ORIGINAL ARTICLE

Hubs of belief networks across sociodemographic and ideological groups

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Abstract
Beliefs are essential components of the human mind, as they define personal identity, integration and adaptation to social groups. Most theoretical studies suggest that beliefs are organized as structured networks: the so-called belief system. According to these studies and their empirical implementation using graph-theoretical approaches, a belief is any proposition considered as true by the respondent. In a recent contribution, we introduced a novel operationalization: a proposition is a belief if (1) it is taken to be true; and (2) the subject declares to be willing to hold it even if irrefutable evidence were hypothetically argued against it. Here, we implement this operationalization using a graph theory approach to investigate the network organization of the belief system in a sample of 108 participants, as well as the differences between key ideological (left- vs. right-wingers) and sociodemographic features (younger vs. older, female vs. male). We identified a well-coordinated network of interlocked spiritual, prosocial and nature-related beliefs, which displays a dense core of 10 hub nodes. Moreover, we observed how specific social liberalist beliefs and transcendental or individualistic/prosocial viewpoints are articulated within left- and right-wingers networks or younger and older participants. Interestingly, we observed that females tend to engage in denser belief networks than male respondents. In conclusion, our research expands tangible scientific evidence of the belief system of humans through the network study of belief reports, which in turn opens innovative ways to study belief systems in social and clinical samples.

1 Introduction

According to the philosopher Jose Ortega y Gasset, beliefs are the central backbone of the human person: whereas ideas span from irrelevant thoughts to scientific truths, beliefs constitute the 'container' (and not the content) of our mind.

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In this context, humans do not have beliefs: we *are* beliefs (Ortega y Gasset 1968). Further, since we are 'political animals' (Aristotle 1967), analyzing belief systems in depth would allow us to gain a richer knowledge on social dynamics (Pechey 2010), as well as to increase the understanding of our mind (Connors and Halligan 2015). However, the internal structure of belief networks and their group-specific characteristics remain to be deciphered.

In general terms, analytical philosophy defines 'belief' as a proposition that is accepted to be true by the believer. This definition has been embraced by mainstream psychology and social science. For example, The Stanford Encyclopedia of Philosophy states that "Contemporary Anglophone philosophers of mind generally use the term 'belief' to refer to the attitude we have, roughly, whenever we take something to be the case or regard it as true" (Schwitzgebel 2019). As a consequence, implicit or explicitly, most empirical approaches on belief and belief systems operationalize belief as any proposition considered as true. This standard definition of belief does not capture their decisive feature which, as we

have thoroughly explained elsewhere (Camina et al. 2021; Bernacer et al. 2021), is the commitment of the believer with the veracity of the proposition at the time it is uttered. In a nutshell, we think that "I believe that the door is open," "I believe that the theory of evolution is correct," or "I believe that God exists," cannot be considered part of the same psychological process, even though the verb 'believe' is used in all cases. Whereas all these propositions may be considered as true by someone, they point to different psychological states, beyond their content. From our point of view, the distinctive feature of believing is the subjective conviction on the veracity of a proposition, even if incontrovertible evidence could be hypothetically argued against it. Therefore, we have operationalized beliefs in a more restrictive way than previous empirical studies: a belief is (1) a proposition that is taken to be true, and (2) which the subject is willing to hold even if 'irrefutable' evidence could be hypothetically argued against it (Camina et al. 2021). This 'strong' notion of belief, similar to a 'conviction,' is intended to expose the unique mental state of believing in contrast with that of knowing or opining, both of which would fulfill (1), but not (2). In all, our previous theoretical work sets a restrictive framework to investigate the distinctiveness of beliefs with respect to similar psychological states.

Even though some initial characterizations embraced an atomistic approach (i.e., beliefs exist as discrete entities that are largely independent of each other) (Price 1934, 1969), most current stances are holistic, and defend the existence of an interconnected network of beliefs (Brandt and Sleegers 2021; Davidson 1973, 1984; Quine and Ullian 1970). Converse defined the belief system as "a configuration of ideas and attitudes in which the elements are bound together by some form of constraint or functional interdependence" (Converse 1964, p. 3). As proposed by Abelson, belief systems are a body of structured concepts and depend largely on evaluative and affective components, as opposed to knowledge systems (Abelson 1979). Although the holistic view is widely accepted in the scientific community (Griffiths 2014; Michel et al. 2011; Spicer 1971), the hubs of belief networks, both at a population and group-specific level, are still not well characterized.

Recent research on cognitive science and neuroscience has studied various aspects of beliefs and belief systems. For example, Coltheart et al (2018) focused on the neural basis of delusional belief formation, showing that transcranial magnetic stimulation of the dorsolateral prefrontal cortex may induce, similar to hypnosis, delusional beliefs (feeling one's hands magnetically attracted, experiencing arm levitation or rigidity, and taste hallucination). Wolfe and Williams (2018) studied the subjective conscious awareness toward the change of a single belief: the educative effectiveness of spanking. Similarly, although following a network approach, Friedkin and collaborators

(2016) analyzed how logic constraints may have an impact on belief systems, where the network nodes were 'believers' (people having different degrees of certitude on the presence of mass destruction weapons in Iraq) that may influence other nodes. In other words, their study is on 'believer systems,' rather than on belief networks per se. The same approach was followed by Nedić and collaborators (2019), who understand 'belief system' as a social network of believers considering a proposition as true.

The application of graph theory to belief systems (taking individual beliefs as nodes) has been recently introduced by Boutyline and Vaisey (2017), who analyzed centrality in political beliefs. They show that 'ideological identity' (operationalized as an ordinal variable from 1-extremely liberal to 7-extremely conservative) was the most central hub of the network. Further, Brandt et al (2019) used a similar approach to unveil whether symbolic (i.e., emotional attachment) or operational (i.e., opinions on specific issues) components were more central in political belief systems. In line with Boutyline and Vaisey, they show that symbolic-related beliefs are more central, and they are stronger influencers of behaviors. These works operationalize beliefs as propositions with which respondents show their strength of agreement. For example: "Have you made changes to your daily routine in order to protect the environment? 1 (definitely no) to 7 (definitely yes)" (taken from Brandt et al. 2019). This approach allows the study of belief systems as correlation matrices: two beliefs are strongly connected if their score, across participants, is strongly correlated. According to our operationalization, respondents either believe or not in a proposition, since we assume, as other scholars have previously done, that beliefs may not "come in degrees" (Moon 2017). Thus, we do not build correlation matrices, but co-occurrence matrices: two beliefs are strongly connected if both items fulfill the criteria to be considered as beliefs in a high number of respondents.

The main goal of our study is to implement this novel operationalization of belief and to expand previous network analyses on belief systems to spiritual, social and scientific, as well as political, issues. To do so, we assessed volunteers with a 90-item survey, asking whether they agreed with each item and whether they would change their mind in light of irrefutable evidence against it. After detecting beliefs, co-occurrence matrices of beliefs across the sample were built, and a between-subject belief system was constructed. The analysis of this belief system and particular group-specific networks, such as political (left- vs right-winger), gender (female vs male) and age (≤ 30 vs. > 30), allowed us to gain a deeper understanding on the nature of belief hubs, and their distinct configuration across sociodemographic groups.

2 Methods

2.1 Participants

An initial sample of 162 individuals were recruited through advertisements in the main campus of the University of Navarra, press releases and posts in social networks, which included a link or QR code to access the electronic survey. Data were collected between February and March, 2019, and it was anonymized: no personal information was requested. Basic sociodemographic information was collected (gender, age group, civil status, current occupation) at the end of the survey. However, we did not collect information on psychological/psychiatric conditions or current psychopharmacological status. Fifty-four individuals did not complete the entire survey, so they were excluded from analyses using co-occurrence matrices and from any sociodemographic analyses, since they did not provide sociodemographic data. Thus, a total of 108 participants were included in the final sample for the analyses of co-occurrence matrices (sex: 59 female; age: 55 between 18–30 yr, 24 31–40 yr, 18 41–50 yr; 9 51–60 yr, 2 above 60 yr). Analyses with correlation matrices did not require the collection of information from the same number of participants, so all available subjects were included in this approach. The study was approved by the Committee for Ethics in Research of the University of Navarra (protocol number: 2018.191).

2.2 Survey

Participants were administered the survey in Google Forms. After the survey, they answered sociodemographic questions [sex, age, country of residence, political preference ("In general, does your vote usually go to political parties considered as…?: right-wing, left-wing, other"), level of education, mother tongue, marital status, number of children, cohabitation status, mother's level of education, number of courses retaken, current employment]. The survey consisted of 100 propositions (e.g., "I think that the theory of evolution is correct," "I think that all human beings deserve respect," "I think there is extraterrestrial life"), and participants were asked to select their degree of agreement (1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree). According to our theoretical framework (Camina et al. 2021), believing is a propositional attitude that must fulfil two conditions: (1) taking the proposition as true, (2) even considering hypothetically irrefutable proof against it. Thus, if participants selected 5 or 4 (i.e., 'strongly agree' or 'agree') after each proposition, they were asked Question

2: "If you were given irrefutable proof against this, would you change your mind?" (Yes/No). If they answered as 'no,' the item was tagged as a belief for that participant. They were presented a similar question if they selected 1 or 2 ("If you were given irrefutable proof supporting this, would you change your mind?"), although, for simplicity, we have not analyzed 'disbeliefs' in this report. After data collection, 10 propositions (or 'items') were discarded because they contained typographic or writing errors that made interpretation difficult. Hence, 90 propositions were finally analyzed (Table S1). They were categorized according to their content as nature/science-related (in green in all networks in the current manuscript), religious/spiritual (yellow), social-liberal stereotyping (red), conservative stereotyping (blue), individualistic/egocentric stereotyping (cyan), and prosocial (pink) items. Each category contained 15 items. Note that there is a thematic continuum within items and, whereas some of them clearly pertain to one category (Item 38: "There is one God or several gods" is religious/spiritual), others could be ascribed to various groups (Item 59: "Life depends on a spiritual power that cannot be explained at all" is ascribed to nature/science category, although it could be also within the religious/spiritual category). In these cases, the main criterion has been to reach an equal number of items per category.

2.3 Data analyses

2.3.1 Data preprocessing and construction of co-occurrence matrix

Our graph theory approach consists of building between-subject networks from beliefs frequencies and co-occurrence, similar to previous research on semantic memory (Goñi et al. 2011). Thus, each node corresponds to a belief (a proposition that is taken as true, and entails the commitment of considering it as true even in light of hypothetical irrefutable proof against it; note that, in order to simplify the analyses and interpretability of the results, we have excluded beliefs against the veracity of the proposition or disbeliefs, that is, when subjects disagree with the proposition), whose size depends on the number of participants who believe in it. Edge (between-node connections) thickness is a proxy of the number of co-occurrences between pairs of beliefs: a thicker edge between two beliefs entails that both co-exist in a high number of participants. Thus, the inputs to build the networks are co-occurrence square matrices with 90 (i.e., number of items in the survey) rows and columns, each cell containing the number of subjects for whom those items were beliefs (i.e., they agreed or strongly agreed with the proposition, and declared that they would not change their mind even in light of 'irrefutable' proof against it).

In general terms, we performed two different kinds of analyses: a set of evaluations focused on the belief network from the whole group, and additional investigations to disentangle common and specific networks of between-sociodemographic groups. The co-occurrence matrix for the whole group belief network was built as follows: (1) For every volunteer, we first designed a 90-by-2 matrix: for each item, if the participant agreed or strongly agreed with the proposition, we labeled as 1 the first column (0 otherwise); then, if they would not change their mind in light of 'irrefutable' proof against the proposition, the second column of this individual matrix was labeled as 1 (0 otherwise). Please note that all items considered as beliefs (i.e., with a 1 in the second column), necessarily go together with a 1 in the first column: the respondent agrees with it (1 in the first column), and would not change their mind in light of hypothetical irrefutable evidence (1 in the second column). If the respondent does not agree with the proposition (0 in the first column), the item cannot be considered as a belief (necessarily, 0 in the second column). If the respondent agrees or strongly agrees with the proposition (1 in the first column), but would change their mind in light of hypothetical irrefutable proof against it (0 in the second column), the subject *agrees* with the proposition, but does not *believe* in it. (2) Then, we designed a 'belief co-occurrence matrix' containing only those items considered as beliefs (labeled as 1 in both columns of the previous matrices), and another 'agreement co-occurrence matrix,' including those items with which subjects agree or strongly agree (coded as 1 in the first column), irrespective to the answer to the second question (coded as 0 or 1 in the second column). Thus, co-occurrence matrices were 90-by-90 matrices containing the total number of subjects who believed in or agreed with all possible pairs of items. Necessarily, the number in a particular cell of the 'agreement co-occurrence matrix' was greater than the number in that cell of the 'belief co-occurrence matrix' (in an extreme case both numbers could be equal, but this peculiarity did not happen in our data). (3) Then, we carried out two steps: (3a) a threshold of 25% of the maximum possible value (total number of participants, 108) was selected to discard spurious co-occurrences among the data; thus, only pairs of items co-occurring in at least 27 participants were further considered; (3b) we normalized each matrix ('belief' and 'agreement' co-occurrence matrices) by subtracting the matrix' minimum from each value, and dividing between the subtraction of the minimum from the maximum of the matrix. Thus, we obtained two matrices whose values ranged from 0 to 1. Normalization at this stage was necessary because, otherwise, the value of every cell in the 'belief matrix' would have been lower than its counterpart in the 'agreement matrix'. Consequently, subtraction in step 4 would have always produced a negative number. (4) The next steps were the subtraction of the 'agreement

normalized matrix' from the 'belief normalized matrix,' removal of negative values (to exclude those pairs of items that behaved as 'agreements' rather than as 'beliefs'), and normalization of the resulting matrix as above. In conclusion, the final matrix contained values between 0 and 1, and higher values indicated a higher co-occurrence of pairs of items that specifically behaved as 'beliefs' (and not just as 'agreements'). All these procedures were carried out in MATLAB R2018a (Mathworks).

With regard to network analyses between sociodemographic groups, we compared belief systems of right- vs left-wingers, younger (≤ 30) vs older (> 30) participants, and female vs male. After assigning participants to their corresponding group, steps 1, 2 and 3a were followed as above concerning data preprocessing. Note that the number of participants varied for each sociodemographic group (right-wingers, 59; left-wingers, 22; younger, 55; older, 53; female, 59; male, 49) and therefore the 25%-threshold produced a different number in each case. After this initial preprocessing, we ended up with one co-occurrence matrix for each group. Then, we followed two different approaches to assess networks with common and specific beliefs for the two groups under analysis. First, we intended to build a single network including both common and specific beliefs for each group. To do so, after step 3a, we ended up with one co-occurrence matrix per group whose cells contained the number of co-occurrences above threshold. Those beliefs that only appeared in one group were tagged as such (for example, L or R in Fig. 3), whereas those beliefs common to both ideological or sociodemographic groups were tagged with a B. After this, a single network per group including common and specific beliefs was built. Centrality and segregation analyses (see below) were excluded from these networks, since the main goal was to have a general picture of common and specific mechanisms in the belief system. The second approach was intended to build the distinctive network for each ideological or sociodemographic group. Thus, in order to focus on those pairs of items which were different between groups, we performed pairwise chi-squared tests ($p < 0.05$ as threshold for significance, with False Discovery Rate to correct for multiple comparisons) between groups of interest (right- vs left-winger, younger vs older, female vs male) for each single cell of the matrices (i.e., for every 90-by-90 co-occurrence). Thus, steps 3b and 4 (creation and normalization of co-occurrence matrices) were carried out in matrices that were specific for each sociodemographic group, in comparison with its counterpart. Similarly, with respect to step 4, instead of subtracting the 'agreement' matrix from the 'belief' matrix, the 'belief' matrix of each group was subtracted from that of its counterpart. In other words, the belief matrix of group B (i.e., right-wingers) was subtracted from that of group A (i.e., left-wingers); hence, positive values corresponded to those pairs of beliefs

specifically occurring in group A (but not B), whereas negative values pointed to pairs of beliefs present in group B (but not A). Finally, the matrix with positive values was normalized as explained above, and the one with negative values was normalized after inverting the signs.

2.3.2 Correlation matrices

Even though our main interest is to empirically apply our restrictive operationalization of belief, we have also analyzed the data following previous methodologies for comparison (Boutyline and Vaisey 2017). Thus, apart from using a dichotomous approach on beliefs (one subject either believes or not in a proposition), which produced co-occurrence matrices, we also built matrices whose cells contained the correlation coefficient (Pearson's r value) for the degree of agreement (from 1 = strongly disagree to 5 = strongly agree) for each pair of items. Thus, if participants tended to strongly agree (or strongly disagree) with two items, these items were expected to be 'connected', and their correlation coefficient would be high. After building the correlation matrix at group level, we discarded r values lower than 0.2 to remove possibly spurious correlations. For the sake of clarity, we also discarded negative correlations.

2.3.3 Network parameters

From a psychological perspective, we are interested in detecting the beliefs of a sample of volunteers, and describing the configuration of beliefs as a network at group level. Once beliefs have been detected with our novel operationalization, our main objective is to find 'deep-seated beliefs', which are expected to be connected with many other beliefs, especially with other hubs, configuring the scaffold of the system (Echarte et al. 2016). At the same time, this would entail the detection of peripheral or superficial beliefs, that is, those showing a loose connectivity in the whole system. We assume that the whole network may have different layers of complexity, and we could be able to find subnetworks of beliefs with a varied level of connection between nodes. Finally, we intend to find different networks (both in terms of structure and content) in different ideological and sociodemographic groups.

Therefore, we are exploring two network parameters: centrality and segregation. With respect to centrality, we are looking for those nodes behaving as hubs (i.e., deep-seated beliefs, those with more connections and strongest connections with other nodes; in other words, beliefs co-occurring with many other beliefs, and in a greater number of participants), and also those showing a loose connectivity in the whole system. For that reason, we assessed centrality for each network using the weighted degree parameter. Beliefs with higher weighted degree values are expected to be the central or deepest beliefs of the system, since they have: (a) a strong connection with other beliefs; and/or (b) a connection with many other beliefs. Having either one or both attributes (which are captured by weighted degree) would qualify as a central belief. Also, we used the k-core as a segregation parameter, which allows to find subnetworks within the whole network. The different values of k-core in a network should be understood as layers of increasingly complex (unweighted) subnetworks. Hence, higher k-core values point to subnetworks including highly interconnected nodes in terms of the number of edges, irrespective to connection strength (i.e., number of participants for which both beliefs co-occur). Network analyses were carried out in Pajek (Batageli and Mrvar 1998) and matrices were prepared in MATLAB R2018a (Mathworks).

2.3.3.1 Weighted degree
According to Freeman (1978), the degree of a focal node is the number of adjacencies in a network, i.e., the number of nodes that the focal node is connected to. This measure can be formalized as follows (Eq. 1) (Freeman 1978):

$$k_i = C_D(i) = \sum_j^N x_{ij}$$

where i is the focal node, j represents all other nodes, N is the total number of nodes, and x is the adjacency matrix, in which the cell xij is defined as 1 if node i is connected to node j, and 0 otherwise (Opsahl et al. 2010). The degree can be generalized as weighted degree (i.e., sum of weights) in weighted networks (Barrat et al. 2004; Newman 2004; Opsahl et al. 2008), which is formalized as follows (Eq. 2):

$$s_i = C_D^w(i) = \sum_j^N w_{ij}$$

where w is the weighted adjacency matrix, being $w_{ij} > 0$ if the node i is connected to node j, and representing the weight of the tie.

To sum up, the weighted degree of a node is a centrality measure that takes into consideration the weights of ties, which has been the preferred measure for analyzing weighted networks (Barrat et al. 2004; Opsahl et al. 2008) like ours. Regarding our data, connection strength points to the number of participants that consider a pair of items as beliefs (in the case of co-occurrence matrices), or to the correlation coefficient between two items (in the case of correlation matrices).

2.3.3.2 K-core
Weighted degree does not inform whether nodes are clustered within the network. To find these clusters or subnetworks, we used the k-core decomposition. This algorithm considers the connections of all nodes within a cluster. These clusters are called k-cores, where k indicates the minimum (unweighted) degree of each node within

the core; for instance, a 2-core contains all nodes that are connected with at least a degree of 2 to other nodes of the network. Note that k-core values are integers because they indicate the number of edges, irrespective to its weight. Through k-core decomposition, a network is organized as a set of successive k-cores (or k layers) until a maximum value is obtained. To sum up, the k-core can be defined as a maximal subnetwork in which each node has at least degree k within the subnetwork (de Nooy et al. 2002).

3 Results

First, we present the structure of the belief-specific network for the whole group, using both our restrictive operationalization of beliefs (with co-occurrence matrices) and strength of agreement as previous reports (with correlation matrices). Second, we describe the networks resulting from the sociodemographic analyses, which include common mechanisms and belief-specific networks after pairwise comparisons (chi-squared tests; multiple comparison corrected) between political preferences (left- vs right-winger), sex (female vs male), and age (under 30 vs over 30).

3.1 Group belief-specific network

3.1.1 Co-occurrence matrices

After data processing and filtering, 20 propositions were obtained as part of the belief network (Table 1; Fig. 1). The five most central propositions were the following: item 38, item 19, item 25, item 34 and item 21.

The k-core-based segregation analysis revealed five layers within the network structure. These layers are represented with different numbers within nodes in Fig. 1. The most central cluster (7-core) may be considered the core beliefs at the group level, and was composed of 10 items (Table 1, bold typesetting): 38, 19, 25, 34, 21, 66, 5, 24, 86 and 76. Note that this cluster includes spiritual/religious (38, 19, 21), prosocial (24, 34, 66, 5, 76, 86) and conservative (25) beliefs.

In conclusion, the belief network of the whole sample contained 20 nodes, most of them of prosocial content, but also spiritual/religious issues. Half of them constituted a subnetwork of nodes strongly interdigitated.

3.1.2 Correlation matrices

We also used a 90-by-90 matrix containing Pearson's r correlation coefficients on the level of agreement for each item

Table 1 Items conforming the belief network for the whole sample

#	Item	WD
38	**There is one God or several gods**	**6.66**
19	**God answers people's prayers**	**6.64**
25	**Business decisions should influence religious or ethical principles about what is right or wrong**	**5.73**
34	**One should help those who are weak and cannot help themselves**	**5.69**
21	**The soul or spirit survives death**	**4.27**
66	**People should help those less fortunate than them**	**3.94**
5	**All human beings deserve respect**	**3.49**
24	**The value of a person's life is more important than the value of any institution**	**3.24**
86	**Being controlled or dominated by others is intolerable**	**2.80**
26	There is a spiritual component in every person	2.21
76	**Political leaders should be more aware of the human side of their programs**	**2.08**
64	Human needs should always be ahead of economic considerations	1.35
29	It is interesting to learn and develop new hobbies	1.04
17	We should have the religious authorities to make decisions about moral issues	0.83
44	The complexity of the world suggests that it was intentionally designed by an intelligent creator	0.77
68	Same-sex relationships are correct	0.59
41	There are demons or evil spirits	0.17
15	When I die I will see loved ones who have died before me	0.14
28	It is important to pay your debts	0.04
14	When I die I will be judged	0.02

#, Item number according to the survey (Table S1); WD, Weighted degree.

Items in bold typesetting indicate those items of the core network (k = 7)
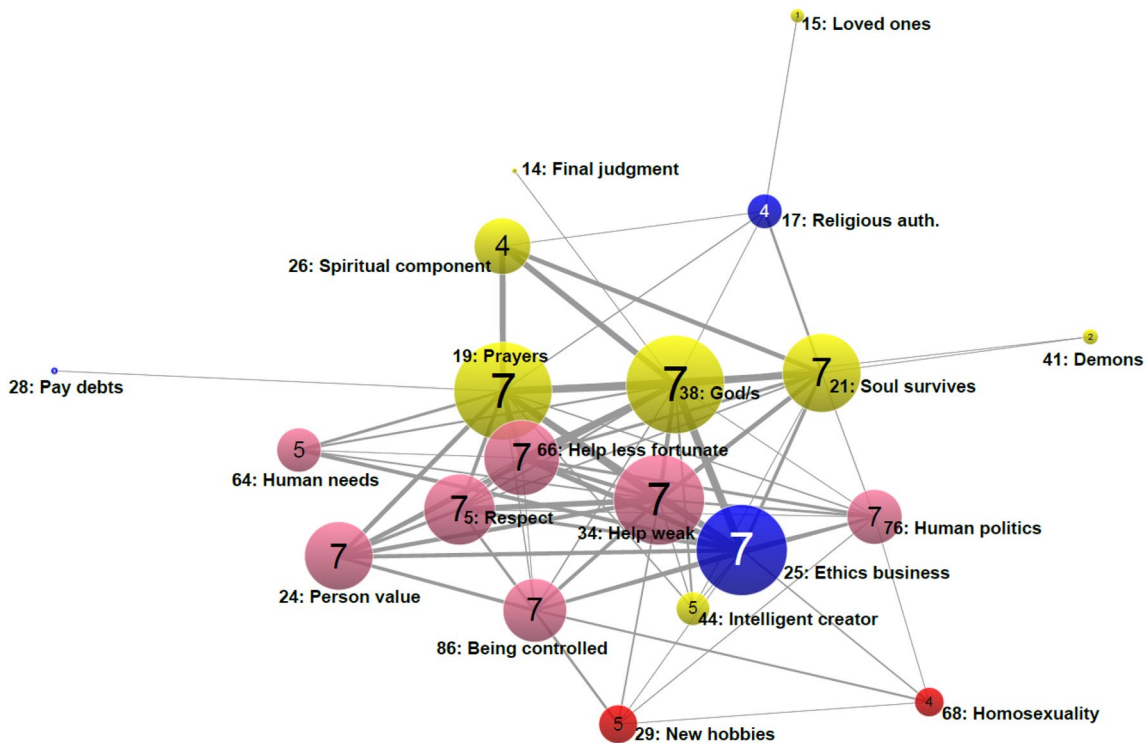
Fig. 1 Belief network for the whole sample, organized by Kamada-Kawai free energy. Node size is proportional to weighted degree, edge thickness is weighted by connectivity strength, and numbers within nodes indicate k-core. In all networks throughout the manuscript, node colors correspond to the different categories of survey items: nature/science (green), religious/spiritual (yellow), social-liberal stereotype (red), conservative stereotype (blue), individualistic/ego-centric stereotype (cyan), prosocial stereotype (pink). Item number and a short description is shown adjacent to the node. For a full description of survey items, see Table S1

to build the group network. With this approach, by definition, the network is more populated (Fig. 2), since it includes all items of the survey, whereas with our restrictive operationalization of beliefs only some of the items should be considered as beliefs. In this case, the network showed a cluster of 15 highly interconnected nodes (k = 12), which mainly included propositions with religious/spiritual content (3, 8, 14, 15, 17, 19, 21, 26, 37, 38, 41, 44, 47, 59 and 90). Some of these nodes showed a high WD (top-five WD values: 19, 21, 38, 44 and 15). Next, the network contained a small 11-core cluster of items with varied contents (5, 25, 77 and 85), whose WD was lower. After one single node (item 8) highly interconnected (k-core = 8) but with relatively low WD (2.53), there was a relatively large 7-core cluster including mostly social-liberal items (10, 11, 20, 23, 30, 46, 54, 56, 57, 61, 66, 68, 71, and 89). After a smaller 6-core cluster with mainly nature/scientific items, the largest cluster was composed of 33 nodes loosely connected (5-core) which in general contained items with conservative, individualistic and science/nature-related content. The complete information on centrality and segregation for this correlation network is shown in the supplementary information (Table S2).

In conclusion, even though our novel operationalization of belief is more restrictive, and it produces a smaller

network, the most central items are very similar to those obtained with correlation matrices. Interestingly, items with spiritual/religious content are the most central nodes in both cases, showing that these results do not strictly depend on our restrictive operationalization.

3.1.3 Interim discussion: comparison between co-occurrence and correlation matrices

In this article, we implement a novel operationalization of belief to be applied to psychological and social sciences, which was described in detail elsewhere (Camina et al. 2021). Previous work understands belief as a proposition that is considered to be true by the respondent. We contend that this definition does not capture the unique psychological state of believing, since it can be equally applied to preferences, opinions, perceptions, predictions, etc. According to our analysis, someone believes in a proposition when they agree with it, and commit to agree even if hypothetical irrefutable proof against it were presented. This could be possible at least for two reasons: the subject might have such a strong evidence supporting the proposition that any proof against it would be defeated; alternatively, they could
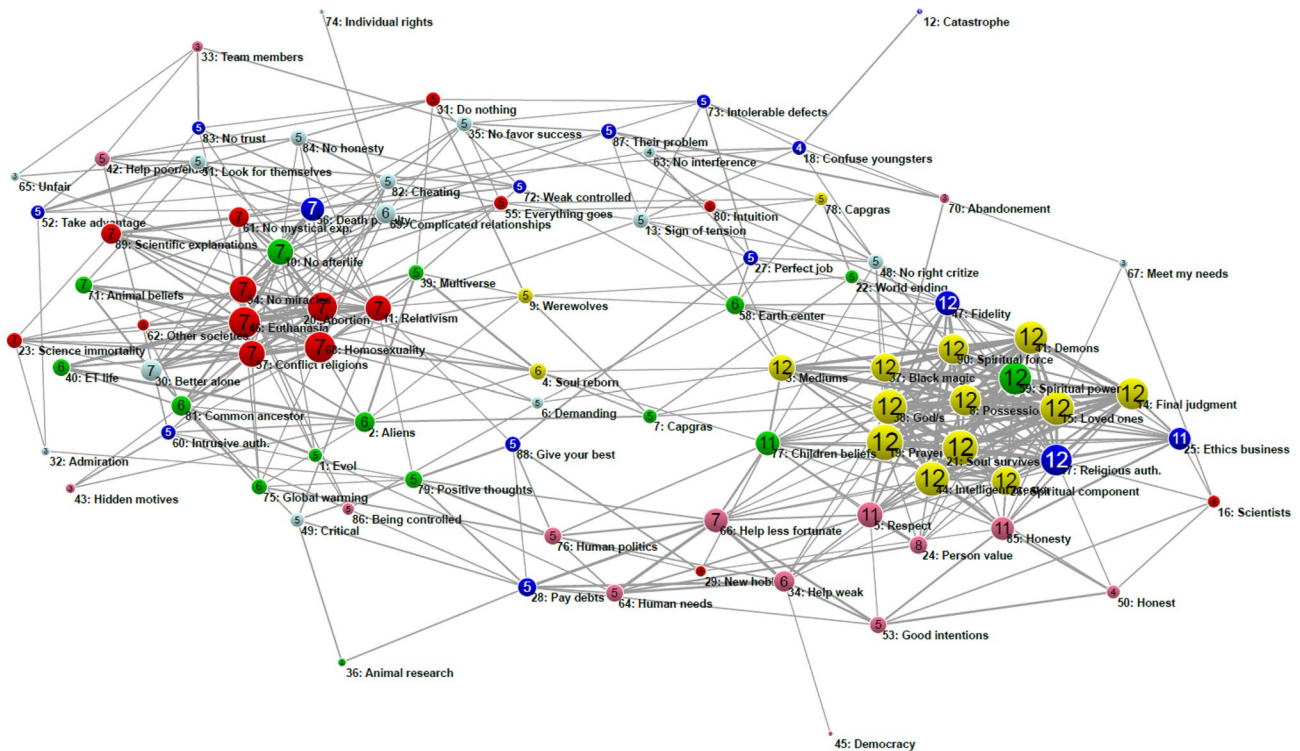
Fig. 2 Group network from correlation matrices on agreement strength. Network showing pairwise correlations on agreement strength for all items of the survey. The densest subnetwork (k-core = 12) included spiritual/religious items, whereas a 7-core cluster contained social-liberal items. The network is automatically organized by Kamada-Kawai free energy. Node size is proportional to weighted degree, edge thickness is weighted by connectivity strength (in this case, Pearson's r coefficient), and k-core is shown within nodes. See Fig. 1 legend for color code

discard the mere possibility of existence of evidence against the proposition.

From a practical point of view, the two different ways of operationalizing beliefs result in two different approaches: according to the 'classical' definition, belief networks can be analyzed as correlation matrices, since respondents may express different levels of agreement with 'beliefs' (i.e., propositions taken as true). However, our perspective leads to study belief networks as co-occurrence matrices, since beliefs are dichotomous: a subject either believes or not in a proposition. Do both operationalizations lead to different answers on network analyses of belief systems?

The first difference is obvious: the number of nodes. Whereas the correlation matrix approach assumes that all items in the survey are beliefs, our proposal is intended to detect which items among the survey behave as beliefs. Hence, the network based on a correlation matrix (Fig. 2) is 'noisier' than the graph using a co-occurrence matrix (Fig. 1), whose nodes are the propositions with which respondents show a higher level of commitment. The former and more general approach may overweigh items with similar content (i.e., 'correlated' content) to the main hubs, even though its content is not fully convincing for respondents.

For example, item 8 ("Some people are possessed by evil spirits") is a hub using correlation matrices, but not with the co-occurrence matrix. This is due to the strong correlation with items with a religious/spiritual content in general. However, our restrictive approach shows that only 18 respondents (out of 108) are fully committed with the veracity of the proposition even if hypothetical irrefutable proof against it were presented, whereas 51 and 63 respondents believe (according to our operationalization) in items 19 and 38. In other words, many subjects tend to agree with evil possessions just because they believe that God exists; but, crucially, they are open to reconsider the former in light of new evidence, and not the latter. Our approach, therefore, is more suitable to detect those items that are strongly established in the person's worldview.

Further, the use of correlation matrices would produce a critical limitation in the following analyses: the comparison of belief networks between different sociodemographic groups. With a correlational approach, the correlation coefficient between two items is very high if most subjects give the same response to both items. In other words, there would be a strong correlation if most subjects agree, are neutral, or disagree with both items. When comparing belief networks

among sociodemographic groups, this is an important limitation. For example, the correlation coefficient between items 38 ("There is one God or several gods") and 19 ("God answers people's prayers") is 0.7271 for left-wingers, and 0.6724 for right-wingers. There is no significant difference between groups. However, most left-wingers (63.6%) disagreed or strongly disagreed with item 19, and most right-wingers (64.4%) supported it. With respect to item 38, 36.4% of left-wingers disagreed, and 78% of right-wingers agreed with it. When considering our dichotomous characterization, 22.7% and 31.8% of left-wingers believed in items 19 and 38, respectively, whereas figures scaled up to 57.6% and 69.5% for right-wingers. Again, data point to intergroup differences that would not be captured by previous approaches. As a consequence, we restrict subsequent analyses to the novel operationalization that we implement in this report.

In conclusion, we empirically show that our conceptualization is more specific to detect those propositions with which respondents have a unique commitment, and is more appropriate to find between-group differences in belief systems.

3.2 Sociodemographic belief networks

3.2.1 Political preference: left-wingers vs right-wingers

As part of the survey, participants were asked about their political preference. Twenty-two participants answered 'left,' 59 participants chose 'right,' and the remaining 27 responders answered either 'other' or typed an answer. In the current analysis, we compare left-winger (N = 22) with right-winger (N = 59) participants.

Political-preference groups were matched in terms of age (45% of left-wingers were under 30, whereas 46% of right-wingers fell under this age; $\chi^2 = 0.0006$, $p = 0.98$), sex (68% and 54% female in left- and right-wingers, respectively; $\chi^2 = 1.279$, $p = 0.26$) and civil status (23% and 29% were married in left- and right-wingers, respectively; $\chi^2 = 0.3$, $p = 0.58$).

After building co-occurrence matrices for each group, the value of each cell was compared between groups with chi-square tests. After FDR-correction for multiple comparisons, 437 (out of 4005 possible co-occurrences, 10.9%) were significant. They mainly affected item 68 (significant differences in co-occurrences with 31 items), 5 and 29 (with 30 items), 75 and 76 (with 28 items). Before showing the differences and specificity of networks for each group, we will show a single network displaying the common beliefs and specific nodes for each group. This graph (Fig. 3) shows that
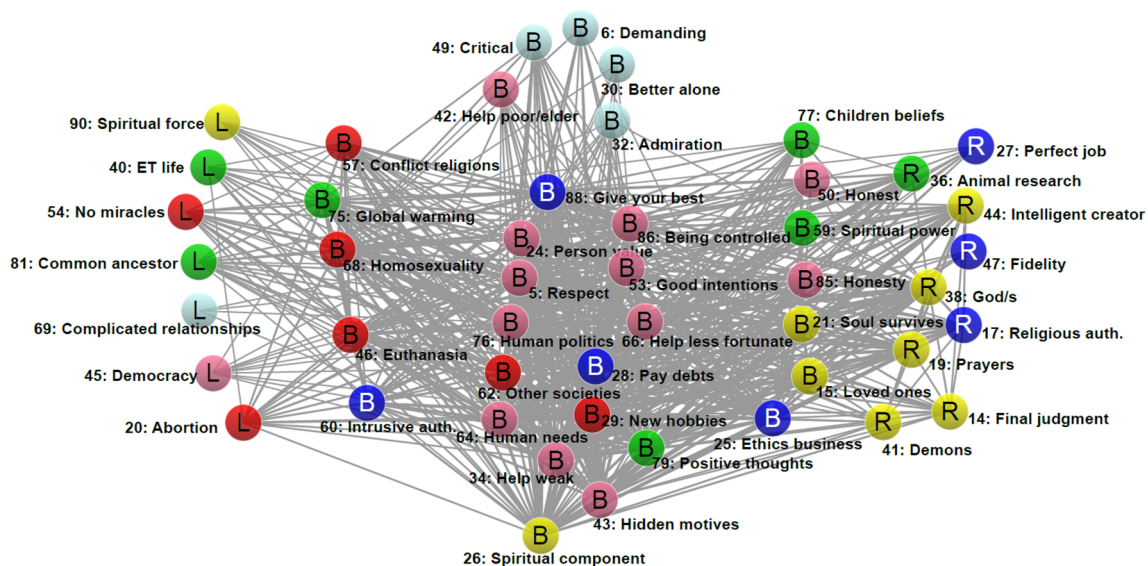
Fig. 3 Common and distinctive beliefs for left- and right-winger participants. Network showing common and distinctive beliefs for left- and right-winger participants. L = nodes distinctive of left-wingers; R = nodes distinctive of right-wingers; B = common nodes for both groups. Distinctive beliefs are shown in either the left or right part of the network. The adjacent groups of beliefs labeled with a B are common beliefs preferentially linked to either the left- or right-wingers (for example, item 41 is common for both groups, but it is directly linked to right-wingers' distinctive beliefs, and indirectly linked to left-wingers' distinctive beliefs through other common beliefs; item 46 is the opposite case). Nodes in the central part of the network are common beliefs directly linked to either left- or right-wingers' distinctive beliefs. Centrality and segregation measures are not shown in this network. See Fig. 1 legend for color code

most specific beliefs for right-wingers have a spiritual/religious content, whereas those of left-wingers have a varied content, including nature/science and social-liberal items. Next, there is a layer of common beliefs that directly connect with the specific nodes of each groups, and indirectly with other common beliefs for its counterpart. For example, items 77, 50, 59, 81, 21 and 15 are common to both groups, but they are directly connected to right-wingers' specific beliefs. On the other hand, items 57, 75, 68, 46 and 60 are also common, but they are directly connected to left-wingers' specific beliefs, and indirectly (through other common beliefs) to right-wingers' specific items. Beliefs shown in the central part of the graph (i.e., 24, 5, 76, 62, 64) are common and directly connected to the specific beliefs of each group. Interestingly, they have mostly a prosocial content.

With respect to the specific belief networks for each group, we stress that these networks were obtained after detecting which pairs of items were statistically different between groups (with chi-squared tests and FDR correction). Therefore, the group-specific most representative beliefs may not be the most frequent items in absolute terms in each group, but the most frequent in comparison with those of the other group. As it is shown in Fig. 4, in terms of nodes (or beliefs), both networks had similar numbers: 37 and 40 for the left- and right-wing voters, respectively.

According to the weighted degree metric, the most central specific beliefs of the left-wingers (Table 2) were item 75, 68, 57, 46 and 20. On the other hand, the five most central specific beliefs of the right-wing voters (Table 3) were item 19, 38, 44, 17 and 36.

In conclusion, both groups showed a common belief network including mainly prosocial items. The specific left-winger belief network included mainly social-liberal propositions at its core, whereas in the right-winger group the hubs had mainly a spiritual/religious content.

3.2.2 Age: younger (≤ 30) vs older (> 30) participants

With regards to age, 55 participants declared to be between 18 and 30, whereas 53 were older than 30. Samples were matched in terms of political preference (51% of younger participants voted right-wing parties, whereas 58% of older participants did so; $\chi^2 = 0.626$, $p = 0.43$), and sex (56% and 53% of the younger and older groups, respectively, were female; $\chi^2 = 0.136$, $p = 0.71$). However, as expected, they were unbalanced in terms of civil status (7% and 70% of younger and older participants were married, respectively; $\chi^2 = 44.82$, $p < 0.00001$). Therefore, differences in the belief system between age groups could not be distinguished from those of civil status, and vice versa.

In this case, after FDR-correction, 209 pairs of items (5.2%) were significantly different between both groups. Item 64 had significant differences with 19 items, item 42

with 18 items, and item 14 with 17 items. Items 64 and 42 have a prosocial content, and item 14 refers to afterlife judgement. With respect to the single network for both groups (Fig. 5), there were only 3 (items 16 and 20, with social-liberal content, and item 6, with individualistic content) and 5 (27 and 47, conservative; 14, religious/spiritual; 42 and 45, prosocial) specific beliefs for younger and older participants, respectively. As it happened with political ideology, most common beliefs (i.e., those directly connected to specific beliefs of both groups) had a prosocial content (Fig. 5).

With respect to group-specific belief networks, we followed the same procedure as with political preference, and hence differences in co-occurrences are reported for those pairs of items that were significantly different between groups. After this, 33 (Table 4) and 37 (Table 5) group-specific beliefs were found for younger and older participants, respectively (see Fig. 6A and B). The five items with the highest weighted degree were the following for the younger group: 46, 6, 32, 5 and item 24. These items have a varied content, from de defense of euthanasia (social-liberal) to prosocial beliefs in favor of people in need, and considering other people too demanding (considered as an individualistic item). With respect to older participants, the most central specific beliefs were item 42, 14, 27, 64 and 60. The content of these propositions referred to helping those in need (prosocial), afterlife judgment (spiritual/religious), perfectionism (conservative), and considering authorities as intrusive (conservative).

3.2.3 Gender: Female vs. Male

We collected data from 59 women and 49 men, and both groups were balanced in terms of political preference (54% of female participants voted right-wing parties, whereas 55% of male participants did so; $\chi^2 = 0.0081$, $p = 0.93$), age (54% and 49% were under 30 in the female and male group, respectively; $\chi^2 = 0.296$, $p = 0.59$) and civil status (37% and 41% were married in the female and male group, respectively; $\chi^2 = 0.140$, $p = 0.71$).

In the case of gender, after FDR-correction, 386 pairs of items (9.6%) were significantly different between both groups. Item 5 had significant differences with 37 items, item 24 with 36 items, item 29 with 34 items, and items 66 and 79 with 33 items. With respect to the single network of both groups (Fig. 7), male participants had only 1 specific belief (that is, 1item considered as a belief for male respondents, which was not a belief for female participants). This was item 81, which was strongly connected to item 34, and, through it, with the remaining common beliefs. On the other hand, items spanning all contents (45, 42, 27, 30, 47, 59, 90, 41, 6, 77 and 20) were specific beliefs of the female group,
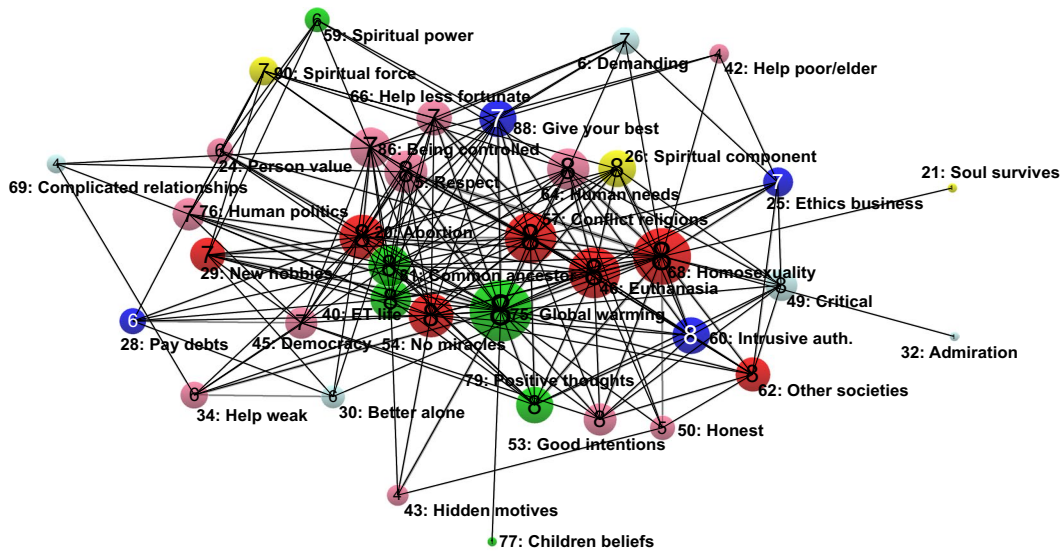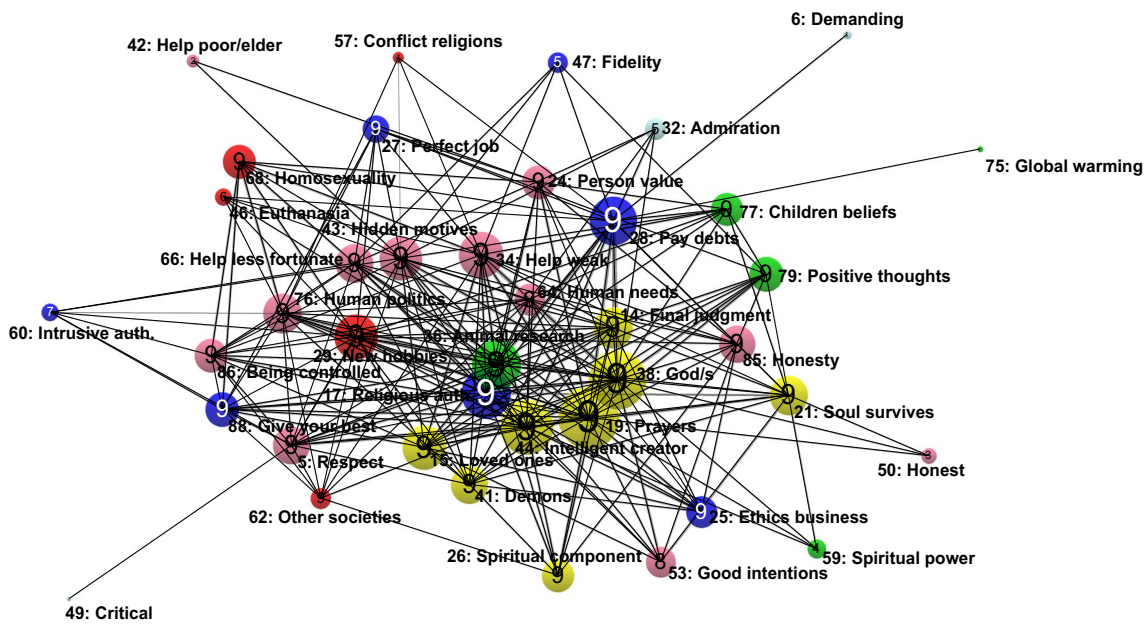
Fig. 4 Specific belief networks for left- and right-winger participants. Specific belief network for left- (**A**) and right-wingers (**B**), organized by Kamada-Kawai free energy. Node size is proportional to weighted degree, edge thickness is weighted by connectivity strength, and numbers within nodes indicate k-core. See Fig. 1 legend for color code

and where densely connected with items shared with male respondents.

With respect to group-specific belief networks, they were greatly unbalanced in terms of number of nodes: after comparing each possible co-occurrence between groups, there were 42 specific beliefs for female participants (Table 6),

and 16 items for males (Table 7) (see also Figs. 8A and 8B, respectively). The five most central items for female participants were the following: 5, 29, 77, 24 and 66. Their content included helping others in need, openness to new experiences, and children having beliefs. With respect to male participants, the five most central specific beliefs were

Table 2 Items conforming the group-specific belief network for left-wingers

#	k-core	Item
75	8	Humans cause global warming
68	8	Same-sex relationships are correct
57	8	Organized religion is one of the main sources of human conflicts
46	8	Euthanasia, that is, ending the life of a human who is incurably ill to limit suffering, is correct
20	8	Abortion is correct
54	8	Most things called miracles are pure chance
5	8	All human beings deserve respect
64	8	Human needs should always be ahead of economic considerations
81	8	Human beings share a common ancestor with apes
86	7	Being controlled or dominated by others is intolerable
40	8	There is extraterrestrial life
26	8	There is a spiritual component in every person
60	8	Government authorities tend to be intrusive and controlling
79	8	Positive thoughts and attitudes improve physical well-being
88	7	You always have to give your best
66	7	People should help those less fortunate than them
29	7	It is interesting to learn and develop new hobbies
62	8	Ideas about what is right and what is wrong that other societies have, even if they are different from mine, may be valid for them
53	8	Most people generally have good intentions
76	7	Political leaders should be more aware of the human side of their programs
45	7	Democracy is the best system of government
49	8	People tend to be either critical or indifferent to others
25	7	Business decisions should influence religious or ethical principles about what is right or wrong
90	7	I am part of a spiritual force on which all life depends
6	7	People are often too demanding
34	6	One should help those who are weak and cannot help themselves
28	6	It is important to pay your debts
24	6	The value of a person's life is more important than the value of any institution
50	5	Most of the people I deal with are honest and faithful
59	6	Life depends on a spiritual power that cannot be explained at all
30	6	It is better to be alone than to feel "tied" to other people
43	4	There are people who act with hidden motivations
42	4	Whatever we do for the poor and the elder, it will never be enough
69	4	Relationships are complicated and interfere with freedom
21	1	The soul or spirit survives death
32	1	It is very important to get recognition, compliments and admiration
77	1	Young children (under 6 years old) are capable of having beliefs

Items are ordered by centrality (weighted degree)

item 36, 25, 32, 49 and 53. They referred to the adequacy of using animals for research, ethical principles in business, the importance of recognition, and, contradictorily, people having good intentions and people being either critical or indifferent with others.

In conclusion, the belief network for female participants was much denser than for male volunteers. Both networks, albeit strikingly unbalanced, had were varied in terms of item contents. In any case, the most central specific belief for male respondents had a nature/science-related content (supporting animal research), whereas the hubs for female participants were mainly prosocial and spiritual/religious.

**Table 3** Items conforming the group-specific belief network for right-wingers

#	k-core	Item
19	9	God answers people's prayers
38	9	There is one God or several gods
44	9	The complexity of the world suggests that it was intentionally designed by an intelligent creator
17	9	We should have the religious authorities to make decisions about moral issues
36	9	It is okay to use animals for medical research
28	9	It is important to pay your debts
34	9	One should help those who are weak and cannot help themselves
29	9	It is interesting to learn and develop new hobbies
15	9	When I die I will see loved ones who have died before me
43	9	There are people who act with hidden motivations
14	9	When I die I will be judged
76	9	Political leaders should be more aware of the human side of their programs
21	9	The soul or spirit survives death
66	9	People should help those less fortunate than them
41	9	There are demons or evil spirits
5	9	All human beings deserve respect
85	9	Being absolutely honest is good for doing business
79	9	Positive thoughts and attitudes improve physical well-being
88	9	You always have to give your best
24	9	The value of a person's life is more important than the value of any institution
86	9	Being controlled or dominated by others is intolerable
68	9	Same-sex relationships are correct
26	9	There is a spiritual component in every person
77	9	Young children (under 6 years old) are capable of having beliefs
64	9	Human needs should always be ahead of economic considerations
25	9	Business decisions should influence religious or ethical principles about what is right or wrong
53	8	Most people generally have good intentions
27	9	It is important to do a perfect job in everything
32	5	It is very important to get recognition, compliments and admiration
62	9	Ideas about what is right and what is wrong that other societies have, even if they are different from mine, may be valid for them
47	5	Fidelity to one's ideals and principles is more important than having an open mind
59	4	Life depends on a spiritual power that cannot be explained at all
60	7	Government authorities tend to be intrusive and controlling
46	6	Euthanasia, that is, ending the life of a human who is incurably ill to limit suffering, is correct
50	3	Most of the people I deal with are honest and faithful
42	2	Whatever we do for the poor and the elder, it will never be enough
57	4	Organized religion is one of the main sources of human conflicts
6	1	People are often too demanding
75	1	Humans cause global warming
49	1	People tend to be either critical or indifferent to others

Items are ordered by centrality (weighted degree)

4 Discussion

In this study, we describe the belief network of a small sample of volunteers, and the group-specific web of beliefs for crucial sociodemographic groups. In a previous work, we operationalized the concept of belief to determine what kind of propositions should be considered as beliefs in empirical studies: those with which the subject agrees and expresses their commitment to keep considering as true even with hypothetical irrefutable proof against it. Given this restrictive definition, 20 beliefs (out of 90 candidate propositions) configured the network at a group level. A core subnetwork
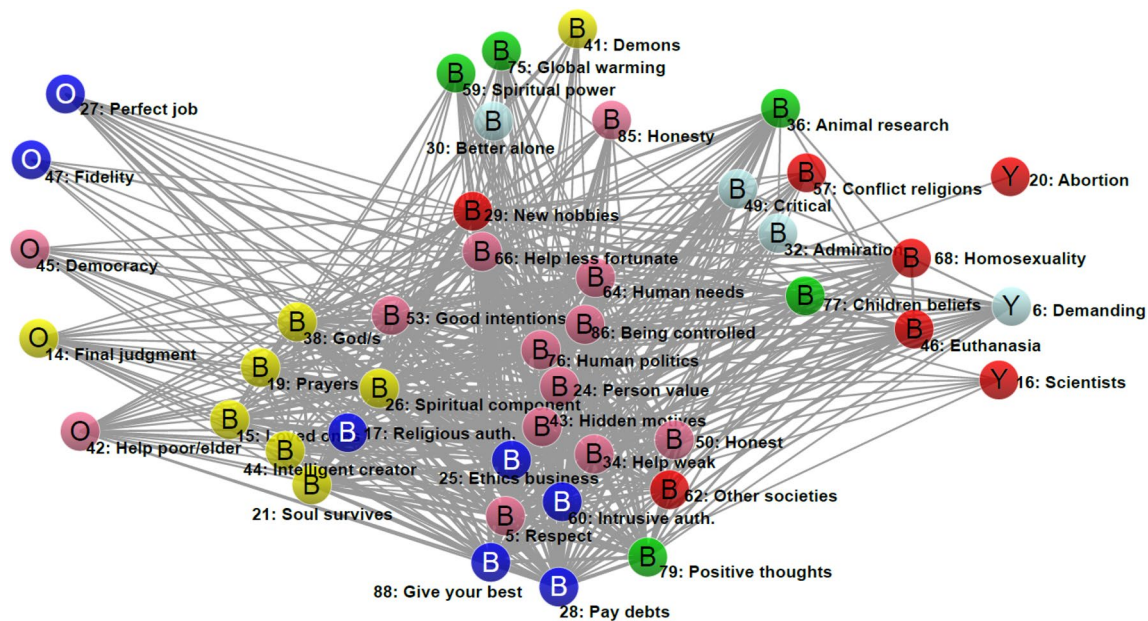
Fig. 5 Common and distinctive beliefs for younger and older participants. Network showing common and distinctive beliefs for younger and older participants. Y = nodes distinctive of younger (under 30) participants; O = nodes distinctive of older participants; B = common nodes for both groups. Distinctive beliefs are shown in either the left or right part of the network. The adjacent groups of beliefs labeled with a B are common beliefs preferentially linked to either the younger or older group (for example, item 46 is common for both groups, but it is directly linked to the distinctive beliefs of the younger group, and indirectly linked to the older group's distinctive beliefs through other common beliefs; item 38 is the opposite case). Nodes in the central part of the network are common beliefs directly linked to either left- or right-wingers' distinctive beliefs. Centrality and segregation measures are not shown in this network. See Fig. 1 legend for color code

included 10 spiritual/religious and prosocial beliefs. Concerning sociodemographic groups, the most central beliefs of the group-specific web for left-wingers included social liberalist beliefs, whereas those of the right-wingers were mainly spiritual/religious. The belief hubs for younger participants were a mix of social liberalist, individualistic and prosocial propositions, and those for older respondents were spiritual, conservative and prosocial. Finally, the female's belief network was much denser than that of male participants; in both cases, hubs were varied in terms of content.

Previous empirical research has defined belief as any proposition considered as true by the agent. This broad definition makes difficult to distinguish beliefs from, for example, knowledge, opinions or preferences. In order to expose the specific mental state of believing, we proposed the finer-grained operationalization described above. It allows to describe how group-wise convictions are interconnected in a web structure. Previous research has analyzed single beliefs (Wolfe and Williams 2018), aberrant beliefs (Coltheart et al. 2018), beliefs of a single typology (Boutyline and Vaisey 2017), or interaction between believers (Friedkin et al. 2016). Our main goal was to carry out a wide description of the belief system, but with a restricted conceptualization of belief. Thus, we constructed a survey including religious/spiritual, nature-/science-related, and social (regarding social-liberalist, conservative, individualistic and prosocial stereotyping) propositions to detect which of them were firmly held by volunteers. This has, at least, two possible limitations: 1) beliefs (i.e., nodes in the graph) are restricted to those propositions included in the survey; 2) given our strong conception of belief (willingness to hold it even in light of hypothetical irrefutable evidence against it), results could be biased to transcendental propositions. With respect to the former, 90 propositions would be enough for an initial description of the belief network at a group level; in any case, future research could be designed to ask volunteers for freely expressing their beliefs, having received first a clear explanation on the definition. With respect to the latter, most of the beliefs included in the web for the whole group are transcendental and social. Results suggest that participants could consider a proposition as a belief (according to our operationalization) because they would reject hypothetical irrefutable evidence against it, but also because they do not base their assertion on evidence. Either way, it is interesting to note that about 10% of respondents *believed* in the theory of evolution, that is, held it as true irrespective to the possibility of a (scientific) paradigm shift about it. Consequently, even though our conceptualization may be biased toward transcendental and social issues, it also captures scientific beliefs.

We were interested in detecting the deep-seated beliefs at a group level, as well as those more superficial. Thus, we used weighted degree and k-core analyses to characterize networks. First, we decided to use weighted degree (instead of betweenness centrality, for instance) because we intended to detect both central and superficial beliefs (in psychological terminology), that is, those nodes behaving as hubs (with more connections and strongest connections with other nodes), and also those showing loose connectivity in the whole system. Hubs are expected to provide the system with the scaffold on which the rest of the system is anchored. They attract nodes that, having a content related to the hub, do not have a remarkable presence in the belief system. Some items co-occur in a relatively low number of participants, and with a restricted number of other beliefs. However, if those beliefs with which they co-occur are hubs, the item is attracted by the core subnetwork and is given more relevance. Such is the case, for example, of item 44 in the main network (Fig. 1). Interestingly, if one hub were removed from the system, the whole network would be expected to collapse, unless another would take its place. Each centrality measure has its limitations: in the case of weighted degree, it does not inform about the global configuration of the network, but it detects hubs and peripheral nodes. Concerning betweenness centrality, it highlights which nodes have the shortest path to get to other nodes; consequently, it does consider the global configuration of the network, but it cannot detect nodes that are not located in the shortest path between two other nodes (which are expected to be the peripheral or superficial beliefs). In turn, the analysis of betweenness centrality of the belief network at a group level reveals a lower number of nodes (38, 19, 17, 21, 25, 76, 34, 86, 5, 66, 29; N = 11) than using weighted degree (38, 19, 25, 34, 21, 66, 5, 24, 86, 26, 76, 64, 29, 17, 44, 68, 41, 15, 28, 14; N = 20). These lists of items are in decreasing order of centrality; note that results are very similar, and items with a higher weighted degree also have higher betweenness centrality. Even though we are interested in hubs, we would also like to have a picture of the whole belief system. This is why weighted degree was used instead of other centrality measures, assuming its pros and cons with respect to betweenness.

With respect to segregation, the k-core should be understood as a parameter to find subnetworks within the whole network. The different values of k-core in a network point to layers of increasingly complex (unweighted) subnetworks. Items with higher k-core value are probably similar to those with a higher weighted degree, but k-core only takes into consideration the number of connections and not the connection strength. Both measures (weighted degree and k-core) are correlated but not identical. For example, in the group network item 76 ("Political leaders should be more aware of the human side of their programs") is in the 7-core subnetwork with a weighted degree of 2.085, whereas item 26 ("There is a spiritual component in every person") is in the 4-core subnetwork with a weighted degree of 2.21. The latter is more central because it is strongly connected to the most dominant hubs of the network (mainly items 38, 19 and 21, all of them with a spiritual content similar to item 26; the normalized connectivity strength is 0.7646, 0.7775 and 0.5973, respectively), whereas the former is interconnected with more nodes (5, 19, 21, 25, 29, 34, 38, 66, 68, 86), but with weaker connectivity (normalized values of 0.0582, 0.2147, 0.1578, 0.3221, 0.1475, 0.3105, 0.0983, 0.3842, 0.0388, 0.3532, respectively). In conclusion, both measures are similar but complementary since each has its own nuances, and together they point to core beliefs. Core or deep-seated beliefs may be misleadingly understood as the central nodes inaccessible to new beliefs; by contrary, dense clusters are characterized by being open to other beliefs in the system, including incoming beliefs, if they are compatible. In other words, core beliefs are the funnel through which new beliefs have to enter to be part of the system. Let us suppose the following proposition: "Genetic manipulation of embryos is acceptable to enhance human species." This is expected to be part of the belief system if core beliefs are compatible with it. In any case, further research may focus on deeper conceptual analyses and use other parameters to detect new aspects in belief networks.

Considering the whole sample and the methodological criteria established above (discarding co-occurrences below 25% of the sample, that is, 27 participants), the belief system contained 20 nodes with varied content. Half of them conformed a subnetwork of densely interconnected hubs, which could be considered the group-wise core beliefs. It is important to note that, even though our experimental approach point to the most central beliefs at a group level, they need not be the core personal beliefs. Classical theoretical accounts consider the core beliefs as those deep-seated elements of the system that are extremely resistant to change, and which sustain more peripheral and temporary nodes (Converse 1964). To obtain the personal belief system with a similar approach, individuals should have to be assessed with the same survey at several time points –possibly about 20. This would be impractical with a 90-item survey, and the current work may be useful to select the subset of beliefs that could be analyzed as central hubs at the personal level in future research. In the current report, core beliefs are those that more frequently co-occur among participants. Future research using different methodologies may clarify whether core beliefs at an individual level are similar to those that we have found in our research, at a group level.

The intergroup comparisons revealed the specific belief systems of political, age and sex groups. Importantly, as we explained in the methods and results, the interrelations between nodes of these group-specific networks are those

Table 4 Items conforming the group-specific belief network for younger participants

#	k-core	Item
46	4	Euthanasia, that is, ending the life of a human who is incurably ill to limit suffering, is correct
6	4	People are often too demanding
32	4	It is very important to get recognition, compliments and admiration
5	4	All human beings deserve respect
24	4	The value of a person's life is more important than the value of any institution
43	4	There are people who act with hidden motivations
68	4	Same-sex relationships are correct
36	4	It is okay to use animals for medical research
16	4	We should have prestigious scientists to make decisions about moral issues
29	4	It is interesting to learn and develop new hobbies
25	4	Business decisions should influence religious or ethical principles about what is right or wrong
34	4	One should help those who are weak and cannot help themselves
50	4	Most of the people I deal with are honest and faithful
41	3	There are demons or evil spirits
88	4	You always have to give your best
28	4	It is important to pay your debts
57	4	Organized religion is one of the main sources of human conflicts
77	4	Young children (under 6 years old) are capable of having beliefs
30	4	It is better to be alone than to feel "tied" to other people
66	4	People should help those less fortunate than them
21	3	The soul or spirit survives death
75	4	Humans cause global warming
86	2	Being controlled or dominated by others is intolerable
17	3	We should have the religious authorities to make decisions about moral issues
49	3	People tend to be either critical or indifferent to others
76	2	Political leaders should be more aware of the human side of their programs
19	1	God answers people's prayers
38	1	There is one God or several gods
20	1	Abortion is correct
53	1	Most people generally have good intentions
64	1	Human needs should always be ahead of economic considerations
79	1	Positive thoughts and attitudes improve physical well-being
85	1	Being absolutely honest is good for doing business

Items are ordered by centrality (weighted degree)

statistically different with respect to their counterpart, after chi-squared tests and false discovery rate correction. This means that, for all possible 90-by-90 co-occurrences between the survey items, only those co-occurrences significantly different between groups are present in each network. For that reason, both group-specific belief systems may share the same belief: only co-occurrences, and not beliefs per se, are compared. Comparison between ideological groups clearly yielded a social liberalist and a spiritual belief network for left- and right-wingers, respectively.

Classically, stereotyping has been considered as an exaggeration of reality (Allport 1954), although recent research suggest that it may have cognitive support (Graham et al. 2012; McCauley 1995). Whereas these studies emphasize outgroup stereotyping, we show an objective group-wise polarization based on personal opinions, so it is unrelated to previous ingroup or outgroup attitudes. Similarly, age-specific networks reveal relatively individualistic beliefs for younger participants, and transcendental and prosocial elements for older respondents. Regarding sex, the most

**Table 5** Items conforming the group-specific belief network for older participants

#	k-core	Item
42	6	Whatever we do for the poor and the elder, it will never be enough
14	6	When I die I will be judged
27	6	It is important to do a perfect job in everything
64	6	Human needs should always be ahead of economic considerations
60	6	Government authorities tend to be intrusive and controlling
45	6	Democracy is the best system of government
53	6	Most people generally have good intentions
26	6	There is a spiritual component in every person
79	6	Positive thoughts and attitudes improve physical well-being
47	6	Fidelity to one's ideals and principles is more important than having an open mind
44	5	The complexity of the world suggests that it was intentionally designed by an intelligent creator
43	5	There are people who act with hidden motivations
86	6	Being controlled or dominated by others is intolerable
66	6	People should help those less fortunate than them
28	6	It is important to pay your debts
76	5	Political leaders should be more aware of the human side of their programs
15	4	When I die I will see loved ones who have died before me
88	5	You always have to give your best
34	6	One should help those who are weak and cannot help themselves
62	4	Ideas about what is right and what is wrong that other societies have, even if they are different from mine, may be valid for them
38	4	There is one God or several gods
29	5	It is interesting to learn and develop new hobbies
59	5	Life depends on a spiritual power that cannot be explained at all
85	4	Being absolutely honest is good for doing business
5	4	All human beings deserve respect
57	4	Organized religion is one of the main sources of human conflicts
24	3	The value of a person's life is more important than the value of any institution
21	3	The soul or spirit survives death
41	3	There are demons or evil spirits
19	2	God answers people's prayers
25	2	Business decisions should influence religious or ethical principles about what is right or wrong
17	2	We should have the religious authorities to make decisions about moral issues
75	2	Humans cause global warming
36	1	It is okay to use animals for medical research
77	1	Young children (under 6 years old) are capable of having beliefs
30	1	It is better to be alone than to feel "tied" to other people
49	1	People tend to be either critical or indifferent to others

Items are ordered by centrality (weighted degree)

striking result was the different density of both networks. The number of nodes of the female group (42) is not very different compared with the left- (37) and right-winger (40), or with the younger (33) and older (37) groups. However, the belief network of the male group has 16 nodes. This means that, when building the group-specific belief matrices, fewer belief pairs were significantly different in favor of the male group, which could be due to three different non-mutually exclusive reasons: 1) male participants agree/strongly agree with fewer survey items; 2) they are less resistant to change
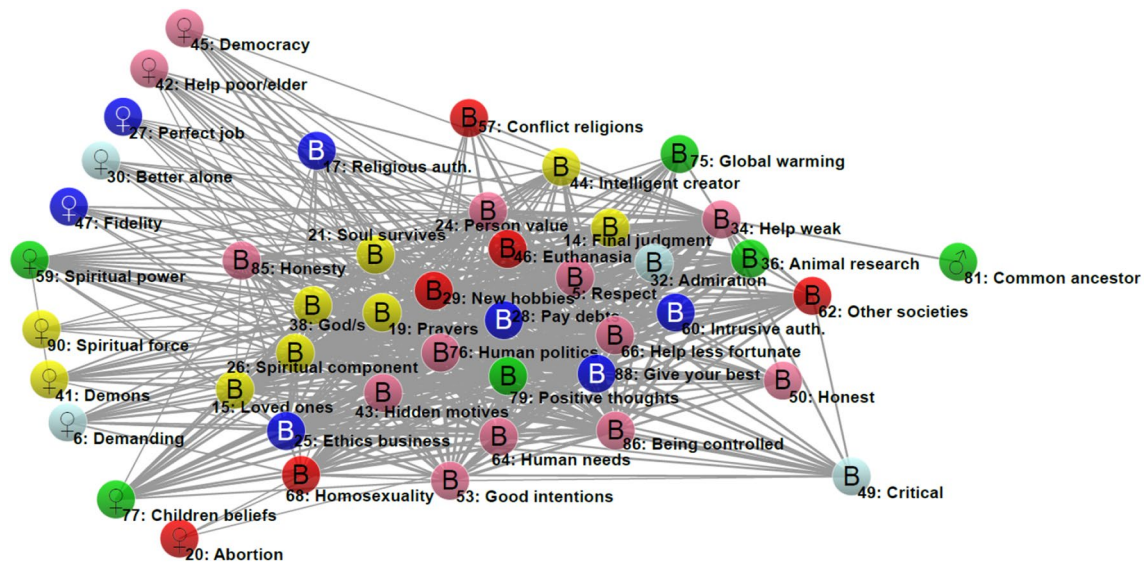
A Younger participants
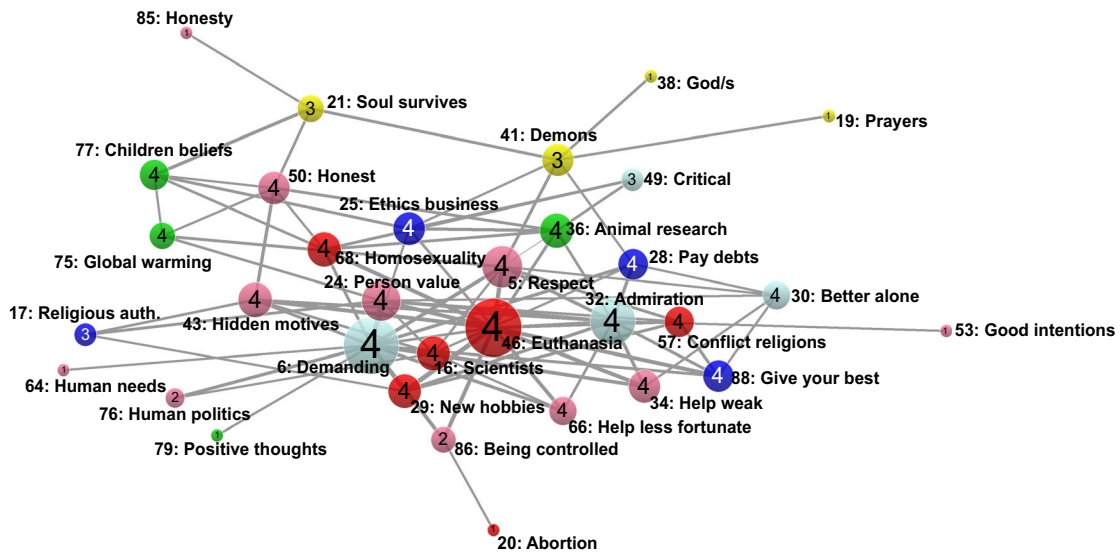
B Older participants
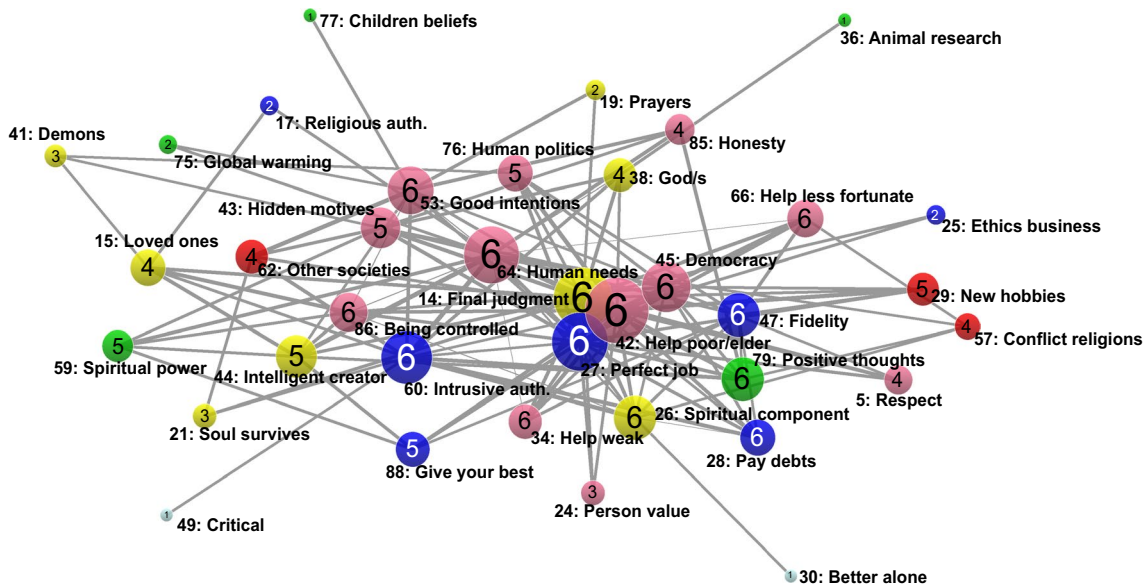
Fig. 6 Specific belief network for younger (**A**) and older (**B**) participants, organized by Kamada-Kawai free energy. Node size is proportional to weighted degree, edge thickness is weighted by connectivity strength, and numbers within nodes indicate k-core. See Fig. 1 legend for color code

Fig. 7 Common and distinctive beliefs for female and male participants. Network showing common and distinctive beliefs for female and male participants. ♀=nodes distinctive of female participants; ♂=nodes distinctive of older participants (only item 61); B=common nodes for both groups. Distinctive beliefs are shown in either the left or right part of the network. The adjacent groups of beliefs labeled with a B are common beliefs preferentially linked to either the female or male group (for example, item 34 is common for both groups, but it is directly linked to the only distinctive belief of the male group (item 61), and indirectly linked to the female group's distinctive beliefs through other common beliefs; item 17 is the opposite case). Centrality and segregation measures are not shown in this network. See Fig. 1 legend for color code

their agreement (i.e., they are open to revise their agreement in light of irrefutable proof against the proposition); 3) they are more heterogeneous than the female group in the beliefs they hold. With respect to the first possibility, the average agreement strength for all items was similar for both groups (2.95 for male, 2.98 for female), and the average percentage of participants agreeing or strongly agreeing with propositions was 42.6% and 41.8% for female and male, respectively. About the second possibility, the average percentage of participants for which an item was a belief was slightly higher in the female group (31.5% vs 24.7% in male), although this difference was statistically non-significant ($\chi^2=0.3199$, $p=0.5717$). The clearest difference appears when assessing the third possibility, that is, comparing, for each item, the percentage of participants for which the item was a belief: in 63 of them (out of 90 items), the proportion of participants that believed in the proposition was higher in the female group than in the male group. A chi-squared test for every item (comparing the proportion of female and male participants for which the item was a belief) revealed 14 significant differences (at a $p<0.05$), being 13 of them in favor of the female group (items 5, 19, 21, 24, 26, 29, 34, 48, 64, 66, 76, 77 and 79, being item 1 more prevalent in males). Moreover, the highest proportion for the male group was 69% (item 34), versus 93% for the female group (item 66). In conclusion, the belief system of the female group is more populated because, for nearly 15% of the survey items, the proportion of female participants believing in the proposition is significantly higher. This would produce further differences when comparing co-occurrence matrices, resulting in a denser network for the female group. In conclusion, male participants showed a higher within-item variability than female respondents, which ended up in strikingly different between-group belief networks.

All these analyses have an important constraint that should be taken into account for interpretability: only

Table 6 Items conforming the group-specific belief network for female participants

#	k-core	Item
5	15	All human beings deserve respect
29	15	It is interesting to learn and develop new hobbies
77	15	Young children (under 6 years old) are capable of having beliefs
24	15	The value of a person's life is more important than the value of any institution
66	15	People should help those less fortunate than them
19	15	God answers people's prayers
79	15	Positive thoughts and attitudes improve physical well-being
59	15	Life depends on a spiritual power that cannot be explained at all
85	15	Being absolutely honest is good for doing business
34	15	One should help those who are weak and cannot help themselves
28	15	It is important to pay your debts
26	15	There is a spiritual component in every person
76	15	Political leaders should be more aware of the human side of their programs
88	15	You always have to give your best
64	15	Human needs should always be ahead of economic considerations
41	15	There are demons or evil spirits
15	15	When I die I will see loved ones who have died before me
86	15	Being controlled or dominated by others is intolerable
6	13	People are often too demanding
43	14	There are people who act with hidden motivations
21	15	The soul or spirit survives death
44	15	The complexity of the world suggests that it was intentionally designed by an intelligent creator
42	13	Whatever we do for the poor and the elder, it will never be enough
17	12	We should have the religious authorities to make decisions about moral issues
14	12	When I die I will be judged
47	12	Fidelity to one's ideals and principles is more important than having an open mind
27	12	It is important to do a perfect job in everything
45	11	Democracy is the best system of government
30	11	It is better to be alone than to feel "tied" to other people
25	10	Business decisions should influence religious or ethical principles about what is right or wrong
68	8	Same-sex relationships are correct
53	10	Most people generally have good intentions
38	15	There is one God or several gods
90	7	I am part of a spiritual force on which all life depends
50	7	Most of the people I deal with are honest and faithful
57	5	Organized religion is one of the main sources of human conflicts
32	5	It is very important to get recognition, compliments and admiration
49	4	People tend to be either critical or indifferent to others
75	4	Humans cause global warming
60	3	Government authorities tend to be intrusive and controlling
20	3	Abortion is correct
62	2	Ideas about what is right and what is wrong that other societies have, even if they are different from mine, may be valid for them

Items are ordered by centrality (weighted degree)

Table 7 Items conforming the group-specific belief network for male participants

#	k-core	Item
36	2	It is okay to use animals for medical research
25	2	Business decisions should influence religious or ethical principles about what is right or wrong
32	2	It is very important to get recognition, compliments and admiration
49	2	People tend to be either critical or indifferent to others
53	2	Most people generally have good intentions
68	2	Same-sex relationships are correct
60	2	Government authorities tend to be intrusive and controlling
62	2	Ideas about what is right and what is wrong that other societies have, even if they are different from mine, may be valid for them
86	2	Being controlled or dominated by others is intolerable
46	1	Euthanasia, that is, ending the life of a human who is incurably ill to limit suffering, is correct
43	2	There are people who act with hidden motivations
38	1	There is one God or several gods
34	1	One should help those who are weak and cannot help themselves
75	1	Humans cause global warming
81	1	Human beings share a common ancestor with apes
88	1	You always have to give your best

Items are ordered by centrality (weighted degree)

'positive beliefs' (i.e., believing that something is true) were considered. Our experimental approach also allows to detect 'disbeliefs', defined by Quine and Ullian as "believing a sentence false" (Quine and Ullian 1970, p. 8). For example, following our results on political ideology, "I think that abortion is correct" is a belief for 45.5% of left-winger participants, and a disbelief for 64.4% of right-winger respondents. We have not analyzed in depth the latter concept, since building networks with beliefs and disbeliefs at the same time is impractical, and duplicating the results with disbelief networks would be excessively repetitive.

In conclusion, we contribute to network science research with a study that shows the network structure of the belief system at a group level, including putative nodes from several domains (nature/science, spiritual/religious, social-liberal, conservative, individualistic and prosocial). This approach also allows to build group-specific networks in comparison with a reference group. Future research may focus on disbeliefs, other domains in terms of content, or comparisons between clinical and control groups. Also, our study could be useful to design programs of social intervention: for example, if an organization or political party would want to promote a particular social liberalist issue within right-wingers, it would be pointless to try to intervene in core beliefs; however, stressing common core beliefs between groups (such as 'all human beings deserve respect') would be a more effective way to intervene. In any case, considering the stereotyped polarization revealed by our analyses (Bernacer et al. 2021), we believe that social interventions should be addressed to minimize confrontation and promote conciliation between groups: core beliefs could be a key element for this purpose.
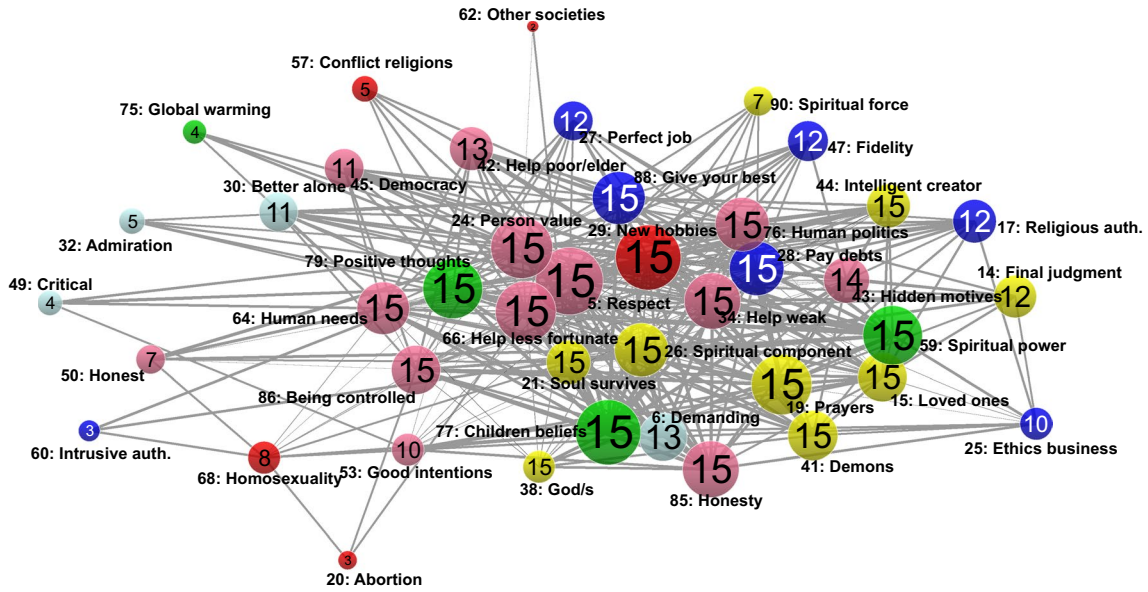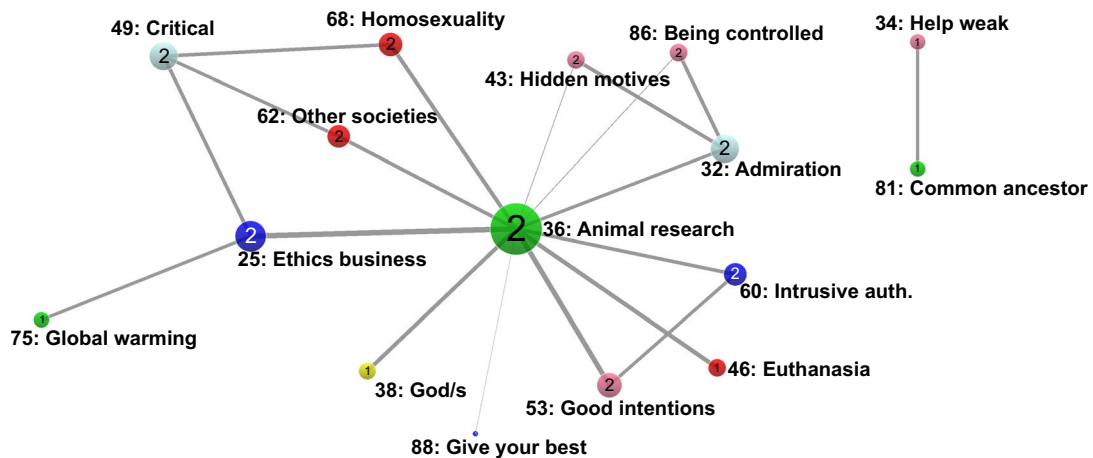
Fig. 8 Specific belief networks for female and male participants

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