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The relationship between social capital and inflammatory biomarkers in early adulthood: A longitudinal study

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Abstract

Higher levels of social capital (SC) are associated with better health status. However, there is little evidence of the impact of SC on biological health outcomes in the early ages. To identify the association between SC in adolescence and inflammation levels in early adulthood. Prospective study using data from 2435 participants from the Epidemiological Health Investigation of Teenagers in Porto cohort. SC was assessed at age 17 through a self-administered questionnaire, and high-sensitivity C-reactive protein (hs-CRP) and leucocytes were measured in a fasting blood sample at 17 and 21 years-old. A principal components analysis was performed to identify the domains of SC. Simple linear regressions were performed to assess the association between SC components and inflammatory status at 17 and 21 years old. Pathway analysis was performed to assess the direct, indirect, and total effects of SC on hs-CRP and leucocyte levels. We did not find a significant total effect between SC at 17 years-old and hs-CRP at 21 years-old. However, the *Trust/Reciprocity* dimension showed a significant direct effect between SC and hs-CRP levels at 21 (β = −0.065, 95% CI: −0.129; −0.001), as well as a significant total effect (β = −0.075, 95% CI: −0.139; −0.011). Regarding leucocyte levels, total SC at 17 years-old was associated with leucocytes levels at 21 (β = −0.115, 95% CI: −0.205; −0.024). Significant direct (β = −0.104, 95% CI: −0.194; −0.014) and total effect (β = −0.107, 95% CI: −0.199; −0.015) of Trust/Reciprocity on leucocyte levels were observed. Adolescents with higher SC have a low inflammatory level in early adulthood, especially those with greater levels of trust/reciprocity.

KEYWORDS

adolescents, early adulthood, inflammatory levels, social capital

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1 | INTRODUCTION

Social capital (SC) has been widely considered to influence health (Abbott & Freeth, 2008; Bravo Vallejos, 2017; Rocco & Suhrcke, 2012). SC can be defined as the resources to which individuals and groups have access through their social networks (Ehsan et al., 2019; Moore & Carpiano, 2020; Moore & Kawachi, 2017; Rocco & Suhrcke, 2012) or social ties (Neves et al., 2018), and takes three complementary forms: dimension (cognitive, structural, bonding, bridging, and linking); setting (family/household, workplace, and neighbourhood/community); and level (individual or community) (Agampodi et al., 2015; Moore & Kawachi, 2017; Villalonga-Olives & Kawachi, 2015).

Higher levels of SC have been positively associated with better health outcomes, such as self-reported health, mortality, and life expectancy (Riumallo-Herl et al., 2014) and behaviours such as smoking, alcohol use, physical activity, vegetable consumption and sleep among adults (Nieminen et al., 2013). Self-reported poor health —mental and/or physical—has been frequently associated with low SC (Ehsan et al., 2019; Kawachi et al., 1997; Lee & Jung, 2018; Rodgers et al., 2019). A systematic review found that cognitive SC, measured at the individual level, is a protective factor against developing common mental disorders, such as depression and anxiety (Ehsan & De Silva, 2015), and another showed that SC may be an important protective factor for some physical health outcomes, such as some types of cancer and cardiovascular diseases (Rodgers et al., 2019). Yet, the effect sizes of SC on mortality and morbidity tend to be small and only consistent when using individual-level measures (Xue et al., 2020). Indeed, SC can also be linked with poorer health, namely through the exclusion of non-group members, excess effort asked of certain group members, limitation of freedom to act differently from the group (especially when high bonding capital), and downward-levelling norms (Berkman et al., 2014).

SC can, thus, be linked to health through several mechanisms. At the individual level, it may facilitate access to information or support, and social reinforcement, while at the group level, it may potentiate favourable or unfavourable health behaviours through social contagion, informal social control and collective efficacy, exclusion of outsiders, freedom restriction, or norms (Berkman et al., 2014). Thus, either due to its positive or negative, direct or indirect influence on health behaviours, such as smoking, or due to the effect on psychological well-being due to affective support, SC may affect individuals' inflammatory status (Caliri et al., 2021; Cunliffe, 2016).

In recent decades, a clear biological link between adverse environmental conditions and disease risk has been reported (Adler & Stewart, 2010; Berkman et al., 2014; Brunner, 1997). Specific pathophysiological mechanisms have been explored through which adversity can become embedded in the biology of individuals (Braveman & Gottlieb, 2014; Cunliffe, 2016). Inflammation is the immune system's response to harmful stimuli and can be one of the biological mechanisms that may explain the link between adversity and health. There is evidence showing that adversity in early life and disadvantaged social circumstances seem to be associated with changes in inflammatory markers levels (Berkman et al., 2014), such as high levels of C-reactive protein (CRP), amyloid protein A, fibrinogen, leucocyte count, and cytokines (Fraga et al., 2015), and with inflammation-related diseases in adulthood (Fraga et al., 2019). Poorer socioeconomic circumstances at birth seem to impact inflammatory processes in the first decade of life, putting children on a higher risk trajectory (Soares et al., 2020), and can significantly be associated with higher prevalence of chronic low-grade inflammation in adolescence (Fraga et al., 2019). SC, and the benefits that a child receives from social relationships, are positive social determinants of health, and can contribute to help children exposed to adversity to achieve healthy outcomes across the life course (Duh-Leong et al., 2021).

Economic and social adversities are linked to poorer health, and it has been hypothesised that inflammation can be the potential link between social relationships and poorer health. Individual social support is known to buffer stress reactions which might decrease stress-induced inflammatory reactions (Bowen et al., 2014). A previous study in adult women showed that positive relationships were associated with lower plasma IL-6 levels (Friedman et al., 2005). A review exploring this association concluded that results were mixed, limiting to state an unequivocal link between social relationships and inflammation, but studies were mostly focused on adults and some methodological issues were raised (Penwell & Larkin, 2010). However, research on SC remains predominantly focused on analyses of general populations (mostly middle-aged adult individuals) and geographically bound communities, such as neighbourhoods or local community settings, states, and countries (Neves et al., 2018), and most of the evidence is based on ecological and cross-sectional designs (Berkman et al., 2014). While these are useful designs, greater use of longitudinal data would offer better information about the possible causal role of SC, especially in the early years (Rodgers et al., 2019). Therefore, investigating the relationship between SC and inflammatory biomarkers, especially in childhood and adolescence, can be beneficial in enhancing our understanding of the causal mechanisms linking SC to health (Rodgers et al., 2019), and in understanding when these mechanisms arise in life so that timely interventions can be designed and delivered (Riumallo-Herl et al., 2014). To fill in this gap in the literature, this study aims to investigate the relationship between SC in adolescence and inflammatory markers in early adulthood.

2 | METHODS

2.1 | Study design and participants

This study used data from the Epidemiological Health Investigation of Teenagers in Porto cohort study, which recruited 13-year-old adolescents born in 1990 and enroled in all (27) public and 19 private schools in Porto, Portugal (Ramos & Barros, 2007). This study was previously designed to investigate the determinants of cardiovascular health.

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At recruitment (2003–2004), 2159 of the 2786 eligible adolescents agreed to participate (78% response rate). In the second wave (2007–2008), when they were on average 17 years old, 1716 participants from the first wave were re-evaluated (79% of the first wave sample) plus 783 adolescents who, then, had moved to schools in Porto. In the third wave (2011–2013), 1764 participants aged 21 were re-evaluated (70% response rate). Participants filled in self-administered questionnaires, which collected information on individual and family health history, well-being, behavioural and sociodemographic characteristics, and physical measurements, including fasting blood samples, were carried out in all waves.

Our study included all participants evaluated at 17 (timepoint 1) and 21 years of age (timepoint 2), which makes a total of 2435 participants. As imputation was used no participant was excluded. Of these, 51.7% were female and 48.3% were male. About half were occasional, weekly and/or daily users of alcohol (48.2%) and exposed to second-hand smoke (50.2%), while 14.0% were occasional and/or daily smokers. A fourth had allergies (26.0%), 12.7% were overweight, and 11.5% had asthma. Regarding parental education (and considering the parent with the highest level) the average number of years of completed education was 10.7 years. The sample sociodemographic characteristics are shown in Table 1.

2.2 | Social capital

To measure SC, we analysed the answers obtained from the module applied at 17 years of age; this module was not applied at age 21 (Neves et al., 2018). All items (listed in Table 2) have a 3-point Likert scale and separate questions were asked about informal networks (family and friends)—items 1–6; formal networks (attending religious services; working on boards or committees; attending sports or cultural community activities)—items 7–9; civic participation (volunteer for community activities)—item 10; social support (financial and emotional support)—items 11–14; level of trust in people and institutions (feeling that you can rely on your neighbours)—items 15 and 16; reciprocity (believing that potential help is available)—items 17 and 18; and informal social control—item 19.

Indeed, when focusing on the resources related to social networks and social ties, informal networks (family and friends) were assessed through items SC1 to 6 and SC11 to 12 (which refer to the social support given), while formal networks (attending religious services; working on boards or committees; attending sports or cultural community activities) are assessed through items SC7 to 9 and SC13 to 14. Considering the dimensions, the cognitive dimension could be observed in items that assess the level of trust in people and institutions, assessed through items SC15 and 16; reciprocity, through items SC17 and 18, and informal social control, through item SC19. Bonding could be observed in SC4 to 6 (expressing the deepening of established relationships), bridging in items 8–10 (expressing joining activities with people from other social circles, from religious to sports or volunteering), and linking in item 7 (as activity in political associations or organisations tends to foster relationships with individuals from other levels of power). Regarding the setting, family/household was expressed in items 1–3, 11–12, workplace 7 and 9, and neighbourhood/community in items 11–12 and 17–18. If observing the SC as a personal resource, items 5–10, 15–16, and 18–19 contribute to its assessment, while as communitarian it may be assessed through items 1–4, 11–14, and 17.

TABLE 1 Sociodemographic characteristics, comorbidities, and inflammatory status of the sample.

Sex			
Female [n, (%)]		1259	(51.7)
Male [n, (%)]		1176	(48.3)
Behaviours			
Alcohol consumption [n, (%)]		1173	(48.2)
Tobacco consumption [n, (%)]		342	(14.0)
Exposure to second-hand smoke [n, (%)]		1222	(50.2)
Comorbidities			
Allergies [n, (%)]		632	(26.0)
Asthma [n, (%)]		279	(11.5)
Rhinitis [n, (%)]		186	(7.6)
Diabetes mellitus [n, (%)]		22	(0.9)
Obesity [n, (%)]		150	(6.2)
Overweight [n, (%)]		309	(12.7)
Parental education [μ ($\pm$SD)]		10.7	($\pm$4.6)
Inflammatory status			
17 years	hs-CRP [μ ($\pm$SD)]	3.4	($\pm$9.3)
	Leucocyte [μ ($\pm$SD)]	6.5	($\pm$1.7)
21 years	hs-CRP [μ ($\pm$SD)]	2.2	($\pm$3.9)
	Leucocyte [μ ($\pm$SD)]	6.7	($\pm$1.8)

Abbreviations: μ, mean, SD, standard deviation.

Principal component analysis (PCA) was performed to identify the number of domains suggested by the data collected through these items, and which items belong to each domain (Table 2) so that we could build the final variable for analysis. The PCA was performed using the oblimin rotation. Principal components were selected if their eigenvalue was higher than 1.00. Items with an absolute factor loading equal to or greater than 0.40 were interpreted as having a strong correlation with the principal component. The internal consistency was tested using Cronbach's alpha coefficient and the ideal value of Cronbach's alpha for good internal consistency is 0.70. This analysis was followed by confirmatory factor analysis (CFA), using the Schmid Leiman Factor method, to confirm the existence of an overall component.

The PCA revealed that it is appropriate to retain three principal components, which explain approximately 60.73% of the total variance. The first component (PC1) was strongly associated with items

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TABLE 2 Principal component analysis: Correlations between the items of the original social capital variable and the rotated principal components (oblimin rotation).

Item	Description	PC1[a]	PC2[a]	PC3[a]
SC1	Living with parents	0.27	−0.01	**0.42**
SC2	Living with siblings	−0.09	0.04	**0.80**
SC3	Living with grandparents	0.10	0.04	**0.71**
SC4	How often are you with other family members?	0.38	−0.02	0.33
SC5	How many close friends do you have?	0.45	0.01	0.40
SC6	How often do you socialise with friends?	**0.48**	0.03	0.31
SC7	Do you participate in a political organisation, pupil association or public organisation?	**0.72**	0.04	0.14
SC8	Do you attend places of worship/joins activities organised by a religious institution?	**0.59**	0.02	0.13
SC9	Do you belong to a sports, music, dance, drama, or scout group?	**0.66**	0.03	0.10
SC10	Do you do voluntary work?	**0.75**	0.04	0.07
SC11	Do you get economic support from family, friends, or neighbours?	**0.81**	−0.01	−0.17
SC12	Do you get emotional support from family, friends, or neighbours?	**0.83**	−0.00	−0.19
SC13	Do you get economic support from public institutions or charitable organisations?	**0.83**	0.02	0.00
SC14	Do you get emotional support from public institutions or charitable organisations?	**0.85**	0.02	0.02
SC15	Can you trust most people?	**0.68**	0.08	0.04
SC16	Can you in public institutions, police, health services and municipal services?	0.01	**0.89**	−0.02
SC17	People around you are willing to help each other	−0.01	**0.91**	−0.01
SC18	Do you help neighbours or other people in your community?	−0.02	**0.92**	0.01
SC19	Do you usually react/intervene if you witness inappropriate behaviour?	0.03	**0.88**	0.00
% Variance		44.28	9.96	6.50
Alfa Cronbach		0.92	0.92	0.60

Abbreviations: PC, Principal component; SC, social capital.

[a]The items associated with each principal component were showed in bold.

6–15 which we designated *Social Support and Participation*; the second component (PC2) with items 16, 17, 18, and 19 which we designated *Trust and Reciprocity*; and finally, the third component (PC3), with items 1, 2 and 3, designated *Informal Networks*. The overall component was designated *total SC*.

Considering the three identified components, we performed a three-factor CFA which demonstrated the existence of a general factor (alpha = 0.93; omega $H = 0.81$). Thus, the SC variable used in the final analysis was continuous, assessed at age 17, and analysed globally (total SC) and then by its components.

2.3 | Inflammatory biomarkers

High-sensitivity CRP (hs-CRP) (mg/L) and leucocytes (x10^9/L) were used as inflammatory markers. A fasting blood sample was taken at 17 and 21 years of age. Regarding hs-CRP, values below the detection limit (<0.2 mg/L) were assigned a value equal to half of the detection limit. To minimise the influence of acute infections on the results, we excluded participants whose hs-CRP concentration was >10 mg/L and leucocytes >11 × 10^9/L. Blood parameters were measured in the Clinical Pathology Department of the São João Hospital Centre, Porto, according to standard laboratory methods.

2.4 | Covariates

We included as covariates sex, comorbidities (allergies, asthma, rhinitis, diabetes mellitus, and obesity/overweight), exposure to second-hand smoke (considered exposed if cohabitants smoke), tobacco consumption (occasional and/or daily smoking) and alcohol consumption (occasional, weekly and/or daily consumption). Parental level of education was used as an indicator of the adolescents' socioeconomic status and was measured as the number of completed years of education (considered the highest level of education obtained by the parents). We use parental education as a proxy to define socioeconomic status because is a reliable indicator that encompasses not just income but also educational attainment and financial security, and this variable also discriminate better social differences (Aaro et al., 2009; Braveman et al., 2005).

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2.5 | Statistical analysis

Interaction by sex in the association between SC and inflammatory markers was assessed, but this was not significant, so results are presented for the total sample. Potential confounders (comorbidities, tobacco use, second-hand smoke exposure, alcohol consumption, socioeconomic status) were tested, and the final model was adjusted for sex and tobacco use. Due to the non-normal distribution of the hs-CRP variable, a logarithmic transformation was performed.

Regression coefficients (β) and 95% Confidence Intervals (95% CI) were calculated using linear regression models to assess the relationship between the different SC components (*Social support and participation; Trust and Reciprocity; Informal Networks*; and *total* SC) and inflammatory levels (hs-CRP and leucocytes) at 17 and 21 years of age.

Pathway analysis was performed to estimate regression coefficients (β) and 95% CI to assess the direct, indirect, and total effects of cumulative *total* SC at 17 years, and *Trust and Reciprocity*, on inflammatory status. Pathway analysis was conducted based on the theoretical model represented in Figure 1, through which SC at 17 affects inflammatory status at 17 and 21 years old. The model was built based on the results obtained from the association analysis between the SC and inflammatory status (Table 3) and based on the literature review. As posited in Figure 1, SC may affect the inflammatory status in the short term through exposure to higher stress levels, with subsequent changes in hs-CRP and leucocytes (a) (Bowen et al., 2014). Yet, as individuals with lower SC may use tobacco as a copying strategy (Sakai-Bizmark et al., 2020) and tobacco use may be involved in the stress pathway (Madsen et al., 2007), we studied if tobacco could be indirectly involved in the effect of SC and inflammatory status (d + e). The effect of SC may also occur at the longer term, due to chronic levels of deprivation and stress, and this effect can occur either due to the lower levels of SC observed at age 17 and maintained through time (c) and indirectly through the change in inflammatory status at age 17 (a + b). The Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), and the Root Mean Square Error (RMSEA) were used to assess the fit of the models. A CFI and TLI equal to or greater than 0.90 and an RMSEA less than 0.05 indicate a good model fit. Data were analysed using the Statistical Package for Social Sciences (SPSS®), version 17.0, and R (R Core Team, 2014) version 3.1.2.

3 | RESULTS

The association of the *total* SC and the three dimensions (*Social support and participation; Trust and Reciprocity; Informal Networks*) with inflammatory levels (hs-CRP and leucocytes) at ages 17 and 21 is shown in Table 3. At 21 years, a higher SC score was found to be associated with lower values of hs-CRP concentration, and this association was statistically significant for the *total* SC score ($\beta = -0.07$; 95% CI: −0.14; −0.00) and *Trust and Reciprocity* ($\beta = -0.10$; 95% CI: −0.18; −0.02). This association was also found for leucocytes concentration, with a statistically significant association for *total* SC score ($\beta = -0.11$; 95% CI: −0.20; −0.02) and *Trust and Reciprocity* ($\beta = -0.11$; 95% CI: −0.22; −0.00). No significant association was found between the different dimensions and the concentration of hs-CRP or leucocytes at 17 years.

SC was associated with sex ($\beta = 0.11$, 95% CI: 0.03; 0.19) and smoking ($\beta = 0.08$, 95% CI: 0.00; 0.16), and these factors also showed an association with inflammatory status ($\beta_{smoking} = 0.39$, 95% CI: 0.23; 0.55; $\beta_{sex} = -0.65$, 95% CI: −0.76; −0.53). Comorbidities, alcohol consumption, exposure to environmental smoke and socio-economic circumstances (the parent's level of education) did not show a significant association with SC nor with inflammation levels in young adults (Supplementary Material, Table S1).

Considering the hypothesis illustrated in Figure 1, Table 4 presents the total, direct and indirect effect of SC (*total* SC, and *Trust and Reciprocity* dimension) on hs-CRP and leucocytes levels, and the fit values. Both models showed a good fit.

For the model testing the effect between total SC and the levels of hs-CRP, we did not find a significant direct effect between SC and hs-CRP levels at 17 years-old, nor a significant total effect between SC at 17 years-old and hs-CRP at 21 years-old. Though, the *Trust and Reciprocity* dimension showed a significant direct effect between SC and hs-CRP levels at 21 years-old ($\beta = -0.065$, 95% CI: −0.129; −0.001), as well as a significant total effect ($\beta = -0.075$, 95% CI: −0.139; −0.011).

Regarding leucocyte levels, total SC at 17 years old was associated with leucocytes levels at 21 years old ($\beta = -0.115$, 95% CI: −0.205; −0.024) and a significant total effect ($\beta = -0.101$, 95% CI: −0.193; −0.009). The model testing the association between *Trust and Reciprocity* and leucocyte levels also showed a direct effect ($\beta = -0.104$, 95% CI: −0.194; −0.014) and a total effect ($\beta = -0.107$, 95% CI: −0.199; −0.015), both significant.

Tobacco consumption was associated with both hs-CRP and leucocyte levels at 17 years old.

4 | DISCUSSION

This study shows that higher scores of SC in adolescence are associated with lower levels of hs-CRP and leucocytes at age 21, that is, adolescents presenting higher levels of SC are likely to present a lower degree of inflammation in early adulthood, even if the association between SC and inflammatory markers was not observed at age 17. The dimensions of trust and reciprocity in adolescence are especially associated with a lower inflammation level in early adulthood.

Previous research in other population groups has found a link between other SC-related factors and lower levels of inflammation. A systematic review showed that greater social integration and social support are significantly related to lower levels of inflammation (Uchino et al., 2018). People who are socially integrated or have larger social networks are likely to show lower plasma levels of IL-6 and CRP (Kiecolt-Glaser et al., 2010). The results of a meta-analysis

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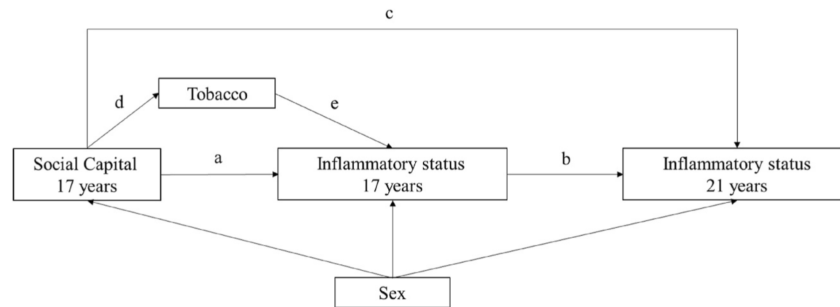

FIGURE 1 Hypothesised mechanism between social capital (SC) at age 17 and inflammatory status (high-sensitivity C-reactive protein and leucocytes) at ages 17 and 21. (a) Direct effect of SC on inflammatory status at 17 years; (b) effect of inflammatory status at 17 on inflammatory status at 21; (c) direct effect and (a + b) indirect effect of SC on inflammatory status at 21 years; (d + e + b) indirect effect of SC on inflammatory status, via tobacco.

TABLE 3 Association between cumulative SC in adolescence, and the different SC components, with inflammatory markers (hs-CRP and leucocyte concentration) at 17 and 21 years of age.

(a) hs-CRP concentration				(b) Leucocyte concentration			
Social capital	**Beta**	**CI 95%**	***p*-value**	**Social capital**	**Beta**	**CI 95%**	***p*-value**
At 17 years				At 17 years			
Social support/participation	−0.04	(−0.15; 0.07)	0.51	Social support/participation	0.05	(−0.06; 0.16)	0.39
Trust and Reciprocity	−0.04	(−0.14; 0.07)	0.48	Trust and Reciprocity	−0.04	(−0.15; 0.07)	0.51
Informal Networks	0.02	(−0.07; 0.12)	0.63	Informal Networks	0.03	(−0.07; 0.13)	0.50
Total SC	−0.05	(−0.17; −0.01)	0.36	Total SC	0.03	(−0.06; 0.13)	0.48
At 21 years				At 21 years			
Social support/participation	0.03	(−0.05; 0.12)	0.46	Social support/participation	0.01	(−0.10; 0.13)	0.82
Trust and Reciprocity	−0.10*	(−0.18; −0.02)	0.01	Trust and Reciprocity	−0.11*	(−0.22; −0.00)	0.04
Informal Networks	−0.02	(−0.10; 0.05)	0.58	Informal Networks	−0.05	(−0.15; 0.06)	0.39
Total SC	−0.07*	(−0.14; −0.00)	0.04	Total SC	−0.11*	(−0.20; −0.02)	0.02

Note: Analyses adjusted for sex.
Abbreviations: hs-CRP, high-sensitivity C-reactive protein; SC, social capital.
*p-value <0.05.

also showed that social isolation and loneliness may be linked to systemic inflammation in adolescents (Smith et al., 2020).

SC is not a discrete concept, and its components comprehend distinct phenomena. Some evidence suggests that a higher level of general trust is associated with improved health outcomes (Abbott & Freeth, 2008). The impact of trust on health could facilitate other aspects of SC. For instance, trust may promote the development of social networks, which in turn can enhance health. Additionally, trustfulness may reduce anxiety and fear about the behaviour of others, thereby mitigating the adverse physiological consequences of chronic stress. Therefore, trust and reciprocity may help to protect against chronic stress by reducing anxiety about the behaviour of others (Abbott & Freeth, 2008).

The absence of a significant association between SC and inflammatory status at 17 years of age might be the result of a very early stage in the causal relationship, hence the importance of studying the impact in the medium/long term with longitudinal designs. Embodiment of socioeconomic deprivation tends to occur after a chronic exposure to higher stress levels (Wirtz & von Kanel, 2017), which may not be observed in the shorter term. Indeed, higher changes in the CRP and leucocyte may be only found after repeated and longer periods of dysfunction in the autonomic nervous system and hypothalamic-pituitary adrenal axis, due to the production of pro-inflammatory cytokines and CRP after the chronically elevated secretion of stress hormones (Wirtz & von Kanel, 2017). In fact, the Dunedin birth cohort showed that early life stress in the form of childhood maltreatment, such as mother rejection at age 3, exposure to strict discipline at ages 7 and 9, and repeated episodes of severe physical punishment through age 11, was found to be a predictor of higher CRP, fibrinogen, and white blood cell count at age 32 (Rohleder, 2019) Furthermore, acute stress has profound, rapid, short-term, and differential effects on several components of the

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TABLE 4 Path analysis between social capital and hs-CRP levels at age 17 and 21.

Model total SC*	β	CI 95%	p-value	Model trust/reciprocity	β	CI 95%	p-value
(a) Path analysis between social capital and hs-CRP levels at age 17 and 21							
a (SC17 > CRP17)	−0.047	(−0.142; 0.048)	0.330	a (SC17 > CRP17)	−0.050	(−0.140; 0.039)	0.271
b (CRP17 > CRP21)	0.217*	(0.172; 0.262)	0.000	b (CRP17 > CRP21)	0.217*	(0.172; 0.262)	0.000
c (SC17 > CRP21)	−0.050	(−0.114; 0.015)	0.131	c (SC17 > CRP21)	−0.065*	(−0.129; −0.001)	0.047
d (SC17 > tobacco)	0.021*	(0.001; 0.041)	0.039	d (SC17 > tobacco)	0.014	(−0.006; 0.034)	0.169
e (tobacco > CRP17)	0.390*	(0.230; 0.551)	0.000	e (tobacco > CRP17)	0.390*	(0.229; 0.550)	0.000
Indirect effect (ab)	−0.010	(−0.031; 0.010)	0.332	Indirect effect (ab)	−0.011	(−0.031; 0.009)	0.274
Indirect effect (deb)	0.002	(−0.000; 0.004)	0.063	Indirect effect (deb)	0.001	(−0.001; 0.003)	0.191
Total effect	−0.058	(−0.123; 0.006)	0.075	Total effect	−0.075*	(−0.139; −0.011)	0.022
CFI = 0.993; TLI = 0.964; RMSEA = 0.017 CI 95% (0.000; 0.044)				CFI = 0.993; TLI = 0.966; RMSEA = 0.016 CI 95% (0.000; 0.043)			
*p-value < 0.05				*p-value < 0.05			
(b) Path analysis between social capital and leucocytes levels at age 17 and 21							
a (SC17 > LEUC17)	0.025	(−0.068; 0.118)	0.271	a (SC17 > LEUC17)	−0.013	(−0.104; 0.078)	0.777
b (LEUC17 > LEUC21)	0.410*	(0.356; 0.465)	0.000	b (LEUC17 > LEUC21)	0.409*	(0.354; 0.464)	0.000
c (SC17 > LEUC21)	−0.115*	(−0.205; −0.024)	0.047	c (SC17 > LEUC21)	−0.104*	(−0.194; −0.014)	0.024
d (SC17 > tobacco)	0.021	(0.001; 0.041)	0.169	d (SC17 > tobacco)	0.014	(−0.006; 0.034)	0.167
e (tobacco > LEUC17)	0.379*	(0.212; 0.546)	0.000	e (tobacco > LEUC17)	0.381*	(0.214; 0.548)	0.000
Indirect effect (ab)	0.010	(−0.028; 0.048)	0.274	Indirect effect (ab)	−0.005	(−0.043; 0.032)	0.777
Indirect effect (deb)	0.003	(−0.000; 0.007)	0.191	Indirect effect (deb)	0.002	(−0.001; 0.005)	0.189
Total effect	−0.101*	(−0.193; −0.009)	0.022	Total effect	−0.107*	(−0.199; −0.015)	0.022
CFI = 0.993; TLI = 0.964; RMSEA = 0.017 CI 95% (0.000; 0.044)				CFI = 0.994; TLI = 0.969; RMSEA = 0.016 CI 95% (0.000; 0.043)			
*p-value < 0.05				*p-value < 0.05			

Note: All models were adjusted for sex and tobacco consumption at age 17.

Abbreviations: CFI, Comparative Fit Index; hs-CRP, high-sensitivity C-reactive protein; RMSEA; Root Mean Square Error; SC, social capital; TLI, Tucker-Lewis Index.

immune system (Rohleder, 2019), but these changes are most likely observed in the increase of circulating IL-6, and of IL-1beta, IL-10 and TNF-alpha, yet at smaller levels, but not in CRP levels (Rohleder, 2019; Wirtz & von Kanel, 2017). As such, our results show this medium/long-term impact and support the hypothesis that an early investment in adolescent SC may have beneficial effects in adulthood.

According to the literature, socioeconomic circumstances influence the inflammatory status, either directly, through stress mechanisms that lead to the triggering of a cascade of mechanisms leading to the chronic release of CRP, or indirectly through the effect resulting from the adoption of less healthy behaviours (Fraga et al., 2019; Soares et al., 2020). However, our results show that SC has a direct effect on inflammatory markers regardless of the individual's socioeconomic circumstances. On the other hand, SC may not be strongly associated with socioeconomic circumstances in this specific Portuguese sample as its society tends to be centred on family relationships, which may allow high levels of SC, regardless of socioeconomic circumstances, especially regarding the existence and maintenance of informal networks and family emotional and economic support (Leao et al., 2018).

Regarding the effect of behaviours in the inflammatory status, only smoking proved to be relevant to the relationship between SC and inflammation, which is justified by the fact that peer group influence is one of the main determinants for adolescents to initiate smoking behaviour (Rachiotis et al., 2020). Besides, a study shows a positive dose–response relationship between amount of cigarette smoking and elevated CRP levels (Madsen et al., 2007). Concerning alcohol, we did not find any relationship which is in accordance with the literature. Several studies suggest that alcohol consumption is associated with a decreased probability of elevated CRP levels and moderate alcohol consumption is associated with low CRP levels (Raum et al., 2007; Sierksma et al., 2002; Stewart et al., 2002).

Considering the role of SC in preventing inflammation in early adulthood, it is important to identify and implement interventions

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that promote SC and, which would indirectly reduce the risk of a chronic inflammatory state in early adulthood. The literature suggests some evidence-based interventions in younger populations (Sweet & Appelbaum, 2004; Villalonga-Olives et al., 2018; Wakefield & Sheldon, 2013). Fujiwara et al. (Villalonga-Olives et al., 2018) developed a programme to create a home visiting service for mothers with newborns. In these home visiting programs during early childhood, trained professionals regularly visit at-risk parents and families with young children and provide them with information, support, and/or training on child health, development, and care based on the family's needs. Visitors may be nurses, social workers, parent educators, or other professionals within the community (Wakefield & Sheldon, 2013). In this case, the home visit was aimed at assessing the health status of the newborn and mother and evaluate parenting in general. This home visiting programme used social trust and a sense of security in the community, two forms of SC, and contributed to reduce the stress level of newborn mothers (Villalonga-Olives et al., 2018). In addition, there is evidence that these programmes prevent child maltreatment and improve children's cognitive, social, and emotional development. Home visiting programmes during early childhood have also been shown to improve birth outcomes, parental behaviours, and attitudes. These effects are maintained and observed until children reach the age of seven (Sweet & Appelbaum, 2004). Family Connects is an evidence-based model that supports all families of newborns and is committed to strengthening bonds for families of newborns and linking them directly to supportive community care resources. This programme works with community partners to provide vital in-home clinical care by nurses and referrals to local supports for newborns and their family members. The Family Connects Model is designed to support optimal maternal-child health and advance equitable outcomes, while promoting better aligned community care systems (Dodge et al., 2022).

Head Start and Early Head Start are US federal programs that provide funding for children ages 0–5 from low-income families to receive quality early education services (Chazan-Cohen et al., 2023). Research suggests that two-generation early childhood programs, which aim to promote not only the best parenting practices and family well-being but also the development of children, can help build young children's and their families' resilience in the face of adversity (Chazan-Cohen et al., 2023). Support for parenting in various forms (such as home visits, case management, or parent education) played a significant role in achieving positive outcomes for children and families. When Early Head Start parents received education or job training, it not only positively influenced maternal employment but also had broader positive effects on family and child outcomes (Chazan-Cohen et al., 2023).

Another intervention, Kids First, which aims to give children in vulnerable situations a good start in life, brings the community together through targeted community meetings and partnership development (Villalonga-Olives et al., 2018). The programme has been promoting institutional SC by increasing social resources, hiring locally, and encouraging staff to deepen community links, with results in the SC of vulnerable children (Villalonga-Olives et al., 2018) and potentially in lower levels of inflammation at subsequent ages. This programme has demonstrated that effective health interventions need to be implemented at multiple levels.

It should be noted, that despite the existence of various interventions for the promotion of SC, their potential importance and, thus, the reduction of the risk of chronic inflammation in young people, the evidence for their effectiveness is not consistent (Shiell et al., 2020). Thus, despite the enthusiasm for developing interventions and health policies that increase SC, there is no clear evidence that unequivocally supports the decision for public health intervention. In the future, it would be important to develop interventions for this specific population—adolescents—and to assess their real-world effect and the health gains, as well as to study the characteristics associated with a greater (or lower) effect.

This study has some limitations. First, we cannot discard measurement errors since there are no standard instruments to assess SC at the individual level. However, the instrument used in the adolescent includes the items recommended in the assessment of SC in the younger population and is in accordance with literature (Berkman et al., 2014). Besides, the SC module administered at 17 years of age was not administered at 21, therefore, the association of SC with inflammatory markers at 21 was not controlled for variables of SC collected at 21. Although we cannot disregard the importance of SC at 21 in this association, substantial changes in SC at the end of adolescence are not expected, and thus, we believe that this would not substantially modify the results. The second limitation is related to the measurement of the inflammatory status. In this study, we used hs-CRP and leucocytes as inflammatory markers. However, there are other markers frequently used in similar studies, such as IL-6 (Soares et al., 2020). Although the information on interleukin-6 and other markers could reinforce our results, there is evidence showing that CRP, as well as leucocyte count, are good measures in population studies and are widely known as markers of chronic inflammation (Fraga et al., 2015). Finally, this study was performed using a cohort from a specific area (Porto, Portugal). We believe that the link between SC and the inflammatory status can be observed in other regions, but it cannot be obviated that the levels and the importance of certain dimensions of SC may vary across cultures.

Despite these limitations, this study has the strength of being the first to attempt to understand the causal mechanisms that may relate SC to health in the transition between adolescence and early adulthood. The use of longitudinal data allowed us to observe the evolution of inflammation status and to establish its relationship with SC. As SC is a social determinant with a positive impact on health from a young age, it is important in future studies to understand how early it influences dysregulation in immunological processes and whether this early dysregulation

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predicts the risk of subsequent diseases at young age and adulthood. Also, it would be important to identify and implement interventions targeting SC in adolescents to, thus, reduce the risk of a chronic inflammatory state on early adulthood.

5 | CONCLUSIONS

In conclusion, adolescents with higher SC present lower inflammatory levels in early adulthood, especially those with higher trust and reciprocity. Early interventions, which contribute to increasing SC in adolescence may have an impact on the inflammatory status in adulthood, with potentially positive consequences as a protective factor in the development of comorbidities.

AUTHOR CONTRIBUTIONS

Paula Teixeira: Conceptualization, methodology, formal analysis, writing—original draft. **Teresa Leão**: Conceptualization, methodology, writing—reviewing and editing. **Milton Severo**: Methodology, formal analysis, writing—reviewing and editing. **Elisabete Ramos**: Writing—reviewing and editing. **Sílvia Fraga**: Conceptualization, methodology, supervision, writing—reviewing and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

The Ethics Committee of Hospital S. João, Porto, Portugal, approved the study. The study was carried out according to the Helsinki Declaration and the appropriate standard procedures were developed to guarantee data confidentiality and protection. All participants—parents and adolescents—received written and oral information explaining the purpose and design of the study and written informed consent was obtained from both. The authors declared no potential conflicts of interest with respect to the research and authorship.

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