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Exploring variation in active network size: Constraints and ego characteristics

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ABSTRACT

Studies of active personal networks have primarily focused on providing reliable estimates of the size of the network. In this study, we examine how compositional properties of the network and ego characteristics are related to variation in network size. There was a negative relationship between mean emotional closeness and network size, for both related and unrelated networks. Further, there was a distinct upper bound on total network size. These results suggest that there are constraints both on the absolute number of individuals that ego can maintain in the network, and also on the emotional intensity of the relationships that ego can maintain with those individuals.

1. Introduction

Personal social networks in humans appear to consist of a series of sub-groupings arranged in a hierarchically inclusive sequence (Zhou et al., 2005). An individual ego can be envisaged as sitting in the centre of a series of concentric circles of acquaintanceship, which increase in size with a scaling ratio of ~3 (Zhou et al., 2005; Hill and Dunbar, 2003). As the number of alters in each layer of the personal network increases, the level of emotional intimacy and level of interaction between ego and alter decreases (Dunbar, 1998; Hill and Dunbar, 2003; Mok et al., 2007).

The innermost layer of the personal network is the support clique, which can be defined as all those individuals from whom one would seek advice, support or help in times of severe emotional or financial distress (Dunbar and Spoors, 1995), and averages about five members (Milardo, 1992). The next layer out is the sympathy group, which can be defined as those with whom an individual contacts at least monthly, and averages 12–15 members (Buys and Larson, 1979; Dunbar and Spoors, 1995). Studies of these 'inner' layers of the network have provided detailed information on the size and composition of these networks, the types of support that flow through the networks, the ties between alters in these networks and how these networks change over time (e.g. Degenne and Lebeaux, 2005; Fischer, 1982; McPherson et al., 2006; Plickert et al., 2007).

The active network refers to alters that ego feels they have a personal relationship with, and make a conscious effort to keep in contact with (Hill and Dunbar, 2003), or alters whom ego has contacted within the last 2 years (Killworth et al., 1998). Studies of this outer layer of the network have thus far focused primarily on determining effective methods for estimating network size (Fu, 2007; Hill and Dunbar, 2003; Killworth et al., 1984; McCarty et al., 2001).

The different techniques used to measure the active network have a number of important practical applications, such as estimating hard-to-count subpopulations (Killworth et al., 1998) and produce broadly similar results in terms of the mean network size (between 100 and 300). These studies always reveal a large range of network sizes (with network sizes ranging from 20 to over 500) but none of these size differences have been explainable by ego characteristics such as gender, age or socio-economic status and thus the causes of variation in active network size are still poorly understood (Bernard et al., 1990).

At the innermost levels of the personal network, in contrast, many ego characteristics have been shown to affect network size and composition. Egos who are single and without children tend to have larger networks than egos who are married and/or have dependents (Dunbar and Spoors, 1995; Johnson and Leslie, 1982; McCannell, 1988). Networks show strong homophily by gender, such that female networks are dominated by females, and male networks by males (McPherson et al., 2006; Roberts et al., 2008). Female networks also tend to contain a greater proportion of kin than male networks (McPherson et al., 2006). Socio-economic status (as measured by education, occupation and income) is positively correlated with network size and also with network diversity (Campbell et al., 1986; McPherson et al., 2006). Network size tends to decline after 65 (Fung et al., 2001; Marsden, 1987), although a more recent survey found no association between age and network size (McPherson et al., 2006).

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The first aim of this study is to examine whether these demographic ego characteristics shown to affect network size and composition in the innermost layers of the network can also explain some of the variation in network size at the active level of the personal network. The second aim is to examine how the compositional properties of networks vary with network size. Ties between ego and alter can be thought of on a crude level as either 'strong' or 'weak' (Granovetter, 1973, 1983). Do large networks consist of many weak ties, or are large networks simply 'scaled up' versions of small networks, with more strong ties *and* more weak ties than small networks?

Strong ties are those alters at the inner layers of the network (support clique and sympathy group), and they provide extensive emotional, instrumental and social support to ego (Fischer, 1982; van der Poel, 1993). Maintaining these close, emotionally intense relationships is extremely cognitively demanding, partly because "the partner is important as a unique individual and is interchangeable with none other" (Ainsworth, 1989, p. 711). It takes a long history of interaction in a variety of contexts and emotional commitment to build up and maintain these relationships (Degenne and Lebeaux, 2005). Very close relationships have higher frequencies of both face-to-face and telephone contact than those slightly less close, but still important relationships (Boase et al., 2006; Mok et al., 2007). Even in close relationships, if an active effort is not made to maintain the relationship, it tends to decay over time (Cummings et al., 2006; Dindia and Canary, 1993).

In contrast, weak ties are more distant acquaintances of ego, and are less important in providing emotional or instrumental support or social companionship. However, weak ties are important in providing access to a greater variety of information, ideas and experience, because they are more numerous, more heterogeneous and – crucially – less likely to be connected to each other than strong ties (see Granovetter, 1983 for a review). Weak ties act as a form of social capital – one definition of which is "investment in social relations with expected returns" (Lin, 1999, p. 30). These weak ties are contacted less frequently than the strong ties (Hill and Dunbar, 2003), although a minimal level of contact may be necessary to keep the relationship active, and weak ties do show decay over time (Burt, 2000, 2002; Feld, 1997; Krackhardt, 1998). Further, information about the status of the relationship, the characteristics of the alter and their connections with others still need to be cognitively stored and managed (Donath, 2008; Whittaker et al., 2002), which may place a limit on the number of weak ties individuals can maintain at a given level of emotional intensity (Dunbar, 2008).

When considering the strength of tie between two individuals, the degree of relatedness also needs to be taken into account. Kinship itself provides a powerful bond over and above the personal relationship between two individuals. There are norms and expectations that assistance will be provided to kin, regardless of the personal relationship between the two individuals (Espinoza, 1999; Wellman and Wortley, 1990). Further, an ego is linked to kin through many different ties, and the network is dense, in that many of the network partners have ties themselves, simply through the fact that they are part of the same family (Plickert et al., 2007). In contrast, a friendship network is typically much less dense, with fewer of the network members having ties between themselves. The high level of 'structural embeddedness' in kin networks means that even if two individual kin do not maintain their dyadic relationship, they will still be linked and hear important news about each other through the wider kin network. The role of 'kin-keepers' – typically female members of the family who pass on family news and keep members of the extended family in contact with each other – is important in maintaining the extended kin network (Leach and Braithwaite, 1996; Rosenthal, 1985). In contrast in a dyadic friendship, the emphasis is on both friends maintaining the relationship, otherwise it will decay over time (Burt, 2000). The combination of the obligation to help kin, and the high level of structural embeddedness means that kin are both cognitively and time-wise less demanding relationships to maintain than non-kin relationships.

The fact that as the number of alters in each layer of the personal network increases, the level of intimacy and level of interaction between ego and alter decreases (Hill and Dunbar, 2003; Mok et al., 2007) suggests that there are constraints on the number of relationships ego can maintain at a given level of intensity (Zhou et al., 2005; Roberts, 2009; see also Bernard and Killworth, 1973). These constraints may be cognitive (e.g. being able to keep track of a large number of relationships simultaneously) and/or time budgeting (e.g. building a relationship with an individual to a particular level of intensity takes a certain amount of time). Individuals only have a finite amount of time and cognitive effort to put into interacting with others and maintaining their network ties (Milardo et al., 1983; Pool and Kochen, 1978; Tooby and Cosmides, 1996) and there is evidence both for cognitive and time constraints on network size. In terms of cognitive constraints, the size of an individual's support clique is correlated with the number of levels of intentionality that an individual can process, whilst the size of their sympathy group is related to performance on a working memory task (Stiller and Dunbar, 2007). In terms of time constraints, individuals entering into a new romantic relationship show both a decrease in social network size (Johnson and Leslie, 1982) and a decrease in frequency and duration of actual interactions with network members (Milardo et al., 1983).

If network size is constrained by cognitive and/or time budget issues, we can make two predictions. First, we predict that large networks are *not* simply scaled up versions of small networks, but that large networks have more weak ties, because the number of strong ties that an ego can maintain is limited. Second, if there are constraints on the maximum number of individuals that can be maintained in the network (i.e. there are only so many 'slots' or 'friendship niches' [Tooby and Cosmides, 1996] in the active network available to be filled), we predict that egos with large related networks would have smaller unrelated networks, as has been demonstrated at the sympathy group level (Dunbar and Spoors, 1995). Thus, if an individual is born into a large extended family, this extended family will preferentially be given many of the slots available in the active network, and there will be fewer slots left over to fill with unrelated individuals (see Pool, 1980 as cited in Granovetter, 1983 for a similar argument). This logic only applies if those born into large extended families actually maintain contact with a large number of these family members, and this will be examined in this study.

An important question that arises in the discussion of strong and weak ties is exactly how to quantify tie strength. Marsden and Campbell (1984) examined a range of measures that could be used to assess tie strength, including emotional closeness, duration of relationship, the frequency of contact and type of relationship (kinship, neighbour, co-worker, friend). They concluded that a measure of the emotional intensity of a relationship is the best indicator of tie strength. Frequency of contact overestimates the strength of tie between neighbours and co-workers (see also Hill and Dunbar, 2003; Mitchell, 1987), and duration of relationship overestimates the strength of ties between relatives. Thus, we took emotional closeness as an indication of the intensity of the relationship, reasoning that strong ties would have a higher level of emotional closeness than weak ties.

2. Methods

2.1. Participants

Due to the length of the questionnaire participants were asked to complete (typically the questionnaire takes between one and two hours to complete), snowball and *ad libitum* sampling methods were used. Respondents were recruited from the personal networks of TVP or TK and some of these network members recruited further respondents not known personally to TVP or TK. The personal obligation between the respondent and the person handing out the questionnaire significantly increases the likelihood that questionnaires will be completed and returned. Previous studies (Dunbar and Spoors, 1995; Hill and Dunbar, 2003) found this method to be very effective. The questionnaires were physically distributed to the respondents, and once completed were posted back in pre-stamped envelopes. The data were collected between December 2004 and February 2005. Consistent gender differences have been found in male and female networks (Dunbar and Spoors, 1995), so the sample was restricted to females, in order to eliminate such effects, and allow for a more detailed examination of other ego factors affecting network size. A total of 160 respondents returned completed questionnaires (a return rate of ~80%). All of the respondents lived in Belgium, and this database has previously been used to examine the effect of childlessness on social investment in kin (Pollet et al., 2006).

2.2. The social network questionnaire

We used a social network questionnaire to measure the active network. Respondents were asked to provide demographic information including age, highest educational qualification, marital status and type of accommodation occupied. Respondents were asked to list all their known and living relatives – both genetic kin and affinal kin. Affinal kin were defined as the kin of the spouse or 'long-term partner'. Respondents were also asked to list other unrelated people in their network with whom they consider that they have some sort of personal relationship and for whom all of the following three conditions apply: (i) they have contact details; (ii) they have had some sort of contact within the last 12 months; (iii) they feel they would wish the relationship to continue. Respondents were asked to look through any lists of addresses (mobile telephone address book, e-mail address book, handwritten address book, list of telephone numbers) to prompt their memory. For each alter, respondents were asked how emotionally close they felt to the alter on a scale of 1–10 (where 10 is very close), and when they last contacted the alter.

For the purposes of this study, only related alters contacted in the last 12 months were included in the analysis, even though participants were asked to list all their related alters on the questionnaire. We imposed this constraint because we are here interested in relatives that form part of ego's active network – i.e. those related alters whom ego contacts on a regular basis, as opposed to distant related alters with whom ego may have little – if any – contact. In fact, there was a strong correlation between the number of related alters contacted in the last 12 months and the total number of related alters in the network (Spearman's $r_s = 0.85$, $p < 0.001$). For consistency, we also only included unrelated alters if they had actually been contacted in the last 12 months. This was because, although participants were instructed only to list unrelated alters if they had contacted them in the last 12 months, a small number of unrelated alters included by respondents had in fact not been contacted during this time period. As would be expected, there was a highly significant correlation between the number of unrelated alters listed in the questionnaire and the number of unrelated alters contacted in the last 12 months (Spearman's $r_s = 0.99$, $p < 0.001$).

2.3. Statistical analysis

The data were checked for normality using a Kolmogorov–Smirnov test. Age, mean emotional closeness, ratio of male to female alters, and network sizes were all not normally distributed (all $p < 0.001$). We have therefore used nonparametric tests, except for one set of stepwise regression analyses where no alternative exists. For the stepwise regression analyses, the data were log or square-root transformed to achieve normality where possible. For related network size, unrelated network size and emotional closeness, a square-root transformation achieved normality (Kolmogorov–Smirnov tests, all $p > 0.05$) It was not possible to achieve normality for the variables ratio of male to female alters and age even after transformation (Kolmogorov–Smirnov test, both $p < 0.001$), so untransformed values were used in the regression analysis. Effect sizes are reported using Pearson's correlation coefficient, *r*, where appropriate.

In order to examine whether there are constraints on the absolute number of individuals in the network, we used a method which estimates the best fit equation for the upper (or lower) bound of any graphical relationship (Blackburn et al., 1992). Upper bound analysis uses a subset of the points in a scatterplot in a linear regression to determine whether they represent a constraint on the dependent variable (in this case unrelated network size). The independent variable (in this case related network size) is divided into evenly sized classes, the maximum value in each class is selected, and a linear regression calculated using these maximum values only. The statistical significance of this upper-bound regression is assessed using ANOVA. If related network size does not constrain unrelated network size, the set of maximum values will not form a consistent pattern, and the regression will not be significant. If, however, there is an upper limit on network size and therefore related network size does constrain network size, we would expect that those with larger related networks will have smaller unrelated networks, and vice versa. Thus, although there is expected to be many data points below the upper bound (i.e. individuals with network sizes well below the maximum), the constraint should be evident in those individuals operating close to the maximum network size (i.e. those with large unrelated or related networks), and it is these data points that are used in the regression analysis. This method has been widely used in ecological studies (e.g. Fernandez and Vrba, 2005; Lessin et al., 2001; Podos, 1997) and was used by Stiller and Dunbar (2007) to examine whether the level of intentionality sets an upper limit on the size of the support clique.

3. Results

3.1. Participant characteristics

The age of respondents ranged from 18 to 63 years ($M = 37.32$, $SD = 13.05$). There was a bimodal distribution of ages, with peaks at 25 and 50 years old. 73.1% of the sample had completed higher education, 66.9% were working (part-time or full-time), 79.4% had a partner and 58.1% owned their house (including those with a mortgage).

3.2. Network size and composition

Mean network size was 71.84 ($SD = 33.07$, $Mdn = 70$), with a range of 10–168 (Fig. 1). The shape of the distribution of network sizes is similar to that found in other studies of active networks (Bernard et al., 1990; Hill and Dunbar, 2003), although with a shorter tail at the upper end of the distribution. The detailed breakdown of the network by relatedness and gender is shown in Table 1. Overall, there are significantly more females in the network than males (Wilcoxon signed-ranks test: $T = 1411$, $N = 155$ (five ties), $p < 0.001$, $r = -0.66$). According to the criteria of Cohen (1992), the effect size (r) is large for the comparison of unrelated male and female alters in the network. Although there are significantly more female genetic kin in the network than male genetic kin ($T = 3414$, $N = 138$ (22 ties),

Table 1
Mean network size (and percentage of complete network) by relationship and gender of alters.

Relationship	Male	Female	Total	Significance	Effect size (*r*)
Unrelated (% of network)	12.66 (16.62)	18.59 (25.88)	31.26 (43.51)	<0.001	−0.67
Genetic kin (% of network)	13.06 (18.20)	13.91 (19.36)	27.29 (37.99)	0.003	−0.23
Affinal kin (% of network)	6.57 (9.15)	6.70 (9.33)	13.30 (18.51)	0.517	−0.05
Total network (% of network)	32.29 (44.95)	39.20 (54.56)	71.84 (100)	<0.001	−0.66

Note: Column and row totals may be inconsistent due to rounding and incomplete completion of questionnaire.
Significance levels show *p* values for Wilcoxon signed-ranks test on number of males and females in network for each relationship type.

$p = 0.003$, $r = -0.23$), the effect size is small, and given the large sample size this result may not be of biological significance.

3.3. Emotional closeness and network size

As a preliminary, graphical examination of how emotional closeness between ego and alter varies with network size, the networks were split into three evenly sized groups based on total network size–small networks (under 56 alters, $n = 56$), medium networks (56–82 alters, $n = 54$) and large networks (over 83 alters, $n = 50$). Fig. 2a and b shows the proportion of alters (out of the total number of alters in the network) at each level of emotional closeness. In this and in all subsequent analysis, related alters include both genetic and affinal kin. For unrelated alters, the distribution of emotional closeness for small, medium and large networks was broadly similar, following a normal distribution, with a peak at level 6 emotional closeness, and fewer alters who are either very close (emotional closeness 9 or 10), or not very close (emotional closeness 1 or 2). For related alters, however, large networks had proportionally more ties at emotional closeness 2 than small or medium networks. Further, for both related and unrelated alters, small networks had a greater proportion of alters at emotional closeness 10 than medium or large networks.

3.4. Predictors of network size

To examine the compositional properties of networks of differing size in more detail, and also to determine whether any ego characteristics are predictors of network size, two multiple regression analyses were carried out – one with the size of the unrelated network as the dependent variable, and one with the size of the related network as the dependent variable. The compositional network measures entered as independent variables were the mean emotional closeness between ego and alter and the male: female ratio of alters. These network measures were calculated separately for related and unrelated alters. Demographic properties of the ego – age, whether or not ego had a higher education, owned a house, was working, had a partner – were also entered as independent variables. Whether or not ego had a higher education, owned a house and was working were used as indicators of socio-economic status. The results of the regression analysis are presented in Tables 2 and 3.[1]

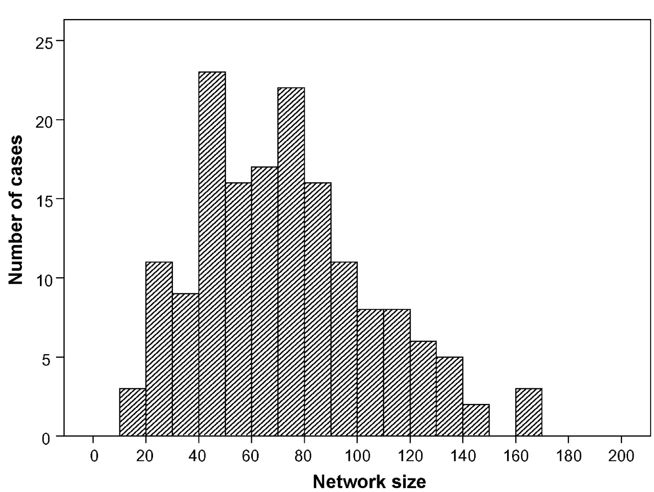

Fig. 1. Distribution of active network sizes.

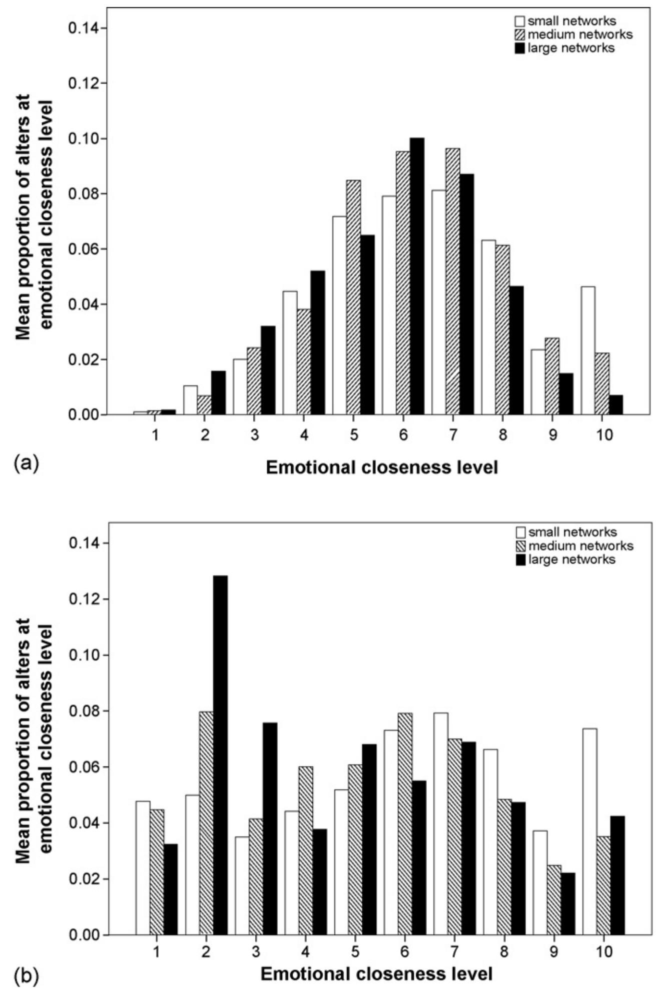

Fig. 2. Mean proportion of alters (out of total network) at each level of emotional closeness for small (under 56 alters, $n = 56$), medium (56–82 alters, $n = 54$) and large (over 83 alters, $n = 50$) networks. Emotional closeness scale: 1 not very close, 10 extremely close. (a) Unrelated alters. (b) Related alters (includes genetic and affinal kin).

[1] The regression models were checked for multicollinearity based on the average variance inflation factors (VIF). Field (2005) suggests that if the average VIF is substantially greater than 1, or if the largest VIF is greater than 10, then the regression may be biased due to the effects of multicollinearity. The average VIF for the related networks model was 1.08, for the unrelated networks model was 1.02, and all the VIF values were under 1.2. This indicates that collinearity is not a serious problem for these two regression models.

Table 2
Summary of stepwise regression analysis for variables predicting unrelated network size ($N = 154$).

Variable	*B*	*SE B*	*β*
Constant	7.61	1.39	–
Has ego had higher education (YES/NO)	0.83	0.29	0.22**
Square root (Mean emotional closeness)	−1.31	0.54	−0.19*
Unrelated sex ratio (male:female)	0.56	0.23	−0.18*

Note: Final model: $R^2 = 0.12$, $F(3, 150) = 7.07$, $p < 0.001$.
Excluded variables: Age of ego; Does ego have a partner (YES/NO); Is ego working (YES/NO); Does ego own house (YES/NO).
* $p < 0.05$.
** $p < 0.01$.

Table 3
Summary of stepwise regression analysis for variables predicting related network size ($N = 156$).

Variable	*B*	*SE B*	*β*
Constant	9.39	0.96	
Square root (mean emotional closeness)	−2.14	0.38	−0.39***
Does ego have a partner (YES/NO)	1.01	0.34	0.22**
Has ego had a higher education (YES/NO)	0.74	0.29	0.18*
Does ego own house (YES/NO)	0.55	0.27	0.15*

Note: Final model: $R^2 = 0.29$, $F(4, 151) = 15.71$, $p < 0.001$.
Excluded variables: Age of ego; Is ego working (YES/NO); Related sex ratio (male:female).
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

For unrelated networks, whether the ego had completed higher education was the only demographic characteristic included in the model and was positively related to network size. Mean emotional closeness was negatively related to network size – thus egos with larger unrelated networks are, on average, less emotionally close to the alters in their network than egos with smaller networks. Finally, the male: female sex ratio was positively related to network size – females with larger networks tended to have a greater proportion of unrelated male alters in their network as compared to females with smaller networks. This effect was not due to females with a partner acquiring their partners' male friends – there was no significant difference in the male: female sex ratio of females with (*Mdn* = 0.68) and without partners (*Mdn* = 0.63), Mann–Whitney $U = 1876.5$, $N = 157$, $p = 0.465$, $r = -0.06$.

For related networks, mean emotional closeness was the most important predictor of network size, and was again negatively related to network size. Egos with a partner had larger related networks – this is unsurprising, as having a partner adds affinal kin to the related network. Completing higher education and owning a house were positively associated with network size. The age of the ego and whether or not they were working were not significant predictors of network size for related or unrelated networks.

3.5. Relationship between related network size, unrelated network size and total network size

There was no overall correlation between the ratio of related to unrelated alters in the network, and total network size (Spearman's $r_s = 0.089$, $p = 0.268$). Thus large networks are not dominated either by related or unrelated alters.

We used the method described by Blackburn et al. (1992) to examine the upper bound on network size, as revealed by the number of unrelated alters in the network plotted against the number of related network members (Fig. 3). There are a large number of small networks in the lower left quadrant of Fig. 3 – these are egos who only contact a small number of related and unrelated individuals per year. For this analysis, we are examining what places the upper limit on network size, so egos with small networks (under 56 alters) were excluded on the grounds that they would distort the analysis (see Blackburn et al., 1992; Lawton, 1990 for discussion of this issue). The analysis was carried out on egos with medium and large networks (networks with 56 alters and over, $n = 104$), as it is in these networks where we are most likely to see the constraints on network size operating.

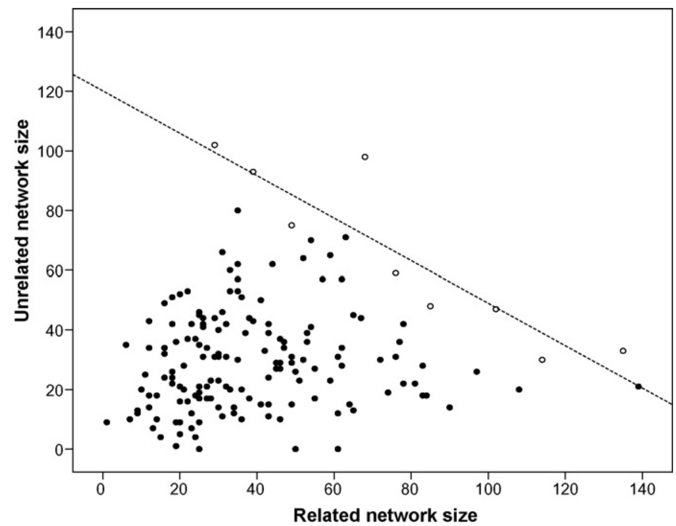

Fig. 3. Number of unrelated alters in network plotted against number of related alters in network. Following Blackburn et al. (1992), an upper bound slope, indicated by the broken line, has been estimated using 10 size classes: $Y = 120.17 + -0.71X$. Open circles indicate data points used in upper bounds analysis. Upper bounds analysis based on medium and large networks only (56 alters and over, $n = 104$).

There is no fixed criterion for selecting the number of size classes to use in the upper bound analysis. Blackburn et al. (1992) suggests that any number between six and fifteen is satisfactory, so long as each class contains several values, so that the maximum can be realistically estimated. Because of the potential for biasing the analysis with subjective class widths, we analysed the data by binning related network size into between 6 and 16 class sizes, which produced 10 sets of data for the upper bounds analyses. In all ten of the analyses, the regression analysis was significant ($p < 0.05$), indicating that no matter how many size classes are used, an upper constraint emerges on the absolute number of people egos can maintain in their network. The slope of the regression line varied between −0.54 and −0.75 (i.e. was always greater than −1.0). When 10 size classes were used (as shown in Fig. 3), the results of the upper bound analysis were: $r^2 = 0.82$; $F_{1,7} = 31.05$, $p = 0.001$. The regression equations can be used to calculate the mean upper limit on network size, and this varied between 136.3 and 150.0 depending on the number of class sizes used.

Related network size (rather than unrelated network size) was used as the explanatory variable in the upper bound analysis as related alters appear to be relatively nondiscretionary contacts. There was a strong correlation between related alters contacted in the last 12 months and total number of related alters in the network (Spearman's $r_s = 0.85$, $p < 0.001$; see Fig. 4). The respondents contacted a mean of 75.4% (*SD* = 20.0) of all related alters within the last year. Thus, individuals born into large families tend to have large numbers of related alters in their active network, and in this way related network size acts to constrain unrelated network size, rather than vice versa.

To reinforce this conclusion, we tested to see whether the upper bound on network size would emerge no matter what two demo-

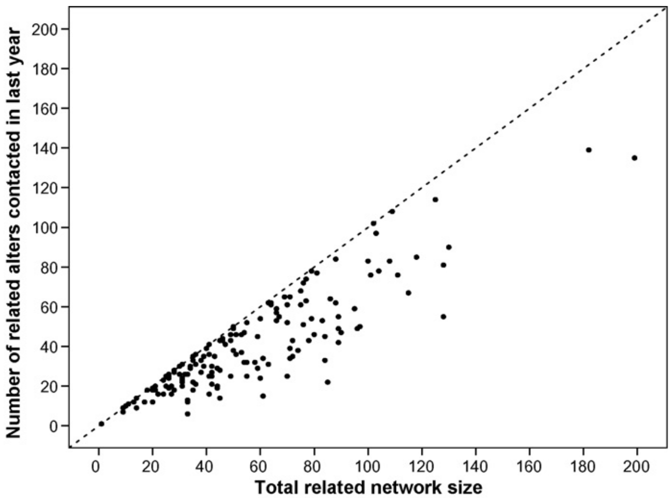

Fig. 4. Number of related alters contacted in the last 12 months plotted against total number of related alters in network. Dashed line represent contact with all of related alters in network in last 12 months.

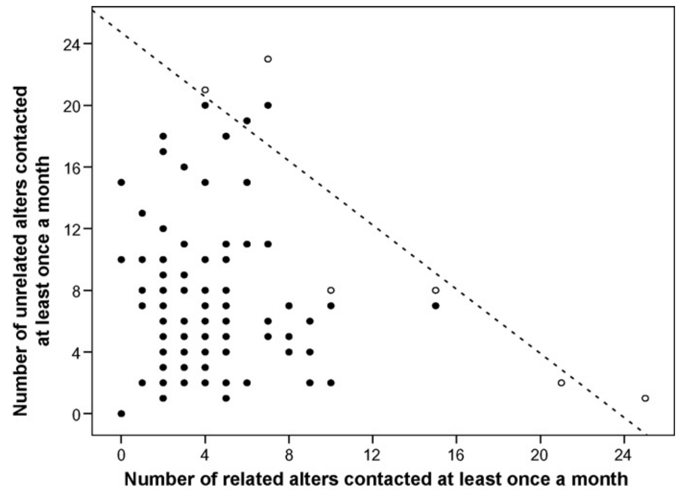

Fig. 6. Number of non-kin contacted at least once per month plotted against number of kin contacted at least once per month. Based on data from Dunbar and Spoors (1995). Following Blackburn et al. (1992), an upper bound slope, indicated by the broken line, has been estimated using seven size classes: $Y = 24.72 + -1.04X$. Open circles show data points used to calculate upper bounds regression line.

graphic variables were used. For this purpose, we used the number of male and female alters in the network. Again, the analysis was run on networks which included a minimum of 56 alters and the data binned into between 6 and 16 size classes. This produced seven sets of data for the upper bound analysis, both for when the number of males was treated as the dependent variable, and when the number of females was treated as the dependent variable. With males treated as the dependent variable, the regression slope varied between +0.28 and +0.53, with five of the regressions significant, and two of the regressions not significant (see Fig. 5). With females treated as the dependent variable, the regression slope varied between +0.53 and +0.59 and all seven regressions were significant. The distinct upper bound therefore only appears if the number of related alters is treated as the explanatory variable and the number of unrelated alters as the dependent variable. Using two other mutually exclusive variables (number of male and female alters in the network) produces markedly different results, with positive rather than negative regression slopes.

To examine whether this upper constraint also applies to networks at the inner levels, we reanalysed the data from Dunbar and Spoors (1995) on the number of related and unrelated alters contacted monthly, the definition used to define the sympathy group. Related network size was binned using divisions of four, three and two related network members, producing 7, 9 and 13 size classes. All three regression analyses based on these size classes were significant ($p < 0.05$), with the slopes of the regression lines varying between −0.94 and −1.04. When seven size classes were used (as shown in Fig. 6), the results of the upper bound analysis were: $r^2 = 0.82$; $F_{1,4} = 18.56$, $p = 0.013$. The mean upper limit on sympathy group size varied between 23.8 and 24.4. Thus, there is a clear upper constraint on the absolute number of people that egos can maintain in their sympathy group.

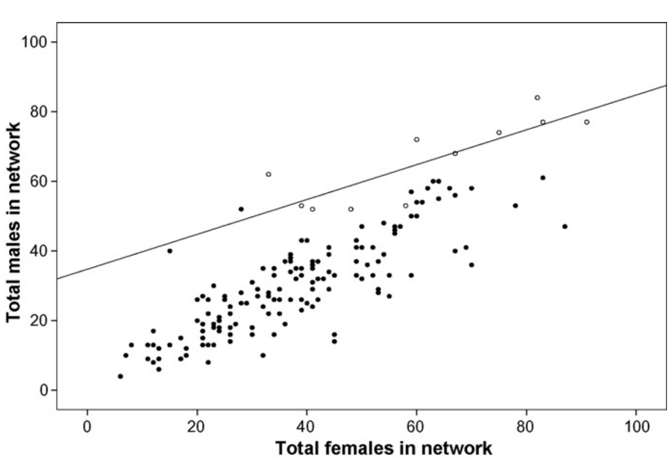

Fig. 5. Number of male alters in network plotted against number of female alters in network. Following Blackburn et al. (1992), an upper bound slope, indicated by the broken line, has been estimated using 11 size classes: $Y = 34.77 + -0.50X$. Open circles indicate data points used in upper bounds analysis. Upper bounds analysis based on medium and large networks only (56 alters and over, $n = 104$).

4. Discussion

In the light of time and cognitive constraints operating on network size we made two predictions about the composition of active networks of different sizes. First, that large networks would contain a greater proportion of weak ties as compared to small networks, and second that egos with large related networks would have smaller unrelated networks (i.e. there should be an upper bound on network size). The first prediction was supported by the results. Mean emotional closeness was an important predictor of network size for both related and unrelated networks. Egos with larger networks tended to be, on average, less emotionally close to alters in their networks as compared to those egos with smaller networks. This demonstrates that large networks are not simply scaled up versions of smaller networks, but that there are important compositional differences between large and small networks. To a certain extent, there appears to be a trade-off between the number of alters in the network, and the emotional intensity of each relationship in the network–smaller networks contain fewer individuals, but at a higher level of emotional closeness than large networks.

The second prediction was also supported. There appears to be a constraint on the absolute number of people egos can maintain in their network, as revealed by the upper bounds analysis of the number of related and unrelated alters in the network. The mean upper limit on network size at around 136–150 is very close to the group size of 150 predicted for humans by Dunbar (1993), based on the size of the human neocortex and the relationship between group size and neocortex size in non-human primates. The reanalysis of data from Dunbar and Spoors (1995) on the number of related and unrelated alters contacted at least monthly (i.e. the sympathy group), also revealed a clear upper bound on sympathy group size. The mean upper limit on network size for sympathy groups was around 24, which corresponds to the upper limits found on sympathy groups in the literature (Buys and Larson, 1979; Zhou et al., 2005).

There was a strong correlation between the total size of an ego's family, and the number of related alters they contact during the course of a year (this study), or per month (Dunbar and Spoors, 1995). On average, the respondents in this study contacted three-quarters of their entire family during the course of the year. Thus an individual born into a large family will tend to fill many of the slots in their active network with related alters, and have fewer slots available for unrelated alters. These results suggest that, at the level of the active network, people place a premium on maintaining family contacts, and only extend their network of contacts beyond the family if they have spare capacity in their total network size.

It is noteworthy that the slope of the upper bound was close to −1.0 for the sympathy group, but varied between −0.5 and −0.8 (i.e. was always greater than −1.0) for the active network. This suggests that at the level of the active network, maintaining related alters is less costly than maintaining unrelated alters, whereas at the level of the sympathy group it is equally costly to maintain related and unrelated alters. This may reflect the difference between the more emotionally intense relationships at the level of the sympathy group and the extended network of distant kin (with a high level of structural embeddedness) at the active network level, with whom egos tend to have only infrequent contact (Mok et al., 2007).

This distinct upper bound at the level of both the sympathy group and the active network suggests that the constraint on network size may impose an upper limit on the number of individuals with whom a stable social relationship can be maintained at different levels of intensity at each layer of the personal network (support clique, sympathy group, active network), rather than dictating the mean size of each of these layers (Stiller and Dunbar, 2007). Below this upper bound, a broad range of network sizes would be expected, due to social, personality, demographic, life history and other circumstantial factors (Dunbar, 1996).

The two types of constraints identified by this study may be related – as the number of alters in the network increases, the level of mean emotional closeness decreases, and ultimately this sets a limit on the absolute number of alters that can be maintained in an active network. Below a certain level of emotional closeness, alters are likely to drop out of the active network, and instead be included in the 'global network', which includes alters who the ego would recognise, know the name of and feel it appropriate to greet (Pool and Kochen, 1978), but not necessarily make an effort to keep in regular contact with.

In terms of ego characteristics, egos with a partner had a larger related network size. Having a partner draws affinal relatives into ego's network, thus increasing their related network size. Educational level was a predictor of both unrelated and related network size, and owning a house was a predictor of related network size. Socio-economic status also correlates with network size at the support and sympathy group level (Campbell et al., 1986). Intriguingly, the male: female sex ratio was positively related to unrelated network size–large networks contained proportionally more male alters relative to the number of female alters. This may be related to the fact that female–female friendships tend to be more emotionally intense than female–male friendships (Benenson and Christakos, 2003; Reis et al., 1985), and thus female egos with larger networks may find it easier to maintain male friendships than female friendships.

The way in which constraints on network size operate in practice, and whether they are primarily time or cognitive constraints, is still unclear (Stiller and Dunbar, 2007; Zhou et al., 2005). One of the ways to examine the operation of these constraints would be to examine communication patterns within large and small networks, given that the frequency of communication is related to the emotional closeness between two individuals, when proximity and work connections are controlled for (Hill and Dunbar, 2003).

In the last two decades, there has been a proliferation of new ways to communicate with others, including email, mobile phones, social network sites and other types of communication over the Internet (boyd and Ellison, 2008; Duck, 2008; Stefanone and Jang, 2008). A key question is whether these new forms of communication relax time constrains and/or cognitive constraints on network size and thus allow for larger network sizes (i.e. increase the number of 'slots' available) at each layer of the personal network (Donath, 2008). There is some evidence that email (Boase et al., 2006) and social network sites (Ellison et al., 2007) do allow for larger total network sizes but it is less clear whether this is also the case for the inner layers of the personal network (support clique and sympathy group). These relationships may require more of the rich and in-depth communication that takes place in real-time through phone or, especially, face-to-face to maintain (Mok et al., 2007; Utz, 2007).

The sample in this study was limited to females, to eliminate gender effects, and allow a more detailed analysis of the factors other than gender influencing network size and structure. Whether the presented results would also apply to males remains to be seen. We expect that men's active networks would be male-biased and contain a lower proportion of kin, as is the case at the support clique and sympathy group level (Dunbar and Spoors, 1995; McPherson et al., 2006). It would be particularly interesting to see if the strong correlation between the total family size and number of family members contacted per year holds for males – we suspect that the correlation would be less strong for males than it was for females. However, the constraints that limit network size should operate on males and females equally.

This research utilised snowball and ad libitum methods to recruit respondents. Ideally, a large sample taken at random from the population would be used, as the sample here cannot be taken as being representative of the population of Belgium as a whole. However, the constraints that place an upper limit on network size should operate regardless of the sample used, and thus we expect that the results would not change substantially with a wider sample.

A further issue to address is the way in which network structure affects the level of maintenance required to sustain personal networks. The high level of structural embeddedness of kinship networks should act to reduce the maintenance required to sustain kin relations – this may be especially true of distant kin relations, with whom ego has less frequent contact (Mok et al., 2007). Friendship networks may also differ in their structure between individuals – some egos may have lots of friends who are isolates, whilst other egos may have lots of friends who are connected to each other. The latter type of network should be easier to maintain than the former, as the connections between friends help to sustain relationships and it may also be easier to socialise with groups of friends, rather than having to see friends individually.

There is evidence from students (Feld, 1997; Krackhardt, 1998) and bankers (Burt, 2000, 2002) that decay rates of relationships are higher when they do not have mutual contacts (i.e. friends or work colleagues in common), but as far as we are aware the relationship between structural embeddedness, relationship maintenance and overall network size has not been examined. Given the size of the active network, collecting information on all alter–alter ties is an enormous task for respondents, but McCarty et al. (2007) demonstrated that not all alter–alter ties need to be assessed to create an accurate picture of network structure, which makes this task more feasible.

In summary, mean emotional closeness was negatively related to both related and unrelated network size, and there was a distinct upper bound on total network size, at the level of both the active network and sympathy group. These results suggest that there are constraints both on the absolute number of individuals ego can maintain in the network, and also on the emotional intensity of the relationships that ego can maintain with those individuals.

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References

Ainsworth, M.D.S., 1989. Attachments beyond infancy. American Psychologist 44, 709–716.
Benenson, J.F., Christakos, A., 2003. The greater fragility of females' versus males' closest same-sex friendships. Child Development 74, 1123–1129.
Bernard, H.R., Killworth, P.D., 1973. On the social structure of an ocean-going research vessel and other important things. Social Science Research 2, 145–184.
Bernard, H.R., Johnsen, E.C., Killworth, P.D., McCarty, C., Shelley, A., 1990. Comparing four different methods for measuring personal social networks. Social Networks 12, 179–215.
Blackburn, T.M., Lawton, J.H., Perry, J.N., 1992. A method of estimating the slope of upper bounds of plots of body size and abundance in natural animal assemblages. Oikos 65, 107–112.
Boase, J., Horrigan, J.B., Wellman, B., Rainie, L., 2006. The strength of Internet ties. Pew Internet & American Life Project. Retrieved 10 July, 2008, from: http://www.pewinternet.org/pdfs/PIP_Internet_ties.pdf.
boyd, d.m., Ellison, N.B., 2008. Social network sites: definition, history and scholarship. Journal of Computer-Mediated Communication 13, 210–238.
Burt, R., 2000. Decay functions. Social Networks 22, 1–28.
Burt, R., 2002. Bridge decay. Social Networks 24, 333–363.
Buys, C.J., Larson, K.L., 1979. Human sympathy groups. Psychological Reports 45, 547–553.
Campbell, K.E., Marsden, P.V., Hurlbert, J.S., 1986. Social resources and socioeconomic status. Social Networks 8, 97–117.
Cohen, J., 1992. A power primer. Psychological Bulletin 112, 155–159.
Cummings, J.N., Lee, J.B., Kraut, R., 2006. Communication technology and friendship during the transition from high school to college. In: Kraut, R., Brynin, M., Kiesler, S. (Eds.), Computers, Phones and the Internet: Domesticating Information Technologies. Oxford University Press, New York, pp. 265–278.
Degenne, A., Lebeaux, M.-O., 2005. The dynamics of personal networks at the time of entry into adult life. Social Networks 27, 337–358.
Dindia, K., Canary, D.J., 1993. Definitions and theoretical perspectives on maintaining relationships. Journal of Social and Personal Relationships 10, 163–173.
Donath, J., 2008. Signals in social supernets. Journal of Computer-Mediated Communication 13, 231–251.
Duck, S., 2008. Silver anniversary essay: a past and a future for relationship research. Journal of Social and Personal Relationships 25, 189–200.
Dunbar, R.I.M., 1993. Coevolution of neocortical size, group size and language in humans. Behavioral and Brain Sciences 16, 681–735.
Dunbar, R.I.M., 1996. Determinants of group size in primates: a general model. In: Maynard Smith, J., Runciman, G., Dunbar, R.I.M. (Eds.), Evolution of Culture and Language in Primates and Humans. Oxford University Press, Oxford, pp. 33–57.
Dunbar, R.I.M., 1998. The social brain hypothesis. Evolutionary Anthropology 6, 178–190.
Dunbar, R.I.M., 2008. Cognitive constrains on the structure and dynamics of social networks. Group Dynamics: Theory, Research and Practice 12, 7–16.
Dunbar, R.I.M., Spoors, M., 1995. Social networks, support cliques and kinship. Human Nature 6, 273–290.
Ellison, N.B., Steinfield, C., Lampe, C., 2007. The benefits of facebook "friends": social capital and college students' use of online social network sites. Journal of Computer-Mediated Communication 12, 1143–1168.
Espinoza, V., 1999. Social networks among the urban poor: inequality and integration in a Latin American city. In: Wellman, B. (Ed.), Networks in the Global Village. Westview, Boulder, CO, pp. 147–184.
Feld, S.L., 1997. Structural embeddedness and stability of interpersonal relations. Social Networks 19, 91–95.
Fernandez, M.H., Vrba, E.S., 2005. Body size, biomic specialization and range size of large African mammals. Journal of Biogeography 32, 1243–1256.
Field, A., 2005. Discovering Statistics Using SPSS, 2nd ed. Sage, London.
Fischer, C., 1982. To Dwell among Friends: Personal Networks in the Town and City. University of California Press, Berkeley, CA.
Fu, Y., 2007. Contact diaries: building archives of actual and comprehensive personal networks. Field Methods 19, 194–217.
Fung, H.H., Carstensen, L.L., Lang, F.R., 2001. Age-related patterns in social networks among European Americans and African Americans: implications for socioemotional selectivity across the life span. International Journal of Aging and Human Development 52, 185–206.
Granovetter, M.S., 1973. The strength of weak ties. American Journal of Sociology 78, 1360–1380.
Granovetter, M., 1983. The strength of weak ties: a network theory revisited. Sociological Theory 1, 201–233.
Hill, R.A., Dunbar, R.I.M., 2003. Social network size in humans. Human Nature 14, 53–72.
Johnson, M.P., Leslie, L., 1982. Couple involvement and network structure—a test of the dyadic withdrawal hypothesis. Social Psychology Quarterly 45, 34–43.
Killworth, P.D., Bernard, H.R., McCarty, C., 1984. Measuring patterns of acquaintanceship. Current Anthropology 25, 381–397.
Killworth, P.D., Johnsen, E.C., McCarty, C., Shelley, G.A., Bernard, H.R., 1998. A social network approach to estimating seroprevalence in the United States. Social Networks 20, 23–50.
Krackhardt, D., 1998. Simmelian ties: super strong and sticky. In: Kramer, R.M., Neale, M. (Eds.), Power and Influence in Organizations. Sage, Thousand Oaks, CA, pp. 21–38.
Lawton, J.H., 1990. Species richness and population dynamics of animal assemblages. Patterns in body size: abundance space. Philosophical Transactions: Biological Sciences 330, 283–291.
Leach, M.S., Braithwaite, D.O., 1996. A binding tie: supportive communication of family kinkeepers. Journal of Applied Communication Research 24, 200–216.
Lessin, L.M., Dyer, A.R., Goldberg, D.E., 2001. Using upper boundary constraints to quantify competitive response of desert animals. Oikos 92, 153–159.
Lin, N., 1999. Building a network theory of social capital. Connections 22, 28–51.
Marsden, P.V., 1987. Core discussion networks of Americans. American Sociological Review 52, 122–131.
Marsden, P.V., Campbell, K.E., 1984. Measuring tie strength. Social Forces 63, 482–501.
McCannell, K., 1988. Social networks and the transition to motherhood. In: Milardo, R.M. (Ed.), Families and Social Networks. Sage, Newbury Park, CA, pp. 83–106.
McCarty, C., Killworth, P.D., Bernard, H.R., Johnsen, E.C., Shelley, G.A., 2001. Comparing two methods for estimating network size. Human Organization 60, 28–39.
McCarty, C., Killworth, P.D., Rennell, J., 2007. Impact of methods for reducing respondent burden on personal network structural measures. Social Networks 29, 300–315.
McPherson, M., Smith-Lovin, L., Brashears, M.E., 2006. Social isolation in America: changes in core discussion networks over two decades. American Sociological Review 71, 353–375.
Milardo, R.M., 1992. Comparative methods for delineating social networks. Journal of Social and Personal Relationships 9, 447–461.
Milardo, R.M., Johnson, M.P., Huston, T.L., 1983. Developing close relationships: changing patterns of interaction between pair members and social networks. Journal of Personality and Social Psychology 44, 964–976.
Mitchell, J.C., 1987. The components of strong ties among homeless women. Social Networks 9, 37–47.
Mok, D., Wellman, B., Basu, R., 2007. Did distance matter before the Internet? Interpersonal contact and support in the 1970s. Social Networks 29, 430–461.
Plickert, G., Cote, R.R., Wellman, B., 2007. It's not who you know, it's how you know them: who exchanges what with whom? Social Networks 29, 405–429.
Podos, J., 1997. A performance constraint on the evolution of trilled vocalizations in a songbird family (Passeriformes: Emberizidae). Evolution 51, 537–551.
Pollet, T.V., Kuppens, T., Dunbar, R.I.M., 2006. When nieces and nephews become important: differences between childless women and mothers in relationships with nieces and nephews. Journal of Cultural and Evolutionary Psychology 4, 83–94.
Pool, I.D., Kochen, M., 1978. Contacts and influence. Social Networks 1, 5–51.
Reis, H.T., Senchak, M., Solomon, B., 1985. Sex differences in the intimacy of social interaction: further examination of potential explanations. Journal of Personality and Social Psychology 48, 1204–1217.
Roberts, S.G.B., 2009. Constraints on network size. Proceedings of the British Academy, in press.
Roberts, S.G.B., Wilson, S., Fedurek, R., Dunbar, R.I.M., 2008. Individual differences and personal social network size and structure. Personality and Individual Differences 44, 954–964.
Rosenthal, C.J., 1985. Kinkeeping in the familial division of labor. Journal of Marriage and the Family 47, 965–974.
Stefanone, M.A., Jang, C.-Y., 2008. Writing for friends and family: the interpersonal nature of blogs. Journal of Computer-Mediated Communication 13, 123–140.
Stiller, J., Dunbar, R.I.M., 2007. Perspective-taking and memory capacity predict social network size. Social Networks 27, 93–104.
Tooby, J., Cosmides, L., 1996. Friendship and the Banker's Paradox: other pathways to the evolution of adaptations for altruism. Proceedings of the British Academy 88, 119–143.
Utz, S., 2007. Media use in long-distance friendships. Information, Communication and Society 10, 694–713.

van der Poel, M.G.M., 1993. Delineating personal support networks. Social Networks 15, 49–70.
Wellman, B., Wortley, S., 1990. Different strokes from different folks: community ties and social support. American Journal of Sociology 96, 558–588.
Whittaker, S., Jones, Q., Terveen, L., 2002. Contact management: identifying contacts to support long-term communication. In: Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work, New Orleans. Retrieved 10 July, 2008 from http://portal.acm.org/citation.cfm?id=587078.587109&coll=portal&dl=ACM.
Zhou, W.-X., Sornette, D., Hill, R.A., Dunbar, R.I.M., 2005. Discrete hierarchical organisation of social group sizes. Proceedings of the Royal Society of London, Series B 272, 439–444.