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REVIEWS

Feature Review

The Anatomy of Friendship

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Friendship is the single most important factor influencing our health, well-being, and happiness. Creating and maintaining friendships is, however, extremely costly, in terms of both the time that has to be invested and the cognitive mechanisms that underpin them. Nonetheless, personal social networks exhibit many constancies, notably in their size and their hierarchical structuring. Understanding the processes that give rise to these patterns and their evolutionary origins requires a multidisciplinary approach that combines social and neuropsychology as well as evolutionary biology.

Trends

Having friends has dramatic effects on our happiness, mental well-being and longevity.

There is a limit to the number of friends we can manage at any one time, sometimes known as 'Dunbar's number'.

This limit is imposed by a combination of the time and the cognitive demands (the latter a function of prefrontal cortex volume) of maintaining relationships.

There are striking gender differences in how relationships are maintained.

The Internet has not (yet) changed any of this.

The Meaning of Friendship

Over the past two decades, considerable evidence has emerged to suggest that the most important factor influencing our happiness, mental well-being, physical health, and even mortality risk, not to mention the morbidity and mortality of our children, is the size and quality of our friendship circles – something that also turns out to be true for anthropoid primates (Box 1). Friends provide moral and emotional support, as well as protection from external threats and the stresses of living in groups, not to mention practical and economic aid when the need arises.

In this article, I examine the evolutionary origins of friendship, present evidence that their number and quality are limited by a combination of cognitive capacity and the time we can afford to devote to them, and highlight the closely intertwined role that neurobiology and social psychology play in this. The conventional approach in psychology would be to drill down to ever finer detail on a single theme. Instead, I will do the reverse and step back in order to see the bigger picture. By integrating findings from a number of very different disciplines, I aim to show how and why the different elements combine in a way that provides a richer, more comprehensive understanding of friendship.

First, however, some definitions. For present purposes, I define friends as the people who share our lives in a way that is more than just the casual meeting of strangers; they are the people whom we make an effort to maintain contact with, and to whom we feel an emotional bond. That includes members of our extended family as well as more conventional friends (i.e., people not biologically related to us); it also includes our romantic partners. It is not uncommon for people to refer to their romantic partner or even their mother/sister as 'their best friend'.

Although there are important differences between family (kinships) and friends (friendships) [1–4], and both differ in important ways (notably sexually) from romantic relationships, all three types of relationship have 'meaning' for us in an emotional sense, and they provide us with explicit social and emotional benefits that strangers, casual acquaintances, and business partners do not. Emotional closeness, or 'oneness' [5], defined as how two individuals feel about each other, can be reliably measured through a variety of psychological instruments [6] and may reflect universal underlying cognitive mechanisms for interpersonal relationships [7]. Emotional closeness captures how interdependent two individuals are and how willing one is to

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Box 1. Friendship and Health

There is now extensive evidence that having friends protects you against both mental and physical illness, helps you recover quicker when you fall sick or have surgery, and makes you feel happier and more contented with life [170–181] (Figure I). Friends have a bigger effect on our susceptibility to disease and the risk we face of dying than anything else except giving up smoking [182]. In this respect, family relationships have the same effect as conventional friendships [183–185]. Similar findings have been reported for primates: female baboons who have more 'friends' (grooming partners) have lower cortisol titres [186,187], have more offspring and live longer [188–190]. This is also true for wild horses and zebra [191–193]. While friends may promote health directly by giving assistance when needed, bonding activities that upregulate the endorphin system (physical contact, laughter, singing, dancing; Box 3) may also influence health directly through the effect that endorphins seem to have on the immune system [194].

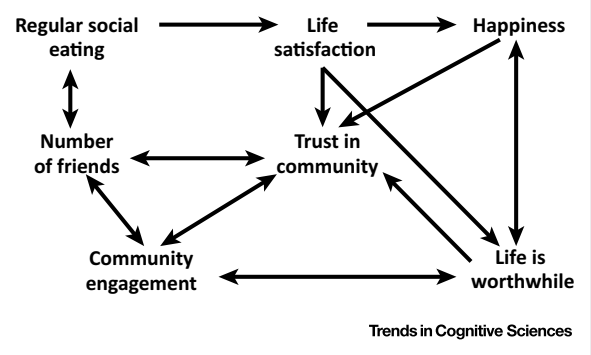

Figure I. Factors Influencing Well-Being. Path analysis of data from a UK stratified national survey (balancing age, gender, and geographical distribution) of 2000 adults to show the causal relationships between major social and psychological variables relating to well-being. In essence, having more close friends and eating more meals with other people have positive effects on satisfaction with life, happiness, sense of engagement with and trust of one's local community. Redrawn from [222].

help the other [8,9]; in turn, this appears to regulate the availability of social, psychological, and even economic support [10,11].

Taken together, human friendships of all kinds bear many similarities to the bonded relationships found in monkeys and apes [12–14]. By bonded relationships, I mean relationships that are long-lasting rather than casual, involve close attention to the partner (e.g., by frequent visual monitoring [13,15]), and a constant desire to be physically with the partner. This bears a close similarity to the definition used in the literature on human relationships, where the consensus identifies two distinct dimensions often labelled 'being close' and 'feeling close' [6].

Although relationships have been a topic of considerable interest to social psychologists over many decades [16,17], there has been a strong tendency to focus on dyadic relationships (romantic couples, best friends, mother–infant dyads). Yet all such relationships are embedded into extended social networks that both influence and are influenced by the dyadic relationships that make them up. Social network analysis (Box 2) has provided deep insights into the structure and dynamics of relationships in the past decade or so, and provides an important, but largely overlooked, tool for social psychology.

The Limits to Friendship

Defining friendships in this wide sense, how many friends do we typically have? The average size of personal social networks seems to be about 150, whether these are determined from face-to-face contacts [18,19], telephone call databases [20], or postings in online environments [21–23]. This includes all extended family relationships as well as friends in the more

Box 2. Social Networks

Social psychology has tended to focus mainly on individuals and their attitudes and behaviour, viewing the social context mainly in the form of dyadic relationships (romantic relationships, individual friendships, parent–offspring relationships). However, both the individual and these dyadic relationships are embedded in a much wider social network that both influences and is influenced by these relationships. Over the past decade or so, social network analysis (SNA) has evolved out of sociology by way of statistical physics to become an important methodology for exploring both small- and very large-scale social worlds [195]. This highly quantitative field provides a number of statistical indices that describe relationships and the structure of networks in ways that allow us to understand some of their dynamics. Among important metrics, some of which are properties of the network and others of the individual, are degree (the number of primary social partners an individual has), density (the proportion of all possible dyadic relationships that actually exist), clustering coefficient (the probability that, if A and B are friends with C, they will also be friends of each other), and betweenness centrality (a measure of the extent to which an individual is linked, directly or indirectly, to every other individual in the network – and hence a pivotal member of the community). Some of these indices relate directly to Heider's structural balance theory from social psychology [196]. In addition, SNA metrics allow us to examine the structure of networks in such a way as to define subgroups and identify social isolates.

conventional sense. More surprisingly, this turns out to be a common size for human organisations, including community size in hunter–gatherer societies and village size in many small-scale traditional and historical societies, as well as the size of certain units in modern armies [24].

What defines this group of people seems to be recognition of a mutual, reciprocal relationship of trust and obligation, combined with a willingness to act prosocially. Trust is central to this, not least because it underpins everything from how we interact with each other (I trust that you will not stab me when my back is turned) to our willingness to offer help (I trust that you will pay me back one day) to trading (I trust that you are not selling me substandard goods) [10]. Conventionally, of course, most of these 'friends' will be other humans, but there seems in principle no reason why some of us might not include our pets, dead ancestors who are still meaningful to us, religious figures like God or saints, or even fictional characters – providing we deeply believe that we have meaningful, reciprocated relationships with them. (The extent to which this actually happens is a topic worth investigating, because it may slide into areas of deep psychological interest such as delusions and stalking. In such cases, individuals commonly believe their feelings are reciprocated by their target, even when this is not true and the targets have gone out of their way to make this clear.)

It is, however, important to note that while a figure of about 150 is a widely consistent mean value for social network size across populations, and even cultures, the variance around this mean is actually wide (roughly 100–250) [18,24]. Some of this variance is inevitably due to personality: extraverts, not too surprisingly, have larger social networks than introverts [25–28]. This may reflect different social or lifestyle strategies. Data on self-ratings of emotional closeness suggest that, because the amount of social capital we have seems to be fixed, those who have larger networks on average have weaker relationships (they choose to spread their available social capital thinly across a large number of individuals), whereas those with smaller networks prefer to spread it thickly among fewer [28].

There is also a strong age effect, with 20-year olds typically having more friends than 60-year olds [18,23,29,30]. This may reflect greater social promiscuity among 20–30-year olds whose principal need may be to search as widely as possible in order to find the most congenial lifelong friends and romantic partner(s); as they age, and particularly once reproduction sets in, many of the less congenial relationships are shed in order to concentrate what time and effort is available on the relationships that matter most – something that is also seen in female baboons when the demands of lactation force mothers to withdraw from casual relationships [31,32]. A period of relative stability in network size probably follows during middle age, giving way to the

well-known phenomenon of rapidly declining network size, and associated increasing loneliness, in old age [33,34]. A similar effect has been noted in monkeys [35,36]. In humans, at least, this late decline in sociality is mainly a consequence of reduced energy and willingness to pursue the kinds of social activities needed to find new friends.

The Circles of Friendship

In contemporary societies, most personal social networks consist of extended family (including in-laws, or affines) and friends in about equal proportions [19]. These form two separate, but interlocked, subnetworks (family vs. friends) that typically interact only to a limited extent. Notably, we seem to treat close in-laws as though they were genetic family, and for the good biological reason that they share with us a genetic interest in our offspring [1]. People who come from large extended families have proportionately fewer friends [19], suggesting that we give preference to kin, presumably because of what has been termed the 'kinship premium' (the greater willingness to act altruistically towards kin) [2]. It is worth noting that in traditional small-scale societies, with communities of typically 100–200 individuals [37], almost everyone is kin either by descent or by marriage [38], and the few that are not kin are usually given honorary kinship status (rather in the way we might refer to an unrelated female adult as 'aunty'). In the modern world, our reduced family sizes mean that we have many unfilled slots in our network capacity, so we fill these with unrelated friends [39].

A second orthogonal dimension in social networks is the way we rank individuals in terms of emotional closeness. We do not invest either time or emotional capital (the two are in fact closely related; Figure 1) equally in our friends. Something like 40% of our total social effort (whether indexed as time or emotional closeness) is devoted to just five people (the five most important to us), with another 20% given to the 10 next most important [10]. In other words, 60% of our social effort is divided between just 15 people (those most likely to provide us with support [10]).

This patterning in how we interact with friends leads to networks being structured as a series of hierarchically inclusive layers (or circles) that run outwards from the network 'owner' (conventionally labelled 'ego') through sets of relationships that increase progressively in number of

Figure 1. Emotional Closeness Correlates with Frequency of Contact. Mean (±standard errors) frequency of contact (indexed as month since last contact) plotted against emotional closeness scale score (1 = low, 10 = high). Based on ratings of 20 249 personal network members by 270 UK and Belgian women. Source of data [19].

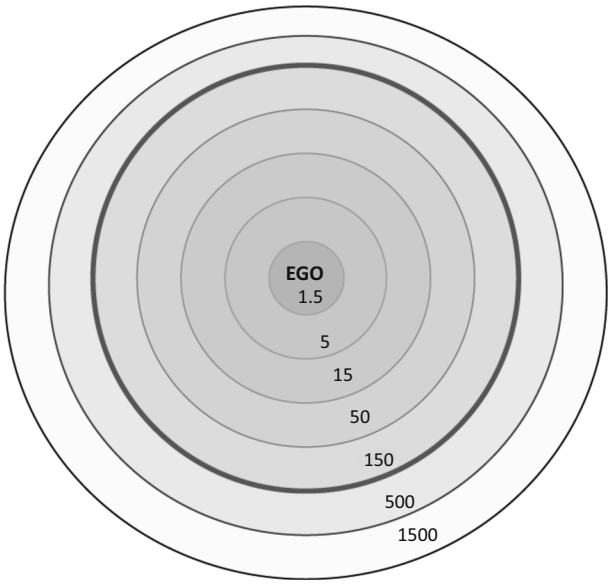

Figure 2. The Circles of Friendship. An individual (ego) sits within a series of hierarchically inclusive circles, or layers, of friendship that have a very distinct scaling ratio (each layer is three times the size of the one inside it). The heavy line demarcates the 150 layer, the typical size of personal social networks. Beyond this are acquaintances (500 layer); the layer at 1500 appears to represent the limit on the number of faces we can put names to. Frequency of contact, rated emotional closeness, and willingness to act altruistically towards a given alter all decline across the successive circles [2,10].

members (usually known as 'alters') but decrease in average emotional closeness and frequency of contact (Figure 2). These layers have been identified in a wide range of social media, including face-to-face personal networks [10,18,40], telephone call datasets [20], science coauthorship networks [41], posting patterns in both Facebook and Twitter [23,42,43], and exchanges in online gaming worlds [44]. Counting cumulatively, these layers have very distinct sizes (approximately 1.5, 5, 15, 50, and 150) with a consistent scaling ratio: each layer is three times the size of the layer immediately inside it. We might characterise these layers as primary partner(s), intimate, best and good friends and, finally, just friends (the 'active network').

Beyond the 150 layer lie two more layers that maintain the same scaling sequence: one at 500 (acquaintances: people we know, but do not have meaningful relationships with and on whom we could not count for support) and one at 1500 (probably the number of faces we can put names to, but this has yet to be formally confirmed). These layers are also present in the organisational structure of hunter–gatherer societies [45,46], the structure of modern armies [47] and, of all places, even in the size distribution of German residential campsites [48]. These same layers, with exactly the same scaling ratio, are also present in the social networks of some highly social mammals (chimpanzees, baboons, elephants, dolphins) [49].

In primates, the different layers provide different benefits (minimising predation risk for the outer layer, buffering against stresses of group-living for the inner layer), and the same seems to be true for humans. The likely key functions are emotional support for the 5 layer, regular social partners (and perhaps childcare exchange network) for the 15 layer, the 'social party' circle for the 50 layer and the broad reciprocal support and information-exchange network for the outermost 150 layer [50]. A similar distinction has been drawn in sociology between weak and

strong ties that, respectively, provide information exchange and close support [51,52]. For this reason, the 5-layer has sometimes been labelled the 'support network': it can be reliably elicited by asking people to list everyone they would go to for emotional, social and economic support in times of extreme need [10]. The 15-layer is well known in social psychology, where it has been labelled the 'sympathy group' (all the people whose death tomorrow would cause great distress) [53]. The 150 and, perhaps, 500 layers may provide crucial economic buffering in small-scale societies [50,54,55].

A Two-Process Model of Social Bonding

In anthropoid primates, close friendships act as coalitions, one of whose functions is to buffer the individual, and particularly females, against the stresses that arise from living in close spatial proximity. Primates (and humans) live in groups mainly to minimise external ecological threats such as predation risk, raiding by neighbours, or environmental risk [50,54,55]. In effect, primate groups are implicit social contracts: the relationships on which they are built are promissory notes guaranteeing support at some (unspecified) future time when the need arises [56]. However, living in close proximity incurs costs: the mammalian reproductive endocrinology system is extremely sensitive to stress, and even minor levels of stress can disrupt it. As a result, females suffer increasing levels of infertility as group size increases in both primates and humans [57–66], as well as in many other mammals. The endocrinology underpinning this is now well understood [67–71].

In the more socially complex primates that live in large social groups, females, in particular, use friendships to buffer themselves against these costs [57]. Such alliances cannot be created on the spur of the moment: they have to be created ahead of time so that they will function effectively if and when the need arises [56]. As a result, these relationships are often lifelong (in some cases based on matrilineal kinship). Willingness to provide these benefits depends on commitment, and hence the emotional closeness of the relationship, and this requires the investment of a considerable amount of time and effort – in primates through social grooming [72,73], in humans through time spent interacting [15,24]. In humans, the amount of time spent interacting with someone correlates with the perceived emotional closeness (Figure 1) [10,19], and this in turn correlates with the expectation of support [74]. Likelihood of future support also correlates with time spent grooming in anthropoid primates [57].

To provide a sufficiently robust mechanism, primate relationships are underpinned by a two-process mechanism that is all but unique [15]. One component is based on social grooming, the other involves a more explicitly cognitive component. These appear to work in tandem with each other: the first creates an emotional (psychopharmacological) platform off which cognitive relationships of trust, obligation and reciprocity can then be built by the second [15]. The first of these is very costly in terms of time, while the second (derivative of the social brain hypothesis [75,76]) is costly in terms of cognition and, hence, neurological demand. I explore each of these in turn in the following two sections.

How Time Limits Friendship Networks

Time is a limited resource for all animals [77] including humans [78,79], and if the quality (and hence functionality) of a relationship depends on the time invested in it [10], each individual has to decide how to distribute his/her available social effort, or capital, across his/her network. The network layers of Figure 2 appear to be associated with very specific contact values (Figure 3) [10,19,20]. If someone is contacted less often than the defining rate (once a week for the 5-layer, once a month for the 15-layer, once a year for the 150-layer) for more than a few

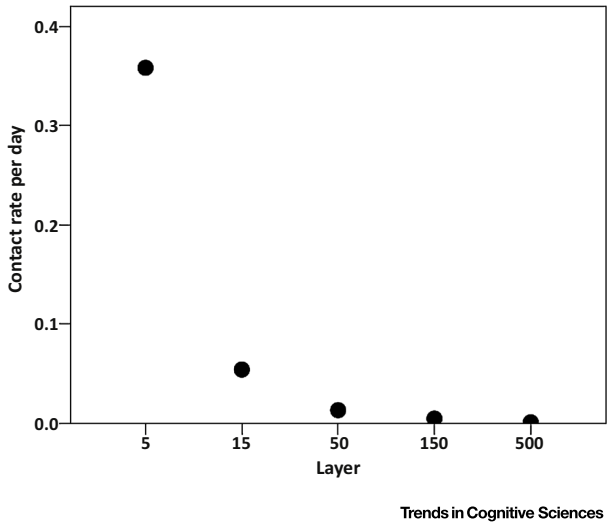

Figure 3. Frequencies of Contact. Mean frequency with which the average ego contacted each of the alters in each layer of their social network. Reproduced, with permission, from [10].

months, emotional closeness to that individual will inexorably decline to a level appropriate for the new contact rate [80–84]. That time limits the number of relationships we can have is evident in romantic relationships: these are so focussed and costly in terms of time investment that, when we fall in love with someone (and hence bring a new person into the 5-layer in the centre of our social world), we typically lose one close family member and one close friend, reducing our '5-layer' to just four people for the duration of the period of infatuation [85].

The rate at which relationships decay when we fail to contact the person is so rapid that, following a period of reduced contact, we often compensate by talking to the person concerned for much longer than would normally be the case [86]. In effect, absence really does make the heart grow fonder. Baboon mothers exhibit a similar effect. Because females are forced to reduce the time they spend interacting when the baby's demand for milk peaks in the later months of lactation (due to the time cost of the extra feeding needed to produce milk), they rely on their partner to keep the relationship going; later, once the baby has been weaned and their time budget is back to normal, they seem to compensate by shouldering more of the burden of maintaining the relationship [31,32].

That social investment has real implications for the benefit a relationship provides is evidenced by the fact that network density (interconnectedness) influences willingness to act altruistically towards a member of even the innermost layers [87]. Whether this is because densely connected networks act as their own policemen (if A upsets B, C will hear about it) or because they are somehow more tightly cross-bonded with a greater sense of mutual obligation [88] remains to be determined.

Agent-based models show that a layered structure emerges naturally as the optimal way to distribute social effort when trying to simultaneously optimise two or more different social and ecological objectives under a time constraint [89,90]. Importantly, the observed layer sizes (5, 15, 150) arise only when community size is large, mortality is high (e.g., when predation risk is high), and alliances provide significant benefits (as, e.g., against internal stresses) [90] – conditions that are uniquely characteristic of humans and the most social anthropoid primates.

Not only do personal social networks vary considerably in their interconnectedness [87], but each of us seems to have our own personal signature for how we distribute our social effort among our network members – in effect, a unique social fingerprint [84]. This fingerprint remains remarkably stable across time even when there is considerable change in network membership: when a particular friendship dissolves, it seems that we insert a new person into exactly the same emotional slot and see them just as often as the previous occupant [84]. At least among younger adults, turnover in network composition can be as high as 40% in as little as a year [84].

There is an important distinction between friendships and family relationships: family relationships seem to be much more resilient to lack of contact than friendships [91]. This may be because kinship carries with it an extra dimension of emotional closeness over and above that indexed by emotional closeness rating scales (the 'kinship premium' [1,2]) or because the kinship subnetwork is more interconnected than the friendship subnetwork [88]. Kinship networks are often associated with 'kin-keepers' who make it their business to keep everyone updated on the state of the network [92,93]; this probably helps to maintain high levels of interconnectedness which may, in turn, allow relationships to be maintained by lower rates of dyadic contact.

In anthropoid primates, the time component involves grooming [72,73], an activity that, while undoubtedly having hygienic benefits, is mainly important because it triggers the brain's endorphin system [94–97]. The relaxing, opiatelike effect produced by endorphins seems to play a crucial role in establishing and maintaining bonded relationships, providing the psychopharmacological platform off which a cognitive relationship can be built.

Although much has been made of the social relevance of oxytocin over the past two decades [98–100], in fact its social functionality seems to be much less important than that of the endorphin system. For one thing, oxytocin's sphere of influence seems to be confined to dyadic relationships, and perhaps only to romantic relationships; even there, its apparent functionality often disappears when we control for endorphins [101]. By contrast, the β-endorphin and dopamine systems have a much wider scope of influence, with the former being especially important for social predispositions and the latter for network aspects of sociality, as well as both influencing dyadic relationships (Box 3).

It has been suggested that the evolution of lifelong relationships in the primate lineage necessitated the exploitation of a more robust bonding mechanism [102,103]. Although the oxytocin system may play an important role in sociality among mammals in general, it has two major disadvantages. First, animals appear to habituate to its effects rather quickly [104]. Second, its functionality seems to be strictly endogenous: if you have the relevant allele, you will behave more prosocially towards others [105,106], but it will not make others behave any better towards you. By contrast, the endorphin system acts exogenously: it can be triggered in other individuals by grooming [107–110], and this is even true of humans [111]. In effect, oxytocin makes you behave prosocially, but the endorphin system allows you to make others behave prosocially towards you.

The main drawback with the endorphin system is that it is very time-consuming to activate through social grooming. Because the strength of a friendship depends on the time invested in it and time is limited, there is an inevitable upper limit on the size of groups that can be maintained this way at about 50 [72,73]. In part, this is a consequence of the fact that the physical contact involved in grooming (and its human equivalents: petting, stroking, cuddling)

Box 3. The Social Neuropeptides

Over the past decade or so, much has been made of the role of oxytocin (and occasionally vasopressin) in prosociality [98–100,104–106]. One problem with this has been that most studies have failed to control for the effects of the many other candidate neuroendocrines and neurotransmitters [101]. The endorphin system, for example, is central to grooming-based relationships in primates [96,97,107–110] as well as both physical contact [111] and other bonding behaviours [114–121] in humans. Positron emission tomography has shown that, in humans, the density of μ-receptors for β-endorphin, especially in the orbitofrontal cortex, correlates with attachment style [197], and there is a correlation between pain tolerance (a proxy for endorphin receptor density) and social network size [198]. Indeed, it is now apparent that the differences in vole mating behaviour that were used to justify the oxytocin story can just as easily be attributed to differences in the genes for endorphins [199,200]. Grooming (or stroking) activates the endorphin system via the afferent c-tactile (CT) neurons, a unique set of neurons that run from the hairy skin directly into the brain (with no return loop). These neurons are unmyelinated, and hence very slow, and respond only to light, slow stroking [201].

A large-scale study of 33 SNPs for six neuroendocrines/peptides at three levels of sociality (social predisposition, dyadic relationship quality and embedding in social networks) [101] indicated that oxytocin is specific to dyadic (explicitly romantic) relationships (although in many cases the significance of this relationship is lost when controlling for endorphins), β-endorphin is most strongly associated with social predispositions (e.g., attachment style), but has a wide influence across all three domains and dopamine is most strongly associated with network indices but also has wide influence across all three domains (Figure I). Note that endorphins and the dopamine system are closely associated in that upregulation of one often causes upregulation of the other [202,203]. By contrast, the other three neurochemicals examined (testosterone, serotonin and vasopressin) were much more limited in their impact.

Neuroendocrine	Social domain		
	Disposition	Romantic dyad	Social network
Oxytocin	4	45	10
β-endorphin	30	20	10
Dopamine	12	37	50
Vasopression	12	0	0
Serotonin	0	0	25
Testosterone	25	0	0

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Figure I. Genetics of the Social Neurohormones. Percentage of SNPs for six social neuroendocrines/peptides that are significantly associated with each of three major domains of sociality (prosocial predisposition, romantic relationships and social network) [101].

involves a level of focus and intimacy that does not allow for grooming more than one individual at a time (at least, not without some jealousy ensuing). Perhaps because of the endorphin effect, this form of physical contact is so intimate and elicits such strong emotional responses that we humans are very selective in where we will allow others to touch us: there is a strong correlation between how much of the body surface can be touched by someone and the emotional strength of our relationship with them [112].

So limiting is this effect that when, during the later course of human evolution, we needed to increase the size our social networks beyond the 50 limit in other primates, we had to find new ways of triggering the endorphin system remotely so that we could 'groom' several individuals at the same time. In the likely order in which they appeared in human evolution [113], these have included laughter [114,115], singing [116,117], dancing [118,119], and emotional storytelling [120], all of which have been shown (either indirectly by changes in pain threshold or directly by positron emission tomography) to trigger the endorphin system, and thereby generate an increased sense of bonding [117–121]. Because they do not involve direct physical contact, these behaviours bypass the intimacy restriction and allow us to create much larger networks.

Importantly, it does this only with respect to the individuals actually involved in the activity, even though these are strangers: it seems to have no effect on existing relationships if these individuals are not physically present at the time [118].

A Crucial Role for Cognition

On the cognitive side, some form of cost accounting (a totting up of favours owed and promises broken) must be important [10]. A survey of the causes of relationship breakdown, for example, has identified lack of caring, poor communication, jealousy, and alcohol/drugs as the main causes (accounting for approximately 57% of all breakdowns) [122], all of which suggest that some kind of tally is being kept. However, there have been no studies that have explored the cognitive bases of this accounting process (other than to emphasise the obvious need to remember past interactions).

The data on relationship breakdown should remind us that trust plays a crucial role in building and maintaining relationships [10,123,124]. The functionality of friendships (emotional support, unstinting help) depends implicitly on trust that, over the long haul, the relationship will be in approximate economic balance (i.e., debts will be repaid eventually). While close friendships (those in the innermost layers) may well involve unstinting altruism and, at least in the short term, less emphasis on scorekeeping, score-keeping and the monitoring of reputations are nonetheless likely to become increasingly important in the outer layers. Interestingly, despite the kinship premium, breakdown of family relationships is unexpectedly common compared to friendships [122]. This may be because, whereas friendships simply drift apart after minor breaches of trust, kin (and romantic partners) are initially more tolerant but eventually, after many breaches of trust, so much strain has been put on the relationship that it undergoes a catastrophic fracture. As a result, the sense of 'hurt' is greater and reconciliation is invariably difficult to engineer [122].

Friendships are cognitively demanding because they are implicit social contracts – in effect, promises of future support. This makes them particularly susceptible to freeriding (taking the benefits without paying all the costs). Freeriding, in its many forms (stealing others' property, reneging on obligations, behaving ungenerously and, at least in humans, trading once too often on someone's good nature or spreading rumours about their motives), is very destructive of relationships and rapidly leads to the collapse and contraction of social networks because people become unwilling to trust more than their closest friends [125,126].

The ability to inhibit prepotent responses plays a crucial role in preventing this: without this, individuals will constantly risk destabilising their relationships, either by making excessive demands on their friends, unthinkingly taking their property, or making comments that offend (gossiping). To make relationships work, we have to appreciate that we need to forgo some of our personal desires and preferences in order to allow everyone else to satisfy theirs, otherwise they will leave to find a more congenial social environment.

This capacity to inhibit our actions probably depends on a second crucial cognitive mechanism, namely, mentalising (or mind reading, the ability to understand and work with many other individuals' mindstates; Box 4). There is now considerable evidence to suggest that the number of friends an individual has correlates with their mentalising skills [127–129]. Mentalising has been shown, using both reaction time tasks and fMRI, to be cognitively more demanding than working with more conventional physical facts [130], perhaps because it involves modelling others' mindstates in virtual reality (as opposed to making simple direct inferences from behaviour happening right in front of us). Mentalising skills have been shown to correlate with

Box 4. Mentalising

Developmental studies have identified theory of mind (ToM, the ability to understand another person's mindstate and intentions, and hence use words like 'intend', 'believe', 'imagine', 'suppose') as a critical transition in children's social development [204]. Although ToM (the most basic level of mentalising) may be a uniquely human trait, there is some evidence to suggest that great apes also possess it [205]. However, ToM is just one step in a series of recursive mentalising steps (I 'believe' that you 'think' that she 'wonders' whether he 'supposes' . . .) known as the levels of intentionality [206,207]. These higher-order capacities play a crucial role in our ability to manage conversations [136] and our enjoyment of both humour [208] and fiction [209,210], as well as imposing limits on the number of friends we can have [128,129].

grey matter volume in the brain's theory of mind network, especially the medial/orbitofrontal prefrontal cortex [128,131,132].

Mentalising competences seem to have a natural upper limit at about five orders of intentionality, including one's own mindstate (Box 4). This seems to have important implications for conversational dynamics, for example. A number of observational studies of freely forming conversations in a variety of contexts and cultures indicate that there is a consistent upper limit of about four on the number of people that can be involved in a conversation [133–138]. Similar constraints have even been noted in the sizes of conversations in plays, TV dramas, and films [136,139–141]. If a fifth person joins the conversation, it is likely to break up into two or more conversations within a very short time [135,138]. This is an extremely sensitive effect: conversations concerned with factual matters or the mindstates of those actually involved in the conversation have an upper limit at four members, but when the mindstate of someone not physically present is being discussed the conversation has an upper limit of three members (and this is also true of Shakespeare's plays) [136].

To maintain the coherence and cohesion of our social networks over the long haul required for the benefits they provide, we not only need to manage each of our dyadic relationships, but also need to be sensitive to the complex network of relationships within which these dyadic relationships are embedded: behaving badly towards a friend is likely to jeopardise my relationship with that friend's friends (a reputational effect), and may even invite retribution from them (a policing effect). While our time may be devoted mainly to a small number of people, our cognitive effort needs to be spread more widely because we have to be aware of the consequences that our actions will have for our entire social network. Aside from mentalising, this depends on sophisticated second-order cognitive skills like causal reasoning, analogical reasoning, one-trial learning, the comparison of alternative outcomes and, especially, the ability to inhibit prepotent actions. This set of skills is explicitly associated with the brain's frontal pole (Brodmann area 10), a brain region that exists only in the anthropoid primates [142] and, at least in humans, forms part of the key centre for mentalising skills in the orbitofrontal and medial prefrontal cortex [128,129,131,143].

These cognitive demands of maintaining friendships underpin the 'social brain hypothesis' (Box 5). This is best known for the correlation between brain size and social group size in primates, although group size is really the outcome of cognitive capacities associated with maintaining many relationships (and hence reflects the kinds of cognitive competences discussed earlier, with memory playing only a subservient role).

A number of neuroimaging studies of humans have now shown that individual differences in the size of the social network (indexed variously as the number of friends and family, the number of principal friends in the 15-layer and the number of friends listed on Facebook) correlate with neocortex volume, and especially the frontal cortex and the brain's so-called mentalising

Box 5. The Social Brain Hypothesis

The social brain hypothesis is an explanation for the evolution of large brains in primates: primates evolved larger brains (and especially neocortices) than any other animal species so as to handle the unusual complexity of their social world [75,76,154,211,212]. Although there continue to be attempts to claim that foraging skills rather than social skills explain primate brain evolution, all of these either commit egregious statistical errors (use inappropriate statistical analyses [213]), confuse correlations for causes [214], or fail to distinguish carefully between mechanisms, constraints and evolutionary causes or, worse still, attempt to test the hypothesis where it manifestly does not apply (see [154]). In any case, the social brain hypothesis is an ecological hypothesis: it asserts that primates solve their ecological problems socially rather than by individual trial-and-error.

In primates, there is a robust relationship between social group size and neocortex volume (Figure I). In other species of mammals and birds, this relationship is manifested as a qualitative difference between pair-bonded species who have big brains and smaller-brained promiscuous species [211,215], reflecting the considerable cognitive demands of maintaining pair–bonds (something that we are all very familiar with on a daily basis).

Notice that, in Figure I, the apes lie on a separate grade to the prosimians and monkeys, suggesting that their relationships have a higher cognitive demand. Interpolating human neocortex size into the ape relationship yields a predicted value for human social groups of approximately 150 (95% confidence interval, 100–250) [24]. There is now considerable evidence for groupings of exactly this size in both personal social networks [18–23] and human organisations [45,46].

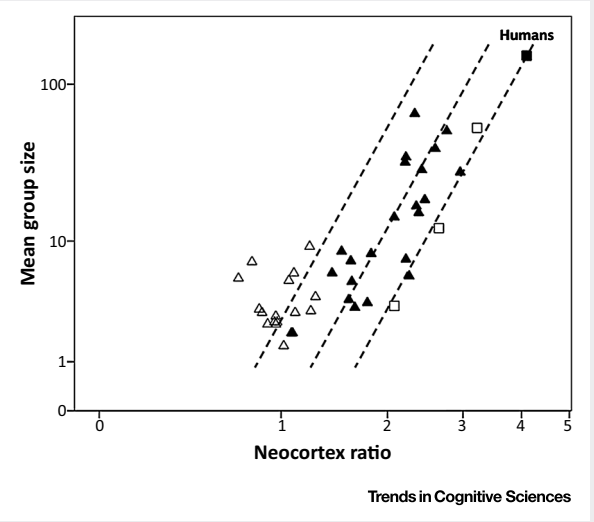

Figure I. Social Brain Hypothesis. Mean social group size plotted against neocortex ratio (neocortex volume divided by volume of rest of brain) for 45 primate genera, showing the position of modern humans. The different symbols represent prosimians (unfilled triangles), New and Old World monkeys (filled triangles), apes (unfilled squares), and modern humans (filled square). Note that Old World monkeys and apes belong to the same taxonomic grouping, so the fact that New and Old World monkeys are intermixed is not a consequence of simple phylogenetic divisions within the primates, but reflect similarities and differences in sociocognitive skills. Broken lines are regressions for prosimians, monkeys, and apes, respectively. Redrawn with updated group sizes from [76].

network (a neural network linking the prefrontal cortex, the temporoparietal junction and parts of the temporal lobe) [128,129,144,145]. Similar findings have been reported for at least one monkey species [146]. Thus, the social brain hypothesis (as a cognitive constraint on both group and personal network size) applies not just between species, but also, within species, between individuals.

Although the social brain data inevitably imply that there is a genetic component to these capacities, the social brain relationship in fact depends on considerable learning through a long

developmental period [147,148]. In humans, the frontal lobes, in particular, do not reach their final adult state (full myelination) until the mid-20s [149], and there is developmental and neuroimaging evidence to suggest that key cognitive skills (including mentalising, the ability to recognise emotional states from facial cues and the capacity to focus attention) do not reach full adult competence (or become automated) until the later teens or even early 20s [150–153]. This should remind us that the social world is so complex and dynamic that simply having massive computational capacity (a big brain) is not, of itself, enough; a great deal of trial-and-error learning, social learning, and cultural inheritance of behavioural rules, as well as real-time practice in social decision making, is needed to achieve full adult proficiency [154]. This no doubt explains why primates in general, and humans in particular, have developmental periods that are so much longer than is strictly necessary for mere physical maturation, and why the length of their developmental periods correlates specifically with both neocortex size (and not total brain volume) [147].

The Seven Pillars of Friendship

One of the most striking things to emerge out of the friendship literature in the past decade or so has been the homophily effect: friends tend to be similar to each other on many dimensions (though personality is not often one of these) [155]. Personal social networks are commonly homophilous for gender, for example: men's networks have significantly more men in them and women's networks have significantly more women [26,40]. In part, this seems to reflect the fact that men and women have different social styles (Box 6). Even conversations have a striking tendency to segregate by sex once they exceed four individuals [135]. In addition, friendships have been shown to be homophilous for ethnicity, age, religion, education, and social values [16,156–160].

More detailed analyses of friendship patterns suggest that friendships are based on a limited number of dimensions. We have identified seven key dimensions: language (or, better still,

Box 6. Gendered Networks?

Aside from striking gender homophily of networks [26,40], the two sexes exhibit a number of important differences in respect of friendships. One is that, while both sexes have broadly similar social networks, women consistently have larger inner layers than men, in most cases significantly so [18,127,129]. This correlates with women's typically better performance on mentalising tasks [127,132]. Second, women seem to have a category of friend that is almost unknown among men, namely, a same-sex best friend (a BFF, or 'best friend forever'), in addition to a romantic partner [216]. Although this additional individual is occasionally male, the great majority are women: in a sample of 257 women's best friends, just 18.3% were men [217]. It is unlikely that many of these male BFFs were extra lovers, since it seems difficult to maintain two equally intense sexual relationships simultaneously [85].

The two genders also differ in what maintains the emotional closeness of friendships over time. For women, this involves making the effort to spend more time talking together (either face-to-face, by phone or via the Internet), whereas talking has almost no effect on men's friendships; what maintains the emotional quality of men's friendships is increased investment in 'doing things together' (sports, drinking, etc.) [91]. Although doing things together does benefit women's friendships, it has much less effect than it does for men.

These contrasts parallel differences in social media and phone use (women account for around two-thirds of active Facebook users [218,219] and make longer and more frequent phone calls [29]) as well as differences in style of aggression (men are more likely to respond with physical violence, while women are more likely to use verbal aggression [220]). Analyses of a large national mobile phone database suggest that women focus their phone calling on an opposite sex person of similar age much more than males do, and they do so from a much earlier age and continue for considerably longer [221].

In sum, women seem to invest more heavily in their relationships than men, whose relationships seem to be much more casual (even in the case of their most intimate relationships) [217]. For this reason, women's friendships often seem to be more fragile and susceptible to catastrophic breakdown [122].

dialect), place of origin (i.e., where you grew up), educational history, hobbies/interests (including musical tastes), sense of humour, and worldview (moral views, religious views, political views) [160–162]. Broadly speaking, these seem to be interchangeable: a 4-star relationship can involve any combination of these seven dimensions. Taken together, they constitute the set of beliefs and rituals that remind us who we are, where we come from and why we form a single community with a common set of values and convictions. They thus play an important role in identifying the wider community as well as specific friendships. In respect of friendships, the more of these we share with someone, the more intimate our relationship with them will be, the closer the friendship layer they will lie in, and the more willing we will be to help them out [160,162]. We might aspire to form friendships with charismatic individuals or influential people, but friendship is a two-way process: a relationship will only emerge if they are willing to be our friends. Like all of us, they have limits on the number of friends they can manage and they will have their own preferences and priorities.

In small-scale societies, all of these seven dimensions identify a community that shares a common ancestry and lives in a particular area (a kin group). They bind the community into a unified group that can act together, and in doing so they also identify the individuals who will reliably come to our aid. Almost unavoidably, they emphasise an Us-versus-Them distinction, bringing this classic topic from social psychology into the friendship frame in a crucial way. In addition, of course, the community acts as guarantor: being a member of your community means that you know how they will see the world, how trustworthy they are likely to be, whether they will appreciate the same jokes as you do, and even how elliptical (and hence efficient) you can be in conversation. They will understand your metaphors, for example, without you having to laboriously explain them. There is also the implicit knowledge that someone in the extended network will be wagging their finger at them if they default on their obligations to you. This form of network policing probably plays an important role, and may explain why some communities, such as the Hutterites, insist on splitting their communities once they exceed 150 individuals in size [163].

The fact that these traits are mainly cultural rather than biological has an added advantage: they can change through time and so point to a very specific community of shared interests. This may be important in preventing freeriders from invading the community and exploiting the goodwill of its members: without the costly investment of growing up in the community, freeriders will find it difficult to learn the right social style or local knowledge. A modelling exercise suggested that a rapid turnover in dialect, for example, is a very effective way of reducing freeriders' opportunities to invade because they are always one step behind the rest of the community [164]. Dialects are especially valuable in this respect because they have to be learned young: no one who learns a second language, or even dialect, later in life ever speaks it like a native. Hence, it may be no accident that the seven pillars of friendship are also all things that we acquire mainly during childhood. Other ethnic markers of community membership (the clothes one wears and even one's hairstyle) play a similar role, though most of them are more easily faked [165]. Nonetheless, to the extent that they are costly to learn or acquire, they flag up membership of the community. Indirect evidence of this comes from the fact that 19th-century American utopian communities that demanded more sacrifices as the price for joining survived for longer [166].

These dimensions can, nonetheless, be used individually to establish 'first-pass' relationships with strangers, especially if the item in question is rare in the wider population [162,167]. In effect, we seem to use the 'pillars of friendship' to create one-dimensional clubs that allow us to exchange altruism with strangers without having to engage in the time-consuming process of a

lengthy assessment. Indeed, socially labelled kinship (a one-dimensional club based on relatedness) might well have been the origins of this: I must be a member of your community because I can explain exactly how we are related. Notice that, in contrast to immediate family whom we know because we grew up with them, we identify distant kin only because someone tells us we are related (a linguistically based cue) – yet still treat them emotionally as kin.

This capacity to create one-dimensional clubs seems to be central to our ability to build stable mega-communities (towns, cities, nation states) that consist mainly of strangers. In effect, mega-communities (those significantly larger than 1500 individuals) are based on inferring community membership from just one or two of the seven pillars of friendship. This creates weak relationships, but nonetheless ones sufficiently functional to maintain coherence and social commitment – providing the costs are not too great. Since the number of shared pillars (or traits) is correlated with the emotional closeness to the relationship layer [160], these distant relationships are necessarily weak.

Has the Internet Changed Our Social World?

A natural question to ask is whether the advent of the digital world, and social networking sites in particular, has changed any of these patterns. Relationships require a significant time investment (Figure 3) and there is a very strict upper limit of four on the number of people we can engage in conversation at any one time [133–138], making it difficult, given the limit on the time available each day for social activities (approximately 20% of our day, based on activity budget studies [168]), to have an unlimited number of friends. Since digital media allow us to interact simultaneously with infinitely many individuals, they offer the potential for a radical increase in social network size. Indeed, perhaps in anticipation, most social networking sites set a high limit on the number of friends that an individual can have (e.g., 5000 on Facebook).

In practice, it seems that the digital world has had very little effect on the size or structure of our social networks [23]. An analysis of the number of friends on a million Facebook pages yielded a highly skewed distribution with a modal value of 150–250 [30], about what one would expect given the typical age of Facebook users (see earlier discussion). More importantly, analysis of the frequency of reciprocated postings (as an index of meaningful relationships) in a Facebook dataset yields exactly the same social network layering as in face-to-face networks, with the same numbers of individuals in each layer and virtually the same contact frequencies [42,43].

It seems that our psychology is not designed to handle an unlimited number of interactions simultaneously. Even when online, we tend to assume that we are engaged in an intimate conversation with a few individuals. Communication channel may also be important in this context. Participants in a diary study were asked to evaluate the quality of the interactions they had had with their five best friends each day: face-to-face and Skype outperformed the phone and text-based channels [texting, short message service (SMS), email and social networking sites] by a considerable margin [169]. Importantly, perhaps, interactions that involved laughter, whether real or digital (e.g., emoticons), were rated more highly than those that did not. What face-to-face and Skype interactions share is a sense of copresence (being in the same room together); in addition, they provide visual cues that allow us to monitor and adjust the flow of the interaction more effectively (thereby avoiding *faux pas*, for example) and radically increase the speed of interaction (facilitating repartee, and hence laughter). Single-channel (e.g., phone) or text-based media are simply too impoverished or too slow.

This suggests that it may be difficult to circumvent the human cognitive limits on relationships, even when technology might allow us to do so. The intimacy created by focussed, directed

interactions may be the important ingredient determining relationship quality. This in turn may be subject to the cognitive limits of mentalising and hence the number of individuals with whom we can directly engage at any given moment [136]. It is hard to see how any form of digital technology will ever overcome this, even though it may be socially beneficial to do so.

Concluding Remarks

Friendships (including family) are the single most important factor affecting our health and well-being. However, friendships are costly to maintain, both cognitively and in terms of the time that needs to be invested in them. These limit the number of friends we can have to around 150, and obliges us to distribute our social time/capital unevenly among them as a function of the benefits they provide us with. The endorphin system seems to play a crucial role in the maintenance of friendships, and many of the behaviours we use in social contexts (laughter, singing, storytelling) seem to be especially good at triggering endorphins. Among the issues that merit more detailed study are the reasons why the sizes of the different friendship layers have so distinctive a scaling ratio, the role of trust in the maintenance and breakdown of relationships and how gender differences in social style influence the number and quality of our friendships (see Outstanding Questions).

Outstanding Questions

Why do the layers of the social network (in both humans and other mammals) have a fractal scaling ratio of about 3. It may have something to do with the geometry of relationships and the fact that triads appear to be more stable than dyads.

How is it that a linguistic cue of family membership (this is your second cousin twice removed) is sufficient to trigger a sense of emotional closeness (a 'kinship premium'), especially in the outer layers of the network where all family ties are linguistic rather than the result of growing up together?

Besides mentalising, what cognitive mechanisms are involved in maintaining friendships?

What are the cognitive bases of trust?

What role does development play in the correlation between brain size/organisation and the number of friends? There is evidence that, in primates, the social skills required to support a large social group have to be learned, requiring a long period of socialisation.

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