 'A9': 'Pertusis', 'A8': 'Tuberculosis'},
'Q7' : {'Q': 7, 'text': 'Which of these are brands of cigarettes?', 'A1': 'Marlboro', 'A0': 'Camel', 'A3': 'Pall Mall Box', 'A2': 'Newport', 'A5': 'Seagram's', 'A4': 'Pyramid', 'A7': 'Windsor', 'A6': 'Black Velvet', 'A9': 'Solo', 'A8': 'Black Turkey'},
'Q8' : {'Q': 8, 'text': 'Which of these are slang terms for marijuana?', 'A1': '420', 'A0': 'weed', 'A3': 'chronic', 'A2': 'ganja', 'A5': 'smack', 'A4': 'reefer', 'A7': 'DnB', 'A6': 'tilt', 'A9': 'heavenly green', 'A8': 'José Garcia'},
'Q9' : {'Q': 9, 'text': 'Which of these were ever colonies of France?', 'A1': 'Ivory Coast', 'A0': 'Senegal', 'A3': 'Morocco', 'A2': 'Quebec', 'A5': 'India', 'A4': 'Vietnam', 'A7': 'Brazil', 'A6': 'Florida', 'A9': 'Egypt', 'A8': 'South Africa'},
'Q10' : {'Q': 10, 'text': 'Which of these countries still have a monarchy (may only be ceremonial)?', 'A1': 'Japan', 'A0': 'United Kingdom', 'A3': 'Thailand', 'A2': 'Sweden', 'A5': 'France', 'A4': 'Saudi Arabia', 'A7': 'Russia', 'A6': 'Germany', 'A9': 'Brazil', 'A8': 'China'},
'Q11' : {'Q': 11, 'text': 'Which of these countries produce a lot of oil?', 'A1': 'Venezuela', 'A0': 'Saudi Arabia', 'A3': 'Norway', 'A2': 'Nigeria', 'A5': ' Zimbabwe', 'A4': 'Quatar', 'A7': 'Singapore', 'A6': ' Sweden', 'A9': 'Japan', 'A8': 'Panama'},
'Q12' : {'Q': 12, 'text': 'Which of these countries possess nuclear weapons?', 'A1': 'France', 'A0': 'Russia', 'A3': 'China', 'A2': 'Israel', 'A5': 'Germany', 'A4': 'Pakistan', 'A7': 'Nigeria', 'A6': 'Saudi Arabia', 'A9': 'Spain', 'A8': 'Mexico'},
'Q13' : {'Q': 13, 'text': 'Which of these file types are video?', 'A1': '.mkv', 'A0': '.mp4', 'A3': '.wmv', 'A2': '.avi', 'A5': '.csv', 'A4': '.mov', 'A7': '.flac', 'A6': '.xls', 'A9': '.mp3', 'A8': '.msi'},

'Q14' : {'Q': 14, 'text': 'Which of these are web browsers?', 'A1': 'Firefox', 'A0': 'Internet Explorer', 'A3': 'Opera', 'A2': 'Safari', 'A5': 'Slate', 'A4': 'Chrome', 'A7': 'Pipes', 'A6': 'Expedition', 'A9': 'Telegram', 'A8': 'Adele'},
'Q15' : {'Q': 15, 'text': 'Which of these are versions of the Linux operating system?', 'A1': 'Debian', 'A0': 'Ubuntu', 'A3': 'RHEL', 'A2': 'Fedora', 'A5': 'IIS', 'A4': 'Slackware', 'A7': 'Technitium', 'A6': 'Kodiak', 'A9': 'Go', 'A8': 'Oracle'},
'Q16' : {'Q': 16, 'text': 'Which of these are HTTP status codes?', 'A1': '500 Internal Server Error', 'A0': '100 Continue', 'A3': '404 Not Found', 'A2': '301 Moved Permanently', 'A5': '500 Deleted', 'A4': '502 Bad Gateway', 'A7': '303 Payment Processing', 'A6': '600 Encrypted', 'A9': '101 Use Proxy', 'A8': '209 Download Complete'},
'Q17' : {'Q': 17, 'text': 'Which of these are garments (pieces of clothing)?', 'A1': 'Tunic', 'A0': 'Shirt', 'A3': 'Shawl', 'A2': 'Sarong', 'A5': 'Jayanti', 'A4': 'Camisole', 'A7': 'Cornik', 'A6': 'Wristlings', 'A9': 'Frutiger', 'A8': 'Cheapnik'},
'Q18' : {'Q': 18, 'text': 'Which of these are craftsman’s tools?', 'A1': 'Chisel', 'A0': 'Saw', 'A3': 'Caliper', 'A2': 'Bevel', 'A5': 'Skree', 'A4': 'Awl', 'A7': 'Whisket', 'A6': 'Wry', 'A9': 'Brutch', 'A8': 'Skane'},
'Q19' : {'Q': 19, 'text': 'Which of these are red wines?', 'A1': 'Cabernet sauvignon', 'A0': 'Merlot', 'A3': 'Sangiovese', 'A2': 'Malbec', 'A5': 'Chardonnay', 'A4': 'Pinot noir', 'A7': 'Moscato', 'A6': 'Semillon', 'A9': 'Riesling', 'A8': 'Gewürztraminer'},
'Q20' : {'Q': 20, 'text': 'Which of these are card games?', 'A1': 'Hearts', 'A0': 'Rummy', 'A3': 'Bridge', 'A2': 'Poker', 'A5': 'Yatzhe ', 'A4': 'Cribbidge', 'A7': 'Bocce', 'A6': 'Croquet', 'A9': 'Manhattan', 'A8': 'Black 2s'},
'Q21' : {'Q': 21, 'text': 'Which of these are electronic components that might be found in an electrical circut?', 'A1': 'Inductor', 'A0': 'Resistor', 'A3': 'Transistor', 'A2': 'Capacitor', 'A5': 'Signer', 'A4': 'Diode', 'A7': 'Annulus', 'A6': 'Subductor', 'A9': 'Zenoid', 'A8': 'Boson'},
'Q22' : {'Q': 22, 'text': 'Which of these are cryptocurrencies?', 'A1': 'Litecoin', 'A0': 'Bitcoin', 'A3': 'Monero', 'A2': 'Etherium', 'A5': 'AlphaBay', 'A4': 'Ripple', 'A7': 'PayPal', 'A6': 'DCA', 'A9': 'Dwork', 'A8': 'Liberty Ledger'},
'Q23' : {'Q': 23, 'text': 'Which of these countries contain many ancient pyramids?', 'A1': 'Egypt', 'A0': 'Mexico', 'A3': 'Sudan', 'A2': 'India', 'A5': 'Greece', 'A4': 'Indonesia', 'A7': 'Congo', 'A6': 'Turkey', 'A9': 'Japan', 'A8': 'Mongolia'},
'Q24' : {'Q': 24, 'text': 'Who of these are famous criminals?', 'A1': 'Ted Kaczynski', 'A0': 'Al Capone', 'A3': 'Timothy McVeigh', 'A2': 'Pablo Escobar', 'A5': 'Harvey Parnell', 'A4':

'Jim Jones', 'A7': 'John Goodman', 'A6': 'Sid McMath', 'A9': 'Pavel Tikhonov', 'A8': 'Buster Keaton'},

'Q25' : {'Q': 25, 'text': 'Which of these books have more than 1,000 pages?', 'A1': 'Les Miserables', 'A0': 'Infinite Jest', 'A3': 'War and Peace', 'A2': 'Atlas Shrugged', 'A5': 'Pride and Prejudice', 'A4': 'Cryptonomicon', 'A7': 'Fahrenheit 451', 'A6': 'Harry Potter and the Prisoner of Azkaban', 'A9': 'Science, and its Antecedents', 'A8': 'To Kill a Mockingbird'},

'Q26' : {'Q': 26, 'text': 'Which of these are units of distance?', 'A1': 'Meter', 'A0': 'Mile', 'A3': 'Parsec', 'A2': 'Furlong', 'A5': 'Newton', 'A4': 'Angstrom', 'A7': 'Pitch', 'A6': 'Pascal', 'A9': 'Annum', 'A8': 'Hertz'},

'Q27' : {'Q': 27, 'text': 'Which of these are exercise programs?', 'A1': 'Zumba', 'A0': 'CrossFit', 'A3': 'Pilates', 'A2': 'Barre', 'A5': 'Shiatsu', 'A4': 'Tabata', 'A7': 'Gooba', 'A6': 'Reflexology', 'A9': 'NTP', 'A8': 'UltraMaxFit'},

'Q28' : {'Q': 28, 'text': 'Which of these are internet abbreviations?', 'A1': 'ROFL', 'A0': 'LOL', 'A3': 'GG', 'A2': 'BRB', 'A5': 'QTY', 'A4': 'DM', 'A7': 'AET', 'A6': 'FUM', 'A9': 'MRLO', 'A8': 'TT'},

'Q29' : {'Q': 29, 'text': 'Which of these words have similar meaning to the word “fancy”?', 'A1': 'adorned', 'A0': 'ornate', 'A3': 'resplendent', 'A2': 'cushy', 'A5': 'effective', 'A4': 'spiffy', 'A7': 'esulent', 'A6': 'virile', 'A9': 'thalassic', 'A8': 'adscititious'},

'Q30' : {'Q': 30, 'text': 'Which of these are types of computer cables?', 'A1': 'USB', 'A0': 'HDMI', 'A3': 'SATA', 'A2': 'Ethernet', 'A5': 'WiFi', 'A4': 'FireWire', 'A7': '2Interlink', 'A6': 'D-High', 'A9': 'HDD', 'A8': 'RTC'},

'Q31' : {'Q': 31, 'text': 'Which of these are types of cancer?', 'A1': 'Lymphoma', 'A0': 'Lukemia', 'A3': 'Mesothelioma', 'A2': 'Melanoma', 'A5': 'Lymnoma', 'A4': 'Sarcoma', 'A7': 'Vitisus', 'A6': 'Colerectia', 'A9': 'Cellenia', 'A8': 'Tradoma'},

'Q32' : {'Q': 32, 'text': 'Which of these are fabric patterns?', 'A1': 'Paisley', 'A0': 'Calico', 'A3': 'Plaid', 'A2': 'Pinstripe', 'A5': 'Periwinkle', 'A4': 'Tartan', 'A7': 'Stilted', 'A6': 'Snapdragon', 'A9': 'Tahoma', 'A8': 'Arvo'}

}

There values were collected on a final page:

age in years

gender	1=Male, 2=Female, 3=Other
engnat	1=English native language, 2=Not native english speaker

These values were calculated from technical information:

country	the user's network location
screenw	screen width in pixels
screenh	screen height in pixels
introelapse	The time spend on the landing page in seconds
testelapse	The time spent on the page with the questions in seconds
surveyelapse	The time spent on the final page in seconds

This data has not been cleaned at all (so you may want to remove people who spent to little time on questions, or people who got easy questions wrong), except for that (1) ages < 13 were not stored, (2) users were asked "Did you try your best and can we store your data and use for research?" and those who did not answer yes were not stored.