Research article

Curiosity for information predicts well-being during COVID-19 Pandemic: Contributions of loneliness and daily lifestyle

Losecaat Vermeer, A.B.^{1,2 *}, Muth, A.^{1,2}, Terenzi, D.^{1,2,3}, Park, S.Q.^{1,2,3 *}

¹ Department of Decision Neuroscience and Nutrition, German Institute of Human Nutrition
Potsdam-Rehbrücke, Germany

² Charité-Universitätsmedizin Berlin, Corporate member of Freie Universität Berlin, Humboldt-
Universität zu Berlin, Berlin, Germany

³ Deutsches Zentrum für Diabetes, Neuherberg, Germany

(*) correspondence to: annabel.losecaat_vermeer@dife.de; soyoung.q.park@gmail.com

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Abstract

The COVID-19 pandemic confronted humans with high uncertainty and lockdowns, which severely disrupted people's daily social and health lifestyles, enhanced loneliness and reduced well-being. Curiosity and information-seeking are central to behavior, fostering well-being and adaptation in changing environments. They may be particularly important to maintain well-being during the pandemic. Here, we investigated which motives drive information-seeking, and whether and how curiosity and information-seeking related to well-being and mood (excitement, anxiety). Additionally, we tested whether daily diet contributed to this relationship during lockdown. Participants ($N=183$) completed questionnaires measuring curiosity, information-seeking, social and mental health. Using a smartphone app, participants submitted their daily food intake and lifestyle ratings for a week. We found participants had highest motivation to seek positive (vs. negative) information, concerning themselves more than others. Both trait curiosity and information-seeking predicted higher well-being, by reduced loneliness. Trait curiosity also predicted well-being and excitement days later. Considering diet, people with lower curiosity consumed food high in dopamine precursor tyrosine, whereas high-sugar intake increased anxiety, only in people with relatively low, but not high, trait curiosity. Taken together, curiosity and information-seeking may benefit well-being and mood in high uncertain and challenging times, by interacting with lifestyle measures (loneliness and nutrition).

Keywords: Curiosity; information-seeking; well-being; loneliness; diet; COVID-19

Introduction

The 2020 COVID-19 pandemic has confronted humans with high uncertainty and severely disrupted human societal daily life. Strict lockdowns induced a dramatic decrease in individual well-being, lifestyle changes including diet, and significantly reduced social interactions resulting in increased loneliness and stress ^{1,2}. Alongside these effects and the acute threat of the virus, the constant and unlimited information shared through news outlets and social media exposed individuals to vast amounts of information – accurate and inaccurate – not only regarding the coronavirus, but also restrictions to daily lives ³. Although information can aid decisions to obtain reward and avoid harm, individuals are generally motivated to avoid news they expect to have a negative impact on their feelings ^{4,5}. The abundance of COVID-19-related information likely enhanced uncertainty and feelings of anxiety, negatively impacting well-being ³. Yet, how much knowledge is wanted in times of high uncertainty and loneliness, and how it relates to one's well-being is unclear. A better understanding of these relationships during the pandemic is crucial for developing appropriate policies to provide adequate information and protect individuals from loneliness and poor mental health in the future.

Trait curiosity is commonly defined as the intrinsic desire for knowledge and seeking out novel, challenging situations ⁶. This feeling, often compared to the feeling of hunger or thirst, is expressed in information-seeking behaviors such as reading, asking questions, conducting searches online, and watching the news. Both trait curiosity and its behavioral expression are fundamental for motivation, learning, and achieving and maintaining well-being ⁷⁻⁹. For instance, trait curiosity is positively associated with life satisfaction and well-being ¹⁰ and better coping with unfamiliar, uncertain information and challenging interactions ⁸. Curiosity may facilitate such behaviors and promote well-being through positive emotions and reducing uncertainty. According to the broaden-and-build framework ¹¹, positive emotions broadens people's scope of attention and thinking, promote exploration and engagement with their environment to build knowledge, and regulate

negative emotions, thereby reducing uncertainty and enhancing psychological resiliency. Hence, being curious and gathering information can be beneficial for coping with challenging situations. Moreover, what information people want to know (e.g., positive or negative) may reflect their mental state and mood ⁴. Despite curiosity and information-seeking being integral to behavior, we know little about how it relates to well-being in an extensive period of social restrictions during an acute global health crisis.

Social interaction is critical for mental well-being ¹². In novel situations, we may be more eager to seek information from others (e.g., through observation) than by ourselves to minimize harm and avoid risk ^{13,14}, possibly demonstrating a self-other distinction in information-seeking. The imposed social restrictions reportedly increased loneliness by 20-30% during the pandemic, being highest during the first European lockdown in Spring 2020. Even later into the COVID-19 restrictions (i.e. late November 2020), 24% of 4436 adults partaking in a UK survey of the Mental Health Foundation (www.mentalhealth.org.uk) reported feeling lonely. Loneliness refers to the subjective feeling or perceived social isolation, and predicts negative life outcomes related to physical and mental well-being, including depression and anxiety ^{15,16}. However, not all individuals of this survey had been experiencing loneliness. Interestingly, loneliness has been associated with stable personality traits such as extraversion and openness ^{17,18}. Yet, it is unknown whether such relation exists for trait curiosity, and if so, whether loneliness plays a mediating role in the relation between curiosity and mental well-being.

Besides social impact, lockdowns also affect our daily lifestyle ¹. Daily lifestyles including diet are hypothesized to significantly impact mental well-being. In particular, fruits and vegetables, and large amino acids including tyrosine and tryptophan predict outcomes such as positive mood, better mental health and higher curiosity ^{19, for a review 20,21}, whereas sugar intake had mixed effects, by predicting lower well-being but more curiosity ¹⁹. Tyrosine and tryptophan are essential precursors

of neurotransmitters dopamine and serotonin, important for motivation and mood, respectively^{22,23}. For instance, acute tyrosine and tryptophan depletions cause impairments in reward processing (e.g. reduced motivation for rewards) and lower mood^{24,25}. Furthermore, studies have implicated a key role for dopamine in motivating information-seeking and exploration, as shown by the dopamine reward circuitry signalling the value of information^{4,26,27}, and the relief of curiosity²⁸. Based on these findings, changes in tyrosine and tryptophan from the food we eat may influence curiosity and information-seeking motivation, and thereby influencing our affective mental state. Simultaneously, lockdown-induced stress and loneliness may alter diet by preferring high-fat and high-carb food, as suggested by stress studies in animals²⁹ and humans³⁰, and thus negatively impact curiosity and well-being. A question we aimed to explore is whether there is any link between curiosity, both trait and behavior, with daily intake of macronutrients and amino acids during the lockdown, to predict well-being and mood.

In this preregistered study, we first investigated whether individuals are motivated to seek particular information specific for themselves and about others in an uncertain time involving increased loneliness, namely during the pandemic lockdown. Second, we examined how individual's curiosity relate to mental well-being and mood. We assessed both individual's trait curiosity level and their information-seeking motivation as an expression of curiosity. We hypothesized that trait curiosity is associated with individual's mental well-being and mood (i.e. positive and negative mood). Third, based on previous studies reviewed here, we explored if relationships between curiosity with well-being and with mood are dependent on dietary intake during lockdown. To test these hypotheses, we conducted an online study in adults living in Germany and Austria ($N=183$) during a national lockdown in the period from 10 November – 23 December 2020. Participants completed questionnaires assessing trait curiosity, information-seeking, loneliness, mental health, and COVID-19-related impact (e.g., work situation, regulation compliance). Afterwards, participants submitted their self-rated levels of mood, well-being, and food intake for 7 days during lockdown.

Results

Hundred eighty-seven participants signed up via Prolific for one of two preregistered online studies (i.e. one for Germany and one for Austria, see Methods). We excluded four participants with self-reported severe depression symptoms (i.e. Beck Depression Inventory score >30, see Methods), resulting in 183 participants who completed the questionnaire battery. Of those participants, a total of 172 participants submitted their daily food intake and mood ratings for at least two days using the food-diary app. Therefore, analysis on daily mood and food observations were performed on these 172 participants. In Table 1, we provide descriptive statistics.

Table 1. Descriptive statistics

Characteristic	Total sample (N = 183) ¹	Sample with diary data (n = 172) ^{1*}
Age	28.51 (8.94)	28.52 (8.98)
BMI	23.91 (4.44)	23.93 (4.06)
Gender		
female	74 / 183 (40%)	69 / 172 (40%)
male	109 / 183 (60%)	103 / 172 (60%)
Nationality		
Austrian	37 / 183 (20%)	34 / 172 (20%)
German	130 / 183 (71%)	128 / 172 (74%)
Other	16 / 183 (8.7%)	10 / 172 (5.8%)
Country of residence		
Austria	54 / 183 (30%)	46 / 172 (27%)
Germany	129 / 183 (70%)	126 / 172 (73%)
COVID-19 rules compliance (0-100)	82.33 (19.71)	81.70 (19.97)
¹ Mean (SD); n / N (%)		
*minimum of 2 diary submissions		

COVID-19 pandemic lockdown (November 2020 – December 2020)

Figure 1. Outline of the study. On the first testday, participants completed personality questionnaires measuring curiosity, mental well-being, demographics among others (see Methods). Subsequently, using the food-diary app, participants submitted their daily food intake for a week, and their ratings on well-being, mood and other lifestyle factors once a day.

Drivers of information-seeking

Curiosity and information-seeking behavior can be driven by distinct motives. Generally, people are motivated to seek information they expect to have positive impact on their feelings (valence-dependent), and avoid information that may have negative impact on their feelings or mood^{4,5}. In addition, we do not only acquire information on our own experiences, but also information directed towards and from others³¹.

We first examined how individuals' information-seeking behavior is driven by the valence (i.e. potential positive or negative information) and target of information (i.e. about ourselves or others). To test this, we asked participants how motivated they were at the present time to actively seek information (e.g. through searching the web, reading, asking questions) that was; 1) expected to be positive or negative, and 2) for themselves and about others. Participants rated their motivation on a slider from 0-100 (with 0 not motivated at all, 100 being highly motivated). This provided four ratings that allowed us to test potential drivers predicting information-seeking motivation, by performing a mixed effects model. This model contained within-subject predictors for the valence

(positive, negative) and the information target (self, other) and their interaction. Furthermore, we included random slopes and participants as random intercept.

Overall, participants were motivated to seek information ($M = 66.22$, $p < .001$, against 50 at which participants are neither motivated nor demotivated). Moreover, participants were more motivated to seek positive rather than negative information (i.e. valence-dependent, $\beta = 7.81$, $t(182) = 8.16$, $p < .001$), and information for oneself rather than others (i.e. information target, $\beta = 3.17$, $t(182) = 4.49$, $p < .001$). Importantly, there was a significant valence by information-target interaction ($\beta = -1.11$, $t(182) = -2.10$, $p = .036$, Fig. 2a, Table S1), demonstrating that the valence effect was larger for self compared to others ($\log_e(V_{\text{Wilcoxon}}) = 9.09$, 95% CI [0.05, 0.38], $p = .013$, Fig.S1). This difference was mainly driven by potential positive information (self-other $M = 8.56$, $SE = 1.77$, $t(377) = 4.85$, $p < .001$; negative information: self-other $M = 4.14$, $SE = 1.77$, $t(377) = 2.34$, $p = .091$). In sum, individuals' showed highest motivation to seek positive information concerning themselves.

Trait curiosity and information-seeking

Trait curiosity was assessed via the Curiosity and Exploration Inventory–II scale (⁸, see Methods). As expected ⁸, both subscales, stretching and embracing, correlated ($r = 0.67$, 95% CI [0.58, 0.75], $p < .001$). For this reason, the mean value of all items was taken as a measure of trait curiosity (range = 1.3 – 4.7, $M = 3.08$), with higher values indicating a relatively higher curiosity.

Curiosity typically manifests in information-seeking motivation and -behaviors. Indeed, when correlating motivational ratings for self, other, and valence, we found that participants with higher trait curiosity were more motivated to seek information for self overall ($r = 0.25$, 95% CI [0.10, 0.38], $p = .003$), but not about others ($r = 0.13$, 95% CI [-0.02, 0.27], $p = .246$) or by the valence of information (i.e. positive-negative information: $r = -0.05$, 95% CI [-0.20, 0.10], $p > .999$; p-values are

Holm-corrected), demonstrating that trait curiosity relates to information-seeking motivation for self – independent of valence.

Curiosity and information-seeking relate to mental well-being

One of the main aims was to investigate whether and how individuals' curiosity and information-seeking relate to mental well-being during lockdown. Furthermore, we investigated if such potential associations are mediated by loneliness during COVID-19 restrictions.

Firstly, by computing correlations we found that curious individuals who are, on average, more motivated to seek information also reported higher mental well-being at baseline (Warwick Edinburgh Mental Wellbeing Scale (WEMWBS), Fig. 2b,c). Secondly, participants with increased loneliness feelings reported significantly lower mental well-being ($r = -0.60$, 95% CI $[-0.69, -0.50]$, $p < .001$), had lower levels of curiosity ($r = -0.35$, 95% CI $[-0.47, -0.21]$, $p < .001$), and were less motivated to seek information about oneself ($r = -0.20$, 95% CI $[-0.34, -0.05]$, $p = .014$), p-values are Holm-corrected. These results support a relationship between curiosity measures, well-being and loneliness.

Additionally, we tested whether valence and information-target motives of information-seeking correlated with individual's well-being. There were no significant correlations with valence (positive-negative, $r = -0.07$, 95% CI $[-0.22, 0.08]$, $p > .999$), information target (self-other, $r = 0.12$, 95% CI $[-0.03, 0.26]$, $p = .437$), or simply information-seeking about others ($r = 0.07$, 95% CI $[-0.08, 0.22]$, $p > .999$). In summary, the link between curiosity and well-being was independent of information valence and information target. Therefore, subsequent analyses were focused on information-seeking for self.

Figure 2. Information-seeking, curiosity, individual well-being (WEMWBS) and contributions of loneliness. **a)** Information-seeking motivation is influenced by valence (positive, negative) and information target (self, other). Dots represent individual ratings. Error bars are SEM. Asterisks (*) indicate statistically significant differences: *** $p < .001$. **b)** Correlation between trait curiosity and well-being. **c)** Correlation between information-seeking and well-being. **d)** Mediation model illustrating loneliness partially mediates the trait curiosity - well-being relationship. **e)** Mediation model illustrating loneliness fully mediates the information-seeking - well-being relationship. Betas are unstandardized, total effect (c), direct path (c').

Positive links between curiosity and well-being are mediated by subjective loneliness

We had preregistered to compute a multiple linear regression to assess the hypothesis that curiosity and information-seeking motivation relate to mental well-being, including loneliness as a covariate. However, as loneliness is integral to the pandemic lockdown and significantly correlates with both measures of interest, we opted for an alternative analysis approach. Specifically, to better understand how curiosity and information-seeking relate to mental well-being in a period with social restrictions, we examined whether loneliness mediated this relationship.

We computed one mediation model for trait curiosity as predictor of well-being with loneliness as mediator, and another mediation model for information-seeking as predictor (see Methods). Indeed,

both models revealed loneliness as a mediator. The relationship between trait curiosity and well-being was partially mediated by loneliness, as the direct effect reduced in size (c' : $B = 4.89$, $SE = 0.63$) compared to the total effect (c : $B = 6.80$, $SE = 0.71$, Fig. 2d; bootstrapped indirect effect ($a*b$) $B = 1.92$, $SE = 0.44$, $Z = 4.35$, $p < .001$, $R^2 = 0.53$). Interestingly, loneliness fully mediated the effect of information-seeking on well-being ($R^2 = 0.38$, bootstrapped indirect effect ($a*b$) $B = 0.08$, $SE = 0.02$, $Z = 2.60$, $p = .009$, Fig. 2e), such that information-seeking predicted higher mental well-being, only through reducing loneliness.

Taken together, we found that the subjective loneliness during COVID-19 pandemic fully mediates the positive relationship between information-seeking and mental well-being, and partially between individual's trait curiosity and well-being. Interestingly, trait curiosity also still had an incremental direct effect on well-being independent of subjective loneliness.

Daily well-being and mood during lockdown is linked to individuals' trait curiosity

So far, we showed that both trait curiosity and information-seeking behavior are associated with baseline mental well-being (WEMWBS) measured at testday one. Next, we also aimed to investigate whether these curiosity measures assessed at day one could predict individuals' averaged daily well-being (i.e. short WEMWBS) and mood (i.e. excitement and anxiety) reported during the rest of the lockdown week, hence have a longer-lasting predictive effect.

Trait curiosity, daily well-being and mood

We found a positive correlation between trait curiosity with individuals' average daily well-being (Fig. 3a), and excitement (Fig. 3b), but not with anxiety (Fig. 3c). These associations were also observed when including trait curiosity and loneliness as predictor and covariates for age, gender, and residency (and trait anxiety level, for anxiety model, see Methods) into a multiple regression

(well-being: beta = 1.06, 95% CI [0.50, 1.63], $p < .001$; excitement: beta = 0.16, 95% CI [0.03, 0.29], $p = .019$; anxiety: beta = 0.08, 95% CI [-0.05, 0.21], $p = .237$).

Figure 3. Associations between trait curiosity, daily well-being and mood. Significant correlations between trait curiosity, daily well-being (a), and daily excitement (b), but not with daily anxiety (c). Mediation models with trait curiosity as predictor and loneliness as mediator predicting daily well-being (d), and daily positive mood (i.e. excitement) (e). Betas are unstandardized, total effect (c), direct path (c').

Next, we investigated whether loneliness also mediated the relationship between curiosity and daily well-being and excitement. The mediation models revealed a significant indirect effect predicting average daily well-being (bootstrapped indirect effect ($a*b$): $B = 0.55, SE = 0.15, Z = 3.68, p < .001, R^2 = 0.31$), and predicting average daily excitement (bootstrapped indirect effect ($a*b$): $B = 0.07, SE = 0.03, Z = 2.74, p = .006, R^2 = 0.12$), illustrating that loneliness partially mediated the relationship between trait curiosity and daily well-being and excitement (Fig. 3d, 3e).

Information-seeking does not predict daily well-being and mood

Information-seeking overall for self did not significantly predict averaged daily well-being ($F(1,170) = 1.43, p = .234$), daily excitement ($F(1, 170) = 2.31, p = .130$), or daily anxiety ($F(1,170) = 0.28, p =$

.598), nor when including covariates (see Supplementary Information (SI)). In sum, the association between information-seeking and individuals' baseline well-being (WEMWBS) was not observed for average well-being, days later into lockdown.

Curiosity, daily dietary intake, and their influence on daily mood

We preregistered to explore whether there is a link between individual's average daily food intake (i.e. nutritive content) and curiosity to predict daily well-being and mood. Moreover, based on associations between dopamine and curiosity and information-seeking^{4,5,26,28}, we explored whether trait curiosity and information-seeking could predict the daily intake days later of large neutral amino acids (LNAA) tyrosine- and phenylalanine (i.e. precursor for dopamine), and tryptophan (precursor for serotonin) relative to other LNAAs^{32,33}. We extracted the quantity of macro- and micro-nutrients including LNAAs from the submitted food in the food-diary app (see Methods).

First, exploring whether trait curiosity and information-seeking associated with intake of tyrosine/LNAA including tyrosine- and phenylalanine/LNAA, and tryptophan/LNAA, we ran a linear regression including gender, because of observed gender differences in food intake (see Table S2). Trait curiosity negatively predicted tyrosine- and phenylalanine/LNAA intake ($\beta = -0.003$, $p = .017$), such that individuals with lower trait curiosity consumed more tyrosine-rich food. Information-seeking motivation also negatively predicted the intake of tyrosine-rich food (i.e. tyrosine/LNAA, $\beta = -0.000$, $p = .014$). Tryptophan/LNAA ratio was neither predicted by trait curiosity ($p = .151$), nor information-seeking motivation ($p = .964$). However, there was a trend for an interaction between trait curiosity and gender predicting tryptophan/LNAA intake ($p = .064$), indicating that women with lower trait curiosity tend to consume more tryptophan-rich food ($\beta = -0.001$, $p = .015$) compared to men ($\beta = 0.000$, $p = .777$).

Next, we examined whether food intake indexed by certain nutrient compositions (i.e. carbs, fat, simple sugars, fruit and vegetables) contribute to the curiosity – daily well-being and mood link. As information-seeking did not show any association with self-rated daily well-being and mood, we focused on trait curiosity only. We included the nutrient compositions (as mean percentage) and trait curiosity into linear models including potential covariates (e.g. gender, residency, age) to predict daily well-being, excitement, as well as anxiety (i.e. three independent models). Food intake showed no significant main effects and interactions with trait curiosity predicting well-being or excitement (all p 's < 0.05, see Table S3+S4). However, we found that sugar intake positively predicted anxiety (beta = 0.25, p = .008), which was influenced by individuals' trait curiosity (interaction: beta = -0.08, p = .005, Fig.4, Table S5). Further decomposing this interaction, by comparing the slopes, showed that sugar intake increased anxiety in participants with low trait curiosity, which effect was reversed in participants with high trait curiosity (high sugar, beta = -0.34, Z = -3.64, p < .001). This was not observed for mean (beta = -0.13, Z = -1.98, p = .053) to low sugar intake levels (beta = 0.09, Z = 1.04, p = .308).

Figure 4. Relationship between trait curiosity and daily anxiety at different levels of sugar intake (high, mean, low).

Discussion

The COVID-19 pandemic has profoundly affected our daily social lives, physical and mental well-being^{1,2}. Trait curiosity and access to adequate information are hypothesized to promote better coping with challenging situations, enhancing well-being, mood, and life satisfaction⁶⁻⁹. In the current study, we investigated whether trait curiosity and information-seeking motivation are linked to individuals' mental well-being and mood during lockdown in a global health crisis, encompassed of extreme loneliness and uncertainty. Furthermore, we investigated whether the relationship between curiosity, well-being, and mood is moderated by the food we consume during the lockdown.

Our results show that both trait curiosity and information-seeking motivation predicted higher well-being and reduced loneliness during lockdown. In line with previous findings^{15,16}, we also found a negative association between loneliness and lower well-being. Interestingly, we found that the association between curiosity and information-seeking with well-being was mediated by individuals' feelings of loneliness. Thus, our data suggests that individuals' information-seeking and curiosity is beneficial for well-being, through reducing loneliness during the lockdown. Moreover, trait curiosity also still predicted well-being independently.

Consistent with the broaden-and-build framework¹¹, being curious and gathering information may foster positive states and coping with social restrictions by reducing loneliness feelings through increased engagement and exploration. Individual differences in loneliness and resilience have previously been linked with personality traits^{17,18}, with people scoring higher on extraversion and openness reporting lower loneliness feelings and higher well-being. Our findings contribute to this, by showing that a person's trait curiosity and information-seeking behavior also predict higher well-being, via diminished impact of loneliness during a socially challenging and uncertain time.

Trait curiosity, but not information-seeking, also predicted daily well-being and positive mood (excitement) on a longer timescale – i.e. averaged across 2-7 observation days into the lockdown. In contrast with trait curiosity⁸, we explicitly asked participants about their motivation for seeking information at the present time, likely capturing their momentary state and motivation to interact with their environment. Hence, this measure may vary within-participants across subsequent days, and consequently might not be a good predictor of daily well-being and mood at later timepoints. Indeed, recent work found that consistency in state curiosity is an important predictor of daily well-being³⁴. These findings suggest that an individual's trait-level curiosity and consistency in state-level curiosity is important to predict well-being and mood on a daily basis, while the momentary motivation to seek information as a behavioral expression of one's curiosity likely relates to well-being and mood on a shorter timescale.

Replicating studies on information-seeking^{27,35}, individuals' were more motivated to seek positive rather than negative information. Additionally, we found that this valence-dependent effect was stronger when information concerned oneself than others, and driven mostly for information that was positive but not negative. While people are generally motivated to seek positive information because of the expected positive feelings from having a positive belief²⁷, good news about others may provide less strong positive feelings. Likewise, vicarious rewards produce less strong reward-related activation than own rewards³⁶. However, social information concerning negative outcomes can still be important in novel situations and when the quality of information is uncertain, to avoid being exposed to risks from first-hand experience.

When feeling lonely, individuals may even be more motivated to seek information about others. Surprisingly, our results showed a non-significant negative relation between information-seeking about others and loneliness, suggesting that feeling lonely does not enhance the willingness to know more about others' outcomes. This is in slight contrast to other findings¹⁶, demonstrating that

people with higher loneliness over-attend to negative social information in the environment. We also did not find a correlation between loneliness and the motivation to seek negative information about others. Instead of providing participants with information, we asked participants whether they actively wanted information about others. The difference between passive information and active information-seeking could explain why we did not find a relation between loneliness and information-seeking concerning others.

Despite showing a valence-dependent motivation to seek information, the link between mental well-being and information-seeking motivation was independent of valence. Seeking information, both positive and negative, can help reduce uncertainty⁵. Moreover, previous findings reported that individuals who are more curious are better capable in regulating and controlling their emotions, and report higher well-being⁸. Hence, our data further suggest that higher well-being relates to high curiosity and motivation to explore knowledge for both positively and negatively valenced information.

Besides the social context, the lockdown also resulted in lifestyle changes including diet³⁷. Healthy eating can protect one's mental health and mood, particularly in challenging and stressful times^{19–21}, with stress predicting lower quality food intake full of carbs, sugars, and fat^{29,30}. Nonetheless, in a previous study¹⁹, fruit and vegetable intake increased well-being and curiosity, although sugar intake decreased well-being but increased curiosity. We explored whether food intake contributed to the effects of curiosity on mood and well-being. In contrast to Conner and colleagues¹⁹, we did not observe a relation between fruit and vegetable intake and curiosity, nor did it predict mood or well-being. However, we found a significant interaction between sugar intake and trait curiosity predicting negative mood during the lockdown. Food high in sugar predicted higher anxiety among people with low trait curiosity, and lower anxiety in those with high trait curiosity. This suggests that high trait curiosity may buffer negative effects of high-sugar on mood, whereas individuals low in

trait curiosity – who typically explore less and regulate their emotions less well, may be particularly susceptible to the negative effects of high-sugar³⁸. Consistent with this, previous studies have linked high-sugar/fat intake to enhanced anxiety (for review,³⁹) and changes in dopamine precursor availability⁴⁰. Possibly, curiosity compensates the effects of sugar on anxiety through its effect on positive mood, motivation and enhanced mesolimbic dopamine activity^{8,27}. Compared to prior food diary studies^{e.g. 19} that assessed self-reported food intake on predefined categories (i.e. sweets, fruit, vegetables, and chips), our study takes a more holistic approach by extracting nutrients as dietary components from the quantity of each food and beverage participants consumed over the day for maximum a week, using a food-diary app.

Protein-rich food contains high amounts of LNAAs including dopamine and serotonin precursors^{32,41}. The reward circuitry, in particular dopamine, have been associated with curiosity and information-seeking^{27,42}. We found that individuals with lower trait curiosity and information-seeking motivation consumed more tyrosine-rich food, providing an indirect link between dopamine and curiosity. Individuals low in curiosity may require foods high in tyrosine to increase dopamine synthesis to regulate their information-seeking motivation and mood. Supporting this, atypical information-seeking motivation has been linked to abnormal dopamine functioning. For instance, enhancing dopamine through levodopa was found to increase information gain for negative non-instrumental information, without affecting mood⁴³. Moreover, there was no observed link between curiosity and food intake containing high-tryptophan levels, potentially suggesting that tryptophan plays a less prominent role in curiosity, or could have specific effects that our measures could not capture^{e.g. 44}. The causal effect of our findings remain open. Future studies should test for the direction of effects of diet and curiosity, for example, using a dietary intervention containing high/low precursors of dopamine and serotonin.

Some limitations and constraints should be considered. First, curiosity and loneliness were only measured once at the beginning of the study, therefore we cannot reveal within-person changes over time and test how they relate to daily changes in well-being and mood during lockdown. Second, despite the positive contributions of curiosity and food on well-being and mood, these findings are strictly correlational and we cannot draw a causal link. It is plausible that the relationships reported here are bi-directional (e.g. food predict curiosity, as shown by for behavior,³²). Intervention experiments are required to establish whether a bi-directional association exists. Third, daily food and mood measures were based on self-report, which suffers from reliability issues and accuracy. Despite this, a strength is that it provided a rich dataset with multiple daily momentary observations, representing a more ecological representation of people's daily food intake under real-life conditions.

In conclusion, trait curiosity and information-seeking motivation predicted higher well-being, investigated during lockdown of COVID-19 pandemic. Importantly, reduced loneliness played an underlying mediating role. Furthermore, high-sugar intake worsened mood during lockdown, specifically in people with low trait curiosity. The causal and exact direction of effects reported here need to be corroborated by future research, and whether these effects can generalize to other social challenging contexts. Our results suggest that curiosity interacts with lifestyle measures (loneliness and diet), indicating the potential to modulate each of these players to potentially increase well-being and mood during a time of crisis.

Methods

Participants

Hundred eighty-three participants were accepted to partake in the online study in the period from 10 November - 23 December 2020 during light and strict lockdown phases in Germany and Austria, respectively. During these lockdown periods, people were asked to reduce social contacts to the necessary minimum and mainly work from home (see <https://www.bundesregierung.de/breg-de/themen/coronavirus/corona-massnahmen-1734724>; from: 28.10.2020; <https://www.sozialministerium.at/Informationen-zum-Coronavirus/Coronavirus---Aktuelle-Maßnahmen.html>, from 17.11.2020)). Participants were recruited via Prolific platform (<https://prolific.co/>). Inclusion criteria were living in Germany or Austria at the time of the study, fluent in German, and no history of psychiatric illness. For the second part of the online study, participants had to log their food intake and their mood daily via a smartphone app (i.e. FoodApp). A priori inclusion criteria were set to a minimum of four days of food and mood entries per person. However, as we preregistered to calculate the average mood and food intake, and to minimize loss of valuable data, we decided to restrict our sample to a minimum of two completed entries for food intake and mood ratings. This resulted in data of a total of 172 participants. Participants received £28 for their participation. This study was preregistered (<https://osf.io/xfcwb>; <https://osf.io/tgpr4>) and approved by the ethical committee from Humboldt University of Berlin (reference code 2020-22).

Questionnaires

Trait curiosity

Individual's trait curiosity was assessed via a validated questionnaire (Curiosity and Exploration Inventory-II (CEI-II); 10 items, ⁸). This scale assesses people's disposition to explore unsolved problems, unpredictable challenges, and unfamiliar experiences, all out of a sense of curiosity about the world. Example items include, "I actively seek as much information as I can in new situations"

and “I prefer jobs that are excitingly unpredictable.” Answers are given on a 5-point scale (1 = very slightly or not at all; 5 = extremely).

Information seeking motivation

Four questions assessing individuals’ motivation to seek information; individuals rated their motivation on a sliding bar (from 0 – 100 (i.e. not motivated to seek information – highly motivated to seek information) for positive/negative expected outcomes related to oneself and about other people; see SI for questions and rating).

Mental-well-being (baseline), loneliness, affective health and COVID-19-related impact

Participants completed standard self-report questionnaires assessing a range of mental and affective health symptoms. These included mental well-being (Warwick Edinburgh Mental Wellbeing Scale (WEMWBS) ⁴⁵, perceived loneliness (UCLA Loneliness Scale ⁴⁶, depression (Beck’s Depression Inventory ⁴⁷, trait anxiety (State Trait Anxiety Inventory ⁴⁸), perceived stress (Perceived Stress Questionnaires ⁴⁹), and also other lifestyle-related questions that were part of a larger study (preregistered under <https://osf.io/nqhjf>) that were not analyzed here. Furthermore, we assessed the impact COVID-19 had on participants’ lives such as how well they complied with the rules, what their current work situation was (e.g. home-office) and whether they or others they knew contracted the virus (see SI for details).

Daily food, well-being and mood

Once a day after 17:00h participants are asked questions about their mental well-being, mood, and lifestyle (e.g. activity) via the food-diary app.

Daily well-being was assessed using the short WEMWBS. Participants were asked to rate how they felt on a scale from 1 to 5. Total scores ranged from 7 to 35, with higher scores reflecting higher

levels of well-being. Mood was assessed based on the Positive Affect Negative Affect Scale ⁵⁰.

Participants were asked to rate one item of each on a scale of 1 to 5; for positive affect feeling excited and for negative affect feeling anxious. Furthermore, participants were also asked to rate how well they slept (sleep), how active they were that day (active) and about quantity and satisfaction of their social interactions that day (social) on a visual analog scale from 1 to 100.

Food intake was assessed via self-report using the food-diary app. Here, participants provided the following information: date and time, type of meal (e.g. breakfast, lunch, snack), whether they ate alone or in company, food item and quantity (in grams or milliliters). Participants are asked to complete the daily food diary and mood questions for 7 days. The output allowed us to extract caloric content and information on macro- and micronutrients of the consumed food using the German BLS data table ⁵¹. We excluded observations from analysis that fell outside the plausible daily energy (caloric) intake, i.e. < 500 kcal/day and > 3500 kcal/day for women, and < 800 kcal/day or > 4000 kcal/day for men ⁵².

Food intake was adjusted for individual energy intake (g/1000kcal/day) as suggested by ⁵³. We multiplied the daily intake of carbohydrate (g/day) by 4 kcal, fat intake by 9 kcal, sugars by 2 kcal to obtain the daily energy derived from each macronutrient (Table S2). Tyrosine and tryptophan to LNAA ratios were calculated by dividing the quantity of tyrosine and of tryptophan by the sum of the other LNAAs (equations 1a,1b,2), and used as a proxy of brain tyrosine and tryptophan levels and ultimately brain dopamine and serotonin levels, respectively ³².

$$\text{Equation 1a: Tyrosine + Phenylalanine ratio} = \frac{(\text{Tyrosine} + \text{Phenylalanine})}{\text{sum}(\text{Tryptophan} + \text{Leucine} + \text{Isoleucine} + \text{Valine})}$$

$$\text{Equation 1b: Tyrosine ratio} = \frac{\text{Tyrosine}}{\text{sum}(\text{Tryptophan} + \text{Phenylalanine} + \text{Leucine} + \text{Isoleucine} + \text{Valine})}$$

$$\text{Equation 2: Tryptophan ratio} = \frac{\text{Tryptophan}}{\text{sum}(\text{Tyrosine} + \text{Phenylalanine} + \text{Leucine} + \text{Isoleucine} + \text{Valine})}$$

504 *Study design*

505 After providing instructions and written consent, participants were invited to complete a battery of
506 questionnaires online assessing trait curiosity, information-seeking motivation, mental health (e.g.
507 mental well-being, loneliness, stress, anxiety), and lifestyle behaviors (including sleep, activity, and
508 social factors).

509

510 Next, participants were asked to install a food-diary app provided by us on their smartphone, and
511 submit a daily diary of their food consumption (i.e. daily intake of food items and beverages) in the
512 app, from which we extracted the total calories, macro- & micronutrients per meal per day. They
513 were also asked to rate their well-being and mood (on a scale from 1-7) once a day for a
514 maximum period of a week using the same app. Furthermore, daily subjective experience
515 regarding sleep quality, activity level and social interactions were also recorded.

516

517 Due to the timing of the lockdown restrictions, we first conducted the online study in Germany as
518 preregistered. While the German study was ongoing, the government in Austria announced an
519 upcoming lockdown. Therefore, we decided to repeat the same experiment in Austria (separately
520 preregistered with same questions and measures). After data collection and because of the small
521 sample in Austria, we instead merged the data of the German sample and the first Austrian sample
522 and included a predictor of residence country in the analysis to account for potential differences in
523 experienced lockdown measures. We chose Austria, as Austria and Germany are geologically close,
524 share the same native language, and are highly comparable both on a social and economic level.

525

526 *Statistical analysis*

527 The analysis plan was preregistered on the public data repository Open Science Framework
528 <https://osf.io/xfcwby>; <https://osf.io/tgpr4>). The data was analyzed using R statistical software (R Core
529 Team, 2020).

Mental well-being was measured once at the beginning of the study (baseline, WEMWBS) and through the app as a day-to-day well-being measure (daily well-being, short WEMWBS). Daily measures of well-being, excitement and anxiety were each averaged per person over the days logged. To test the relationships between trait curiosity, information-seeking motivation and the dependent variables mental well-being (baseline and daily), mood (excitement, anxiety) and food intake, we computed non-parametric (Spearman) correlations and linear regressions. To control for individual differences, we included covariates age, gender and country of residence in the linear models. To avoid biased coefficients due to high correlation, we did not include baseline well-being scores as covariate in the model to predict average daily well-being, and perceived stress (PSQ) in combination with trait anxiety to predict daily anxiety. Furthermore, we investigated which motives drive information-seeking motivation. To test this, we ran a mixed effect model on the ratings for information-seeking with within-subject predictors for the valence and information target, including by participant random intercept and random slopes for the within-subject predictors. Analysis were performed using “lme4” (version 1.1.27)⁵⁴ and “lmerTest”(version 3.1.3)⁵⁵. P-values for linear models were computed using Kenward-Roger approximation. Post-hoc analyses were done using “emmeans” (version 1.6.1)⁵⁶, and “interactions” (version 1.1.0)⁵⁷ for simple slope comparisons, and adjusted for multiple comparisons using the Tukey where relevant. For correlations p-values were adjusted using Holm correction (1979). Note in the preregistration we reported to use the Bonferroni as correction for multiple comparisons, however, we decided for Tukey and Holm instead as it is considered uniformly more powerful. Table and plots were created using “gtsummary” (version 1.4.1)⁵⁸ and “ggplot2” (version 3.3.3)⁵⁹. Mediation analyses were performed to test whether the relationship between information-seeking, trait curiosity and the dependent variables was mediated by feelings of loneliness. Bootstrapping (1000 samples) was performed as implemented in the “lavaan”(version 0.6.8)⁶⁰.

556 Data availability

557 The anonymized data is available from the corresponding authors upon request.

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697 **Author Contribution Statement**

698 A.L.V., A.K.M. and S.Q.P. designed the study; A.L.V. and A.K.M. performed the experiment; A.L.V.
699 analyzed the data and prepared the figures; A.L.V. writing—original draft preparation; A.L.V., A.K.M.,
700 D.T., S.Q.P. writing—review and editing; S.Q.P. funding acquisition.

701

702 **Competing Interests**

The authors declare no competing interests.

Supplementary Information

Results

Information-seeking motives

Table S1. Mixed effect model for information-seeking

Predictors	Estimates	95% CI	Statistic	p-value
Intercept	66.22	63.91, 68.52	56.70	<0.001
Valence	7.81	5.92, 9.70	8.16	<0.001
Information target	3.17	1.78, 4.57	4.48	<0.001
Valence * Information target	1.11	0.06, 2.14	2.10	0.037
<hr/>				
N subjects	183			
Marginal R ² / Conditional R ²	0.114 / 0.677			

Note. Contrasts were set-to-sum. Positive valence and Self as Information target were set to 1.

Figure S1. Motivation to seek information that is expected to be positive rather than negative, for Self and about Others.

Daily well-being and mood

Information-seeking: including loneliness and covariates for age, gender, residency into the model information-seeking for self did not significantly predict daily mental well-being ($F(1,166) = 0.014$, $p = .907$), daily excitement ($F(1,166) = 1.96$, $p = .163$), and daily anxiety ($F(1,165) = 0.14$, $p = .705$).

Curiosity and daily food intake

Table. S2. Descriptives of food composition and behavior, split for gender

Characteristic	Overall, N = 172 ¹	male, N = 103 ¹	female, N = 69 ¹	p-value ²
Calories	1,659.23 (483.42)	1,787.20 (465.34)	1,467.28 (448.00)	<0.001
Fat (%)	35.48 (6.43)	35.53 (5.45)	35.40 (7.72)	0.9
Carbs (%)	46.34 (7.06)	45.66 (6.79)	47.36 (7.39)	0.12
Protein (%)	16.82 (3.47)	17.61 (3.72)	15.64 (2.68)	<0.001
Sugars (%)	5.92 (3.13)	5.37 (3.08)	6.76 (3.03)	0.004
Fruit & Vegetables (g/1000kcal)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	<0.001
Curiosity (trait)	3.08 (0.75)	3.11 (0.65)	3.02 (0.88)	0.4
Information-seeking self	69.25 (18.17)	67.29 (18.31)	72.17 (17.70)	0.085
Daily well-being	22.36 (3.04)	22.49 (3.02)	22.16 (3.09)	0.5
Daily excitement	3.04 (0.65)	3.09 (0.59)	2.98 (0.72)	0.3
Daily anxiety	1.85 (0.64)	1.73 (0.63)	2.02 (0.62)	0.003

¹ Mean (SD), by gender outlier values are winsorized

² Two Sample t-test

% daily energy derived

Table S3. Full model predicting daily well-being levels

Predictors	Daily well-being (mean)		Statistic	p-value
	Estimates	95% CI		
(Intercept)	27.38	-16.37, 71.14	1.24	0.218
Curiosity (trait)	-1.39	-14.79, 12.01	-0.21	0.838
Carbohydrates	-0.09	-0.62, 0.44	-0.33	0.739
Fat	0.02	-0.57, 0.61	0.07	0.948
Sugar	-0.34	-1.18, 0.50	-0.81	0.421
Fruit and Vegetables	0.01	-0.02, 0.03	0.58	0.560
Age	-0.00	-0.05, 0.05	-0.08	0.933
Gender	0.26	-0.20, 0.73	1.12	0.265
Residency (GER, AT)	-0.03	-0.50, 0.45	-0.11	0.912
Loneliness	-0.08	-0.11, -0.05	-5.7	<0.001
Curiosity (trait) * Carbohydrates	0.05	-0.12, 0.21	0.56	0.575
Curiosity (trait) * Fat	-0.00	-0.18, 0.18	-0.03	0.972
Curiosity (trait) * Sugar	0.12	-0.13, 0.38	0.94	0.347
Curiosity (trait) * Fruit and Vegetables	-0.00	-0.01, 0.01	-0.61	0.545
Observations	170			
R ² / R ² adjusted	0.345 / 0.290			

Note: Trait curiosity remained significant ($t(164)=3.72$, $p<.001$) in the reduced (winning) model (including loneliness, age, gender, residency) based on model comparison, but for completeness of the food variables, we report the full model here.

Table S4. Full model predicting daily excitement levels

<i>Predictors</i>	Daily excitement (mean)		<i>Statistic</i>	<i>p-value</i>
	<i>Estimates</i>	<i>95% CI</i>		
(Intercept)	2.80	-7.45, 13.04	0.54	0.591
Curiosity (trait)	0.50	-2.64, 3.63	0.31	0.755
Carbohydrates	0.00	-0.12, 0.13	0.08	0.940
Fat	0.03	-0.11, 0.17	0.41	0.683
Sugar	-0.11	-0.30, 0.09	-1.10	0.275
Fruit and Vegetables	0.00	-0.01, 0.01	0.11	0.915
Age	-0.02	-0.03, -0.01	-3.06	0.003
Gender	0.01	-0.10, 0.12	0.20	0.839
Residency (GER, AT)	0.04	-0.08, 0.15	0.63	0.529
Loneliness	-0.01	-0.02, -0.00	-2.97	0.003
Curiosity (trait) * Carbohydrates	-0.00	-0.04, 0.04	-0.13	0.894
Curiosity (trait) * Fat	-0.01	-0.05, 0.03	-0.49	0.627
Curiosity (trait) * Sugar	0.03	-0.03, 0.09	0.87	0.387
Curiosity (trait) * Fruit and Vegetables	0.00	-0.00, 0.00	0.20	0.842
Observations	170			
R ² / R ² adjusted	0.211 / 0.146			

Note: Trait curiosity remained significant ($t(164) = 2.41, p = 0.017$) in the winning (reduced) model (including loneliness, age, gender, residency) based on model comparison, but for completeness of the food variables, we report the full model here.

Table S5. Full model predicting daily anxiety levels

<i>Predictors</i>	Daily anxiety (mean)		<i>Statistic</i>	<i>p-value</i>
	<i>Estimates</i>	<i>95% CI</i>		
(Intercept)	-2.43	-11.96, 7.09	-0.50	0.615
Curiosity (trait)	1.09	-1.82, 4.00	0.74	0.461
Carbohydrates	0.05	-0.07, 0.16	0.80	0.426
Fat	0.00	-0.13, 0.13	0.03	0.980
Sugar	0.25	0.07, 0.43	2.69	0.008
Fruit and Vegetables	-0.00	-0.01, 0.00	-1.39	0.167
Age	-0.00	-0.01, 0.01	-0.74	0.459
Gender	-0.11	-0.21, 0.00	-1.97	0.050
Residency (GER, AT)	0.02	-0.09, 0.12	0.29	0.768
STAI (trait)	0.02	0.01, 0.03	3.65	<0.001
Loneliness	0.00	-0.00, 0.01	1.10	0.275
Curiosity (trait) * Carbohydrates	-0.02	-0.05, 0.02	-0.87	0.383
Curiosity (trait) * Fat	0.00	-0.04, 0.04	0.05	0.958
Curiosity (trait) * Sugar	-0.08	-0.13, -0.02	-2.71	0.007
Curiosity (trait) * Fruit and Vegetables	0.00	-0.00, 0.00	1.09	0.278
Observations	170			
R ² / R ² adjusted	0.302 / 0.239			

Methods

Table and plots were created using “gtsummary”¹, “sjPlot”² and “ggstatsplot”³.

Questionnaires

COVID-19 impact

We assessed the impact COVID-19 had on participants' lives by asking them to rate how well they complied with the rules, their current work situation (e.g. home-office) and whether they or others they knew contracted the virus:

- *Work situation*: "Arbeiten Sie zur Zeit im Homeoffice bzw. arbeiten/studieren/lernen Sie von zu Hause aus?" ["Do you currently work from home, e.g., work / study / learn from home?"] (answers: 1=Yes, 2=No, I go to the office, 3=No, I am not working at the moment, 4=No, I have lost my job due to COVID-19)

Work situation during COVID-19 lockdown

Figure S2. Work situation. The majority of participants were working from home.

- *Compliance to COVID-19 restrictions, setup by the Government*: "Wie streng befolgen Sie die von der Regierung beschlossenen Regeln und Empfehlungen bezüglich der Einschränkung sozialer Kontakte?" ["How strictly do you follow the rules and recommendations adopted by the government regarding the restriction of social contacts?" (answer: 0 = not at all, 100 = very strict"]

- *Experience with virus (direct, indirect)*: (1) "Gibt es in Ihrem näheren persönlichen Umfeld eine an Covid-19 erkrankte Person?" ["Is there someone in your immediate personal environment who has Covid-19?"] (answer options: 1=Yes, in my environment; 2=Yes, I am or was sick with Covid19 myself; 3=No); (2) "Kümmern oder kümmern Sie sich um eine an Covid-19 erkrankte Person?" ["Do you take care of a person suffering from Covid-19?"] (answer options: 1=Yes, currently; 2=Yes, in the past; 3=No)

Table S6. COVID-19 impact, split by country

	Overall, N = 183 ¹	Austria, N = 54 ¹	Germany, N = 129 ¹	P ²
Follows Covid-19 restrictions	82.33 (19.71)	84.07 (15.15)	81.60 (21.34)	>0.9
Covid-19 infection - self	2 / 183 (1.1%)	2 / 54 (3.7%)	0 / 129 (0%)	0.086
Covid-19 infection - social network	41 / 183 (22%)	12 / 54 (22%)	29 / 129 (22%)	>0.9
Covid-19 patient caretaker				0.8
- Yes, currently	2 / 183 (1.1%)	1 / 54 (1.9%)	1 / 129 (0.8%)	
- Yes, previously	3 / 183 (1.6%)	1 / 54 (1.9%)	2 / 129 (1.6%)	
- No	178 / 183 (97%)	52 / 54 (96%)	126 / 129 (98%)	

¹ Mean (SD); n / N (%)

² Wilcoxon rank sum test; Fisher's exact test; Pearson's Chi-squared test

There were no statistical differences between the Austrian and German sample concerning impact of COVID-19.

Information-seeking motivation

Four questions assessing how willing individuals are to seek information regarding positive and negative information for themselves and about others in current times. For all questions, participants are asked to indicate their motivation using a slider from *I am definitely not motivated to look for information (0)* to *I am highly motivated to look for information (100)* [German: *Ich bin gar nicht motiviert nach Informationen zu suchen (0) -- Ich bin sehr motiviert nach Informationen zu suchen (100)*]. See below.

Wie viele Informationen suchen Sie in AKTUELLEN Zeiten (z.B. im Internet, durch Lesen, Fernsehen, Fragen an Freunde/Familie/etc.). [How much information do you look for in CURRENT times (e.g. on the Internet, by reading, watching TV, asking friends / family / etc.).]

1. Wie sehr sind Sie gewillt, nach Informationen zu suchen, wenn diese Informationen wahrscheinlich POSITIV sind? (also gute Nachrichten) [How motivated are you to seek information, when that information is likely positive? (i.e. good news)]
2. Wie sehr sind Sie gewillt, nach Informationen zu suchen, wenn diese Informationen wahrscheinlich NEGATIV sind? (also schlechte Nachrichten) [How motivated are you to seek information, when that information is likely negative? (i.e. bad news)]
3. Wie sehr sind Sie gewillt, nach Informationen zu suchen, wenn diese Informationen über Andere wahrscheinlich POSITIV sind? (also gute Nachrichten) [How motivated are you to seek information, when that information about others is likely positive? (i.e. good news)]
4. Wie sehr sind Sie gewillt, nach Informationen zu suchen, wenn diese Informationen über Andere wahrscheinlich NEGATIV sind? (also schlechte Nachrichten) [How motivated are you to seek information, when that information about others is likely negative? (i.e. bad news)]

References

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