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Longitudinal associations between risk appraisal of base stations for mobile phones, radio or television and non-specific symptoms

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ABSTRACT

Introduction: Studies found that higher risk appraisal of radiofrequency electromagnetic fields is associated with reporting more non-specific symptoms such as headache and back pain. There is limited data available on the longitudinal nature of such associations and what aspects of risk appraisal and characteristics of subjects are relevant.

Objective: To examine cross-sectional and longitudinal associations between risk appraisal measures and non-specific symptoms, and assess the role of subject characteristics (sex, age, education, trait negative affect) in a general population cohort.

Methods: This study was nested in the Dutch general population AMIGO cohort that was established in 2011/2012, when participants were 31–65 years old. We studied a sample of participants (n = 1720) who filled in two follow-up questionnaires in 2013 and 2014, including questions about perceived exposure, perceived risk, and health concerns as indicators of risk appraisal of base stations, and non-specific symptoms.

Results: Perceived exposure, perceived risk, and health concerns, respectively, were associated with higher symptom scores in cross-sectional and longitudinal analyses. Only health concerns (not perceived exposure and perceived risk) temporally preceded high symptom scores and vice versa. Female sex, younger age, higher education, and higher trait negative affect were associated with higher risk appraisal of mobile phone base stations.

Discussion: The findings in this study strengthen the evidence base for cross-sectional and longitudinal associations between higher risk appraisal and non-specific symptoms in the general population. However, the directionality of potential causal relations in non-sensitive general population samples should be examined further in future studies, providing information to the benefit of risk communication strategies.

1. Introduction

On average, people report more non-specific symptoms such as headache or dizziness when they think they are exposed to radiofrequency electromagnetic fields (RF-EMF) from base stations for mobile phones, radio or television, regardless of actual level of exposure [1–5]. Several studies examined the underlying psychosocial mechanisms in experimental studies with sham exposure [2, 5–8]. However, there is a need for more prospective population studies to gain insight in the long term direction(s) of associations in a general population context.

People form mental models of base stations in their living environment [9]. These internal representations of the external reality shape reasoning, decision making, and behavior and can play a role in individual health responses to the environment [10, 11]. Mental models of base stations can include beliefs about exposure and potential health

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risks, which often do not correspond with the view of experts [12, 13]. For example, there are low correlations between perceived RF-EMF exposure levels on one hand and measured or modelled exposure levels on the other hand [3, 4, 14–16]. At the same time, many people are concerned about potential health risks from EMF [3, 17–19]. They associate EMF exposure with perceived health risks such as cancer, but also with non-specific symptoms such as dizziness or concentration problems, and with sleep disturbance [1, 18, 20–22]. These concerns do not match the results of epidemiological research, which does not indicate clear adverse health effects of RF-EMF exposure from base stations at every day levels of exposure [4, 23–25]. If health effects exist at every day exposure levels, these are likely to be small, and to occur in small (sensitive) groups that have not been identified yet. We will use the term risk appraisal as an overarching term for individual perceptions about personal exposure, health risks, and concerns for personal health. These perceptions can play a role in individual health responses to a potential health hazard [26, 27], regardless of any disparities with epidemiological findings.

A number of studies, mostly experimental studies and studies with electro hypersensitive participants, have examined the link between risk appraisal and increased symptom reporting. There is evidence that nocebo effects can occur, especially in situations with sham EMF exposure [2, 16, 28, 29], or when there is a visible change in the environment such as the placement of a new base station or power line [27, 30]. A nocebo response is the counterpart of placebo, i.e. an adverse health response after a treatment or exposure that is not a direct result of this exposure [29, 31–34]. There is a large overlap in reported symptoms between electrohypersensitivity and other environmental intolerances (multiple chemical sensitivity and infrasound hypersensitivity), and these syndromes share the absence of an established link with actual exposure levels (under blinded conditions) [35]. For each of these syndromes, there is evidence that psychological and behavioral processes play a role. Based on studies with participants who report electro hypersensitivity [6, 36] or idiopathic environmental intolerance [37] there is evidence of a circular process where somatosensory amplification plays a role in amplifying symptoms and risk perception. Other processes may also be important, for instance people who experience many symptoms may be more likely to attribute their symptoms to exposures to an environmental exposure, and become more aware of, and concerned about environmental exposures including EMF [39]. This increased awareness has been described as environmental monitoring [38]. Although experimental studies are important for understanding which psychosocial mechanisms could explain the link between risk appraisal and increased symptom reporting, there is a need for more prospective studies in the general population. With prospective studies it may be possible to gain insight in the direction(s) of associations and the relative importance of mechanisms such as nocebo and incorrect attribution in the general population. This insight is important for the development of adequate risk communication strategies, as well as for the interpretation of possible indirect health effects of exposure, or exposure sources, through risk appraisal. For example, the placement of a new base station could have a negative impact on symptom experiences through increases in perceived exposure [4], but this phenomenon is difficult to disentangle from incorrect attribution of existing or new symptoms to this new exposure source.

Subject characteristics such as sex, age, education, and trait negative affect have been shown to influence both symptom scores and risk appraisal [26]. For example, women consistently report higher risk appraisal and more symptoms than men [40, 41]. As a trait, higher negative affect is associated with higher levels of risk appraisal as well as with reporting more symptoms [37, 42–45]. For other subject characteristics (f.i. education level, race, age) the results regarding risk appraisal are inconsistent across studies, different measures, and type of risks [1, 41, 46–52]. For example, education was associated with higher risk appraisal of mobile phone base stations [52] and smoking [53] but negatively with risks in general [47, 50]. The inclusion of the role of subject characteristics in this prospective study will achieve a more comprehensive understanding of risk appraisal of base stations and its link with symptom reporting.

The first objective of this study was to examine cross-sectional and longitudinal associations between risk appraisal of RF-EMF exposure from base stations for mobile phones, radio, or television, and the experience of non-specific symptoms in a prospective general population cohort. We considered different aspects of risk appraisal with respect to RF-EMF from mobile phone base stations, namely perceived personal exposure in the residential environment, perceived risk that exposure could be a health risk in general, and concerns regarding personal health risks. Secondly, we examined the influence of a number of subject characteristics (sex, age, education, and trait negative affect) on risk appraisal and symptom score.

2. Method

2.1. Population

This study is nested in the AMIGO cohort, which was setup in 2011/2012 (defined here as T0, n = 14,829) to study environmental and occupational determinants of diseases and symptom reporting in the general population (see [54] for a full description). The participants were not specifically recruited for EMF related topics. We studied a follow-up sample of the cohort that participated in two additional questionnaires (in 2013 (defined here as T1) and 2014 (defined here as T2). The selection strategy for the invitations to participate in the follow-up sample is described in detail elsewhere [4]. In short, the purpose of this selection was to achieve contrast in both actual and perceived exposure to RF-EMF from mobile phone base stations, where actual exposure was assessed with the validated 3D geospatial model NISMap [55, 56]. NISMap models exposure at the home address, using data about the position and characteristics of antenna's, elevation and buildings. The selection was achieved by oversampling subjects with high modelled, and/or high perceived exposure at T0. Only participants who answered all questions regarding symptoms, concerns, risk perception, perceived exposure, at both T1 and T2, and trait negative affect at T2, were included in this study (n = 1720). This resulted in the exclusion of n = 484 participants who participated at T1 but not at T2, and the exclusion of an additional n = 24 participants with missing responses on one or multiple key variables.

2.2. Non-specific symptoms

At T1 and T2 we assessed the total symptom score with the somatization scale of the 4 dimensional symptom scale (4DSQ-S), which consists of 16 non-specific somatic symptoms commonly reported in general practices (e.g. headaches, low back pain, and dizziness). According to the 4DSQ manual [57], participants indicated for each symptom whether they were bothered by it during the previous week on a 5-point scale (ranging from no, through to constantly). The scores per symptom were trichotomized and then summed over the symptoms to obtain a total score (no = 0; sometimes = 1, regularly/often/constantly = 2).

2.3. Risk appraisal of RF-EMF exposure to base stations for mobile phones, radio, or television

We assessed risk appraisal of RF EMF from base stations at T1 and T2 with three separate items: 1) Perceived exposure: “To what extent do you think are you exposed to (electromagnetic fields/radiation from) base stations for mobile phones, radio or television (scale of 0-6 where 0 = not at all, 6 = very much)?”. 2) Perceived risk: “To what extent do you think that (electromagnetic fields/radiation from) base stations for mobile phones, radio or television can be a health risk in everyday

Table 1
Participant characteristics, risk appraisal and symptom scores in AMIGO follow-up sample at T1 (2013), n = 1720.

		Perceived exposure T1	Perceived risk T1	Concerns T1	Symptoms T1
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Gender					
Male	n = 804 (47%)	1.69 (1.54)	1.77 (1.63)	1.33 (1.51)	5.41 (5.03)
Female	n = 916 (53%)	2.05 (1.58)	2.35 (1.74)	1.70 (1.69)	6.56 (4.83)
p-Value*		< 0.0001	< 0.0001	< 0.0001	< 0.0001
Test statistic		F(1,1711) = 23.24	F(1,1711) = 52.20	F(1,1711) = 22.71	F(1,1711) = 26.56
Age (in years)					
31–40	n = 192 (11%)	2.39 (1.44)	2.48 (1.61)	1.64 (1.57)	5.75 (4.46)
41–50	n = 437 (25%)	2.03 (1.54)	2.31 (1.72)	1.57 (1.61)	5.73 (4.80)
51–60	n = 630 (37%)	1.86 (1.56)	2.10 (1.72)	1.56 (1.63)	6.52 (5.26)
> 60	n = 461 (27%)	1.55 (1.59)	1.65 (1.65)	1.39 (1.61)	5.72 (4.84)
p-Value*		< 0.0001	< 0.0001	0.17	0.008
Test statistic		F(3,1711) = 15.64	F(3,1711) = 17.06	F(3,1711) = 1.70	F(3,1711) = 3.93
Education					
Low	n = 439 (25%)	1.69 (1.55)	1.84 (1.63)	1.55 (1.66)	7.41 (5.72)
Middle	n = 487 (28%)	1.87 (1.59)	2.14 (1.74)	1.62 (1.63)	6.09 (4.87)
High	n = 794 (46%)	1.99 (1.56)	2.17 (1.74)	1.45 (1.58)	5.21 (4.35)
p-Value*		0.003	0.002	0.18	< 0.0001
Test statistic		F(2,1711) = 5.78	F(2,1711) = 6.28	F(2,1711) = 1.73	F(2,1711) = 32.14
Negative affect[a]					
Lowest tertile	n = 558 (33%)	1.71 (1.58)	1.91 (1.75)	1.29 (1.56)	4.51 (4.18)
Medium tertile	n = 521 (30%)	1.78 (1.52)	1.98 (1.70)	1.38 (1.53)	5.40 (4.20)
Highest tertile	n = 641 (37%)	2.11 (1.57)	2.29 (1.67)	1.85 (1.68)	7.84 (5.56)
p-value*		< 0.0001	0.0001	< 0.0001	< 0.0001
Test statistic		F(2,1711) = 11.70	F(2,1711) = 9.21	F(2,1711) = 21.22	F(2,1711) = 84.12

* *P*-values show the significance of effects in multifactor ANOVAs. First and higher order interactions between factors were not significant.
[a] Negative affect is presented categorically in this table and was assessed at T2 (2014).

situations (scale of 0-6 where 0 = not at all, 6 = very much)?". 3) Concerns: "To what extent are you concerned about your own health because of (electromagnetic fields/radiation from) base stations for mobile phones, radio or television (scale of 0-6 where 0 = not at all, 6 = very much)?". In practice, these scores will mostly represent risk appraisal of mobile phone base stations, as base stations for radio and television are relatively sparse. The specific wording of the questionnaire items was based on the assumption that many participants may not be aware of differences between the appearance of base stations for mobile phones, radio, or television.

2.4. Subject characteristics

The baseline questionnaire in 2011/2012 included questions on sex, date of birth (to calculate age), and education level. We assessed trait negative affect at T2 with a Dutch version of the I-PANAS-SF [58]. This scale consists of ten items (five positive and five negative) such as alert, upset, ashamed. Participants were asked how often (never – always) they experience each of these feelings. A total score for negative affect was calculated from the five negative items. A higher score indicates more negative affect. Positive affect was not analyzed as it fell beyond the scope of this study.

2.5. Statistical analyses

The data were analyzed using SAS enterprise guide 6.1 software. Multifactor Analysis Of Variance (ANOVA) was used to asses mean differences for sex, age, education and negative affect in risk appraisal (perceived exposure, perceived risk, and concerns) and symptom scores, in a cross-sectional analysis of the T1 (2013) questionnaire data. Next, we examined the correlations among variables of interest by calculating Spearman correlations (for the variables: perceived exposure T1, perceived exposure T2, risk perception T1, risk perception T2, concerns T1, concerns T2, Symptoms T1, Symptoms T2, and negative affect T2). The data from the T1 (2013) and T2 (2014) questionnaires were then combined and analyzed with multivariate mixed effect regression models clustered at the subject level with a fixed effect for year to adjust for temporal population trends in total DSQ-s symptom score. Risk appraisal indicators and individual characteristics (sex, age, education, negative affect) were included as predictors of symptom scores. Risk appraisal indicators were included jointly in the multivariate models presented in Table 3, and in separate models in the tables presented in Table 4. The unstructured covariance structure was chosen for the residuals. Additional exploratory analyses included interaction effects between risk appraisal and individual characteristics to examine whether the impact on symptoms differs depending on individual characteristics. We then studied the longitudinal associations between risk appraisal and symptom score with two different types of models. With the first type, the autoregressive linear models, we examined a time lag of one year between risk appraisal indicators and symptom score, and vice versa. These models examined whether the risk appraisal indicators perceived exposure, risk perception and concerns, respectively, at T1 were associated with symptom score at T2 (adjusting for symptom score at T1), and whether symptom score at T1 were associated with perceived exposure, risk perception and concerns, respectively, at T2 (adjusting for T1 values). The second type of longitudinal analyses were fixed effect analyses, where we examined the intra-individual variation in risk appraisal (T2-T1) on the one hand and symptom score (T2-T1) on the other. Fixed effect models only consider within individual variation, effectively adjusting for unmeasured time invariant confounders [59–61].

3. Results

3.1. Subject characteristics

The population characteristics are reported in Table 1. Age and negative affect are presented categorically for presentation in this table. Slightly more women (53%) than men participated in this study. The most common age category was 51–60 years (37%, at T1). A large

portion of the sample had a high education (46%). The results of the multifactorial ANOVAs (Table 1) show the influence of subject characteristics on risk appraisal and symptom scores at T1. Overall, men had lower risk appraisal scores than women and reported lower symptom scores (perceived exposure: $F(1,1711) = 23.24$, $p < 0.0001$, perceived risk: $F(1,1711) = 52.20$, $p < 0.0001$, concerns: $F(1,1711) = 22.71$, $p < 0.0001$, symptoms: $F(1,1711) = 26.56$, $p < 0.0001$). Risk appraisal scores were lower for older participants (perceived exposure: $F(3,1711) = 15.64$, $p < 0.0001$, perceived risk: $F(3,1711) = 17.06$, $p < 0.0001$, concerns: $F(3,1711) = 1.70$, $p = 0.17$). Participants with a low education reported lower risk appraisal scores (perceived exposure: $F(2,1711) = 5.78$, $p < 0.003$, perceived risk: $F(2,1711) = 6.28$, $p < 0.002$, concerns: $F(2,1711) = 1.73$, $p = 0.18$). and higher symptom scores ($F(2,1711) = 32.14$, $p < 0.0001$) than participants with a higher education. These differences in risk appraisal by age and education were significant for perceived exposure and perceived risk but not for concerns about personal health because of EMF from base stations. Negative affect was associated with higher risk appraisal and higher symptom scores (perceived exposure: $F(2,1711) = 11.70$, $p < 0.0001$, perceived risk: $F(2,1711) = 9.21$, $p = 0.0001$, concerns: $F(2,1711) = 21.22$, $p < 0.0001$, symptoms: $F(2,1711) = 84.12$, $p < 0.0001$). First and higher order interaction effects (results not presented) between subject characteristics were not significant.

3.2. Risk appraisal and symptom score

The means of and correlations among variables of interest are presented in Table 1 (with ANOVA of means by subject characteristics) and Table 2 (overall means and Spearman correlations). Note that reported mean scores were not representative of the means in the full AMIGO cohort due to the sampling strategy based on perceived (and modelled) exposure. The Spearman correlations over time among variables measured at T1 and T2 ranged from $r_{Sp} = 0.55$ (risk perception) to $r_{Sp} = 0.77$ (DSQ-s symptom scores). Correlations between different aspects of risk appraisal at the same point in time ranged from $r_{Sp} = 0.58$ to $r_{Sp} = 0.68$.

Multivariate models including all three risk appraisal items (Table 3) showed that perceived exposure and concerns explained unique variance in symptom scores, despite the correlations between these predictors. The regression coefficients for the effects of risk appraisal indicators on symptom score were smaller when trait negative affect was included as a predictor of symptom scores in the model (Table 3), in particular for concerns. Perceived risk was redundant in the multivariate model ($F(1,1715) = 3.10$, $p = 0.08$). When the model with all three indicators of risk appraisal as predictors of symptom scores is adjusted for trait negative affect, the association between concerns and symptom reporting is not significant ($F(1,1714) = 1.05$, $p = 0.31$(Table 3). However, all risk appraisal variables were significant when included as predictors of symptom scores in separate models, despite adjustment for negative affect (Table 4, perceived exposure: $F(1,1714) = 19.40$, $p \leq 0.0001$, perceived risk: $F(1,1714) = 17.27$, $p \leq 0.0001$ concerns: $F(1,1714) = 13.23$, $p \leq 0.0001$). Interaction effects between risk appraisal and individual characteristics were examined in additional exploratory analyses (results not presented), but did not result in improved model fit.

In the longitudinal autoregressive analyses (Table 5) we found that concerns at T1 were significantly associated with higher symptom score at T2 (adjusted for symptom score at T1, concerns t1: $F(1,1717) = 4.04$, $p = 0.04$), and that symptom score at T1 was associated with more concerns at T2 (adjusted for concerns at T1, symptom score T1: $F(1,1717) = 6.66$, $p = 0.01$). In contrast, we found no association between perceived exposure ($F(1,1717) = 0.00$, $p = 0.96$) or perceived risk ($F(1,1717) = 0.12$, $p = 0.73$) at T1 and symptom score at T2, adjusting for symptom score at T1. Also, the associations between symptom score at T1 as predictor and perceived exposure or perceived risk at T2 as outcomes, respectively were not significant (adjusting for baseline values of perceived exposure, respectively perceived risk). The results of fixed effect analyses are presented in Table 6. Intra-individual variation in risk appraisal scores over time was associated with intra-individual variation in symptom scores in the same time period (perceived exposure: $F(1,1718) = 8.36$, $p = 0.004$, perceived risk: $F(1,1718) = 12.44$, $p = 0.0004$, concerns: $F(1,1718) = 3.53$, $p = 0.039$).

4. Discussion

We studied the cross-sectional and longitudinal associations

Table 2
Spearman correlations and overall means and standard deviations in AMIGO follow-up sample that completed questionnaires at T1 (2013) and T2 (2014), (N = 1720).

	perceived exposure T1	perceived exposure T2	risk perception T1	risk perception T2	concerns T1	concerns T2	Symptoms T1	Symptoms T2	negative affect	mean (sd)
perceived exposure T1	-									1.88 (1.57)
perceived exposure T2	0.63	-								1.76 (1.64)
risk perception T1	0.63	0.49	-							2.08 (1.71)
risk perception T2	0.44	0.60	0.55	-						2.06 (1.74)
concerns T1	0.58	0.51	0.67	0.50	-					1.53 (1.62)
concerns T2	0.45	0.59	0.48	0.68	0.60	-				1.51 (1.61)
Symptoms T1	0.13	0.11	0.11	0.07	0.15	0.14	-			6.02 (4.96)
Symptoms T2	0.10	0.12	0.09	0.11	0.14	0.17	0.77	-		6.10 (5.06)
negative affect T2	0.12	0.19	0.12	0.18	0.18	0.24	0.35	0.41	-	8.99 (2.82)

Darker blue colors represent stronger correlations, lighter blue colors represent weaker correlations (color categorization boundaries: < 0.1;0.1 to 0.2;0.2 to 0.3;0.3 to 0.4;0.4 to 0.5; > 0.5).

Table 3
Results of multivariate mixed models with symptom score as dependent variable, clustered at subject level in AMIGO follow-up sample for subjects who completed questionnaires at T1 (2013) and T2 (2014), (N = 1720).

	Model 1. with year, gender, age and education (BIC = 19,191)			Model 2. with year, gender, age, education, Negative Affect (BIC = 18,921)		
Predictor(s)	Parameter estimate (CI)	Test-statistic	p-value	Parameter estimate (CI)	Test-statistic	p-value
Perceived exposure[a]	0.17 (0.06, 0.27)	F(1,1715) = 9.44	0.002	0.13 (0.03, 0.24)	F(1,1714) = 6.21	0.01
Perceived risk[a]	0.09 (−0.01, 0.19)	F(1,1715) = 3.10	0.08	0.09 (−0.01, 0.19)	F(1,1714) = 2.88	0.09
Concerns[a]	0.13 (0.02, 0.24)	F(1,1715) = 5.68	0.02	0.05 (−0.05, 0.16)	F(1,1714) = 1.05	0.31
year of questionnaire (T2)	0.11 (−0.05, 0.27)	F(1,1715) = 1.17	0.18	0.10 (−0.06, 0.26)	F(1,1714) = 1.59	0.21
female gender	0.91 (0.47, 1.35)	F(1,1715) = 16.73	< 0.0001	0.58 (0.17, 0.98)	F(1,1714) = 7.65	0.006
age	0.00 (−0.03, 0.02)	F(1,1715) = 0.01	0.93	0.02 (−0.01, 0.04)	F(1,1714) = 2.21	0.15
Medium education[b]	−1.25 (−1.85, −0.66)	F(2,1715) = 32.13	< 0.0001	−1.07 (−1.62, −0.52)	F(2,1714) = 30.97	0.0001
High education[b]	−2.20 (−2.75, −1.66)	F(2,1715) = 32.13	< 0.0001	−1.99 (−2.50, −1.49)	F(2,1714) = 30.97	< 0.0001
Negative affect				0.64 (0.57, 0.71)	F(1,1714) = 300.28	< 0.0001

Predictors are mean centered.
[a] Likert Scale 0 = not at all to 6 = very much.
[b] The reference category is low education.

Table 4
Results of separate mixed models for each risk appraisal indicator (perceived exposure, perceived risk, and concerns about RF-EMF from base stations) with symptom score as dependent variable clustered at subject level in AMIGO follow-up sample for subjects who completed questionnaires at T1 (2013) and T2 (2014), (N = 1720).

Predictor(s)	Perceived exposure			Perceived risk			Concerns		
	Parameter estimate (CI)	Test-statistic	p-Value	Parameter estimate (CI)	Test-statistic	p-Value	Parameter estimate (CI)	Test-statistic	p-Value
Indicator risk appraisal	0.20 (0.11, 0.29)	F(1,1714) = 19.40	< 0.0001	0.17 (0.09, 0.25)	F(1,1714) = 17.27	< 0.0001	0.16 (0.07, 0.25)	F(1,1714) = 13.23	0.0003
Year (T2)[a]	0.11 (−0.05, 0.27)	F(1,1714) = 1.77	0.18	0.09 (−0.07, 0.24)	F(1,1714) = 1.15	0.28	0.09 (−0.07, 0.25)	F(1,1714) = 1.14	0.29
Female gender	0.61 (0.20, 1.01)	F(1,1714) = 8.68	0.003	0.61 (0.20, 1.01)	F(1,1714) = 8.17	0.004	0.63 (0.23, 1.04)	F(1,1714) = 9.31	0.002
Age	0.02 (−0.01, 0.04)	F(1,1714) = 1.97	0.16	0.02 (−0.01, 0.04)	F(1,1714) = 1.79	0.18	0.01 (−0.01, 0.03)	F(1,1714) = 1.21	0.27
Medium education[b]	−1.06 (−1.61, −0.51)	F(2,1714) = 31.33	0.0002	−1.06 (−1.61, −0.51)	F(2,1714) = 30.86	0.0002	−1.04 (−1.59, −0.49)	F(2,1714) = 29.12	0.0002
High education[b]	−2.00 (−2.50, −1.50)	F(2,1714) = 31.33	< 0.0001	−2.00 (−2.50, −1.50)	F(2,1714) = 30.86	< 0.0001	−1.93 (−2.43, −1.43)	F(2,1714) = 29.12	< 0.0001
Negative affect	0.65 (0.57, 0.72)	F(1,1714) = 310.93	< 0.0001	0.65 (0.58, 0.72)	F(1,1714) = 313.44	< 0.0001	0.64 (0.57, 0.72)	F(1,1714) = 305.63	< 0.0001

Predictors are mean centered.
[a] The reference category is T1 (2013).
[b] The reference category is low education.

Table 5
Results of autoregressive analyses for longitudinal associations between Symptom score and each risk appraisal indicator, clustered at subject level, in AMIGO follow-up sample for subjects who completed questionnaires at T1 (2013) and T2 (2014), (N = 1720).

Model	Outcome variable	Predictors	Estimate (95%CI)	Test statistic	p-value
1	Symptom score T2	Symptom score T1	0.79 (0.76,0.82)	F(1,1717) = 2506.41	< 0.0001
		Perceived exposure T1	−0.01 (−0.10,0.10)	F(1,1717) = 0.00	0.96
2	Symptom score T2	Symptom score T1	0.79 (0.76,0.82)	F(1,1717) = 2517.45	< 0.0001
		Perceived risk T1	0.02 (−0.07,0.10)	F(1,1717) = 0.12	0.73
3	Symptom score T2	Symptom score T1	0.78 (0.75,0.81)	F(1,1717) = 2471.72	< 0.0001
		Concerns T1	0.10 (0.00,0.19)	F(1,1717) = 4.04	0.04
4	Perceived exposure (0–6)[a] T2	Perceived exposure T1	0.65 (0.62,0.69)	F(1,1717) = 1097.40	< 0.0001
		Symptom score T1	0.01 (−0.01,0.02)	F(1,1717) = 1.32	0.25
5	Perceived risk (0–6)[a] T2	Perceived risk T1	0.56 (0.52,0.60)	F(1,1717) = 732.08	< 0.0001
		Symptom score T1	0.00 (−0.01,0.02)	F(1,1717) = 0.30	0.58
6	Concerns(0–6)[a] T2	Concerns T1	0.60 (0.56,0.63)	F(1,1717) = 949.40	< 0.0001
		Symptom score T1	0.02 (0.00,0.03)	F(1,1717) = 6.66	0.01

[a] Likert Scale 0 = not at all to 6 = very much.

Table 6
Results of Fixed effect models* for associations between intra-individual variation over time in risk appraisal indicators and symptom score in AMIGO follow-up sample with subjects who completed questionnaires at T1 (2013) and T2 (2014), (N = 1720).

Models	Predictor(s)	Parameter estimate (CI)	F	p-value
1	Perceived exposure (0–6)[a]	0.17 (0.05, 0.29)	8.36	0.004
2	Perceived risk (0–6)[a]	0.17 (0.08, 0.27)	12.44	0.0004
3	concerns (0–6)[a]	0.12 (0.01, 0.23)	3.53	0.039

[a] Likert Scale 0 = not at all to 6 = very much.
* These fixed effect models only consider within individual variation over time, effectively adjusting for unmeasured time invariant confounders.

between risk appraisal of base stations and non-specific symptoms and the influence of subject characteristics in a prospective general population cohort. Risk appraisal (perceived exposure, perceived risk, personal health concerns because of EMF from base stations) of RF-EMF from base stations was associated with higher symptom scores in cross-sectional and longitudinal analyses. In addition, we showed that subject characteristics in sex, age, education, and trait negative affect were related to both risk appraisal and symptom scores.

4.1. Interpretation risk appraisal-symptom score association

In our study we showed cross-sectional and longitudinal associations between risk appraisal of base stations and symptom reporting in a general population sample, despite the relatively low mean levels of risk appraisal. Previous studies found similar associations between risk appraisal of EMF and symptom scores [2, 3, 6, 27, 38], but most of these studies were experimental, cross-sectional or in specific sub-populations. With longitudinal analyses we aimed to improve our understanding of the directionality of the associations between risk appraisal and symptom scores. Health concerns, but not perceived exposure nor perceived risk, were associated with reporting more symptoms one year later, adjusting for baseline values of the dependent variable. And, vice versa, symptoms were positively associated with reporting more concerns one year later. In the longitudinal fixed effect models, we showed that intra-individual variation between T1 and T2 in risk appraisal scores was associated with intra-individual variation in symptom scores in the same period. These longitudinal analyses show that there are possibly bidirectional causal associations between risk appraisal and symptom scores. An alternative explanation for this result however, could be an unmeasured variable, that changes over time within individuals, and is correlated with both risk appraisal and symptom reporting (for example: current negative feelings). Interestingly, we found some evidence suggesting that at least for personal health concerns, mechanisms in both directions can occur in a general population sample. This would indicate that previously proposed psychosocial mechanisms such as nocebo, incorrect attribution and environmental monitoring are simultaneously responsible for the associations between risk appraisal and symptom reporting in the general population. It will be interesting to further explore to what extent these mechanisms complement and reinforce each other. Although considered in some studies [38, 39] reversed causation mechanisms such as incorrect attribution have not received much attention in prior studies. The role of such mechanisms could be of importance for the effectiveness of intervention strategies targeted at lowering high risk appraisal scores, and for the interpretation of associations between risk appraisal and symptom scores. In future studies, for example with a larger number of repeated measurements and shorter time intervals, may aid the understanding of how these mechanisms occur together and complement each other.

4.2. Subject characteristics

We showed that women, younger participants, participants with a moderate to higher education and higher trait negative affect reported higher risk appraisal scores. Symptom scores were higher for women, for participants with a low education, and for participants high in negative affect. The effect of education level on risk appraisal deserves further study. Previous studies [47, 50, 62] generally reported lower risk appraisal for demographic groups with more power in society, including individuals with a higher education. Our results showed that this principle does not apply to all type of risks, at least not to risk appraisal of RF-EMF from base stations. Possibly, there is a lower familiarity with mobile phone base stations as a potential health risk among participants with a lower education, which may have resulted in lower risk appraisal scores for this group. This could be the result of lower exposure to information among lower educated participants about potential health risks of RF-EMF from base stations due to differences in media consumption as well as social networks.

4.3. Different measures of risk appraisal

Previous studies [3, 26, 63, 64] often focused on a single aspect of risk appraisal, for example perceived exposure or worry about a risk. In this study we analyzed three different aspects of risk appraisal regarding RF-EMF: perceived personal exposure, perceived risks in general, and concerns about personal health because of RF-EMF from mobile phone base stations. Scores on these items reflect in part the interpretation of sensory cues such as the visibility and perceived distance of nearby antennas and other exposure related information. In addition, these scores reflect the interpretation of risk information and beliefs about the accuracy of this information [21]. Finally, the interpretation of bodily sensations could impact both risk appraisal scores, in particular the item related to concerns about personal health, and can also directly affect symptom reporting [37]. Risk appraisal items differed conceptually on two dimensions, respectively personal versus general, and cognitive versus affective beliefs and perceptions. Perceived exposure and concerns addressed the personal situation of the participant, while perceived risk focused on the potential health risk of RF-EMF in general. Perceived exposure (“To what extent do you think you are exposed to..”) and perceived risk (“To what extent do you think that… is a health risk”) predominantly reflected cognitive elements of risk appraisal, or beliefs, while concerns for personal health reflected affective elements [65]. Although the results consistently showed positive associations between risk appraisal and symptoms, regardless of the particular risk appraisal item, there were subtle differences between the results of different analyses. We found higher overall means for perceived risk than for the other two items, in line with research showing that people perceive others as more vulnerable to potential risks than themselves [66, 67]. Correlations with trait negative affect were slightly higher for the more affective item concerns than for perceived exposure and perceived risk. In addition, concerns became redundant when negative affect was taken into account in the multivariate mixed models (Table 3), but only when risk appraisal indicators were jointly included as predictors of symptoms, a contrast illustrated in comparison with Table 4. This difference indicates a greater overlap of concerns with the effect of trait negative affect on symptoms than the other two items. On the other hand, only for concerns we found evidence of temporal precedence of reporting concerns before an increase in symptom score and vice versa. Thus, using different items to assess risk appraisal might lead to slightly different conclusions, which advocates the use of multiple items in future studies to thereby refine the interpretation of the underlying processes.

4.4. Strengths

Our study had a number of strengths. First, it is one of the few large

longitudinal general population studies concerning risk appraisal and symptom reporting. Secondly, as discussed above, we used different measures to assess risk appraisal, and therefore we were able to compare these measures and study their associations with symptom reporting. Thirdly, the AMIGO cohort was recruited to study occupational and environmental health in general and therefore subjects were not prompted to participate in an EMF and health study which could have resulted in biased responses. Moreover, the questions on risk appraisal were embedded within a list of other environmental exposures, such as traffic-related air pollution and noise. Nevertheless, the responses of participants were not completely representative of a general population sample, due to the follow-up selection strategy of oversampling participants with high perceived and modelled exposure. This sampling strategy likely did not result in the selection of a large number of self-identified electro hypersensitive participants. In the survey questionnaires, participants were asked whether they attributed any health problems to an environmental exposure, and if so, they were subsequently asked which environmental exposure and what kind of health problems. The list of potential attributions included EMF exposure sources and free text 'other environmental causes'. In the full AMIGO cohort (n = 14,829), 84 participants attributed health problems to any sort of EMF exposure at baseline (2011/2012 questionnaire). They were all invited for the follow-up questionnaires used in this study, and 27 of them did participate in the follow-up questionnaires. Only six of these participants still reported attribution of health problems to EMF exposure at both follow-up surveys (T1 and T2). Finally, in previous work [4] we did not find associations between modelled ("actual") RF-EMF exposure from mobile phone base stations and symptom reports in the AMIGO cohort. The exposure model NISMap that was used to assess RF-EMF exposure from mobile phone base stations was previously validated for use in epidemiological studies [55]. Therefore, we could be fairly certain that actual exposure did not confound the association between risk appraisal and symptom score in our current study sample.

4.5. Limitations

This study also had a number of limitations. The questionnaires were spaced apart for approximately a year, and it is not certain what lag period is relevant to study longitudinal associations between risk appraisal and symptom scores. Secondly, trait negative affect (T2) was only measured at a single point in time. However, the associations of negative affect with risk appraisal and symptom scores were stronger when measured in the same questionnaire, indicating that the negative affect measure captured both stable ("trait") and occasion specific ("state") variance. The mixed model analyses included risk appraisal and symptom scores at T1 and T2, but included "trait" negative affect only measured at T2. As a result, we overestimated the effect of "trait" negative affect, because a portion of the "state" variance in negative affect was included in the parameter estimates. Finally, we focused on risk appraisal of RF EMF from mobile phone base stations. Studies using measures such as modern health worries show that perceptions of different risks are highly correlated [42] as they are presumed to be part of a more general overarching mental model. Thus, it remains interesting to further study how specific our results on risk appraisal and symptom reporting are for RF-EMF from base stations, as we did not consider risk appraisal of other risks. Similarity in relevant psychosocial mechanisms of symptoms attributed to different environmental health risks in the context of idiopathic environmental intolerance is a tenable theory [35]. Nevertheless, much is yet unclear about the time course and developmental process of idiopathic environmental intolerances, and the contribution of psychogenic mechanisms.

4.6. In summary

In conclusion, this study shows that risk appraisal of mobile phone base stations is cross-sectionally and longitudinally associated with increased symptom reporting in a general population sample. This finding is of interest to public health, as non-specific symptoms are very common in the population, and are associated with a lower quality of life and increased health care use [68, 69]. However, the directionality of potential causal relations in non-sensitive general population samples should be examined further in future studies, providing more information to the benefit of risk communication strategies.

Conflict of interest statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding author.

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