Perceived social isolation and cognition

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Social species, from *Drosophila melanogaster* to *Homo sapiens*, fare poorly when isolated. *Homo sapiens*, an irrepressibly meaning-making species, are, in normal circumstances, dramatically affected by perceived social isolation. Research indicates that perceived social isolation (i.e. loneliness) is a risk factor for, and may contribute to, poorer overall cognitive performance, faster cognitive decline, poorer executive functioning, increased negativity and depressive cognition, heightened sensitivity to social threats, a confirmatory bias in social cognition that is self-protective and paradoxically self-defeating, heightened anthropomorphism and contagion that threatens social cohesion. These differences in attention and cognition impact on emotions, decisions, behaviors and interpersonal interactions that can contribute to the association between loneliness and cognitive decline and between loneliness and morbidity more generally.

Introduction
The health, life and genetic legacy of members of social species are threatened when they find themselves on the social periphery. Social isolation decreases lifespan in the fruit fly [1]; promotes obesity and Type 2 diabetes in mice [2]; exacerbates infarct size and edema and decreases post-stroke survival rate following experimentally induced stroke in mice [3]; promotes activation of the sympathoadrenal medullary response to an acute immobilization or cold stressor in rats [4]; delays the effects of exercise on adult neurogenesis in rats [5]; decreases open field activity, increases basal cortisol concentrations and decreases lymphocyte proliferation to mitogens in pigs [6]; increases the 24 h urinary catecholamines levels and evidence of oxidative stress in the aortic arch of rabbits [7]; and decreases the expression of genes regulating glucocorticoid response in the frontal cortex of piglets [8]. Humans, born to the longest period of abject dependency of any species and dependent on conspecifics across the lifespan to survive and prosper, do not fare well either, whether they live solitary lives or simply perceive that they live in relative isolation (Box 1).

Perceived social isolation, known more colloquially as loneliness, was characterized in early scientific investigations as ‘a chronic distress without redeeming features’ (p. 15) [9]. Recent research suggests that the social pain of loneliness evolved as a signal that one’s connections to others are weakening and to motivate the repair and maintenance of connections to others that are needed for our health and well being and for the survival of our genes (Box 2) [10]. Experimental, cross-sectional and longitudinal studies are beginning to elucidate the various ways in which loneliness is related to, and in some cases affects, human information processing.

Cognitive capacities
Human social processes were once thought to have been incidental to learning and cognition, whereas the social complexities and demands of primate species are now thought to have contributed to the evolution of the neocortex and various aspects of human cognition. Consistent with this reasoning, human toddlers and chimpanzees have similar cognitive skills for engaging the physical world but toddlers have more sophisticated cognitive skills than chimpanzees for engaging the social world [11]; cross-species comparisons have revealed that the evolution of large and metabolically expensive brains is more closely associated with social than ecological complexity [12]; and a composite index of sociality in troops of baboons has been found to be highly correlated with infant survival [13].

Evidence that social isolation might be related to fundamental aspects of cognition comes from animal research showing that isolation impairs learning that requires the inhibition of previously learned responses (e.g. reversal learning, extinction) [14] and from human research showing that loneliness is a risk factor for cognitive decline [15–17] and Alzheimer’s disease (AD) [17]. Gow and colleagues [17] investigated the correlates of changes in mental ability of 488 individuals from the Lothian Birth Cohort Study who were tested at age 11 and 79. Among the variables tested were loneliness, social support and social network (e.g. presence of significant others, number of significant others). After controlling for age-11 IQ, gender, years of education and social class, only loneliness was associated significantly with changes in IQ.

Although loneliness is temporally stable and heritable [18,19], the study by Gow and colleagues does not address the possibility that loneliness is a consequence rather than a predictor of cognitive decline. Two recent longitudinal studies do address this question.

Tilvis and colleagues [15] measured cognition by the mini-mental state examination and the Clinical Dementia Rating at baseline and at one-, five- and ten-year assessments of a population-based sample of 75–85-year-old individuals. Results at the 10-year follow-up assessment revealed APOE4, elevated serum (ionized) calcium and loneliness independently predicted cognitive decline. Wilson et al. [16], in a larger prospective study, assessed 823 older adults (Mage = 80.7 years, SD = 7.1) free of dementia at enrollment. Participants completed an extensive battery of cognitive measures to assess global cognition, episodic memory, semantic memory, working memory, perceptual speed and visuospatial ability. The
Although objective social isolation can affect loneliness [55,56], perceived social isolation (loneliness) is more closely related to the quality rather than quantity of social interactions [55]. This is in part because loneliness is influenced by factors unrelated to objective isolation, including genetics [57], childhood environment [18], cultural norms [58], social needs [59], physical disabilities [55] and discrepancies between actual and desired relationships [60]. Accordingly, perceived social isolation predicts various outcomes above and beyond what is predicted by objective isolation. For instance, loneliness predicts elevated blood pressure [61], morning rise in cortisol [36], reduced physical activity [62], perceptions of the neighborhood environment as unsafe [63], and changes in life satisfaction across a lifetime [17] beyond what could be predicted by social support or objective social isolation. In studies of cognitive functioning, Wilson et al. [16] found no evidence for an influence of social network size or frequency of social activity on cognitive decline or on risk for AD, whereas loneliness persisted in predicting each of these outcomes even when social network size and frequency of social activity were statistically held constant. Similarly, loneliness has been found to predict lifetime change in IQ [17] and changes in depressive symptoms [39] beyond what could be predicted by objective isolation. Experimental manipulation of loneliness [30] and imagined future isolation [64] result in cognitive changes even though objective isolation is not altered in these experimental studies. Perceived (but not objective) social isolation has even been associated with gene expression—specifically, the under-expression of genes bearing anti-inflammatory glucocorticoid response elements and over-expression of genes bearing response elements for pro-inflammatory NF-kB/Rel transcription factors (Figure I) [37]. This finding is paralleled by decreased lymphocyte sensitivity to physiological regulation by the hypothalamic pituitary adrenocortical (HPA) axis in lonely individuals [65], which together with evidence of increased activity of the HPA axis [24,66,67], suggests the development of glucocorticoid resistance in chronically lonely individuals. We, therefore, focus the current review on the association between perceived social isolation and cognition.

lonelier the participants were, the poorer the cognitive performance within each of these domains at baseline, and loneliness was associated with greater cognitive declines in every domain except working memory and episodic performance. Furthermore, 76 individuals developed dementia during the 65-month study period. Cox proportional hazards models that controlled for age, sex and education indicated that loneliness significantly increased the risk of clinical AD, and this association was unchanged when objective social isolation and other demographic and health-related factors served as covariates. Wilson et al. [16] also examined the possible role of depressive symptoms because depression can also contribute to cognitive decline. The loneliness at baseline predicted cognitive decline and the onset of AD even when depressive symptoms served as a covariate. For instance, the association between loneliness and AD risk was reduced by about 16% when controlling for depressive symptoms and remained significant. Depressive symptomatology, by contrast, was marginally related to the risk of AD and this association was reduced by more than half when controlling for loneliness (see also Hertzog et al.) [20].

Brain autopsies were available for 67% of the participants who died during the study; of these, 30% had a clinical diagnosis of AD. Loneliness and the neuropathological measures derived from the brain autopsy were each inversely related to global cognition at the last assessment prior to death, but loneliness was unrelated to the neuropathological measures. Although the mechanism underlying the association between loneliness and cognitive decline has not yet been identified, social isolation was recently shown to decrease central anti-inflammatory responses and survival rate, and increase the infarct size and edema development, following the induction of stroke in mice [3]. The deficits in
reversal learning associated with isolation in animals have also been associated with diminished prefrontal-cortico-striatal functioning (a neural mechanism involved in the inhibition of previously learned responses) [21]. Socially isolated animals also show less dendritic arborization in the hippocampus and prefrontal cortex [22] and decreased brain-derived neurotrophic factor [23]. To what extent loneliness produces similar neurophysiological changes and how such differences contribute to cognitive decline in humans are open questions. Consistent with the animal research,
however, human studies indicate that loneliness impairs executive functioning, specifically the inhibition of prepotent responses. We turn to that evidence next.

**Executive functioning**

Executive functioning includes the capacity to control one’s attention, cognition, emotion and/or behavior to better meet social standards or personal goals, that is, to self-regulate. Early evidence from young adults who performed a dichotic listening task suggested that attentional regulation was poorer in lonely than nonlonely individuals [24]. Participants were asked to identify the consonant-vowel pair presented in the left or right ear. Typically, performance shows a right-ear advantage and performance is better for the ear to which participants have been instructed to attend. Lonely and nonlonely individuals showed an equivalent right-ear advantage under the no-instruction condition and an equivalent attentional shift to the right ear when so instructed, but lonely participants showed a weaker left-ear advantage (the non-prepotent response) when instructed to attend to this ear. Poorer self-regulation when feeling isolated is not limited to attentional control. In cross-sectional and longitudinal research, lonely individuals have been found to have a lower probability of engaging in regular exercise than nonlonely individuals, and the poorer emotional regulation of individuals when they felt lonely mediated the effect [25]. Experimental manipulations that lead people to believe they face a future of social isolation also decrease self-regulation. In an illustrative study, Baumeister and colleagues [26] had the participants complete two questionnaires: an introversion/extraversion test and a personality inventory. Participants were then randomly assigned to receive no feedback (Control Group) or to receive feedback to induce feelings of a future of social isolation (Future Alone), social connection (Future Belonging) or general misfortune (Misfortune Control Group). Results revealed that the Future Alone group performed significantly worse than the other groups on the General Mental Ability Test of the Graduate Record Exam. Feedback of misfortune itself was insufficient to cause poor performance whereas bad news about social connections did.

In subsequent variations on this experimental paradigm, randomly assigned participants to the Future Alone Group, relative to the other groups, performed similarly on a rote memorization task. However, they attempted the fewest problems and made the most mistakes on a logical reasoning task [27], consumed more delicious but unhealthy foods [27] and were more aggressive toward others [28]. Therefore, a perceived future of social isolation did not impair routine mental ability, but did impair the higher order cognitive and self-regulatory processes that are characteristic of executive functioning. A brain scan conducted while participants performed moderately difficult math problems revealed that the brains of the future socially isolated participants were less active in the areas involved in the ‘executive control’ of attention [29].

**Colorations of cognition**

Experimental manipulations of loneliness not only impair executive functioning but also produce higher negative mood, anxiety, anger and depressive symptomatology [30]. An experience sampling study, in which participants were beeped randomly nine times per day for seven days, confirmed that the social interactions of lonely, in contrast to nonlonely, individuals were more negative and less satisfying and such interactions contributed subsequently to more negative moods and interactions [31]. Evidence from behavioral and functional magnetic resonance imaging (fMRI) studies further suggests that loneliness increases attention to negative social stimuli (e.g. social threats). Using a modified emotional Stroop task, lonely participants, relative to nonlonely participants, showed greater Stroop interference specifically for negative social relative to negative nonsocial words [32]. No differences between lonely and nonlonely participants were found in Stroop interference for positive-social words relative to positive non-social words. Stroop interference is used to gauge the implicit processing of stimuli and so these results suggest that loneliness is associated with a heightened accessibility of negative social information. Similarly, Yamada and Decety [33] investigated the effects of subliminal priming on the detection of painful facial expressions. Using signal detection analyses, they found that lonely individuals were more sensitive (d’) to the presence of pain in dislikable faces than were nonlonely individuals.

The patterns of regional brain activation found when lonely and nonlonely individuals think about people also differ [34]. A region associated with reward and appetitive behavior (i.e. ventral striatum) was more strongly activated in nonlonely than lonely individuals when exposed to pleasant social pictures in contrast to pleasant nonsocial pictures (Figure II). By contrast, activation of the visual cortex to the presentation of unpleasant social, in contrast to nonsocial, pictures was directly related to the loneliness of the participant, indicative of greater visual attention to the negative social stimuli. These results are consistent with the behavioral data and indicate that loneliness is related to the attention elicited by negative social stimuli.

A possible effect of loneliness and the priming of social threats is an increased probability that lonely individuals focus on themselves, their needs and their preservation in negative circumstances. To examine this possibility, activation in the temporoparietal junction (TPJ), a region that has been found previously to be activated in theory of mind tasks and in tasks in which individuals take the perspective of another, was also examined [34]. Consistent with this reasoning, TPJ activation was observed when participants viewed unpleasant pictures of people versus objects, and loneliness was inversely related to the amount of activation observed.

The hypersensitivity to negative social information and the diminished pleasure derived from positive social stimuli might be expected to shape social expectations and motivations and contribute to a downward spiraling of negative affect and depressive symptomatology. Indeed, loneliness is related to stronger expectations of, and motivations to avoid, bad social outcomes and weaker expectations of, and motivations to approach, good social outcomes [35]. Furthermore, loneliness and depressive symptoms are distinct states both by measures of statistical [30] and functional independence.
Box 3. Regulatory loop and remaining questions

Given our evolutionary heritage, the human brain and biology have been sculpted to seek meaningful connections with others. In evolutionary time, social groupings were relatively small and stable, and the pain of loneliness may have served both to promote the social connections necessary for the survival of the genes and as a deterrent to selfish actions that were detrimental to the group [58]. The evidence reviewed here, however, suggests that loneliness in contemporary society may sometimes affect human cognition in maladaptive ways (Figure III). Specifically, feeling socially isolated can trigger implicit hypervigilance for social threats, which in turn produces attentional, confirmatory, and memorial biases. Accordingly, lonely individuals are more likely to attend to and construe their social world as threatening, hold more negative social expectations and remember more negative social events than are nonlonely individuals. These cognitions increase the likelihood that individuals engage in behavioral confirmation processes, through which they produce more negative social interactions and elicit evidence confirming that they have little personal control or social value. These dispositions, in turn, alter the nature and likelihood of social engagement and activate neurobiological mechanisms that increase activation of the hypothalamic pituitary adrenal (HPA) axis and diminish sleep quality. Repeated or chronic activation of threat surveillance in a social context, coupled with diminished anabolic processes, may contribute to heightened cognitive load, diminished executive functioning, dysregulated brain and physiological systems, and broad based morbidity and mortality. Although this theoretical model is consistent with the evidence reviewed here, many details remain to be tested and refined. The following questions may be of special import.

- To what extent is loneliness a consequence rather than an antecedent of incipient dementia? Longitudinal and experimental studies suggest loneliness may play a causal role in at least some of the observed associations between loneliness and cognitive functioning, but sensory loss, functional impairments, and cognitive impairments may also lessen social contact and increase loneliness. Questions remain about the extent to which, and conditions under which, the associations between loneliness and cognitive functioning reflect the effects of loneliness, the effects of cognition and the effects of a third variable.

- By what mechanism might loneliness contribute to cognitive decline as people age? Among the possible mechanistic pathways that warrant investigation are the effects of loneliness on: (a) elevated activation of the HPA axis and/or increased inflammatory responses in the brain, each of which may impact cognitive functioning; (b) behavioral or neural plasticity such that older individuals are less able to compensate for age-related degenerative changes in neural systems involved in cognitive functioning; (c) the simplification of social cognition and reduction in social stimulation and engagement that are tantamount to lower cognitive stimulation; (d) cognitive load (and reduction in available cognitive resources available for creative adaptations) produced by chronic surveillance for and protection from threats; (e) elevations in depression and/or reductions in physical activity; (f) the reduction in the number and quality of social interactions; and (g) impairments in the consolidation of learning that may result from diminished sleep quality.

- Does the detrimental effect of loneliness occur later in life or is it cumulative across the lifespan? If cumulative, are the deleterious effects of loneliness on cognition (if causal) reversible? Increasing social contact and social support appear not to be sufficient to lower loneliness or to explain the effects of loneliness on cognition. How does one intervene to reduce perceived social isolation and promote healthy social connections? Does the nature of effective interventions for loneliness differ across age, gender, or ethnicity?

- What are the brain mechanisms underlying the association between loneliness and cognition? Diminished prefrontal-cortico-striatal functioning, dendritic arborization, brain-derived neurotrophic factors and central anti-inflammatory responses are just a few of the possibilities that are suggested by the extant evidence.

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Social cognition

The brains of lonely, in contrast to nonlonely, individuals are on high alert for social threats, so lonely individuals tend to view their social world as threatening and punitive (Box 3). Experimental manipulations of loneliness not only cause people to feel more anxious, fear negative evaluation
and act more coldly toward others [30], but it also causes
them to feel as assessed by ratings of room temperature
[42]. Lonely individuals also tend to form more negative
social impressions of others, and their expectations, attribu-
tional reasoning and actions toward others tend to be
less charitable than shown by nonlonely individuals [43].
When an individual’s negative social expectations elicit
behaviors from others that validate these expectations, the
expectations are buttressed and increase the likelihood of
the individual behaving in ways that pushes away the very
people to whom he or she most wants to be close to better
fulfill their social needs [44,45]. Consequently, lonely indi-
viduals may view themselves to be passive victims in their
social world, but they are active contributors through their
self-protective and paradoxically self-defeating inter-
actions with others [43].

Although loneliness can interfere with a person’s attempts to form stable and trusting social connections with other people, loneliness has been found to promote attempts to form social connections though memorial or inferential means, such as through nostalgic reminiscences [46], imputed parasocial relationships (relationships with imaginary television characters) [47] and digital connections [48]. In addition, loneliness promotes social connection through the anthropomorphism of pets [49], technological gadgets [50], celestial bodies [51], and supernat-
ural entities [51]. This body of work suggests that when
people feel socially isolated it becomes more probable that they will use their cognitive capacities to try to fill the
social void.

Contagion
Loneliness is typically investigated as an individual factor, but because perceived and objective isolation can be differ-
entiated, loneliness can also vary within and across groups.
Network linkage data from the population-based Framing-
ham Heart Study were used to trace the topography of
loneliness in social networks and the path through which
loneliness spreads through these networks [52]. Results
indicated that loneliness occurs in clusters within social
networks, is disproportionately represented at the periph-
ery of social networks, extends up to three degrees of
separation and is stronger for women than men.

Several features of the Framingham study pointed to
loneliness spreading through a contagious process and
moving lonely individuals closer to the edge of social net-
works over time. Contagion is defined as the transmission
of a state by direct or indirect contact, and virulence is
determined, in part, by exposure (i.e. dose). Longitudinal
analyses indicated four findings. First, that loneliness in
one individual at Time 1 was followed by increased lone-
liness in others in the social network by Time 2. Second, the
closer a friend or contact was physically to this individual
at Time 1, the lonelier the friend or contact became by Time
2. Third, loneliness was transmitted from the individual at
Time 1 through friends and contacts to others beyond the
individual’s circle of contacts such that these other indi-
viduals became lonelier by Time 2. Fourth, the trans-
mission of loneliness was stronger when the friendship
between the individual who was lonely at Time 1 and
others in the social network was reciprocal. Importantly,
these results were unchanged when controlling for depre-
ssive symptomatology, indicating that the contagion
of loneliness was not secondary to depression [52].

If loneliness is contagious, the driving away of those who
are lonely functions to keep the contagion in check with the
consequence that those who feel socially isolated become
objectively more isolated. Loneliness not only spreads from
person to person within a social network, but it also
reduces the ties of these individuals to others within the
network. The collective rejection of isolates observed in
human and other primate behavior may therefore serve to
protect the structural integrity of the social entities neces-
ary for humans to survive and prosper.

Data from the Framingham study do not permit
detailed investigation of the means by which loneliness
was transmitted, but this contagion may occur through
three different mechanisms: automatic emotional conta-
gion [53], coextensive self-other overlap and the attendant
susceptibility of shared states [54], and quality of social
interactions [31]. For instance, in an experience sampling
study of everyday behavior, loneliness was associated
with more negative affect and more negative social inter-
actions, the quality of social interactions predicted subse-
quently affective states and vice versa, and more negative social
interactions had longer lasting effects on affect than
positive social interactions [31]. These data are consistent
with the notion that the contagion of loneliness can occur
through the more negative social cognition and interper-
sonal interactions it engenders.

Conclusion
Cognition has been regarded as a quintessential individual
activity. Mental representations and processes were ren-
dered testable in the dawn of the cognitive sciences by virtue
of reverse engineering: mathematical and computer models
were created that specified stimulus inputs, information
processing operations that acted on and transformed these
inputs to produce and change representational structures,
and information processing operations that led to observa-
able responses. Computers today are no longer solitary
devices, but rather they operate as a connected collective
resulting in unforeseen power, capacities, representations
and processes. Social species create emergent organiza-
tions beyond the individual – structures ranging from dyads and
families to institutions and cultures. These emergent struc-
tures evolved hand in hand with neural, hormonal and
genetic mechanisms to support them because the conse-
quent social behaviors helped these organisms survive, re-
produce and care for offspring over a sufficiently long period
so that they too reproduced. These emergent levels of organ-
ization have long been apparent, but identifying their bio-
logical and cognitive bases and consequences is one of the
major problems for the cognitive sciences to address this
century.

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References


8 Poletto, R. et al. (2006) Effects of early weaning and social isolation on the expression of glucocorticoid and mineralocorticoid receptor and 11beta-hydroxysteroid dehydrogenase 1 and 2 mRNAs in the frontal cortex and hippocampus of piglets. Brain Res. 1067, 36–42


11 Herrmann, E. et al. (2007) Humans have evolved specialized skills of social cognition: the cultural intelligence hypothesis. Science 317, 1360–1366


20 Hertzog, C. et al. (2008) Enrichment effects on adult cognitive development: can the functional capacity of older adults be preserved and enhanced? Psychological Science in the Public Interest 9, 1–65


28 Twenge, J.M. et al. (2001) If you can’t join them, beat them: Effects of social exclusion on aggressive behavior. J. Pers. Soc. Psychol. 81, 1058–1069


37 Cole, S.W. et al. (2007) Social regulation of gene expression in human leukocytes. Genome Biology 8, R189.1–R189.113

38 Hawley, L.C. et al. (2006) Loneliness is a unique predictor of age-related differences in systolic blood pressure. Psychol. Aging 21, 152–164


50 Ruiz, J.I. (2007) Emotional Climate in Organizations: applications in
gadgets, gods, and greyhounds. Psychol. Sci. 19, 114–120
anthropomorphism. Psychol. Rev. 114, 864–886
52 Cacioppo, J.T. et al. (2009) Alone in the crowd: the structure and spread
of loneliness in a large social network. J. Pers. Soc. Psychol. 96
53 Hatfield, E. et al. (1994) Emotional Contagion. Cambridge University
Press
54 Slotter, E.B. and Gardner, W.L. (2009) Where do you end and I begin?
Evidence for anticipatory, motivated self-other integration between
55 Hawkley, L.C. et al. (2008) From social structure factors to perceptions
of relationship quality and loneliness: The Chicago Health, Aging, and
Social Relations Study. J. Gerontol. B. Psychol. 63, S375–S384
56 Ruiz, J.I. (2007) Emotional Climate in Organizations: applications in
57 Boomsma, D. et al. (2005) Genetic and environmental contributions to
loneliness in adults: The Netherlands Twin Register Study. Behav.
Genet. 35, 745–752
the Need for Social Connection. W. W. Norton & Company
among divorced and married men and women: comparing the deficit
60 Cacioppo, J.T. and Hawkley, L.C. (In press) Loneliness. In Handbook of
Individual Differences in Social Behavior (Leary, M.R. and Hoyle, R.H.,
eds). Guilford
61 Hawkley, L.C. et al. (2006) Loneliness is a unique predictor of age-related
differences in systolic blood pressure. Psychol. Aging 21, 152–164
62 Hawkley, L.C. et al. (2009) Loneliness predicts reduced physical
activity: cross-sectional & longitudinal analyses. Health Psychol. 28,
354–363
63 Wen, M. et al. (2006) Objective and perceived neighborhood
environment, individual SES and psychosocial factors, and self-
rated health: an analysis of older adults in Cook County. Illinois.
Soc. Sci. Med. 63, 2575–2590
64 Baumeister, R.F. et al. (2002) Effects of social exclusion on cognitive
Soc. Psychol. 83, 817–827
66 Adam, E.K. et al. (2006) Day-to-day dynamics of experience-cortisol
Acad. Sci. U. S. A. 103, 17058–17063
67 Steptoe, A. et al. (2004) Loneliness and neuroendocrine,
cardiovascular, and inflammatory stress responses in middle-aged
men and women. Psychoneuroendocrinology 29, 593–611
Social Exclusion. Science 302, 290–292
69 Delgado, M.R. et al. (2005) An fMRI study of reward-related probability
learning. Neuroimage 24, 862–873
Opin. Neurobiol. 14, 769–776
drugs in humans. Prog. Neuropsychopharmacol. Biol. Psychiatry 31,
1601–1613
72 Wang, Z. et al. (2007) Neural substrates of abstinence-induced
cigarette cravings in chronic smokers. J. Neurosci. 27, 14035–14040
73 Seymour, B. et al. (2007) Differential encoding of losses and gains in
the human striatum. J. Neurosci. 27, 4826–4831
74 Aron, A. et al. (2005) Reward, motivation, and emotion systems
94, 327–337
75 Rilling, J. et al. (2002) A Neural basis for social cooperation. Neuron 35,
395–404
76 Fliessbach, K. et al. (2007) Social comparison affects reward-related
brain activity in the human ventral striatum. Science 315, 1305–1308
77 De Quervain, D.J.F. et al. (2004) The neural basis of altruistic
punishment. Science 305, 1254–1258
78 Cacioppo, J.T. et al. (2009) In the eye of the beholder: individual
differences in perceived social isolation predict regional brain
activation to social stimuli. J. Cogn. Neurosci. 21, 1–10