Health communication and risk perception: A neuroscientific perspective

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Martin Andreas Imhof

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Faculty of Sciences

Department of Psychology

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1. Reviewer: Prof. Dr. Harald Schupp

2. Reviewer: Prof. Dr. Britta Renner

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Abstract

Risk perception is a fundamental variable in models on health behavior change. Based on the assumption that personal risk perception influences behavior change, the dissertation aims to capture mechanisms underlying the perception of health-related risks. Furthermore, the potential of neural measures to assess health communication is examined. In two streams of research, personal risk perception is studied using two common risk behaviors: sexually transmitted infections (STI) and risky alcohol use.

The first part of the dissertation targets mechanisms underlying intuitive social risk perceptions in two studies. Previous work on visually presented social information showed that STI risk perceptions about a person are made fast, effortless, and related to affect. Accordingly, intuitive processes have been ascribed a key role for social risk perception.

One study used event-related potentials (ERP) and a simulated online dating platform to study the perception of multi-modal risk information. The main finding was an interaction of verbal and visual information, seen over anterior-temporal sensors between 270 to 430 ms - indicative of the integration of risk information early in the processing stream. This effect was driven by persons revealing both high verbal and high visual risk. Previous studies related ERP differences in response to persons perceived as risky to affective significance and enhanced attention. Hence, the findings are interpreted as a tagging of high-risk information serving as an alarm function.

A second study had the aim to identify potential stereotypes underlying these social risk perceptions. The main result was that people seem to use a systematic set of cues when asked to evaluate HIV risk and trustworthiness based on person pictures. Furthermore, the cues were used to predict ratings of riskiness and trustworthiness in a new set of pictures.

Overall, the findings of these two studies corroborate the notion of intuitive influences in health-related social risk perceptions. Moreover, the findings support that stereotypical impressions of HIV risk are related to perceived trustworthiness.

From an applied perspective, it is highly relevant to reveal how risk perception is effectively influenced to reach behavior change. Mass-media messages are a crucial strategy to promote public health. Media influences on risk perception, however, do not show simple sender-receiver relations, and many questions remain about how messages affect recipients. Thus, the second part expands the focus to real-life risk communication within three further studies. Short videos are commonly used in health communication. This requires an analysis approach for functional neuroimaging data (fMRI) that can handle complex naturalistic stimuli. Thus, the inter-subject correlation (ISC) analysis was used to elucidate how real-life risk communication unfolds its effects among recipients.

A first study was focused on the properties of fMRI-ISC in use with short video segments. The findings indicated that fMRI-ISC offers a reliable measure of response similarities in use with short videos. The study revealed a gradient of ISC from primary-sensory to integrative, post-sensory regions related to psychological processes, such as saliency or personal relevance. Taken together, the findings suggest the ISC approach as a tool to assess dynamic processes underlying the perception of real-life risk information.

In a second study, fMRI was used to examine how young adults "tune in" to real-life videos about risky alcohol use. The main finding of the study was that strong videos, evaluated to be more effective, commanded enhanced ISC. The enhancement was seen in cortical midline regions and the insula, which have previously been related to narrative engagement, self-relevance, and attention towards salient stimuli. The findings suggest that strong video health messages have greater "neural reach" across the brains of an audience.

The third study expanded the approach to EEG to elucidate the processing of risk communication with a high temporal resolution, and in a further, independent target group. The EEG results revealed consistent ISC differences between strong and weak messages. In an additional stream of analysis, EEG-ISC was connected with fMRI data to identify sources of the spatially distinct correlated components. EEG-ISC co-varied over time with fMRI signal captured in another audience. Specifically, distinct correlated EEG components were related to higher-order, post-perceptual brain regions, such as the insula, the precuneus, the posterior and anterior cingulate and the medial prefrontal cortex. Finally, the potential of EEG-ISC to predict behavior change was explored and revealed relations between ISC and drinking at follow-up for components related to higher-order brain regions. The extension to EEG has translational potential as it provides a more accessible measure to quantify the impact of health messages within the brains of a target audience.

The findings of the three studies suggest that strong messages lead to enhanced engagement of the audience, reflected within more reliably shared brain responses. This engagement is found across two neuroscientific measures and is presumably related to psychological variables, such as saliency or personal relevance. The ISC approach thus offers a promising strategy for tracking the "neural reach" of health communication in target groups.

Overall, the dissertation takes a perspective influenced by health psychology, communication science, and affective neuroscience. A neuroscientific perspective allows a systematic study of how risk information is processed, of what constitutes compelling risk information, and within which group of receivers the information is effective. This perspective presents a promising approach to a better understanding of message reception and behavior change. A better understanding of these mechanisms can improve strategies for communicating health risks and, ultimately – lead to healthier behavior.

Zusammenfassung

Risikowahrnehmung ist eine wichtige Variable in Modellen des Gesundheitsverhaltens. Basierend auf der Annahme, dass selbstbezogene Risikowahrnehmung Verhaltensänderung beeinflusst, ist es das Ziel dieser Dissertation Mechanismen abzubilden, welche der Wahrnehmung gesundheitsbezogener Risiken zu Grunde liegen. Darüber hinaus wird das Potenzial neurowissenschaftlicher Maße zur Untersuchung von Gesundheitskommunikation untersucht. In zwei Forschungsansätzen wird selbstbezogene Risikowahrnehmung mittels zweier verbreiteter Risikofaktoren untersucht: sexuell übertragbare Infektionen (STI) und riskanter Alkoholkonsum.

Der erste Teil der Dissertation beinhaltet zwei Studien welche intuitive soziale Risikoeinschätzungen untersuchten. Bisherige Forschung zu visuell dargebotener sozialer Information zeigte, dass STI-Risikoeinschätzungen über eine andere Person schnell und mühelos gemacht werden und, dass diese Einschätzungen mit affektiven Prozessen in Verbindung stehen. Demzufolge wurden intuitiven Prozessen eine Schlüsselrolle für die Wahrnehmung sozialer Risiken zugeschrieben.

Eine der beiden Studien nutzte die Analyse ereignis-korrelierter Potentiale (EKP) und eine simulierte Online-Dating Plattform um die Wahrnehmung multi-modaler Risikoinformation zu untersuchen. Der Hauptbefund war eine Interaktion verbaler und visueller Risikoinformationen, welche über anterior-temporalen Sensoren im Zeitbereich von 270 bis 430 ms gefunden wurde. Dieser Befund lieferte Anzeichen für eine Integration von Risikoinformationen zu einem frühen Zeitpunkt der Verarbeitung. Der Effekt wurde vor allem durch Personen beeinflusst, die sowohl hoch-riskante verbale als auch hoch-riskante visuelle Information aufwiesen. Frühere Forschung brachte EKP-Unterschiede für „riskant" eingeschätzte Personen mit affektiver Bedeutung und verstärkter Aufmerksamkeit in Verbindung. Folglich werden die Befunde als Kennzeichnung von Hoch-Risiko-Information interpretiert, welche wiederum eine Alarmfunktion darstellen könnte.

Die zweite Studie hatte das Ziel potentielle Stereotype zu identifizieren die den Einschätzungen sozialer Risiken zu Grunde liegen. Der Hauptbefund war, dass Menschen ein systematisches Set visueller Hinweisreize nutzen um HIV-Risiko und Vertrauenswürdigkeit, basierend auf Personenbildern, einzuschätzen. Darüber hinaus konnten diese Hinweisreize genutzt werden um Einschätzungen von Risiko und Vertrauenswürdigkeit in einem weiteren Bilderset zu prädizieren.

Übergreifend betrachtet stützen die Befunde der beiden Studien die Annahme, dass intuitive Prozesse die Wahrnehmung gesundheitsbezogener, sozialer Risiken beeinflussen. Darüber hinaus zeigen die Befunde, dass stereotype Einschätzungen des HIV-Risikos mit wahrgenommener Vertrauenswürdigkeit in Verbindung stehen.

Aus einer anwendungsbezogenen Perspektive betrachtet, ist es hoch relevant zu untersuchen, wie Risikowahrnehmung wirksam beeinflusst wird um Verhaltensänderungen zu erreichen. Massenmediale Botschaften sind eine wichtige Strategie um Gesundheit zu fördern. Medieneinflüsse auf die Risikowahrnehmung hingegen sind nicht durch ein simples Sender-Empfänger Verhältnis gekennzeichnet und viele Fragen darüber, wie Botschaften die Empfänger beeinflussen, sind offen. Daher erweitert der zweite Teil der Dissertation in drei weiteren Studien den Fokus auf reell genutzte Risikokommunikation. Kurze Videos werden häufig in der Gesundheitskommunikation genutzt. Daher wurde ein Ansatz zur Analyse funkioneller magnetresonanztomographischer Daten (fMRT) genutzt, welcher solche komplexen, lebensnahen Stimuli untersuchen kann. Dieser sogenannte „inter-subject correlation“-Ansatz (ISC) wird genutzt um zu beleuchten wie reell genutzte Risiko-kommunikation ihre Wirkung in einer Gruppe von Empfängern entfaltet.

Eine der Studien setzte einen Schwerpunkt auf die Eigenschaften der fMRT-ISC in Verbindung mit kurzen Video-Segmenten. Die Befunde weisen darauf hin, dass die Methode eine reliable Messung der Ähnlichkeit neuronaler Verarbeitung in Verbindung mit kurzen Videos ermöglicht. Die Studie zeigte einen Gradienten der ISC von primär sensorischen, hin zu integrativen, post-perzeptuellen Gehirnregionen, welche mit psychologischen Prozessen wie

Salienz-Verarbeitung oder persönlicher Relevanz in Verbindung gebracht werden. Die Befunde zeigen, dass der ISC-Ansatz genutzt werden kann um die dynamische Verarbeitung reell genutzter Risikoinformation zu untersuchen.

In einer zweiten Studie wurde mittels der fMRT untersucht, wie die Gehirne junger Erwachsener „in Einklang gebracht werden“ währende sie reell genutzte Videos über riskanten Alkoholkonsum betrachteten. Das Hauptergebnis der Studie war, dass „starke“, als effektiv und überzeugend eingeschätzte Videos, zu einer verstärkten ISC führten. Diese Verstärkung wurde vor allem in medial gelegenen Hirnregionen beobachtet sowie der Insula. Diese Regionen wurden in früherer Forschung mit der Verarbeitung von Geschichten, Selbst-Relevanz und gerichteter Aufmerksamkeit auf saliente Stimuli in Verbindung gebracht. Die Befunde legen nahe, dass starke, überzeugende Gesundheitsbotschaften eine größere „neuronale Reichweite“ über die Gehirne des Publikums hinweg erreichen.

Die dritte Studie erweiterte den Ansatz mittels der Elektroenzephalografie (EEG). Dadurch konnte die Verarbeitung von Risikokommunikation mit einer hohen zeitlichen Auflösung und in einer weiteren, unabhängigen Zielgruppe untersucht werden. Die EEG-Resultate zeigten konsistente ISC-Unterschiede zwischen starken und schwachen Videos. In weiteren Analysen wurde die Verbindung zwischen EEG-ISC und fMRT-Daten untersucht um mögliche kortikale Ursprünge der räumlich-distinkten korrelierten EEG-Komponenten zu identifizieren. Es zeigten sich Zusammenhänge zwischen EEG-ISC und dem fMRT-Signal, welches in einem weiteren Publikum gemessen wurde. Insbesondere zeigte sich, dass spezifische, korrelierte EEG-Komponenten mit fMRT-Signal in hierarchisch höher gelegenen, post-perzeptuellen Hirnregionen wie der Insula, dem Präcuneus, dem posterioren und anterioren Cingulum sowie dem medialen präfrontalen Kortex kovariierte. Abschließend wurde das Potenzial der EEG-ISC dahingehend untersucht Verhaltensänderungen vorherzusagen. Es zeigten sich Zusammenhänge zwischen der Veränderung im Trinkverhalten und ISC von Komponenten die mit hierarchisch höher gelegenen Hirnregionen in Verbindung gebracht wurden. Die Erweiterung der Methodik zum EEG hat Potenzial für eine praktische

Anwendung, da das EEG eine einfachere Messung ermöglicht. So könnte beispielsweise die Wirkung von Gesundheitsbotschaften innerhalb der Gehirne einer Zielgruppe untersucht werden.

Die Befunde der drei Studien legen nahe, dass starke, überzeugende Botschaften zu einer verstärkten Publikumswirksamkeit führen, welche sich in einer geteilten Hirnantwort widerspiegelt. Diese verstärkte Ähnlichkeit wurde mittels zweier neurowissenschaftlicher Maße gezeigt und ist möglicherweise mit psychologischen Variablen, wie beispielsweise Salienz und persönliche Relevanz, in Verbindung zu bringen. Der ISC-Ansatz bietet somit eine vielversprechende Strategie um die „neuronale Reichweite" von Gesundheitskommunikation in einer Zielgruppe nachzuverfolgen.

Über alle Studien hinweg zeigt diese Dissertation eine Perspektive auf, die von Gesundheitspsychologie, Kommunikationswissenschaften und der affektiven Neurowissenschaft beeinflusst ist. Eine neurowissenschaftliche Perspektive erlaubt die systematische Untersuchung dessen, wie Risikoinformation verarbeitet wird, was eine überzeugende Risikoinformation darstellt und in welcher Gruppe von Zuschauern die Information wirkt. Diese Perspektive stellt einen vielversprechen Ansatz dar, welcher es ermöglicht besser zu verstehen wie Gesundheitsbotschaften wirken. Ein besseres Verständnis dieser Zusammenhänge kann dazu führen, dass Strategien zur Kommunikation von Gesundheitsrisiken verbessert werden – was letztlich zu gesünderem Verhalten führt.

Prior printed publications

Parts of the results reported in this dissertation have been previously published in the following scientific outlets:

Publications

Imhof, M.A., Schmälzle, R., Renner, B., Schupp, H.T., (in press). Strong health messages increase audience brain coupling. *NeuroImage*. doi: 10.1016/j.neuroimage.2020.116527.

Imhof, M. A., Schmälzle, R., Renner, B., & Schupp, H. T. (2017). How real-life health messages engage our brains: Shared processing of effective anti-alcohol videos. *Social Cognitive and Affective Neuroscience, 12*(7), 1188–1196. doi: 10.1093/scan/nsx044.

Schmälzle, R., Imhof, M. A., Grall, C., Flaisch, T., & Schupp, H. T. (preprint). Reliability of fMRI time series: Similarity of neural processing during movie viewing. *bioRxiv Preprint.* doi: 10.1101/158188. *Pre-print without peer-review.*

Schmälzle, R., Imhof, M. A., Kenter, A., Renner, B., & Schupp, H. T. (2019). Impressions of HIV risk online: Brain potentials while viewing online dating profiles. *Cognitive, Affective & Behavioral Neuroscience, 19*(5). doi: 10.3758/s13415-019-00731-1.

Schmälzle, R., Hartung, F.-M., Barth, A., Imhof, M. A., Kenter, A., Renner, B., & Schupp, H. T. (2019). Visual cues that predict intuitive risk perception in the case of HIV. *PloS One, 14*(2). doi: 10.1371/journal.pone.0211770.

Talks and conference contributions

Imhof, M. A. (2019). *An EEG measure of shared audience engagement during real-life anti-alcohol videos.* Conference contribution in symposium “An update on EEG recording and analyses methods”. Annual meeting Psychologie und Gehirn 2019. Dresden, Germany.

Imhof, M. A., Schmälzle, R., Renner, B., & Schupp, H. T. (2019). *An EEG measure of shared audience engagement during real-life anti-alcohol videos.* Poster presented at the annual meeting of the Social & Affective Neuroscience Society. Miami, USA.

Imhof, M. A., Schmälzle, R., Renner, B., & Schupp, H. T. (2019). *Neural synchrony during reception of real life anti-alcohol health messages.* Conference contribution in event "The Biology of Health, Fear, and Risk Perceptions ", ICA's 69th annual conference. San Diego, USA.

Schmälzle, R., Imhof, M. A., Kenter, A., Renner, B., & Schupp, H. T. (2019). *Impressions of HIV risk online: Brain potentials while viewing online dating profiles.* Conference contribution in event "The Biology of Health, Fear, and Risk Perceptions ", ICA's 69th annual conference. San Diego, USA.

Imhof, M. A. (2018). *Health messages engage our brains.* Invited talk in event "Contemporary problems in adolescents", Visit of the honours community of the faculty of social sciences Utrecht University. Konstanz, Germany.

Schmälzle, R., Imhof, M. A., Renner, B., & Schupp, H. T. (2017). *How health messages reach our brains: Coupled neural dynamics during effective anti-alcohol videos.* Conference contribution in event "Your Brain on Health Communication: Applications of Communication Science in Health and Education", ICA's 67th annual conference. San Diego, USA.

Schmälzle, R., Imhof, M. A., Hartung, F.-M., Barth, A., Renner, B., & Schupp, H. T. (2017). *Signs of HIV risk.* Conference contribution in event "Health Communication and HIV Prevention", ICA's 67th annual conference. San Diego, USA.

Imhof, M. A., Schmälzle, R., Renner, B., & Schupp, H. T. (2017). *How real-life health messages engage our brains: Shared processing of effective anti-alcohol videos.* Poster presented at the annual meeting of the Social & Affective Neuroscience Society. Los Angeles, USA.

Imhof, M. (2016). *Neural reach of health communication: Differences in neural processing during health messages of varying effectiveness*. Invited conference contribution in event "Posterblitz", Annual meeting Psychologie und Gehirn 2016. Berlin, Germany.

Imhof, M. A., Schmälzle, R., Renner, B., & Schupp, H. T. (2016). *Neural reach of health communication: Differences in neural processing during health messages of varying effectiveness.* Poster presented at the annual meeting Psychologie und Gehirn 2016. Berlin, Germany.

1

General Introduction

Humans continue to face a multitude of threats to their health and well-being. Globally seen, human health significantly improved over the last decades. However, non-communicable diseases alone still contribute to more than 40 million deaths per year, that is, more than 70 % of deaths worldwide (World Health Organization, 2019b). Major risk factors for non-communicable diseases are influenceable by human behavior. For example, stopping to smoke, reducing alcohol use, eating healthy, or decreasing sedentary behavior can improve human health on a large scale. In the same vein, the spread of infectious diseases could be influenced by increasing protective behavior, such as hygiene or practicing safer sex. Consequently, a critical aim of health and risk communication is to change health behavior. However, even though the risks are known, there is a large gap between knowledge and behavior.

Risk perception is a fundamental concept in health psychology that can explain why there often is a marked gap between knowledge, intentions, and behavior. Knowing about potential health risks can be seen as a precedent for changing health behavior. This general risk perception, however, is not enough to reach a change in behavior. People not only need to know "binge drinking is detrimental to health". Instead, they need to develop a feeling of being personally at risk of suffering from the consequences of their drinking (for a review, see Renner & Schupp, 2011; Renner, Gamp, Schmälzle, & Schupp, 2015). This personal risk perception has been acknowledged as a prerequisite of behavior change in major theories on health behavior (e.g., Brewer et al., 2007; Ferrer & Klein, 2015; Portnoy, Ferrer, Bergman, & Klein, 2014; Renner & Schwarzer, 2003b; Renner & Schupp, 2011; Sheeran, Harris, & Epton, 2014; Weinstein, 2003). Thus, the understanding of how humans perceive health risks is of fundamental theoretical and practical importance to reach healthier behavior.

The role of feelings and emotions for risk perception

Early models of risk perception often focused on purely cognitive or analytic conceptions of how people understand risks. However, a seminal study by Fischhoff and colleagues (1978) showed that aspects beyond the probability and severity of a given natural hazard influence the perception of risks. In this work, the general pattern was that two dimensions primarily explained perceived risk. One dimension captured whether a risk was unknown, exposure to the risk was involuntary, or if its effects were delayed. The second dimension captured the certainty of being fatal or the number of people suffering (Fischhoff et al., 1978). About forty years later, the distinction into these dimensions, later referred to as uncertainty and dread, still holds, with dread possibly showing even more influence (Fox-Glassman & Weber, 2016). By identifying this dread dimension, Fischhoff and colleagues' work already pointed at the role of feelings and emotions for risk perception.

The importance of affective processes is increasingly recognized and led to the development of influential models of risk perception. For example, the risk-as-feelings approach assumes that feelings heavily influence risk perception and add to cognitive evaluations of risk (Loewenstein, Weber, Hsee, & Welch, 2001; Slovic, Finucane, Peters, & MacGregor, 2004). Consequently, recent models of risk perception distinguish between a rational, deliberative mode of analysis and a mode of risk perception based on intuition (Slovic & Peters, 2006). These models share the assumption that real-life risk perception is often association-based, fast, and mostly automatic. Analytical thinking about risk, in contrast, requires effort and serial processing of information (Loewenstein, O'Donoghue, & Bhatia, 2015; Pachur, Hertwig, & Steinmann, 2012). Over the last decades, models, such as the "risk as feelings" approach or the "affect heuristic“, suggest that risk perception is not only influenced via cognitive evaluation, but also by affect.

While the role of affect and intuition has been acknowledged in theoretical accounts of risk research, these models have been primarily used in research studying general risk perception. Recent research started to link these theories to personal, health-related risk perception. The existence and potential mechanisms underlying intuitive health-related risk perception, though, are challenging to reveal in laboratory experiments. One way of assessing risk perception and behavior is to assess people in situations in which they make risk judgments. Typical circumstances in which people form risk judgments quickly and intuitively are social situations in which humans decide if and how to interact with an unknown person. A model system in which these situations are seen are decisions on the risk of infection with an STI. Using this model system, a series of studies revealed the existence of affective and intuitive processes in the context of personal, health-related risk perception.

Intuitive social risk perception in the context of STIs

STIs represent a socially transmitted health risk which is attributable primarily to behavior. Every day, more than one million get infected with a sexually transmitted infection (STI) worldwide (World Health Organization, 2018). An estimated 400 million people become infected each year with one of the four main STIs chlamydia, gonorrhea, syphilis, and trichomoniasis (World Health Organization, 2019a). Numerous campaigns informed the public that unsafe sex is the primary way of contracting HIV and that consistent condom use is most efficient in preventing infections. As a result, people are mostly well informed about HIV or other STIs and how they can protect themselves against the risk. While infrequent condom use decreased over the last years in Germany, still about 30 % of adults aged 16 to 44 indicate infrequent condom use in case of spontaneous contacts (von Rüden & Töppich, 2015). Thus, STIs represent a health risk for which factual knowledge seems insufficient to motivate consistent protective behavior. Nevertheless, STIs could be influenced by behavior change, rendering social risk judgments in this context a promising model system to assess the gap between knowledge and behavior. Moreover, for STIs, risk perception largely depends on evaluating the risk posed by a potential partner.

Humans form impressions about each other by merely looking at a person (Asch, 1946). Central personality impressions, such as trustworthiness or competence, are formed almost instantly and based on minimal information (Bar, Neta, & Linz, 2006; Kleisner, Priplatova, Frost, & Flegr, 2013; Todorov, Mandisodza, Goren, & Hall, 2005; Todorov, 2008; Todorov, Olivola, Dotsch, & Mende-Siedlecki, 2015; Willis & Todorov, 2006). Intuitive judgments were replicated in many contexts, including skill assessment, political voting, or sentencing decisions (Eberhardt, Davies, Purdie-Vaughns, & Johnson, 2006; Olivola, Funk, & Todorov, 2014; Todorov et al., 2005). Less known, such impressions also seem to be influential in the context of STIs (Swann Jr, Silvera, & Proske, 1995; Thompson, Kent, Thomas, & Vrungos, 1999). People reported to make inferences about a potential partner's risk and make decisions about whether to use protection - even when they do not know much about the person's past (Gold, Karmiloff-Smith, Skinner, & Morton, 1992; Keller, 1993). Moreover, people seem to have a well-developed set of beliefs and stereotypes about which partners are risky (Renner & Schwarzer, 2003a; Williams et al., 1992). Thus, intuitive person impressions seem to underlie health-related stereotypical social risk impressions.

Neuroscientific evidence for intuitive, health-related personal risk perception

Previous neuroscientific evidence confirmed the findings of field reports that people intuitively judge the riskiness of others. In a series of studies, participants were presented with pictures of unacquainted others. Participants then evaluated the depicted person's risk of being infected with HIV. During the presentation of the pictures, event-related potentials (ERPs) were recorded, the brain's electrophysiological response to viewing the pictures. Across several studies, portraits of persons that were perceived as risky concerning an HIV infection led to ERP differences early in the processing stream. Differences for persons perceived risky compared to persons that were perceived safe were seen less than 300 ms after the onset of the portrait pictures (Renner, Schmälzle, & Schupp, 2012; Schmälzle, Schupp, Barth, & Renner, 2011; Schmälzle, Renner, & Schupp, 2012). The speed of these processes supports the evidence for a fast and intuitive mode of risk processing.

ERP differences were also seen at the level of the late positive potential (LPP), an ERP component that has repeatedly been shown to respond to the affective significance of a stimulus (Schupp, Flaisch, Stockburger, & Junghöfer, 2006). Portraits of people perceived as risky led to a larger LPP compared to portraits of those that were perceived safe (Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012). Further evidence suggested that these ERP responses do not generalize to other life-threatening but non-contagious diseases (Barth, Schmälzle, Renner, & Schupp, 2013). Building on the electrophysiological findings, Häcker and colleagues (2015) adopted the paradigm to fMRI to localize brain regions related to the processing of persons perceived risky. When comparing the fMRI signal for risky and safe persons, increased neural activation was seen in structures implicated to form a saliency network - namely the anterior insulae and medial frontal cortices (Häcker et al., 2015). Lastly, two of the studies extended the explicit rating task using both ERP and fMRI data. In these studies, participants freely viewed the pictures before the rating task without evaluating riskiness or knowing the HIV risk context. The neural response to these “implicitly” seen pictures was classified based on the later collected ratings of riskiness. A clear pattern emerged across both studies. Similar neural differences were seen during both the implicit viewing and the explicit rating condition (Häcker et al., 2015; Schmälzle et al., 2011). These findings add support for the intuitive nature of the social risk judgments as they seem to occur spontaneously.

Overall, the human brain seems to process the perceived riskiness of unacquainted others concerning infectious or sexually transmitted diseases, such as HIV. This processing seems to happen in a fast, spontaneous, and thus, intuitive mode - which can be related to motivated attention. In other words, risky-looking persons presumably receive preferential processing within the human brain. This finding has been consistently revealed across two neuroscientific methods. Characteristics of the "risk as feelings" or "affect heuristic" approach were verified within the context of health-related personal risk perception, such as the intuitive and affect-based mode. One part of the current dissertation builds upon these studies. The goal of this part is to extend the understanding of health-related risk perception in the context of STIs.

Intuitive social risk judgments based on multi-modal information

Today, many dates, relationships, and sexual encounters are initiated via websites or dating apps. Dating profiles used in these media commonly present not only pictures but also verbal information. Thus, in real-life situations, decisions are based on multiple streams of information about a person. Within one study of the dissertation, we thus assessed how risk information is integrated from different modalities (Chapter 5). This approach directly extended previous work and targeted how multi-modal risk information gives rise to a representation of a person's riskiness. Based on the previous work, we hypothesized that risk information from different modalities is integrated early in the processing stream. Furthermore, persons revealing high-risk across both modalities were assumed to receive preferential processing – reminiscent of the notion of a neural system sensitive to risk information.

Social risk perceptions of HIV risk seem to be based on stereotypes related to trustworthiness or responsibility (Renner & Schwarzer, 2003a; Renner & Schupp, 2011). However, it is unclear whether there are systematic visual cues that underlie these stereotypical risk perceptions. Accordingly, a further study in the dissertation had the goal to identify if and how certain visual features systematically form stereotypical risk judgments (Chapter 6). Similar to the previous work in the STI context, we used portrait pictures. These pictures are comparable to how people present themselves on social media and thus create an ecologically valid situation. Participants evaluated each picture for a set of features. A Brunswik's Lens Model was adopted to specify the correlational relationship between a criterion, in this case, perceived riskiness, and the features used to form impressions, the so-called "cues" (Brunswik, 1955). We assumed that a systematic set of cues is used to infer risk and trustworthiness. To assess this hypothesis, we calculated cue-criterion associations that may be used to make these inferences intuitively.

Risk information by mass-media health communication

A clear understanding of the mechanisms underlying risk perception is fundamental to understand how humans perceive and react to health risks. From an applied perspective, a further highly relevant question is, "how can we effectively influence risk perception in order to lead people to adopt a healthy lifestyle?" (see Giles, 2011, for a similar notion). Mass-media health communication is an essential building block of primary prevention and risk communication with the goal of changing public risk perception and behavior. A target group can be directly influenced through risk communication, for example, by public health agencies. Providing the public with information on health risks in order to change risk perception and behavior is a central strategy to counter the effects of many behavior-related health risk factors. The aim of minimizing the burden of disease in the population through mass-media health communication seems especially promising given a large number of diseases associated with behavior-dependent health risks, such as smoking, alcohol use, or sexually transmitted infections. Accordingly, the second part of the dissertation focused on how health-related risk communication unfolds its potential across a group of receivers, with the ultimate goal of changing their behavior.

Mass-media health communication and risky alcohol use

Risky alcohol consumption is a significant public health problem. Globally seen, progress towards less risky consumption has stalled or even worsened. Furthermore, consumption is the highest in high-income countries (World Health Organization, 2019b). In the European region, alcohol contributes to about a quarter of deaths between ages 20 to 40, and 5 % of the burden of disease worldwide (World Health Organization, 2014). In the US, mortality due to alcohol-related disease notably increased for young adults aged 25 to 34 (Tapper & Parikh, 2018). Lastly, risky drinking is a significant problem among young adults and college students in particular (Karam, Kypri, & Salamoun, 2007; Slutske, 2005; Wicki, Kuntsche, & Gmel, 2010). Mass-media risk communication is frequently employed to tackle the problem of risky alcohol use. Hence, alcohol consumption presents a highly relevant model system to study the influences of risk communication on risk perception.

Health communication is a crucial instrument to target risky drinking, but it also faces challenges. In Germany, the most prominent governmental organization for health prevention has an annual budget of about 9 million euros for prevention targeting alcohol and drug abuse (Deutscher Bundestag, 2015). This sum contrasts with more than 500 million euros spent annually for alcohol advertisements by the German alcohol industry (Deutsche Hauptstelle für Suchtfragen e.V., 2016). Thus, public health campaigns often compete in an environment that is dominated by stakeholders with interests countering the efforts of the public campaign. The advent of social media provides health agencies with new but similarly competitive channels.

A recent example revealed that pro-vaping hashtags outnumbered the efforts of an FDA anti-vaping campaign by a large margin (Vassey, Metayer, Kennedy, & Whitehead, 2020). These examples illustrate part of the challenges faced by health communication. One way to increase the impact of health communication is to maximize its effectiveness.

Measuring the effectiveness of health messages

Media about health risks shapes public risk perception and behavioral responses. While there is consensus that health campaigns generally work, the reported effect sizes vary from small to medium (Abroms & Maibach, 2008; Noar, 2006; Rains, Levine, & Weber, 2018; Snyder et al., 2004; Wakefield, Loken, & Hornik, 2010). Additionally, only a limited amount of campaigns reported to base campaign efforts on theories and models of behavior change (Atkin & Rice, 2013; Randolph & Viswanath, 2004). Failure to adequately address the sustainability of executed campaigns is another and one of the most substantial gaps in campaign designs (Noar, 2006; Randolph & Viswanath, 2004). The effects of risk information in a population depend on the information itself, the transmission process, and the society's responses (e.g., Kasperson et al., 1988; Kasperson, 2012). This complex interplay renders forecasting of the effects complex. Indeed, adverse or unintended effects for risk communication have been reported for campaigns sent out with good intentions (e.g., Cho & Salmon, 2007; Fishbein, Hall-Jamieson, Zimmer, Haeften, & Nabi, 2002). Taken together, how media influences risk perception is not a simple sender-receiver relation (Atkin & Rice, 2013; Wåhlberg & Sjöberg, 2000). Many questions remain about how these messages affect recipients.

Given that health messages vary in effectiveness, a crucial goal of health messaging research is to uncover what makes them "effective“. Researchers from communication science approached this issue using a variety of measures for message characteristics. A widely used construct is perceived message effectiveness (PME), which is assessed using items such as whether a message is powerful, believable, attention-grabbing, memorable, likable, or convincing (Anderson, Noar, & Rogers, 2013; Falk, Berkman, & Lieberman, 2012; but see Yzer, LoRusso, & Nagler, 2015). PME has often been used in formative research based on the assumption that it serves as a proxy for actual effectiveness (Cappella, 2018; Davis & Duke, 2018; Dillard, Weber, & Vail, 2007; Yzer et al., 2015; but see O'Keefe, 2018; 2019 for a differing view). Other constructs assess facets of media messages, such as argument strength (AS), which allows inferences about whether a message is logical, backed up by reasons, or agreed and persuasive (Kang, Cappella, & Fishbein, 2006; Zhao, Strasser, Cappella, Lerman, & Fishbein, 2011). Message sensation value, in turn, is used to assess features like dramatic impact, physical aspects or novelty, and emotional arousal (Palmgreen, Stephenson, Everett, Baseheart, & Francies, 2002). Taken together, communication scholars have yet to achieve a consensus on how to characterize features of effective health messages. A promising way to inform this research is neuroimaging, which revealed differences in neural processing depending on the above message characteristics (for a review, see Cacioppo, Cacioppo, & Petty, 2018; Kaye, White, & Lewis, 2017).

Neural measures provide insights into how health messages are received and allow delineating brain regions associated with their reception (Cacioppo et al., 2018; Falk, 2010; Kaye et al., 2017; Weber, Fisher, Hopp, & Lonergan, 2018). For example, Langleben et al. (2009) and Seelig et al. (2014) compared smoking and safer sex messages that were either low or high in terms of message sensation value (MSV). In their work, high compared to low MSV messages were associated with increased activation in the occipital cortex, which was interpreted as increased selective attention. Wang and colleagues (2013) assessed neural responses varying with respect to MSV and AS. In their work, occipitoparietal brain regions showed heightened activation during messages high both in MSV and in AS. Weber et al. (2015) similarily exposed participants to messages high or low in both MSV and AS. They additionally included participants showing either high or low-risk cannabis use. An interaction effect for messages high in MSV and AS was mainly observed in the high-risk group. The effect, which was interpreted as counterarguing, was seen in superior temporal, medial, and lateral frontal regions gyrus, as well as the precuneus. Ramsay and colleagues (2013) focused on emotional arousal during strongly and weakly convincing anti-drug messages. They found that both message types elicited activation in limbic and mediofrontal brain regions. Comparing strong and weak messages, however, revealed enhanced activation in lateral prefrontal regions associated with executive control. Taken together, the picture emerging from this work is complex and complicated by the fact that message and receiver-characteristics likely interact. However, the data show that measures related to the effectiveness of health messages prompt differential brain activation in regions related to emotion, attention, and executive functions.

Capturing the dynamic neural response to complex stimuli

A characteristic and favorable feature of the studies mentioned above is that they often used real-life health messages, such as videos. However, the methods to analyze the neural data mostly relied on comparing peaks of activation. Videos, though, are dynamic stimuli that are spatially and temporally complex. The use of conventional analysis methods that rely on a pre-determined stimulation protocol to model the neural signal is thus limited. A promising approach that reveals how audiences respond to dynamic media stimuli is the inter-subject correlation analysis (ISC). In their seminal work, Hasson and colleagues (2004) suggested a paradigm shift in the analysis of neural data. They compared the continuous similarity in neural activation across receivers. Specifically, ISC is a voxel-by-voxel correlation between continuous neural time series of different individuals. In other words, ISC allows identifying where and to what extent the neural signal is correlated across the receivers' brains. The procedure results in a statistical map that reveals which brain regions show inter-subjective similarity in neural processing, or "inter-subject correlation" (see Figure 1.1).

Methodologically, ISC represents a measure of similarity between functional brain responses across individuals that allows assessing the reliability of neural signals in response to a shared stimulus (Hasson, Malach, & Heeger, 2010; Nastase, Gazzola, Hasson, & Keysers, 2019). Thus, ISC can be conceived as a measure of neural inter-rater reliability, revealing the agreement across measures based on different raters at the level of local brain processes. From a communication-theoretical perspective, brain regions revealing ISC can be assumed to be the ones in which a group perceives a message similarly, both physically and psychologically (see Lahnakoski et al., 2014; Schmälzle et al., 2013).

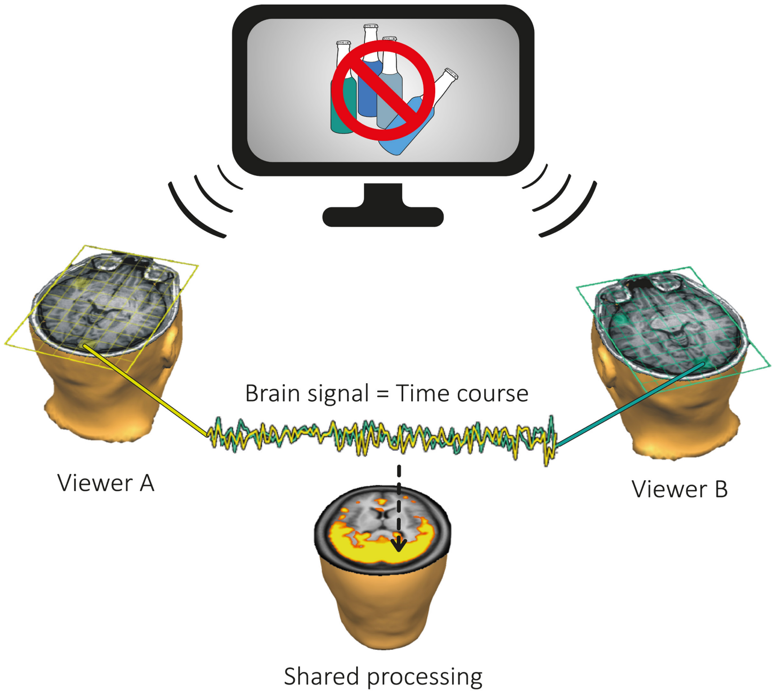

Figure 1.1 | Schematic overview of the inter-subject correlation approach. *Neural response time courses are captured during a dynamic, naturalistic stimulus, e. g., a video health message. The time course of one viewer is compared to those in the corresponding brain region of all other viewers experiencing the same stimulus. The resulting statistical map provides a measure of inter-subject similarity in neural processing at the level of the respective brain regions.*

In the last decade, the approach has been adopted to study a multitude of complex and dynamic stimuli, such as movies or television broadcasts (Cantlon & Li, 2013; Golland et al., 2007; Hasson et al., 2004; Hasson, Landesman et al., 2008; Jääskeläinen et al., 2008; Kauppi, Jääskeläinen, Sams, & Tohka, 2010; Nummenmaa et al., 2012). ISC has further been used to study narrative processing (Honey, Thompson, Lerner, & Hasson, 2012; Nummenmaa et al., 2014; Wilson, Molnar-Szakacs, & Iacoboni, 2008) or music reception (Abrams et al., 2013; Trost, Frühholz, Cochrane, Cojan, & Vuilleumier, 2015). The ISC approach demonstrated to provide a continuous, nonverbal measure of collective engagement at the neural level. This capability offers researchers a dynamic measure to assess information reception unobtrusively and directly on a moment-to-moment base. The ISC approach thus seems promising to quantify the impact of mediated risk information, such as video health messages.

Real-life video health messages often rely on short video clips, lasting less than a minute. A pre-condition for ISC to be suited for assessing video health messages is that it is utilizable with stimuli that do not have the full length of a movie. Thus, in one study of this dissertation, we assessed the robustness of the fMRI-ISC measure in use with short video segments. We captured fMRI responses during viewing short movie clips and assessed the reliability of the fMRI signal using inter-subject and intra-subject correlation across the brain. The main goal was to detail the reliability and properties of the fMRI-ISC in use with short videos, such as video health messages.

Using dynamic neural responses to assess risk perception and risk communication

For ISC to be useful for research on health messaging effects, a pre-condition is the ability to differentiate messages based on communication-relevant factors. Recent work employed ISC to reveal how messages are received. In this work, receiver-sided factors (e.g., directed attention; Ki, Kelly, & Parra, 2016) and message-receiver interactions have been explored using ISC analyses (e.g., level of risk perception; Schmälzle et al., 2013). The technique's potential for research on health communication has been showcased by Schmälzle and colleagues (2013), who assessed the reception of a real-world TV documentary about the swine flu virus H1N1. The study revealed an enhancement of ISC correlation among viewers with higher risk perception in the saliency network (Menon & Uddin, 2010; Seeley et al., 2007). The effect mainly occurred in the anterior cingulate cortex, which has been associated with self-related processing and appraising of threatening information (Mechias, Etkin, & Kalisch, 2010; Schmitz & Johnson, 2007).

Importantly, message-sided factors, such as rhetoric quality and engagement, seem to modulate the amount of ISC in medio-frontal regions (Schmälzle, Häcker, Honey, & Hasson, 2015). In this study, participants listened to political speeches varying in rhetoric quality. The fMRI-ISC analysis revealed that powerful speakers were able to collectively attract the audience's attention, resulting in more strongly aligned brain activity across listeners. Increased ISC was observed for speeches of high rhetoric quality, thus opening up possibilities for research on the impact of messages on viewers via motivated attention, personal relevance, and affective engagement. The aforementioned studies showcase the potential of the approach by revealing that receiver and message characteristics influence the magnitude of ISC during the reception of complex, dynamic stimuli. These findings show promise for understanding risk perception using health-related risk information with high ecological validity.

A highly relevant question is what makes health messages engaging and effective. Thus, in one study of this dissertation, we examined how young adults - a primary target group for alcohol prevention - "tune in" to real-life health messages of varying effectiveness (Chapter 2). In a first study, participants characterized a large sample of videos targeting the risks of alcohol using established measures of message effectiveness. Based on these characterizations, we selected ten of the strongest, most effective, and ten of the least effective videos. In the main study, we used fMRI-ISC to compare the brain responses to these strong and weak exemplars. We assumed that fMRI-ISC could serve as a tool to distinguish strong and weak messages. Furthermore, we determined neural regions that were related to the dynamic reception of the health messages.

A comparable ISC-based approach has been proposed for an application with EEG data (Cohen & Parra, 2016; Cohen, Henin, & Parra, 2017; Dmochowski, Sajda, Dias, & Parra, 2012; Dmochowski et al., 2014; Parra, Haufe, & Dmochowski, 2018). A critical advantage of EEG is its temporal resolution, ranging on the order of milliseconds. Hence, it can complement hemodynamic measures, which offer a good spatial but limited temporal resolution. High temporal resolution is essential for characterizing the reception process of fast-paced audiovisual messages. Prominent examples of such messages, lasting only a minute or less, are video health messages.

Further benefits of EEG are its more accessible nature and relative cost-effectiveness. These characteristics enhance the translational potential, such as integration into message pre-testing. Recent EEG studies in classroom settings, cinema, or during music consumption illustrate this potential (Barnett & Cerf, 2017; Cohen et al., 2018; Dikker et al., 2017; Madsen, Margulis, Simchy-Gross, & Parra, 2019; Poulsen, Kamronn, Dmochowski, Parra, & Hansen, 2017). The concerted use of EEG and fMRI may provide a view on the neural processes underlying the reception of risk communication with both high spatial and high temporal resolution. In other words, this approach may allow capturing phenomena related to risk perception "where" and "when" they arise. Consequently, we capitalized on a multi-method approach across two studies in the present dissertation (Chapters 2 & 3). In these studies, we used the ISC approach to assess the dynamic audience response to real-life video health messages.

In Chapter 3, we extended the fMRI-ISC work of Chapter 2 by using EEG as well as a second, independent target group. We used EEG to capture the brain responses during the reception of the same strong and weak video health messages with high temporal resolution. The main goal was to determine whether EEG-ISC robustly differentiates strong and weak messages and may serve as a marker of effective messages. The enhanced temporal resolution offered by EEG is promising for characterizing the reception of short video health messages. Moreover, we took an innovative approach in which we combine the fMRI data of Chapter 2 and the EEG-ISC findings to identify potential neural generators of correlated EEG components. In further analyses, we assessed changes in participants' drinking over a follow-up period. We adopted a so-called “brain as predictor” approach to extend the fMRI and EEG-ISC findings. Specifically, we explore whether EEG-ISC during message exposure was related to subsequent changes in alcohol consumption.

The capability to predict changes in outcomes based on neural measures represents a critical extension for the use of neuroimaging to assess the effects of health-related risk information. Recent work demonstrated that neural measures could be used to predict behavior (for reviews, see Cacioppo et al., 2018; Cascio, Dal Cin, & Falk, 2013; Falk, Cascio, & Coronel, 2015). One of the first studies explicitly capitalizing on this "brain as predictor" approach in use with health messages was performed by Falk and colleagues (2010). They showed that neural responses in an a priori defined region-of-interest during the perception of messages advocating sunscreen use predicted behavior change one week after the scanning session. The approach links neural processes during exposure to health risk information to subsequent behavioral effects outside the scanner, such as the daily use of sun protection. The ability to predict changes in outcomes allows specifying and testing hypotheses on the underlying mechanisms, which has fundamental theoretical and translational implications

(Berkman & Falk, 2013; Falk et al., 2012; Falk et al., 2015; Gabrieli, Ghosh, & Whitfield-Gabrieli, 2015). Understanding the mechanisms behind behavioral and clinical outcomes is essential. This understanding can be used to improve people's lives (for a review, see Gabrieli et al., 2015).

Overview of the present dissertation

Based on the assumption that risk perception is central to influence behavior change, the overarching aim of the dissertation was to advance knowledge on health-related risk perception. To tackle this aim, this dissertation relied on an inter-disciplinary approach building on theories from health psychology, social and affective neuroscience, and communication science. The aim was approached in two streams of research that focused on the risk factors of sexually transmitted infections and risky alcohol use. These risk factors contribute to a high burden of disease and are remediable by changing behavior. The common objective across the two streams was to shed light on how people perceive and respond to health-related risk information.

Studies on intuitive risk perception in the context of STIs

The first stream extended knowledge on how health-related risk perceptions are formed intuitively. Within the model system of STIs, we targeted the research question, "What are the mechanisms underlying intuitive social risk perceptions?". A central finding of previous work in the context of STIs is that intuitive processes seem to underlie risk perceptions. However, risk information was mostly provided using visual information, such as a picture.

One study built on this work by extending the risk information to a second modality (Chapter 5). The participants experienced a simulated online dating platform mimicking an ecologically valid social judgment situation. The platform allowed providing visual and verbal-descriptive risk information. We relied on an event-related EEG analysis approach to reveal how the risk information is integrated and gives rise to a representation of a person's riskiness.

Social risk perceptions in the context of HIV have been related to stereotypical conceptions of a high at-risk person. However, it is unclear whether there are systematic visual cues that underlie these stereotypical risk perceptions. Accordingly, a further study in this stream assessed if and how cues are systematically utilized for the assumed stereotypical risk judgments (Chapter 6).

Studies on real-life risk communication in the context of risky alcohol use

From an applied perspective, a question of utmost importance is how risk communication effectively influences risk perception. Thus, the second stream of research had the goal to assess how effective risk communication unfolds its potential in target groups. Within the model system of risky alcohol use, we addressed two research questions: "How does real-life risk communication unfold its effects among recipients?" and "Can we link neuroscientific measures of risk communication to behavior change?". We capitalized on the ISC approach to assess the audience's response to dynamic health messages.

In Chapter 2, we examined the reception of real-life video health messages in a target group. In the main study, we used fMRI-ISC to compare brain responses to strong and weak videos in a sample of young adults. The use of neuroimaging in a target group can conceptually be seen as a focus group. Capitalizing on such "neural focus groups" can provide information that may aid in identifying messages that are most likely effective.

In Chapter 3, we built on the fMRI-ISC work and extended the approach to EEG within a second target group. EEG allowed capturing the reception of the video health messages with high temporal resolution. Furthermore, a multi-modal approach capitalizing on both EEG and fMRI data allowed assessing parallels between the fMRI-ISC in Chapter 2 and neural generators of EEG-ISC in Chapter 3. Further analyses relating EEG-ISC during message reception to subsequent behavior change critically extended the paradigm.

In Chapter 4, we examined the robustness of the fMRI-ISC measure in use with short video segments. We assessed the reliability of the fMRI signal using inter-subject and intra-subject correlation. Additionally, we explored whether the aggregation of individual data across groups leads to a more reliable measure at the level of specific brain regions. The main goal was to detail the properties of the fMRI-ISC.

2

How real-life health messages engage our brains: Shared processing of effective anti-alcohol videos

Martin A. Imhof [1 *], Ralf Schmälzle [1 2 *], Britta Renner [1], Harald T. Schupp [1]

[1] Department of Psychology, University of Konstanz, Konstanz, Germany
[2] Department of Communication, Michigan State University, East Lansing, USA
** Both authors contributed equally*

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Abstract

Health communication via mass media is an important strategy when targeting risky drinking, but many questions remain about how health messages are processed and how they unfold their effects within receivers. Here we examine how the brains of young adults - a key target group for alcohol prevention - „tune in" to real-life health prevention messages about risky alcohol use. In a first study, a large sample of authentic public service announcements (PSAs) targeting the risks of alcohol was characterized using established measures of message effectiveness. In the main study, we used the inter-subject correlation analysis of fMRI data to examine brain responses to more and less effective PSAs in a sample of young adults. We find that more effective messages command more similar responses within widespread brain regions, including the dorsomedial prefrontal cortex, insulae, and precuneus. In previous research, these regions have been related to narrative engagement, self-relevance, and attention towards salient stimuli. The present study thus suggests that more effective health prevention messages have greater „neural reach, "i.e., they engage the brains of audience members' more widely. This work outlines a promising strategy for assessing the effects of health communication at a neural level.

Keywords

fMRI; health communication; public service announcements; inter-subject correlation; self; alcohol

Introduction

Risky drinking constitutes a major public health problem in the population at large and young adults in particular. For instance, alcohol contributes to 5 % of the global burden of disease and about a quarter of all deaths between ages 20 to 40 (World Health Organization, 2014). Mass media health messages, particularly public service announcements (PSAs), are frequently used to combat such alcohol- or other behavior-related health problems. While many factors contribute to the effectiveness of public media health messages, a core ingredient of effective campaigns seems to be the potential to address individuals in a self- and emotionally-relevant way (Burnkrant & Unnava, 1995; Dillard & Peck, 2000; Tannenbaum et al., 2015). Functional neuroimaging offers a unique opportunity to measure neural responses to health risk communication media, and this study was designed to shed light on how more and less effective health messages about alcohol are received and processed in the brains of a target audience.

Previous neuroimaging studies provide first insights into neural responses to health communication with varying message characteristics, such as message sensation value and argument strength (for a review, see Kaye et al., 2017). While the former refers to visual and auditory features, novelty and intensity of a message (e.g., Kang et al., 2006; Palmgreen et al., 2002), the latter refers to whether a message is logical, backed up by strong reasons, and persuasive overall (e.g., Kang et al., 2006; Zhao et al., 2011). Health messages varying on these constructs prompted differential blood oxygen level-dependent (BOLD) signal in the medial prefrontal cortex and the precuneus (Langleben et al. 2009; Wang et al., 2013; Weber et al., 2015). Responses in these regions also differed between tailored and non- or less-tailored health messages (Chua, Liberzon, Welsh, & Strecher, 2009; Chua et al., 2011; Wang et al., 2016) and have recently been linked to message-driven behavioral outcomes (Chua et al., 2011; Falk, Berkman et al., 2010; Falk, Berkman, Whalen, & Lieberman, 2011). Furthermore, emerging evidence points to the engagement of anterior cingulate and insular regions during the reception of naturalistic risk and health information (Schmälzle, Häcker, Renner, Honey, &

Schupp, 2013; Wang et al., 2013; Wang et al., 2016). These findings align well with previous research in cognitive, social, and affective neuroscience linking medial prefrontal, anterior cingulate, and insular cortices as well as the precuneus to the processing of self-relevant and emotionally salient stimuli (Amodio & Frith, 2006; Northoff et al., 2006; Seeley et al., 2007; Uddin, 2015). Finally, health message characteristics were also linked to activation in occipital visual (Langleben et al., 2009; Seelig et al., 2014) and inferior parietal brain regions (Wang et al., 2013), likely reflecting differences in attentional processing related to the format and content of the health message.

Most previous research on health message reception has focused on mean level BOLD signal changes. Whereas classical neuroimaging approaches prefer short, simplified stimuli, the inter-subject correlation (ISC) analysis technique can assess audience-wide brain responses towards complex and naturalistic stimuli (Hasson et al., 2004; Hasson et al., 2010). In particular, ISC analysis measures the similarity of fMRI time courses across individuals who are exposed to the same message and reveals where and to what extent message-evoked brain responses concur across receivers. For instance, Schmälzle and colleagues (2015) observed reliable differences in ISC for powerful political speeches in bilateral superior temporal regions and the medial prefrontal cortex, suggesting increased neural engagement across listeners. Furthermore, a recent ISC-study in the health domain examined the reception of an H1N1 documentary that aired on national TV during the epidemic and provided evidence that ISC-coupling varied according to preexisting H1N1 risk perceptions (Schmälzle et al., 2013). This suggests that the ISC approach offers a way to reveal how health messages engage the brains of their target audiences. Importantly, ISC might differentiate between more and less effective health messages according to their ability to motivate recipients to process the information, a core variable in current models of effective persuasion and attitude change (Burnkrant & Unnava, 1995; Dillard & Peck, 2000; Petty, Brinol, & Priester, 2009; Tannenbaum et al., 2015).

The main goal of the present study was to reveal differences of more compared to less effective PSAs in the ability to evoke commonly shared neural processing in neural regions related to motivated stimulus processing. To this end, a large sample of anti-alcohol PSAs from German-speaking public media campaigns was collected. In a first study, ten of the most and ten of the least effective PSAs of this sample were characterized using three established self-report measures of effectiveness: ad effectiveness (Falk et al., 2012), perceived argument strength (Zhao et al., 2011), and perceived message sensation value (Palmgreen et al., 2002). In a second study, these PSAs were shown to young adults, while fMRI data was recorded. Young adults are a main target group of anti-alcohol campaigns, as around 40% of young men and around 30% of young women in Germany show risky alcohol use (Robert Koch-Institut, 2014). We hypothesized that both more and less effective health messages would prompt correlated neural processes across sensory regions. However, more effective health messages should also have greater impact on the audience and lead to enhanced inter-subject correlations of neural activity, particularly in regions associated with self-relevant information processing, emotional salience, and selective attention modulation.

Study 1 - Methods

Participants

93 introductory psychology students (M_{Age} = 22.02, SD = 7.36, 71 females, 80 reported drinking alcohol on regular base) participated for class requirements. Experiments were conducted in mixed-gender groups of 8 to 12 students, and experimental procedures were approved by the ethical committee of the University of Konstanz.

Materials

We screened online video resources and contacted health agencies to obtain a comprehensive sample of German-speaking public service announcements (PSAs) against risky alcohol use. This resulted in an initial database of 68 videos that aired on national television, the social web, and/or cinemas. The PSAs displayed typical contents of anti-alcohol health communication (see Supplementary Material, Table SM1). Exemplars with insufficient physical quality (e.g., resolution, sound) were removed during an initial screening by MI and RS in order to obtain a sample of 50 PSAs, which were then rated towards perceived message effectiveness by an independent sample (N = 9, M_{Age} = 24.1, SD = 4.51, 3 females, 6 reported drinking alcohol). Based on these ratings, we selected the 10 most and 10 least effective PSAs that were targeted at young adults and matched in length. These 20 videos were then resized to a 1280 x 720 pixels resolution, cropped in length to match a multiple of the 2.5 s TR, and amended with a 2-second fade-in and fade-out transition. The sound level was normalized. The mean length of the more and the less effective PSAs did not differ (M_{More} = 58.5 s, SD = 25.93; M_{Less} = 49.5 s, SD = 25.00; t_{18} = .43, p = .8, n.s.).

Procedure

Participants viewed the video stimuli on individual computers equipped with headphones. The series of 20 PSAs was shown in randomized order using E-Prime software (Psychology Software Tools). Self-report ratings for each video were obtained directly after each PSA. The type of self-report varied between subjects, however, each participant evaluated all PSAs for her/his respective scale items. One group (N = 33) rated the PSAs on the 10-item self-report scale of ad effectiveness, including items such as whether a PSA is believable, powerful, or grabbed attention (Falk et al., 2012). A second group (N = 32) evaluated the PSAs on perceived message sensation value using a 17-item scale, including items related to physical characteristics of a message as well as dramatic impact, novelty, and emotional arousal (Palmgreen et al., 2002). A third group (N = 28) extracted the core argument of each PSA and evaluated it according to the perceived argument strength scale adapted from Zhao and colleagues (2011), including plausibility, convincibility, importance, and agreement with the arguments inherent in a message. The first group also evaluated the PSAs using one-item measures for perceived message effectiveness, perceived argument strength, physical production quality, and SAM scales for arousal and valence (Bradley & Lang, 1994).

Study 1 - Results and Discussion

The findings suggest pronounced differences in effectiveness among the large sample of health messages we obtained from authentic anti-alcohol campaigns. Considering established self-report scales, more as opposed to less effective PSAs were rated consistently higher regarding ad effectiveness, perceived message sensation value, or perceived argument strength (see Table 2.1). Furthermore, the analysis of single-item measures of perceived message effectiveness and perceived argument strength confirmed these findings, with significantly higher ratings for more compared to less effective PSAs. In addition, more effective messages were also seen as more arousing but did not differ in valence. Finally, more effective PSAs were perceived as being higher in production quality - albeit with smaller effect size. Inter-rater agreement was very high for all measures (*ICC*s: 0.87 - 0.97, two way random, absolute), suggesting high consistency for the rater's evaluations. Moreover, the same results were obtained when excluding all participants who did not report alcohol consumption on a regular base (N = 13). Overall, these findings support the a priori-categorization into more and less effective PSAs.

Table 2.1 | Self-report results of PSA Characterizations in studies 1 and 2: Mean ratings, statistical comparisons, effect sizes and inter-rater reliability

	Mean *(SD)*		*t* value	*p* value	Cohen's d	ICC [b]
	More Effective	Less Effective				
STUDY 1						
Scales						
Self-reported Ad Effectiveness [a] (N = 33)	6.10 (0.64)	3.81 (0.33)	10.02	< .001	4.50	0.97
Perceived Message Sensation Value (N = 32)	6.07 (0.98)	3.72 (0.64)	6.35	< .001	2.84	0.97
Perceived Argument Strength (N = 28)	6.15 (0.48)	4.58 (0.37)	8.26	< .001	3.66	0.94
Single Item Measures (N = 33)						
Perceived Message Effectiveness	6.61 (0.88)	2.97 (0.61)	10.76	< .001	4.81	0.97
Perceived Argument Strength	6.58 (0.85)	2.98 (0.74)	10.09	< .001	4.52	0.97
Arousal	4.73 (0.60)	3.14 (0.30)	7.47	< .001	3.35	0.89
Valence [a]	4.34 (0.91)	4.97 (0.45)	-1.98	.064	n.s.	0.87
Production Quality	6.68 (1.28)	4.44 (0.94)	4.48	< .001	2.00	0.96
STUDY 2						
Single Item Measures (N = 32)						
Perceived Message Effectiveness	6.51 (1.13)	2.78 (0.64)	9.14	< .001	4.06	0.98
Perceived Argument Strength	6.52 (1.21)	2.63 (0.54)	9.24	< .001	4.15	0.98
Arousal	4.65 (0.98)	2.53 (0.46)	6.19	< .001	2.77	0.95
Valence [a]	4.77 (0.95)	5.35 (0.39)	-1.78	.100	n.s.	0.87
Production Quality	6.75 (1.55)	4.76 (1.07)	3.35	.004	1.49	0.96

Notes. *P*-values were derived from two-sided, independent samples *t*-tests.
[a] Equal variances not assumed. [b] Intra-class correlation, two way random, absolute.

Correlation analysis of self-report measures suggested that scale and single-item measures share a substantial part of their variance. Specifically, the three scale and two single-item measures assessing effectiveness-related message characteristics were highly correlated (r's > 0.87, p's < 0.001). Also, the single-item measure of perceived message effectiveness was highly correlated with the established scales measuring ad effectiveness, perceived message sensation value and perceived argument strength (r's > 0.89, p's < 0.001), justifying its use in examining PSA effectiveness in the fMRI study (Study 2).

Study 2 - Methods

Participants

Thirty-six volunteers from 18 to 30 years of age participated in the study. Four participants were discarded due to excessive head movement, anatomical anomalies, or technical failure, resulting in a final sample size of 32 participants (16 females, $M_{Age} = 23.41$; $SD = 2.96$). All participants had normal hearing, corrected-to-normal vision, and no history of neurological diseases. Participants received course credit or monetary reimbursement. Consent was obtained according to the Declaration of Helsinki, and all procedures were approved by the local ethics committee.

Materials

We used the same 10 more and 10 less effective anti-alcohol PSAs described and characterized in Study 1 as stimulus materials.

Procedure

In a first session (T_1), we assessed fMRI eligibility and obtained self-report measures related to alcohol consumption, risk perception, and behavior. In the main experimental session, participants were asked to attentively view the 10 more effective and 10 less effective PSAs (ITI = 10 s, fixation on blank background). PSAs were presented in pseudo-randomized order, and scanning lasted approximately 45 minutes. Upon leaving the scanner, participants answered the same questionnaires on alcohol-related risk perceptions (T_2). Lastly, all PSAs were again presented to the participants and evaluated using the single-item measures established in Study 1, i.e., perceived message effectiveness, perceived argument strength, arousal, valence, and production quality. One week after the fMRI scan (T_3), participants were invited to answer an online questionnaire containing the same measures as the baseline assessment.

Self-reported alcohol consumption, risk perception, drinking intention, and drinking behavior

Alcohol consumption across the participants was assessed using the AUDIT alcohol screening questionnaire (range: 0 - 40; Babor, Higgins-Biddle, Saunders, & Monteiro, 2001). According to recommendations for the German population (Rumpf, Hapke, Meyer, & John, 2002), three-quarters of the participants showed a tendency towards risky drinking ($M_{\text{Audit}} = 6.41$; $SD = 3.55$; range: 1 - 17). Thus, the sample of young adults was a valid target audience for the anti-alcohol PSAs.

Risk perception and behavior concerning alcohol use were assessed using items adapted from previous work on health risk perception, i.e., baseline levels of alcohol consumption, risk perceptions, intentions, worries, and perceived pressure to change (Renner, 2004; Renner & Reuter, 2012; Schmälzle et al., 2013). There were mostly small, non-significant differences for most measures of risk perceptions when comparing baseline (T_1) and follow up (T_3) measurements. However, the pattern of results consistently suggested positive changes in risk behavior and perceptions concerning alcohol use, and participants reported a small reduction in drinking amount per drinking event ($t_{31} = 2.95$, $p < 0.01$, Cohen's $d = .52$). These results are consistent with what would be expected after a one-shot exposure to a mixed sequence of anti-alcohol PSAs.

MRI acquisition, preprocessing and analysis

MRI data was recorded using a Siemens Skyra 3T System equipped with a 20 channel head coil. Blood oxygenation level-dependent (BOLD) contrast was acquired during health message viewing using a T2*-weighted Fast Field Echo-Echo Planar Imaging sequence (80° flip angle, TR = 2500 ms, TE = 30 ms). Data was obtained in ascending-interleaved slice order (36 axial slices; no gap; FOV = 240 x 240 mm; 80 x 80 acquisition matrix, 3 x 3 x 3.5 mm voxel size).

560 functional volumes were acquired during the audiovisual stimulation. Field of View was adjusted to the AC-PC plane and tilted about 16° (Mennes et al., 2014). Structural images were obtained using a standard T1-weighted scan with 1 x 1 x 1 mm voxel size (FOV = 256 x 256 mm, 192 sagittal slices). Presentation software (Neurobehavioral Systems, Inc.) was used to present the PSAs and to synchronize MRI acquisition. PSAs were projected onto a translucent screen located in the back of the scanner bore. Participants viewed the stimuli via a mirror mounted to the head coil and heard the sound via MR-compatible headphones (MRConfon GmbH) that function optimally within the scanner bore.

Data was preprocessed and analyzed using the BrainVoyager 20 software package (BrainInnovation) and in-house MATLAB code (The MathWorks, Inc.). Functional data was corrected for slice scanning time using sinc-interpolation and corrected for 3D Motion (trilinear/sinc-interpolation). Participants exceeding 3 mm of head movement were excluded. Functional data was spatially smoothed (FWHM = 6 mm) and temporally filtered to remove linear trends and low-frequency shifts using a high pass-GLM-Fourier filter (up to 6 cycles). Functional and anatomical volumes were normalized into the Talairach coordinate system (Talairach & Tournoux, 1988). To compensate for psychological onset transients and signal saturation, the first six TRs were discarded prior to preprocessing. We extracted the single PSA data from the full time course with a shift of two TRs and thus compensated for the lag in hemodynamic responding. Based on visual inspection of the data, two initial TRs were discarded for each PSA to compensate for onset transients.

ISC analysis

Functional data was analyzed using the inter-subject correlation (ISC) approach (Hasson et al., 2004; Hasson et al., 2010), which assesses the voxel-by-voxel correlations between fMRI time courses from different individuals. Because all viewers are exposed to the identical material, ISC result maps provide a measure of the intersubjective similarity of continuous neural processing at the level of individual brain regions. A two-step analysis scheme was adopted in which we first assessed reliably correlated responses within each PSA. Towards this end, voxel-by-voxel ISC values were computed for the time courses of each single

PSA using the response time courses of each subject and the average time course of the rest of the group. After applying the Fisher *Z*-transformation to the individual coefficients, we calculated the average groupwise correlation coefficient *r* for each voxel. Statistical significance for the correlation coefficients was computed via a bootstrapping procedure: Using phase randomization, we generated 1000 phase-shifted bootstrapping time series for every empirical time course in every voxel. The empirical *r*-values were then compared against the obtained null distribution. This procedure was performed separately for all PSAs. This step yielded twenty correlation maps indexing reliable neural processing across participants within each PSA. Then, average correlation maps were calculated for all PSAs (Figure 2.1) as well as separately for more and less effective PSAs (Figure 2.2A). To correct for multiple comparisons, we used FDR correction with $q = 10^{-4}$ (Benjamini & Hochberg, 1995) and a cluster threshold of 50 mm^2.

In a second analysis step, we extracted the individual correlation values for each PSA and for each participant separately. Then, mean correlation values were calculated for the two PSA categories for each participant. For each voxel, this procedure resulted in two vectors containing the mean correlation values between one message recipient and the rest of the group for each of the PSA categories, respectively. These values were Fisher *Z*-transformed and submitted to a two-sided, dependent sample *t*-test on a voxel-by-voxel basis. This procedure reveals voxels exhibiting significant differences in ISC between the two PSA categories. As in previous research (e.g., Schmälzle et al., 2013; Cantlon & Li, 2013), ISC mean difference effects were corrected for multiple comparisons using FDR correction ($q = .05$, 50 mm^2 cluster threshold). Only voxels revealing reliable ISC for either the more or the less effective PSAs (one-sample *t*-test with $p < 10^{-5}$, uncorr.) were included in this analysis. The obtained clusters (Figure 2.2B) were labeled using a Talairach-transformed (Lancaster et al., 2007) maximum probability tissue atlas from the OASIS project (as provided in SPM12 by Neuromorphometrics Inc., under academic subscription). Figures were created using a Talairach-transformed anatomical rendering of the Colin27 Average Brain (Holmes et al., 1998).

Study 2 - Results

Perceived Message Effectiveness

As shown in Table 2.1, self-report measures confirmed the findings from Study 1. Most importantly, more compared to less effective PSAs were perceived as higher in perceived message effectiveness and perceived argument strength. Moreover, the self-report measures again showed a very high agreement between the raters (*ICC*s: 0.87 - 0.98).

Neural processing of Anti-Alcohol Public Service Announcements

Figure 2.1 illustrates the significant inter-subject correlation of spatiotemporal brain activity patterns for both more and less effective PSAs in medial cortical structures extending from anterior and posterior cingulate to the precuneus, and extended parietal cortices as well as to widespread posterior and temporal brain regions. These findings align well with previous research using naturalistic, audiovisual stimuli (Hasson et al., 2004; Hasson et al., 2010; Jääskeläinen et al., 2008; Schmälzle et al., 2013) and indicate that health messages collectively engage large-scale brain systems involved in visual, auditory, higher-order semantic, and attentional functions.

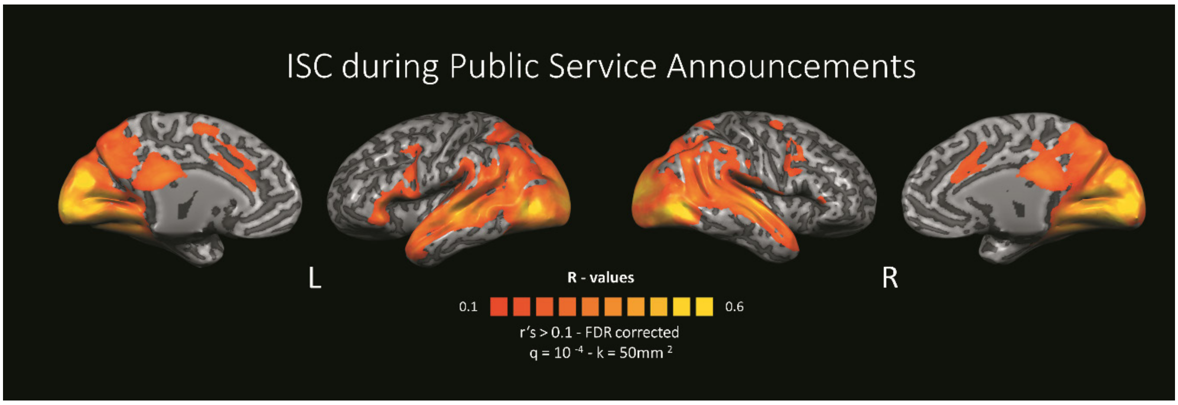

Figure 2.1 | Average inter-subject correlation (ISC) during all anti-alcohol PSAs. *Raw ISC values > 0.1 were displayed on an inflated, anatomical rendering of the Colin27 Average Brain (Holmes et al., 1998). Statistical values were FDR corrected with $q = 10^{-4}$, smoothed, and a voxel contiguity threshold of 50 mm^2 was applied. L = Left hemisphere, R = Right hemisphere.*

More vs. Less Effective Anti-Alcohol Public Service Announcements

We next compared the level of ISC during more vs. less effective PSAs to identify differences in health message reception according to PSA effectiveness. Figure 2.2A shows ISC during more and less effective PSAs separately, and Figure 2.2B reveals brain regions exhibiting significant ISC differences. As can be seen in Figure 2.2A, both categories engaged auditory and visual brain regions. However, marked differences in the relative spatial distribution of ISC are apparent: More effective PSAs elicited heightened ISC in dorsomedial prefrontal (dmPFC), precuneus, and posterior cingulate cortices. Moreover, significant differences were identified in bilateral insula extending to both inferior frontal and posterior insular cortices as well as the right anterior insula. Finally, enhanced ISC emerged for more effective PSAs in supramarginal and superior parietal regions, as well as bilateral occipital regions encompassing primary and extrastriate visual cortices.

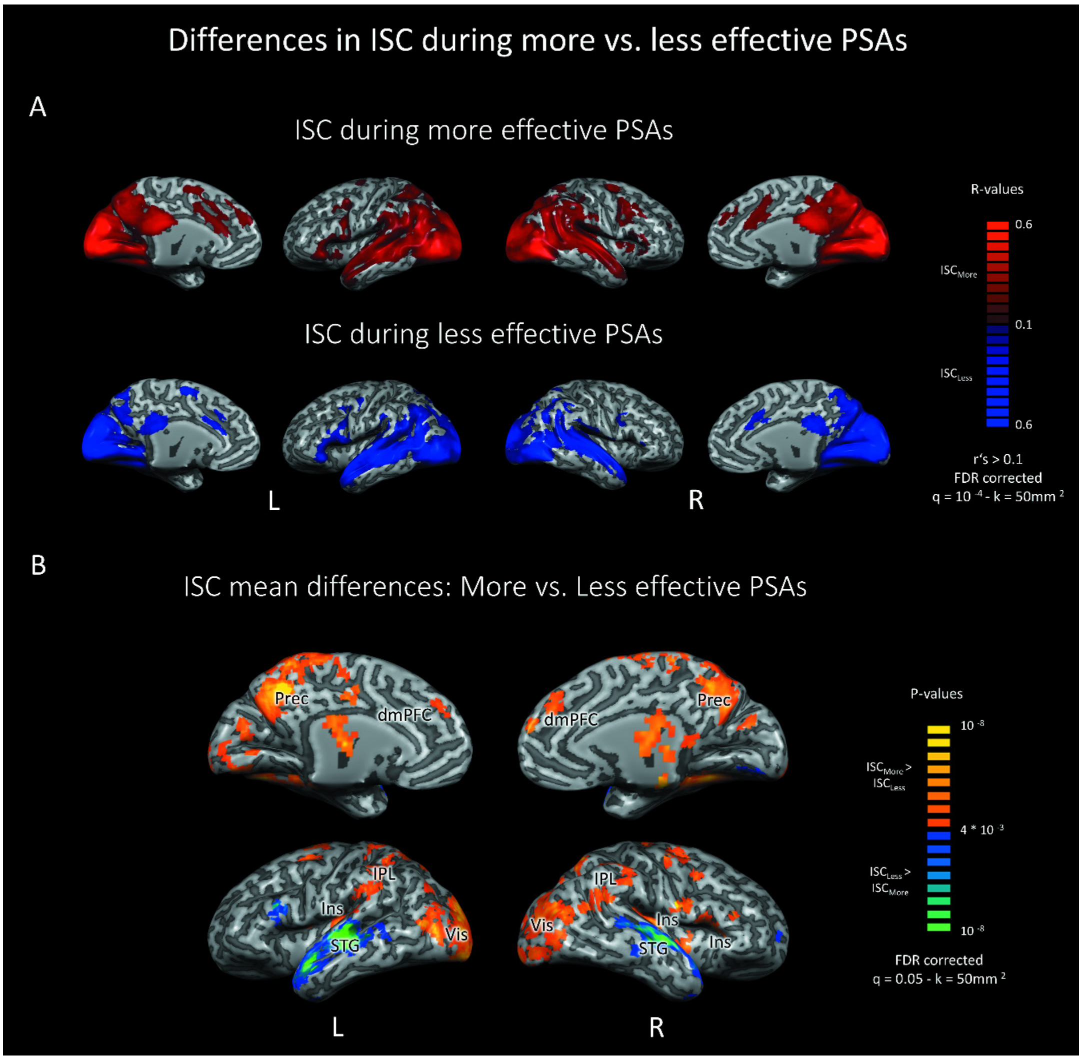

Figure 2.2 | Differences in inter-subject correlation (ISC) during more compared to less effective PSAs. *(A) The differential reach of ISC during more and less effective PSAs throughout the brain. Average raw ISC values > 0.1 were displayed for more (red) and less (blue) effective PSAs. FDR corrected with* $q = 10^{-4}$*. (B) Illustration of significantly higher ISC during more (red/yellow) vs. less (blue/green) effective PSAs. P-values were derived from two-sided, paired t-tests and FDR corrected with q = .05. All statistical values were overlaid onto a Talairach normalized, anatomical rendering of the Colin27 Average Brain (Holmes et al., 1998), and a voxel contiguity threshold of 50* mm^2 *was applied. L = Left hemisphere, R = Right hemisphere, dmPFC = Dorsomedial prefrontal cortex, Ins = Insula, IPL = Inferior parietal lobe, Prec = Precuneus, STG = Superior temporal gyrus, Vis = Visual system.*

The reverse pattern, i.e., larger ISC for less effective PSAs, was observed in temporal regions involved in auditory and language processing. This effect might be due to differences in the amount of spoken language in the PSAs. To test this hypothesis, we performed a control analysis that excluded all PSAs with more than two spoken sentences (2 more / 4 less effective PSAs). Limiting the analysis to these PSAs largely diminished the effect of heightened ISC in temporal regions for the less effective messages (see Supplementary Material, Figure SM1). Thus, larger ISC for less effective PSAs in these regions seems to depend mainly on the amount of spoken language. Furthermore, when controlling for the amount of speech, the finding of increased ISC for more compared to less effective PSAs was accentuated.

To address potential influences of familiarity with PSAs, we re-ran all analyses excluding PSAs that were recognized, as assessed during the post-scanning questionnaire. Three more effective PSAs were recognized by one to four participants each. Control analysis excluding these PSAs confirmed the main results (Supplementary Material, Figure SM 2).

General Discussion

A core ingredient of effective health messages is the ability to evoke recipients' attention and engage them in a self- and emotionally relevant fashion. Furthermore, to be able to evoke effects in large audiences, mass media-based health messages need to have mass appeal, i.e., they have to cater to the common denominator within a recipient group (Freimuth & Quinn, 2004). Here we employed ISC-fMRI to capture the degree of shared brain responses towards fully realistic health messages. The main finding is that effective PSAs about risky alcohol use prompt enhanced cross-recipient brain coupling in cortical midline regions (i.e., dmPFC and precuneus) as well as the insular, parietal, and occipito-temporal regions, known to be involved in the processing of self-relevant, emotional, and salient stimuli. These results suggest functional neuroimaging as a suitable measure for tracking the neural effects of health messages.

The present study shows that effective anti-alcohol messages prompted more similar neural responses across receivers' brains. This effect was particularly strong in regions of the cortical midline, encompassing the dmPFC and precuneus, two regions often implicated in the processing of narrative and social content (Ferstl, Neumann, Bogler, & Cramon, 2008; Mar, 2011). Other lines of research linked these regions to a general role in processing self-related stimuli (Amodio & Frith, 2006; Kelley et al., 2002; Northoff et al., 2006) and self-referential introspection (Gusnard, Akbudak, Shulman, & Raichle, 2001) as well as imagining personally relevant past and future episodes (Addis, Wong, & Schacter, 2007; D'Argembeau et al., 2010; Spreng, Mar, & Kim, 2009). Given this broad set of self-related functions, the heightened ISC in these regions for more effective PSAs may indicate stronger personal involvement, which may - according to the elaboration likelihood model of persuasion - prompt deeper engagement and elaborate message processing (Petty et al., 2009). The suggested role of personal or self-relevance for effective health messaging is also supported by research showing stronger activity in the mPFC and precuneus for self-tailored compared to less or untailored anti-smoking and safer sex messages (Chua et al., 2009; Chua et al., 2011; Wang et al., 2016). Our findings also coincide with work that suggests the dmPFC as part of a neural network related to persuasion (Falk, Rameson et al., 2010). Overall, we suggest that effective health messages lead to deeper personal engagement across multiple viewers, as reflected by shared brain responses in cortical midline regions, which lastly might lead to persuasion.

Accompanying the effects in cortical midline regions, more compared to less effective PSAs also evoked stronger ISC in bilateral insulae. Recent work on the perception of health risk messages also found effects in the anterior insula (Schmälzle et al., 2013; Wang et al., 2013; Wang et al., 2016). For instance, enhanced ISC in the anterior insulae during an H1N1 documentary was linked to risk perception (Schmälzle et al., 2013). Moreover, activations in the anterior insula also varied with HIV risk perceptions towards unacquainted persons (Häcker et al., 2015), and were modulated by anti-smoking health messages (Wang et al., 2013). Similarly, the insula, and especially the anterior insula, is consistently observed in studies on emotionally salient stimulus processing, and has been suggested as a hub regulating attention and working memory processes (Menon & Uddin, 2010). According to these findings, effective PSAs appear to evoke similar signals across viewers in regions involved in saliency, attention, and working memory. While our findings align with the suggested role of the insula in switching between large-scale networks, future research using, e.g., dynamic connectivity (Bassett, Yang, Wymbs, & Grafton, 2015; Fornito, Zalesky, & Bullmore, 2016) and inter-subject functional correlation methods (Simony et al., 2016) is needed to determine the interplay of systems involved in saliency and self-relevance processing with sensory-perceptual systems.

In line with the notion that effective messages engage the brains of their recipients more consistently, we also found differences between more and less effective PSAs in regions involved in attention regulation and expression. Specifically, stronger ISC effects for more effective PSAs were seen in extended regions of the inferior and superior parietal cortices, overlapping the dorsal and the ventral attention networks (Corbetta & Shulman, 2002; Fox, Corbetta, Snyder, Vincent, & Raichle, 2006). Furthermore, more effective PSAs also evoked stronger ISC in occipital visual and adjacent parietal regions, presumably reflecting increased visual attention. This interpretation is supported by research showing increased activations in visual-associative regions towards emotional images, e.g., mutilation and injury (Junghöfer, Schupp, Stark, & Vaitl, 2005; Lang & Bradley, 2010; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005). Overall, our results suggest that the PSAs that were more effective in drawing visual attention were also evaluated as being more effective by both independent raters as well as those whose brains we scanned.

The current findings are compatible with models of persuasion, such as the elaboration likelihood model (ELM, Petty & Cacioppo, 1986), the extended ELM (Slater, 2002), and fear appeal messaging more broadly (e.g., Tannenbaum et al., 2015; Witte & Allen, 2000). For instance, the increased ISC in the dorsomedial prefrontal cortex for more effective PSAs might relate to higher personal relevance, a key variable for elaborate stimulus processing in the ELM (Petty et al., 2009). Similarly, increased ISC in regions of the saliency network and in visual-associative brain regions suggests attentional tuning and deeper message processing. Typical of the genre, the anti-alcohol PSAs employed in this study mostly presented their message via short stories (see Supplementary Material, Table SM1) that vividly exemplify the risks of alcohol consumption (Zillmann, 2002). Furthermore, research on narrative transportation has shown that attentional tuning is accentuated when negative outcomes (e.g., harm, injury) are emphasized (Bezdek & Gerrig, 2017), which is also compatible with the finding of enhanced ISC across viewers during effective PSAs. The anti-alcohol messages in the present study revealed large differences not only in terms of perceived message effectiveness, but also for other message characteristics. Thus, more work is needed to disentangle the effects of individual message characteristics on message effectiveness as well as on measures of collective neural engagement. Furthermore, the more effective messages often contained several features at once (e.g., dramatic images, narratives, or highlighting negative consequences). This makes it difficult to identify which features make a health message more effective, and features may likely interact and have gestalt-like, emergent effects. In addition, while our sample of college students is an important target audience for anti-alcohol PSAs, this homogeneity naturally also limits generalizability. The study of larger samples could not only increase confidence but could also reveal group differences based on attitudes, intentions, and behaviors. Specifically, future work might follow up on existing research (Schmälzle et al., 2013; Weber et al., 2015) and examine whether participants who do or do not engage in a risk behavior also respond more similarly to messages or specific elements therein. In sum, more work is needed to examine causes, mechanisms, and consequences of health messages, and emerging work in the area of health prevention neuroimaging has begun to address these issues (e.g., Cooper, Tompson, O'Donnell, & Emily, 2015; Langleben et al., 2009; Schmälzle et al., 2013; Weber et al., 2015).

We propose that the brain responses to effective messages are likely precursors of shifts in risk perception. Theoretical accounts of health risk perception make an important distinction between the general awareness of a risk and personal risk perception (Renner et al., 2015). While the former represents probabilistic knowledge or factual information that is not necessarily action-relevant or remains detached from experience, the latter seems to be what drives preventive efforts by fostering feelings of being personally at risk (Renner & Schupp, 2011; Schmälzle et al., 2011; Slovic & Peters, 2006; Weinstein, 1989). Such an authentic sense of vulnerability could be achieved by effective messages that are attended, deeply processed, and accepted by the receiver. We suggest that larger ISC during highly effective anti-alcohol PSAs in neural regions associated with self-relevance and risk perception (i.e., dmPFC, precuneus, and insula) might index such a proximal form of message success. Once this is achieved, it should also be more likely for the message to have distal effects, i.e., changes in risk perception and behavior. Thus, neural effects within midline regions and the insula might indicate whether a message „got under the skin" and successfully engaged processes related to risk perception or affect more broadly. Related to this issue, recent research showed that mPFC-activity in response to health messages can predict behavior change such as smoking or sunscreen use (Chua et al., 2009; Chua et al., 2011; Cooper et al., 2015; Falk, Berkman et al., 2010; Falk et al., 2011). Furthermore, a growing body of evidence suggests that large scale population effects can be predicted by neural activity of small-scale target audiences in regions similar to those found in the current study (Falk et al., 2012; Falk et al., 2016). As is often the case, no metrics related to population-level effectiveness were available for the present set of public health campaigns (e.g., Noar, 2006). Thus, future research needs to explore whether effective messages that achieve greater „neural reach" within a sample audience also have greater „mass reach" in the public. Given the advantage of ISC to capture neural responses to content-rich audiovisual PSAs, typically used in health prevention, expanding on the present work may lead to the development of fMRI-based signatures of message effectiveness (cf. Wager et al., 2013). Specifically, to the extent that we can differentiate signatures of more from less effective messages, we might also invert this model and attempt to forecast whether new messages will "catch on."

To conclude, we demonstrate collective-level brain effects of effective health messages about the risks of alcohol on a group of young adults. The main finding is that more compared to less effective health messages evoke more consistent neural responses in brain regions implicated in self-relevant and emotional processing as well as the modulation of attention. Increased ability to capture the dynamic engagement of audiences in health-related PSAs will promote a better understanding of the mediating mechanisms between message exposure and subsequent effects. As such, assessing the „neural reach" of mass media campaigns within recipients contributes to the emerging field of communication neuroscience (Falk, 2010) at the intersection of communication, health, and neuroscience.

3

Strong health messages increase audience brain coupling

Martin A. Imhof [1 3], Ralf Schmälzle [1 2], Britta Renner [1 3], Harald T. Schupp [1 3]

[1] Department of Psychology, University of Konstanz, Konstanz, Germany
[2] Department of Communication, Michigan State University, East Lansing, USA
[3] Centre for the Advanced Study of Collective Behaviour, University of Konstanz, Konstanz, Germany

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Abstract

Mass media messaging is central for health communication. The success of these efforts, however, depends on whether health messages resonate with their target audiences. Here, we used electroencephalography (EEG) to capture brain responses of young adults - an important target group for alcohol prevention - while they viewed real-life video messages of varying perceived message effectiveness about risky alcohol use. We found that strong messages, which were rated to be more effective, prompted enhanced inter-subject correlation (ISC). In further analyses, we linked ISC to subsequent drinking behavior change and used time-resolved EEG-ISC to model functional neuroimaging data (fMRI) of an independent audience. The EEG measure was not only related to sensory-perceptual brain regions, but also to regions previously related to successful messaging, i.e., cortical midline regions and the insula. The findings suggest EEG ISC as a marker for audience engagement and effectiveness of naturalistic health messages, which could quantify the impact of mass communication within the brains of small target audiences.

Keywords

Inter-subject correlation; ISC; EEG; fMRI; Health messages; Alcohol

Introduction

Mass media health campaigns are essential to promote public health. By using mass media, health agencies can reach millions and deliver messages about health risks and desired target behaviors (Rice & Atkin, 2013; Wakefield et al., 2010). A health issue, for which this strategy is common, is risky drinking, a significant problem among young adults and college students in particular (Karam et al., 2007; Slutske, 2005; Wicki et al., 2010). Typically, engaging audiovisual formats and mini-stories are used to make messages salient and increase personal risk perception, but many questions remain about how these messages affect recipients. Neuroimaging is particularly well suited to examine the reception process (Falk, 2010; Falk et al., 2015; Falk et al., 2016; Huskey, Mangus, Turner, & Weber, 2017; Wang et al., 2013; Weber et al., 2015). A promising approach to examine and quantify how audiences respond to dynamic real-life health messages, as for example, videos, is the inter-subject correlation analysis (ISC). In brief, ISC measures the consistency of message-evoked brain responses across recipients, which yields a continuous, nonverbal measure of collective engagement that is well suited to quantify the impact of mass media messages at the neural level (Hasson et al., 2004; Hasson et al., 2010; Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012).

Previous work using this approach, mostly within fMRI research, demonstrated that manipulations of attentional and semantic variables influence the level of ISC across messaging contexts ranging from political rhetoric, to interpersonal communication, and to movie viewing (Hasson, Landesman et al., 2008; Hasson et al., 2012; Lahnakoski et al., 2014; Schmälzle et al., 2015; Silbert, Honey, Simony, Poeppel, & Hasson, 2014; Stephens, Silbert, & Hasson, 2010). For example, using fMRI, Schmälzle et al. (2015) revealed enhanced ISC to political speeches, which were perceived as powerful and engaging. Within the context of health and risk communication, two recent fMRI studies underscore the potential of the ISC approach for audience response measurement: The first study examined the reception of a 30-min documentary on the outbreak of the H1N1 swine flu virus that aired on national TV during the pandemic. The study revealed that the strength of fMRI-ISC in the anterior cingulate cortex depended on viewers' level of risk perception (Schmälzle et al., 2013). The second study showed that the strength of ISC is related to the effectiveness of health messages (Imhof, Schmälzle, Renner, & Schupp, 2017). Specifically, comparing fMRI-ISC during the perception of strong and weak health messages, as defined by perceived message effectiveness in an independent sample, revealed enhanced ISC to strong messages in the dorsomedial prefrontal cortex, precuneus, and the insulae. These studies illustrate the potential of an ISC-based neuroimaging approach to assessing the reception of health messages with a focus on audience-wide responses that are critical for successful mass communication.

Here, we were interested in determining whether electroencephalography (EEG), for which a comparable ISC-based approach has been proposed (Cohen & Parra, 2016; Cohen et al., 2017; Dmochowski et al., 2012; Dmochowski et al., 2014; Parra et al., 2018), can serve as a measure of audience engagement for health messages. One of the most important advantages of EEG is its temporal resolution, which ranges on the order of milliseconds. Thus, it complements hemodynamic measures, which offer a good spatial but limited temporal resolution. Such a high temporal resolution is promising for characterizing the reception process of fast-paced audiovisual prevention messages, which often last only half a minute or less. Further benefits of EEG are its more accessible nature and relative cost-effectiveness. These characteristics enhance the scalability and thus the translational potential of integrating neuroscientific methods into message pre-testing, for example, during the formative stages of a health campaign. Indeed, recent EEG studies in classroom settings, the cinema, or during music consumption illustrate this potential (Barnett & Cerf, 2017; Cohen et al., 2018; Dikker et al., 2017; Madsen et al., 2019; Poulsen et al., 2017).

The main goal of the present study was to determine whether EEG-ISC can robustly differentiate between strong and weak health messages and thus may serve as a possible marker of successful messaging. To obtain a sample of strong and weak messages, we screened German-speaking prevention campaigns on risky alcohol use. The video health messages obtained from this work were screened in terms of perceived message effectiveness, a widely used measure in health communication (PME; Dillard & Peck, 2000; Dillard et al., 2007). The messages revealed pronounced differences in perceived message effectiveness as well as other self-report measures of message characteristics (for details, please see section "Stimulus material" or Imhof et al., 2017). Based on our previous work, we selected ten of the most and ten of the least effective video health messages to form strong and weak health message categories, respectively. Dense sensor EEG was continuously recorded while participants viewed the messages. We then identified correlated components in the EEG signal to quantify the strength of ISC across the audience (Dmochowski et al., 2012; Parra et al., 2018) and to compare the strength of inter-brain coupling during the reception of strong and weak messages. To determine the robustness of the findings, viewing conditions were varied between a free viewing task that resembled real-life viewing conditions and a rating task in which participants evaluated each message's effectiveness. Previous work suggested ISC as a proximal marker of audience engagement, due to attentional or relevance-based factors (Cohen et al., 2017; Dmochowski et al., 2012; Hasson et al., 2012; Imhof et al., 2017; Ki et al., 2016; Schmälzle et al., 2013). In addition, theories of media effects and persuasion assume that selective attention and elaborated processing of a message is crucial for changing attitudes or behavior - and can be brought out for instance by issue involvement, emotion, or personal relevance (e.g., Greenwald & Leavitt, 1984; McGuire, 2013; Petty & Cacioppo, 1986; Petty et al., 2009). Accordingly, we hypothesized that the degree to which recipients' brains respond similarly should be enhanced for strong as compared to weak health messages.

In a second line of analyses, we used both the acquired EEG-ISC and secondary fMRI data to identify the possible origin of the identified correlated components (see Dmochowski et al., 2014 - for a similar approach). In this analysis, fluctuations in ISC measured using EEG over the course of watching the health messages are used as predictors for functional imaging data, which was collected in a second, independent sample viewing the same messages. One goal of this analysis was to identify which correlated EEG components show ISC primarily driven by visual-auditory stimulus characteristics. In addition, we assumed that distinct components can be related to the engagement of brain regions involved in personal relevance, affect, and attentional processes, which are thought to be critical for effective health communication (e.g., Petty et al., 2009; Schmitz & Johnson, 2007). Accordingly, a further goal of this analysis was to test the hypothesis that a subset of correlated components has neural generators in higher-order cortical midline regions and the insula, which have been previously linked to affective- and self-relevant processing of health-related messages (e.g., Imhof et al., 2017; Schmälzle et al., 2013). Moreover, message-evoked brain responses have been used to predict subsequent behavior change, such as smoking cessation or sunscreen use (Chua et al., 2009; Chua et al., 2011; Cooper et al., 2015; Falk, Berkman et al., 2010; Falk et al., 2011). Thus, we additionally assessed changes in participants' drinking behavior over a four-week follow-up period. Using this data, we explored the hypothesis that EEG-ISC during health message exposure as well as self-report measures of risk perceptions and intentions to change behavior are related to changes in drinking behavior.

Material and methods

Participants

Thirty-two participants were recruited at the local university (16 females; between 18 and 34 years old, $M_{\text{Age}} = 22.69$, $SD = 4.32$). All participants had normal hearing, normal or corrected-to-normal vision and no history of neurological or psychological diseases. One participant did not complete the four week follow up questionnaire. To be eligible for the study, participants had to report drinking amounts of at least four alcoholic beverages per week. Five additional participants were excluded due to technical failure or not fulfilling inclusion criteria (e.g., minimal drinking behavior or participation in earlier studies using a similar stimulus set). Excluded participants were not analyzed and immediately replaced to allow the full predetermined sample size. We assessed the participants' drinking behavior using the AUDIT alcohol screening questionnaire (range: 0 - 40; Babor et al., 2001). All participants exhibited risky drinking patterns ($M_{\text{Audit}} = 11.31$; $SD = 4.61$; range: 5 - 24) according to a cut off recommendation for the German population (Rumpf et al., 2002). Participants received either course credit or monetary reimbursement. Written informed consent was obtained according to the Declaration of Helsinki, and all procedures were approved by the ethics committee of the University of Konstanz.

Stimulus material

A sample of fifty German-speaking video health messages against risky alcohol use served as a database from which the 10 of the most and 10 of the least effective messages were selected to form a strong and a weak message category. Length of the messages varied between 20 and 110 s and did not differ between the two categories (M_{Strong} = 58.5 s, *SD* = 25.93; M_{Weak} = 49.5 s, *SD* = 25.00; $t(18) = .43$, *n.s.*, independent samples *t*-test, two-sided). These messages are the same as in our previous research using fMRI, and a more detailed description can be found in Imhof et al. (2017). The video health messages obtained from this work were screened in terms of perceived message effectiveness (PME; Dillard & Peck, 2000; Dillard et al., 2007). The messages revealed pronounced differences in the previous work with respect to PME which was probed using single-item measures as well as questionnaires on ad effectiveness (Falk et al., 2012), perceived argument strength (Zhao et al., 2011), and perceived message sensation value (Palmgreen et al., 2002). As expected, assessing the current test audience's single-item evaluation of perceived message effectiveness confirmed the distinction into strong as compared to weak videos (M_{Strong} = 4.88, *SD* = .98; M_{Weak} = 2.18, *SD* = .46; $t(18) = 7.89$, $p < .0001$; $d = 3.53$, calculated using pooled *SD;* 95%-CI = 1.98 - 3.42; independent samples *t*-test, two-sided). Furthermore, the single-item PME ratings collected within the current EEG test audience were highly correlated to the ratings collected within the previous fMRI audience (Spearman's rank correlation coefficient $\rho = .96$, $p < .0001$).

Stimulus feature extraction and comparison across video categories

In order to assess whether the two categories of video health messages differed with regard to physical features, we assessed changes in video luminance, optical flow, and sound envelope for each of the videos. Analyses were conducted using the Computer Vision System Toolbox implemented in MATLAB. All videos were converted to greyscale by calculating the weighted sum of the R, G, and B components of each pixel. Then, stimulus features were extracted for each video frame: Luminance changes were extracted by calculating the squared difference in pixel intensity from one frame to the next and then averaged across pixels. Optical flow was computed using the Horn-Schunck method as implemented in the MATLAB Computer Vision System Toolbox. For each frame, the average across pixels of the magnitude of the optical flow vectors was calculated. As in Dmochowski et al. (2018), the sound envelope was computed as the squared magnitude of the Hilbert transform of the soundtrack accompanying the respective video health message. The extracted envelope was then downsampled to the video frame rate.

To match the resolution of the EEG-ISC, all stimulus feature time courses were smoothed using a 2 s Gaussian window and resampled to match the resolution of the ISC time course (2 s sliding window, 0.25 s increments) and *z*-scored. Finally, to assess whether frame-to-frame fluctuations of the physical stimulus features differ across video categories and to quantify the change over time for each stimulus feature, we compared the per-video averages (across samples) of the half-wave rectified time course of the first derivative, i.e., the absolute value of the derivative at a given sample point. In order to perform a sensitive comparison across video categories, we compared the measures across categories using two-sided, uncorrected independent samples *t*-tests. There were no differences across video categories (p = .679 - 0.367, $t(18)$ = .42 - 0.93). Box plots visualizing the average change of stimulus features as well as exemplary excerpts of the stimulus feature time courses for luminance changes, optical flow, and sound envelope are shown in Supplementary Figure SM 1.

Procedure

Prior to the experiment (t_1), we assessed EEG eligibility and collected alcohol-related self-report measures of drinking behavior and risk perceptions. In the main session (t_2), health messages were presented in a pseudo-randomized order, alternating between strong and weak exemplars. Videos were presented twice either in "forward" (A-B-C-…) or "reversed" order (…-C-B-A). Presentation software (Neurobehavioral Systems, Inc.) was used to present the video health messages and to synchronize EEG acquisition. Videos were shown with a resolution of 800 * 450 pixels on a 27" flat screen monitor, located approximately 105 cm in front of the participant (~7.64° visual angle vertically). Sound was delivered via speakers inside the shielded chamber. A three-second video fixation was presented prior to each health message. In the "free viewing" block, participants were asked to attentively view the health messages, without any further task instruction. After each video, a blank screen (ITI = 5 s) was presented. In the "rating task" block, participants were asked to evaluate the health messages using a single-item measure of perceived message effectiveness on a seven-point scale. After logging the rating, a blank screen (ITI = 3 s) was presented. There was no difference for average rating time across health message categories (M_{Strong} = 3.44 s, *SD* = .37; M_{Weak} = 3.65 s, *SD* = .34; $t(18) = -1.38$, $p = .18$, *n.s.*, two-sided independent samples *t*-test). Order of task (free viewing vs. rating task), as well as the order in which the video health messages were presented (forward vs. reversed), was counterbalanced across participants. Overall, EEG measurements lasted for approximately 50 minutes with a short pause during the runs to allow for refreshment and re-measuring of electrode impedances. Self-reported risk perceptions related to alcohol were collected after the EEG session (t_2) and, using an online questionnaire, four weeks later (t_3). Additionally, in the follow up questionnaire, we again assessed drinking behavior and risk perceptions using the same items from the baseline measure at t_1. With the exception of one, all participants completed the four week follow up questionnaire (average interval between t_2 and t_3: 29 days, *SD* = 3.4). As in previous work, risk behavior and perceptions concerning alcohol use were assessed using self-report, i.e., detailed alcohol consumption, intentions, worries, perceived pressure to change behavior or perceived health threat (Imhof et al., 2017; Renner, 2004; Renner & Reuter, 2012; Schmälzle et al., 2013).

EEG acquisition and preprocessing

EEG and EOG scalp potential fields were measured with a 256-channel geodesic sensor net (EGI: Electrical Geodesics Inc., Eugene, OR, USA), sampled at 1000 Hz and on-line band-pass filtered from .01 to 400 Hz using EGI Geodesic amplifiers and Netstation acquisition software. Electrode impedance was kept below 40 kΩ, as recommended by EGI guidelines for this type of EEG amplifier. Data was recorded continuously with the vertex sensor (Cz) as reference electrode.

Data segments corresponding to the duration of each video health message were extracted using the open source signal processing toolbox FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011). Offline preprocessing of EEG and EOG data was conducted based on prior work (e.g., Cohen & Parra, 2016; Dmochowski et al., 2012; Parra et al., 2018). Specifically, EEG and EOG data were high-pass (0.5 Hz, Butterworth 6^{th} order; forward/reverse) and notch filtered (50 Hz, Butterworth 4^{th} order; forward/reverse). Eye movement artifacts were corrected by linearly regressing the EOG channels (EGI channels: 1, 10, 18, 25, 31, 32, 37, 46, 54, 226, 230, 234, 238, 241, 244, 248 & 252) from the EEG channels. Outlier samples were identified in each channel (magnitude exceeded four times the distance between the 25^{th} and the 75^{th} percentile of the signal). Samples 40 ms before and after outliers were replaced with zero values. Electrode channels with high variance (magnitude exceeded three times the distance between 25^{th} and 75^{th} percentile) were identified and replaced with zero values. These artifact rejection procedures were performed to discount outlier samples and channels in the subsequent calculation of covariance matrices and were used due to the sensitivity to outliers of the covariance matrices used in the ISC computation (see also Cohen & Parra, 2016; Dmochowski et al., 2012; Parra et al., 2018).

EEG-ISC analysis

EEG-ISC analysis was conducted based on the open source code developed by Parra and colleagues (available at http://www.parralab.org/isc/). Specifically, maximally correlated components were calculated, which represent linear combinations of scalp sensors revealing maximal correlation across viewers. In contrast to a voxel-by-voxel approach, which is often used in fMRI-ISC analyses, the correlated components are calculated via signal decomposition. This spatial filtering enables to detect large-scale activity patterns which otherwise could remain unnoticed using a sensor-by-sensor approach (Dmochowski et al., 2012). To obtain unbiased estimates, correlated components were calculated using within- and between-subject covariance matrices that were averaged across all videos and viewings. Based on inspection of the eigenvalue distribution (Supplementary Figure SM 2) and previous work (e.g., Cohen & Parra, 2016; Dmochowski et al., 2012), we extracted four components that captured most ISC. As in previous work, we visualize the spatial distribution of the components (Figure 3.1a) by calculating the "forward models", representing the covariance between a component's activity and the activity at each sensor (Cohen & Parra, 2016; Dmochowski et al., 2012; Haufe et al., 2014; Parra, Spence, Gerson, & Sajda, 2005). To analyze experimental effects, EEG-ISC - as captured by the four components - was extracted for each video, the two task conditions, and each participant separately. Subsequently, ISC was averaged across strong and weak videos. Two-sided, paired-samples *t*-tests were used to assess the main hypothesis of enhanced EEG-ISC for strong compared to weak health messages (Figure 3.1b). Bonferroni correction was used to account for multiple comparisons. Confidence intervals, as well as effect sizes, are reported in Supplementary Table SR 1. For paired-samples *t*-tests, reported effect sizes represent Cohen's d_z, calculated as the standardized mean difference effect size (Lakens, 2013).

In order to assess possible task and order effects, we submitted the EEG-ISC values for each component to four separate mixed repeated measures analysis of variance (ANOVA). Beside the within-subjects factor "Video Category" (strong/weak), we included the within-subjects factor "Condition" (rating task/free viewing) and the between-subjects factor "Order" (rating task followed by free viewing/free viewing followed by rating task) to test for possible influences due to the rating task and/or repeated viewings. Statistical analyses were conducted using jamovi software version 1.0.4.0 (https://www.jamovi.org/), R version 3.6.1 (https://www.r-project.org/), and the R packages "afex" (https://cran.r-project.org/package=afex) and "emmeans" (https://cran.r-project.org/package=emmeans).

Relating EEG-ISC to neural activation in independent functional neuroimaging data

In a second stream of analyses we calculated the EEG-ISC over time for each video and each of the components (2 s sliding window, 0.25 s increments). These ISC time courses were then used to predict neural activity measured in a second, independent target audience using fMRI. The fMRI data was taken from previous work in which an additional 32 participants (16 females, M_{Age}= 23.41; SD = 2.96) viewed the same alcohol prevention videos while neural data was acquired using a Siemens Skyra 3T MRI System (for details, see Imhof et al., 2017). Blood oxygenation level-dependent (BOLD) signal was acquired using a T_2*-weighted Fast Field Echo-Echo Planar Imaging sequence (TR = 2.5 s, TE = 30 ms, ascending-interleaved slice order, 36 axial slices; no gap; FOV = 240 x 240 mm; 3 x 3 x 3.5 mm voxel size). 560 functional volumes were acquired during the audio-visual stimulation, and scanning lasted approximately 45 minutes. Structural images were obtained using a T_1-weighted scan (1 x 1 x 1 mm voxel size, FOV = 256 x 256 mm, 192 sagittal slices).

Neuroimaging data was preprocessed and analyzed using the BrainVoyager 20.4 software package (BrainInnovation). Functional data was corrected for slice scanning time (sinc-interpolation) and corrected for 3D Motion (trilinear/sinc-interpolation). The functional data was spatially smoothed (FWHM = 6 mm) and temporally filtered to remove linear trends and low-frequency shifts using a high pass-GLM-Fourier filter (up to 6 cycles). Functional and anatomical volumes were normalized into the Talairach coordinate system (Talairach & Tournoux, 1988). As visualized in Figure 3.1, EEG-ISC time courses were extracted separately for each component and the first viewing of each video. For each of the four components, EEG-ISC time courses corresponding to the first viewing of each of the 20 videos were extracted separately. Then, these 80 time courses were each resampled to a 1 sec resolution and *z*-scored. For each component, the time courses of the 20 single videos were concatenated to serve as one parametric predictor in four separate general linear model (GLM) analyses. Periods of fixation and inter-stimulus intervals were modeled as zero estimates and included in the parametric regressors. Within each of the four multi-subject random effects GLM analyses we included the respective parametric regressor convolved with a default two gamma-HRF as implemented in BrainVoyager (time to response peak: 6 s, no shift) and default treatment for temporal autocorrelation (second-order autoregressive). Lastly, contrasts of parameter estimates were constructed as null hypothesis tests of the parametric regressor against zero (two-sided). To correct for multiple comparisons, we applied FWE correction ($p < 0.05$, whole brain) and a cluster threshold of 25 mm^2. All results shown in Figure 3.3, and Figure 3.4 are overlaid onto the left hemisphere of a Talairach-normalized, anatomical rendering of the

Colin27 Average Brain (Holmes et al., 1998). Right hemisphere results are very similar and are visualized in Supplementary Figure SR 2.

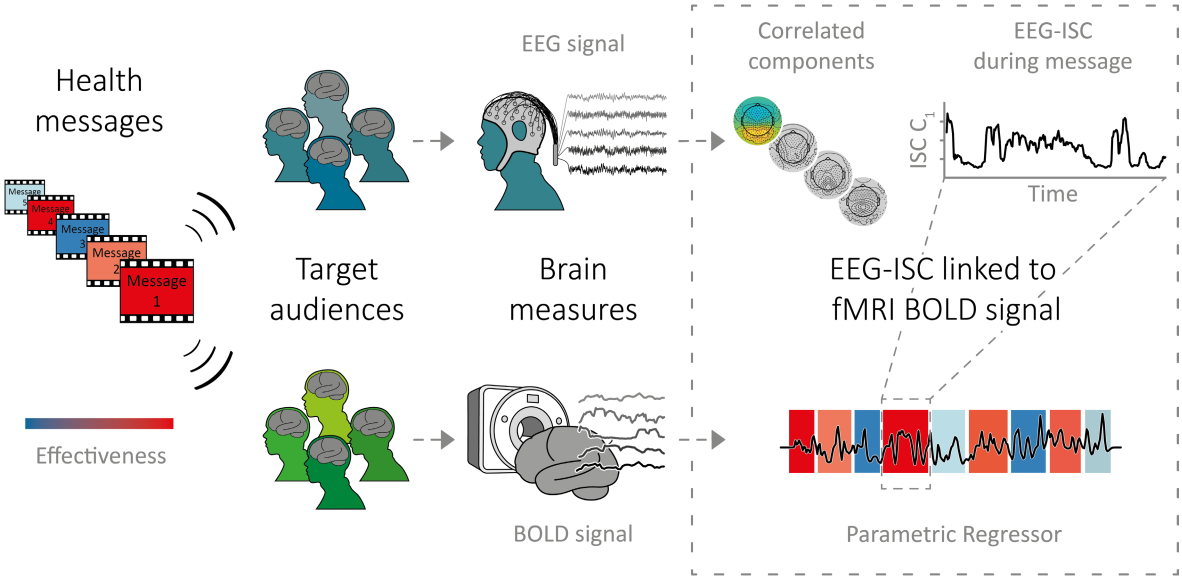

Figure 3.1 | Conceptual overview of the EEG-ISC informed fMRI analysis. *Brain responses of two independent audiences are obtained during watching real-life video health messages. Temporally highly-resolved EEG-ISC time courses are extracted for maximally correlated EEG components. The ISC time courses obtained from the EEG sample are then used as parametric regressors in a general linear model design modeling the BOLD signal within the whole brain. Crucially, the BOLD signal modeled in this design was obtained during message reception of the same video health messages within a second, independent sample of participants.*

To quantify the overlap between the current fMRI-GLM results and previous fMRI-ISC findings, we created statistical maps that include the voxels, which revealed a significant relationship to the parametric regressor of the respective correlated EEG component (as shown in Figure 3.3 / Figure 3.4a). Then, we combined the statistical maps previously published in Imhof et al. (2017), which include all voxels that revealed significant fMRI-ISC during either the strong or the weak messages (Figure 3.4b). Finally, we used these maps to determine the degree to which the voxels found in the EEG-ISC informed fMRI analysis revealed overlap with the combined fMRI-ISC map (Figure 3.4c).

Assessing changes in drinking behavior and their relations to EEG-ISC

We determined changes in alcohol consumption and risk perception following the exposure to the health messages using two-sided, paired-samples *t*-tests. Furthermore, multiple linear regression analysis was used to explore the ability of EEG-ISC to predict changes in subsequent drinking behavior. In two linear regression models, amount and frequency of drinking at follow up were dependent variables. The corresponding drinking measure at baseline, self-reported risk perceptions (worries, need to act, intentions and perceived health threat), as well as level of EEG-ISC, averaged across the 10 strong health messages for each of the components, were entered as independent variables (for the full model description, see Supplementary Table SR 6). We used R version 3.6.1 to create the multiple linear regression models and subsequently computed hierarchical linear regression to infer the amount of additionally explained variance for the predictors-of-interest, as reported in Table 3.1.

Results

Strong health messages prompt enhanced audience brain coupling

To examine the degree of inter-brain coupling within the audience prompted by strong compared to weak health messages, we exposed a test audience of 32 viewers to video health messages while measuring high-density EEG. In the current work, the video health messages were evaluated regarding perceived message effectiveness (PME; Dillard & Peck, 2000; Dillard et al., 2007) and other message-relevant constructs in previous work (Imhof et al., 2017; see section “Stimulus material” for details). Differences in effectiveness were confirmed in the present sample. ($M_{\text{Strong}} = 4.88$, $SD = .98$; $M_{\text{Weak}} = 2.18$, $SD = .46$; $t(18) = 7.89$, $p < .0001$; $d = 3.53$, independent samples t-test, two-sided).

In order to calculate inter-subject correlation (ISC) across viewers, we extracted the four most correlated components of the EEG data. Figure 3.2a visualizes which sensors contribute to the correlated components and reveals distinct topographies for each component using their forward projections. To confirm the hypothesis that strong compared to weak health messages prompt enhanced inter-brain coupling across the audience, we submitted the level of ISC to paired-samples t-tests, which confirmed the hypothesis for all identified components (C_1: $t(31) = 18.18$, $d = 3.21$; C_2: $t(31) = 4.14$, $d = .73$; C_3: $t(31) = 13.94$, $d = 2.46$; C_4: $t(31) = 9.15$, $d = 1.62$; all p‘s < .001, two-sided, Bonferroni corrected; for details, please see Supplementary Table SR 1).

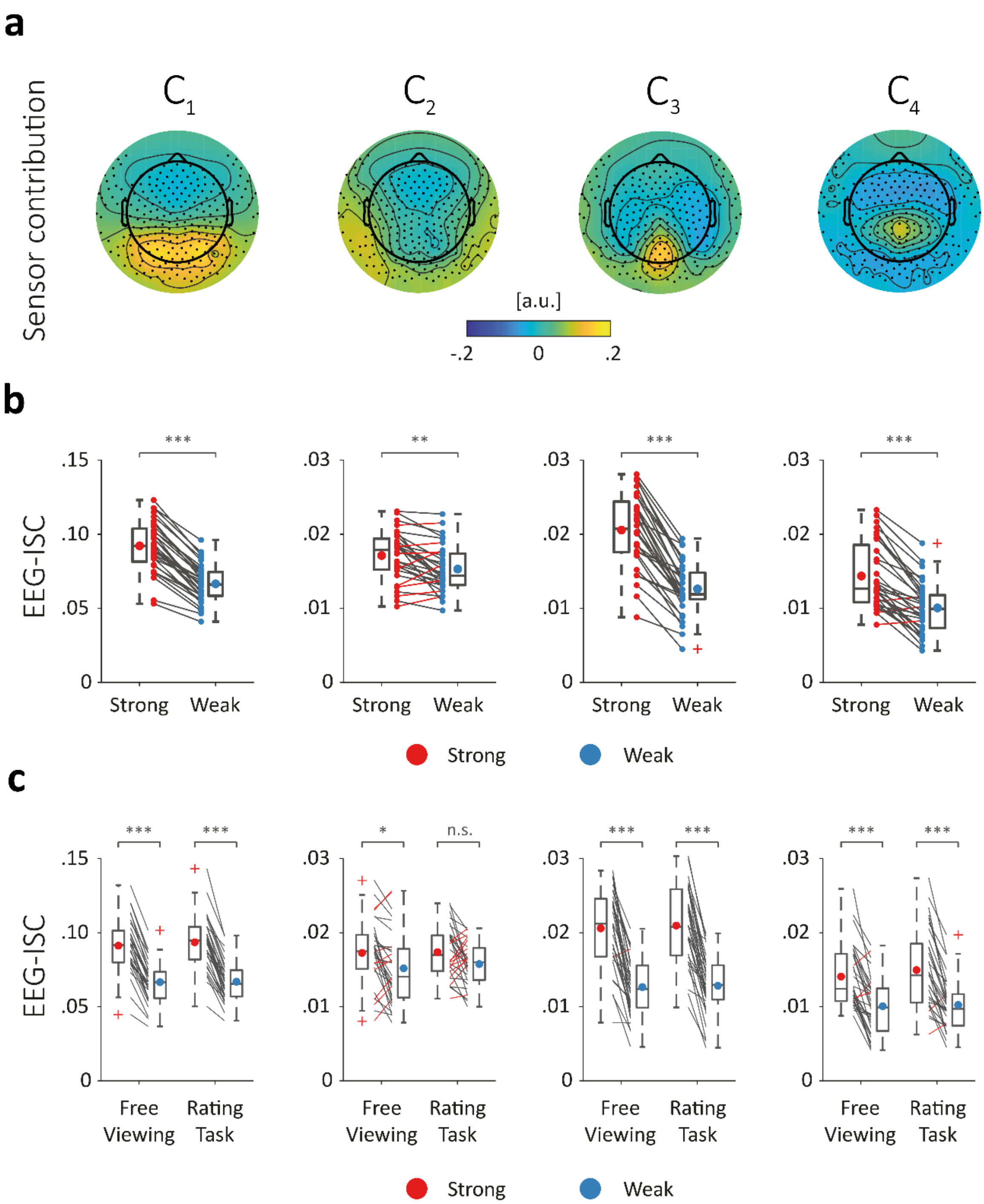

Figure 3.2 | Maximally correlated EEG components reveal differences in ISC during the viewing of alcohol prevention videos. *a) Topographical maps visualize the strength to which each sensor contributes to the correlated component. The maps reveal the contribution by showing interpolated magnitudes of the scalp projections, that is, the forward models of the maximally correlated components C_1 to C_4 (blue to yellow - arbitrary units, polarity of projections normalized). b) Box plots show average EEG-ISC for each component, separated by the message categories Strong (red) and Weak (blue). Connecting lines visualize paired measures for all 32 participants. Participants exhibiting a reversed pattern of results (ISC_{Weak} > ISC_{Strong}) are colored red. c) Stability of EEG-ISC differences is revealed by replicable differences when assessing the data on a more fine-grained level, i.e., during free viewing and a rating task.*

*Box plots show ISC for each component as a function of message category and viewing condition. Colored dots within box represent mean, center lines median, edges represent the 25th & 75th percentiles and outliers are marked by a red cross. For descriptive purposes, significance of paired samples t-tests comparing the two video categories are shown for each experimental cell (*p < .05, **p < .01, ***p < .001; Bonferroni corrected).*

As illustrated in Figure 3.2b, the enhancement of ISC for strong health messages was highly consistent across viewers, i.e., the pattern was expressed in every audience member for C_1 and C_3 (32 out of 32), and in 29 out of 32 participants for C_4. Although still significant, the effect appeared less consistent for $C_{2,}$ with 24 out of 32 participants. Moreover, when computing the correlated components separately for each of the video categories and viewings, the spatial topographies of the components were stable across viewings but revealed seemingly more heterogeneity for weak messages (see Supplementary Figure SR 1). In sum, strong health messages led to a robust enhancement of inter-brain coupling as measured by EEG-ISC.

Enhanced inter-brain coupling to strong messages during free viewing and an effectiveness rating task

In a second step, we examined whether the pattern of enhanced ISC for strong messages varied across viewing conditions, that is, free viewing and an active rating task in which participants evaluated message effectiveness. For each component, possible task and order effects were assessed via four separate mixed repeated measures analyses of variance (ANOVAs) with the within factors "Video Category" (strong vs. weak) and "Condition" (free viewing vs. rating task), and the between factor "Order" based on the sequence of the two conditions, which was counterbalanced across viewers.

As shown in Figure 3.2c, inter-brain coupling, as measured by the level of ISC for the four components, was enhanced for strong compared to weak messages during both task conditions (Main effects of "Video Category": $F(1,30) = 16.61$ to 321.04; all p's $< .001$, $\eta^2_G = .06$ - 0.43 - for details, see Supplementary Table SR 2). The main effects of video category were not qualified by any higher-order interaction in the separate ANOVAs of C_1, C_2, and C_3. For C_4, the interaction of "Video Category x Condition x Order" reached significance ($F(1,30) = 7.10$, $p = .012$, $\eta^2_G = .01$). However, two separate follow up-mixed repeated measures ANOVAs of both the free viewing and the rating task condition data revealed only significant main effects of video category (Free viewing: $F(1,30) = 51.04$, $p < .0001$, $\eta^2_G = .21$; Rating task: $F(1,30) = 62.89$, $p < .0001$, $\eta^2_G = .22$). No other significant effect was found in these separate analyses. For C_1 and C_2, level of ISC decreased from first to second viewing across both task orders resulting in significant interactions of "Condition x Order" (C_1: $F(1,30) = 46.55$, $p < .0001$, $\eta^2_G = .08$; C_2: $F(1,30) = 11.80$, $p = .002$, $\eta^2_G = .07$). Overall, the degree of EEG-ISC prompted by strong messages was consistently enhanced compared to weak messages - during both free viewing and the evaluation task. This pattern was especially pronounced for components C_1, C_3, and C_4. Moreover, to allow a comparison to previous research (Cohen & Parra, 2016; Dmochowski et al., 2014), an additional analysis using the same statistical model but ISC summed across the four components was computed, which revealed similar results (Supplementary Table SR 3).

Relation between EEG-ISC and fMRI signal

To identify candidate brain sources of the maximally correlated components, we used the temporally resolved EEG-ISC responses to model fMRI data obtained during viewing the same health messages. Critically, EEG and fMRI data were recorded from two independent audiences exposed to the same messages, so that data can be integrated across groups (see Dmochowski et al., 2014; Haufe et al., 2018 - for similar approaches). Specifically, the EEG-ISC time courses from each of the four previously identified components were used as a parametric regressor in separate GLM-analyses modeling the fMRI data (see Figure 3.1). In other words, we asked where in the brain the temporal variation of EEG-ISC across the first audience tracked with blood-oxygen-level-dependent (BOLD) signal in the second audience.

As shown in Figure 3.3, the results of the four identified EEG components reveal overlap, but they also show distinct patterns for each of the components. The results show that all four components tracked with BOLD signal in primary visual and auditory cortices as well as unimodal and heteromodal associative cortices (e.g., Mesulam, 1998). Importantly, significant relations between EEG-ISC and BOLD signal extended beyond sensory-perceptual regions. Specifically, BOLD signal within the posterior cingulate cortex (PCC) tracked with EEG-ISC of components C_2 and C_4. Furthermore, signal in the insula and the precuneus was related to EEG-ISC of components C_3 and C_4. Finally, EEG-ISC of component C_4 was additionally related to the fluctuation of BOLD signal within the anterior cingulate (ACC) and dorsomedial prefrontal cortex (dmPFC). Previous research related these higher-order brain regions to personal relevance, affect and attentional processes (Etkin, Egner, & Kalisch, 2011; Murray, Schaer, & Debbané, 2012; Qin & Northoff, 2011; Raichle, 2015; Schmitz & Johnson, 2007; Shackman et al., 2011).

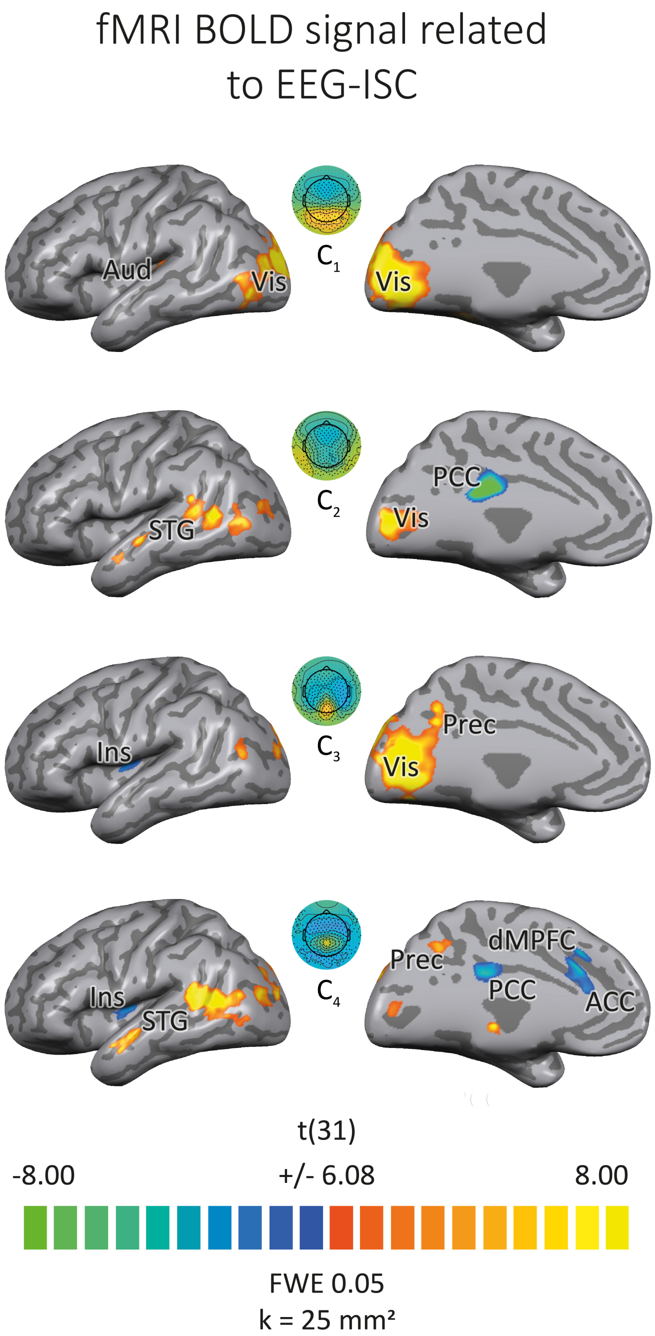

Figure 3.3 | Results of EEG-ISC informed fMRI analyses reveal distinct regions in which BOLD signal tracked with the ISC of correlated EEG components. *a) EEG-ISC fluctuations co-vary with BOLD signal in sensory-perceptual and higher-order brain regions. Illustrations show results of GLM analyses in which ISC time courses of the correlated components obtained in EEG analysis were used as parametric regressors predicting BOLD signal (t-values, FWE corrected for multiple comparisons, $p < .05$; 25 mm² voxel contiguity). ACC = Anterior cingulate cortex, Aud = Auditory cortex, dmPFC = Dorsomedial prefrontal cortex, Ins = Insula, PCC = Posterior cingulate cortex, Prec = Precuneus, STG = Superior temporal gyrus, Vis = Visual system. All visualizations are shown on Talairach-normalized anatomical renderings of the left hemisphere.*

Correspondence between EEG-ISC and fMRI-ISC findings

In addition to providing information on the potential neural generators of EEG-ISC, the EEG-informed fMRI analysis allows to assess the correspondence of our ISC results across two neuroimaging modalities. To facilitate comparison, Figure 3.4 enables to compare the current findings to previous fMRI-ISC findings during processing the same strong and weak health messages (Imhof et al., 2017). Similar to our previous work, the neural regions that show a relation to the identified correlated EEG components extended itself across the cortical hierarchy from "basic" sensory-related to "higher-order" cortical regions (e.g., Mesulam, 1998). When comparing the statistical maps of the two separate streams of analyses, we find that more than 90% of the current findings of the EEG-informed fMRI analysis revealed overlap with the fMRI-ISC findings of the previous work. Given the cross-experimental nature of data acquisition and analysis, marked parallels are found when comparing fMRI-ISC analysis and possible neural generators of the correlated components in the current data.

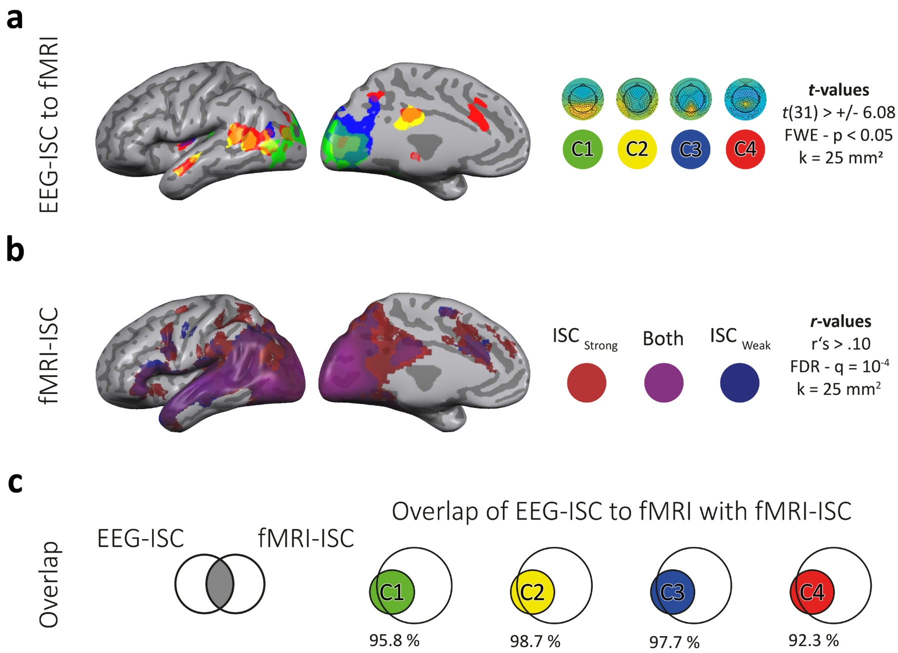

Figure 3.4 | Correspondence between EEG-ISC related to fMRI signal and fMRI-ISC findings from previous work. *a) Results of EEG-ISC informed fMRI analyses reveal regions in which BOLD signal tracked with EEG-ISC. Illustrations show results of GLM analyses in which ISC time courses of the correlated components obtained in EEG analysis were used as parametric regressors predicting BOLD signal (t-values, FWE corrected). b) fMRI-ISC results from Imhof et al. (2017) obtained in an independent participant sample that viewed the same video health messages. R-values obtained in fMRI-ISC analysis are overlaid onto the same anatomical rendering for Strong (red) and Weak (blue) messages (FDR corrected). All visualizations are shown on a Talairach-normalized anatomical rendering of the left hemisphere. c) A large portion of the voxels shown in the statistical maps depicted in a) reveals overlap with the voxels depicted in the statistical maps in b) - for details, please see section "Relating EEG ISC to neural activation in independent functional neuroimaging data").*

Relationship between EEG-ISC and change in drinking amount

In a first step, we determined whether there was any change in alcohol consumption following exposure to the health messages. At the group level, an overall reduction compared to the baseline before exposure to the health message was seen in amount and frequency of drinking within the follow up questionnaire (Amount: $t(30) = 3.11$, $p = .004$, $d = .56$; Frequency: $t(30) = 3.00$, $p = .005$, $d = .54$; $N = 31$, paired-samples *t*-tests, two-sided, uncorrected - for details, see Supplementary Information, Table SR 5). With regard to the amount of drinking, participants on average reported to drink 3 or 4 beverages per drinking event at follow up, corresponding to a lowering of half a scale point. There were no changes in binge drinking or self-report measures probing alcohol consumption on a weekly resolution, that is, the week prior to baseline compared to the week prior to the follow up questionnaire. Specifically, participants consumed on average 8.32 standard beverages ($SD = 5.25$) in the week prior the baseline and 7.90 beverages ($SD = 8.38$) in the week prior to the follow up questionnaire ($t(30) = .24$, $p = .810$, n.s. - see Table SR 5 for details).

In a second step, we used linear regression to explore whether neural measures of health message processing, as well as self-reported risk perceptions, were related to changes in drinking behavior. Significant effects were seen with regard to amount of drinking, but not for drinking frequency. In a linear regression model, ISC averaged across strong health messages for components C_1 to C_4, drinking at baseline, as well as self-reported drinking-related worries, intentions, perceived need to act, and perceived health threat were entered as independent variables, resulting in a significant model for amount of drinking ($F(9,21) = 7.99$, $p < .0001$; adj. $R^2 = .68$). In this model, ISC as captured by components C_3 and C_4, baseline drinking, and self-reported need to act, intentions, and perceived health threat, were significant predictors of drinking at follow up (p's = .03 to < .001; for details, see Supplementary Table SR 6).

Lastly, to determine whether neural measures can make a unique contribution, we computed a hierarchical linear regression analysis. First, we entered amount of drinking at baseline followed by worries, need to act, intentions to change, and perceived health threat, which explained an additional 24.7 % of variance (F_{change} = 5.74, p = .003). Entering ISC of components C_3 and C_4 in the next step explained an additional 9.8 % of variance, resulting in a better model fit (F_{change} = 8.71, p = .002 – see Table 3.1). Adding EEG-ISC of components C_1 and C_2 did not explain additional variance.

Table 3.1 | Results of Hierarchical Regression: Predicting Amount of Drinking at Follow up using Self-Report Measures Alone and then Combining Self-Report Measures with Inter-Brain Coupling

Step	R^2	Adj. R^2	Res. *DF*	*F* values	Model sig.	R^2 change	*F* change	*F* change sig.	AIC
1: Drinking amount at Baseline	.42	.40	29	20.86	$8.435 \cdot 10^{-5}$				56.42
2: Self-report	.67	.60	25	9.95	$2.498 \cdot 10^{-5}$	.247	5.74	.003 **	47.27
3: Brain coupling C_3 and C_4	.76	.69	23	10.63	$6.418 \cdot 10^{-6}$	.098	4.57	.022 *	40.47
4: Brain coupling C_1 and C_2	.77	.68	21	7.99	$4.668 \cdot 10^{-5}$	.010	0.46	.636	43.13

Notes. R^2 = Multiple *R* squared, Adj. R^2 = Adjusted *R* squared, Sig. = Significance. Significance codes: *** $p < .001$, ** $p < .01$, * $p < .05$. Self-report measures: Worries, need to act, intentions & perceived health threat.

Discussion

Health messages are critical for health promotion and disease prevention, but only if they reach and positively engage their target audience. To achieve this at scale, however, messages must be able to attract and sustain attention of the recipients – and collectively across large audiences. Here, we presented members of a target audience with real-life video health messages about risky alcohol use and assessed the collective coupling across their brains during message exposure using inter-subject correlation (ISC). We find that the strength of audience-wide ISC during message receipt is associated with the strength of the messages, that is, their perceived effectiveness. Our findings imply that the strength of ISC within an audience can indicate whether a health message resonates across receivers. Capturing these effects across the brains of an audience may thus provide a promising tool to objectively quantify the impact of mediated health messages and for studying the micro-level processes in response to persuasive messages.

Strong health messages increase audience brain coupling

The main finding is that strong health messages increased inter-brain coupling across the audience. When our test audience was exposed to strong messages, the receivers' brain responses became more closely aligned, whereas messages that people evaluated as being less effective evoked more heterogeneous responses. This effect was found for all identified components and corroborated across two experimental tasks. Our findings are in line with a growing body of research that uses fMRI and EEG to assess the neural base of audience engagement in response to naturalistic stimuli, such as rhetorically strong speeches, engaging movies, or narratives (Barnett & Cerf, 2017; Cohen & Parra, 2016; Cohen et al., 2017; Hasson et al., 2010; Honey et al., 2012; Ki et al., 2016; Lahnakoski et al., 2014; Schmälzle et al., 2015; Silbert et al., 2014). Importantly, the components C_1, C_3, and C_4 found in the present work closely resembled components obtained in previous studies using naturalistic audio-visual stimuli, but different tasks, EEG-systems, and sensor layouts (e.g., Cohen & Parra, 2016; Dmochowski et al., 2012). Recent evidence suggests that correlated EEG components - similar to ISC in fMRI (Schmälzle et al., 2015) - can track attentional and behavioral engagement in an audience (Cohen et al., 2017; Dmochowski et al., 2012; Dmochowski et al., 2014; Ki et al., 2016). This extension of the ISC approach to EEG is promising since it allows a more flexible measurement in real-world contexts and thus offers translational potential for neural measures as a scalable assessment of the audience response to mass-media health communication.

Using EEG-ISC to study real-life mass-media health communication

While studying naturalistic stimuli increases ecological validity, it also raises the issue that real-life health messages may not only differ with regard to content characteristics but also with regard to physical properties. To gain insights into this issue, we extracted changes in luminance, optical flow and sound envelope for each of the videos and found that strong and weak health messages did not significantly differ with regard to these features in the current study (see section "Stimulus feature extraction and comparison across video categories").

However, given the multitude of possible physical features, only a systematic experimental variation of physical and psychological features of messages can solve this issue conclusively.

With respect to content-based characteristics, real-life messages often differ along a number of variables such as message sensation value or argument strength – which is also the case in the current sample of messages (see section "Stimulus material"). More fine-grained analyses of health messages are needed to tackle the challenge of relating ISC-based neural engagement metrics to dynamic message contents and tactics. Given the excellent time resolution, EEG-ISC appears well-suited to identify crucial elements of a message that drive collective audience responses. For example, the proposed measure may answer on a scene-by-scene level to what extent neural engagement is driven by fear appeals and dramatic imagery, and also how these content characteristics interact with physical properties, such as stimulus dynamics or intensity. Moreover, recent work linked think-aloud protocols captured immediately after message exposure to brain activity (Pei, Schmälzle, Kranzler, O'Donnell, & Falk, 2019) and a similar strategy would be feasible for ISC-based approaches (cf. Dmochowski et al., 2012). We anticipate that ISC could indicate if moments of a video or specific elements of the messages "got under the skin" of the recipients and predict upcoming verbal elaborations by recipients that became affectively engaged. Future research may now delve into the contents of messages and examine how variations in the presented arguments or employed message tactics affect the ISC-based engagement metrics. Overall, it may be feasible to include EEG measures in the formative stage of health campaigns to identify, design, and pre-test elements of health messages, as is already the case for eye-tracking to optimize spatial attention allocation (Lochbuehler et al., 2016).

EEG-ISC informed fMRI analyses reveal brain regions related to correlated EEG components

In addition to providing a neural measure of audience engagement, the integration of EEG-ISC and fMRI suggests that the correlated components found in EEG data may tap into distinct functional brain systems. The EEG-informed fMRI analyses identified several brain regions involved in sensory and perceptual analysis, but also revealed the anterior and posterior cingulate cortex (ACC & PCC), the dorsomedial prefrontal cortex (dmPFC) and the insula - regions, which are involved in a broad array of functions relevant to successful messaging and persuasion. These results align with the work of Dmochowski and colleagues (2014), who similarly observed relations between EEG-ISC and BOLD signal for the reception of commercials using an fMRI block-design within superior temporal, inferior frontal and cortical midline regions. Importantly, a robust differentiation of strong and weak health messages emerged in the current study for ISC of components C_3 and C_4, components which the EEG-fMRI correspondence analysis related to cortical midline regions (C_4) as well as to the insula and the precuneus (C_3 & C_4). Numerous fMRI studies have linked these cortical midline regions to a broad set of processes including assessments of personal relevance as well as social and memory-related tasks, and affective evaluation (Apps, Rushworth, & Chang, 2016; D'Argembeau et al., 2010; Etkin et al., 2011; Murray et al., 2012; Qin & Northoff, 2011; Raichle, 2015; Schmitz & Johnson, 2007; Shackman et al., 2011). Furthermore, the insula and ACC have emerged as key nodes in the so-called salience network, which is, together with the PCC, supposedly involved in tuning attention to internal or external information and shifting working-memory resources (Leech & Sharp, 2014; Menon & Uddin, 2010; Raichle, 2015; Seeley et al., 2007). While acknowledging the limits of reverse inference (Poldrack, 2006), the picture that arises based on the current findings and previous work (Imhof et al., 2017; Schmälzle et al., 2013; Schmälzle et al., 2015) is that during strong messages, ISC across an audience is consistently enhanced across multiple recipients, not only within stimulus-driven brain regions, but also within regions related to higher-order processing - such as assessing personal relevance, affective evaluation, and attention.

Inter-subject correlation as a possible marker of message success

From a communication perspective, the correlated brain responses exposed by our analyses represent the common effects of messaging, that is, the degree to which a given message aligns neural processing across multiple receivers. To state the obvious: without a message acting as an "audience-aligner", brain activity across persons is basically uncorrelated (Hasson et al., 2004; Hasson, Landesman et al., 2008). Furthermore, when messages are unengaging or compromised in their meaning, e.g., by presenting unintelligible reversed speech to audiences, then correlated brain activity is relatively weak and confined mostly to sensory areas (Honey et al., 2012; Schmälzle et al., 2015). Thus, we can think of the degree of message-evoked ISC along a continuum ranging from unaligned to strongly aligned (Hasson et al., 2004; Hasson, Landesman et al., 2008; Hasson et al., 2010). On that view, strong health messages were more effective in the sense that they prompted a stronger shared signal in the audience. The EEG-informed fMRI analyses implied that this effect is linked to self-relevance and attentional processes. This finding is particularly promising because personal relevance and the ensuing involvement or central processing represent key constructs in the persuasion literature (e.g., Greenwald & Leavitt, 1984; Petty & Cacioppo, 1986; Petty et al., 2009). Along similar lines, multiple theories in health psychology and risk communication suggest that conveying an authentic feeling of "being personally at risk" is central to successful health messaging (Ferrer & Klein, 2015; Renner et al., 2015; Slovic & Peters, 2006; Weinstein, 1989). Taken together, audience brain coupling of EEG and fMRI can reveal if and how health messages align and prompt shared signal across members of a target audience. By exploiting this ability, the strength of ISC may serve as a proximal marker of health message success.

Identifying such markers of health message success can inform health communication research focused on designing more effective messages. For example, the present findings relate to a recent debate on the usefulness of perceived message effectiveness (PME) for selecting messages that are likely going to be successful. In brief, PME-scales have been used in formative research based on the assumption that they can serve as a proxy for actual effectiveness (Dillard et al., 2007; Yzer et al., 2015). However, recent work by O'Keefe (2019, 2018) argued that PME is not demonstrably related to actual effectiveness in meta-analyses (but see Cappella, 2018; Davis & Duke, 2018). Our results speak to this debate insofar as they show that messages evaluated as high in perceived effectiveness by the participants of our screening sample actually prompted stronger ISC of EEG data in another, independent test audience. Furthermore, exploratory analysis showed that EEG-ISC was predictive of behavior change. Acknowledging that these findings await replication by future research, it can be argued that messages that prompt a stronger initial audience response are more likely to be successful (McGuire, 2013) - whether in the participants who are being tested or in new audiences, including the population level targeted by mass-media campaigns (Dmochowski et al., 2014; Falk et al., 2015; Falk et al., 2016; Huskey et al., 2017; Weber et al., 2015). Considering that mass media health messages can reach large populations, even relatively small advantages in audience engagement may lead to consequential differences in audience impact.

Demonstrating that inter-subject correlation can be reliably measured with EEG is relevant for the issue of group and cultural differences in designing health messages. Empirical evidence demonstrated that message variables can interact with personal variables, such as issue involvement, prior experience, or attitudes towards certain topics, and this can cause differences in neural processing of health messages (Weber, Westcott-Baker, & Anderson, 2013; Weber et al., 2015). Given that EEG is comparatively cheap and can be measured with mobile devices, EEG-ISC may provide means to better assess the targeting of messages to different groups (e.g., Chua et al., 2009; Chua et al., 2011), to make samples less "WEIRD" (Burns et al., 2019; Henrich, Heine, & Norenzayan, 2010) and thus, on the long term more generalizable.

Inter-subject correlation as a possible predictor of message effects

The ultimate goal of health communication is to influence health by successfully informing and persuading people to reduce risky behaviors or engage in preventive action. To help with this endeavor, the EEG-ISC approach may offer a marker of messaging success (Dmochowski et al., 2014). In the current study, EEG-ISC of components C_3 and C_4 was not only related to higher-order brain regions but did also, in addition to self-report measures, predict reductions in risky drinking. By contrast, adding EEG-ISC of components C_1 and C_2, whose neural generators were most likely located in brain regions devoted to sensory and perceptual analysis, did not significantly improve prediction of behavior change. Accordingly, these results support the idea that messages that promote a sense of personal relevance, risk perception, or related psychological processes appear related to the engagement of C_3 and C_4 and are especially apt to motivate behavior change. Indeed, several fMRI studies suggest that message-evoked brain responses in mediofrontal regions are associated with behavior change, e.g., in the context of smoking or sunscreen use (Chua et al., 2011; Falk, Berkman et al., 2010; Falk et al., 2011; Falk et al., 2015). Although the current results are consistent with this work, we emphasize the need for further research and replication using larger sample sizes. For example, the different measures of alcohol consumption employed in the current study revealed variance in the behavioral outcomes – possibly due to differing temporal resolution of the measures or intra-subject variability. In this respect, more fine-grained behavioral measures, such as ecological momentary assessment, could improve both the resolution and the accuracy of assessing changes in alcohol consumption over time (e.g., Smith, Salas, Lewis, & Schüz, 2017).

In general, however, the current approach reveals potential to elucidate how strong messages prompt changes - first, in receivers' brains and then in subsequent health behavior. This result also speaks directly to recent work by Huskey et al. (2017) and Weber et al. (2014), who used a brain-as-predictor approach to predict perceptions of message effectiveness in aggregate audiences. Our study complements this work, first by examining the effects of high and low PME messages on audience brain responses, second by suggesting EEG-ISC as a new, versatile method, and third by the result of the exploratory brain-as-predictor analysis. In sum, the concerted use of self-report, behavioral measures and neural data promises a window onto the pathways through which messages become affectively charged, motivate preventive health action, and ultimately to predict changes in behavior and thus, positive societal outcomes (e.g., Falk et al., 2010; Falk et al., 2015; Falk et al., 2016; Weber et al., 2018). Although this theorizing appears plausible, we note that more work is needed to reveal the functional significance of this putative marker of collective engagement.

Correspondence between EEG- and fMRI-ISC

Beside identifying neural regions that are related to the success of health messages, our analysis linking EEG-ISC to BOLD signal measured in a second, independent target audience enables to replicate and validate the measure with respect to previous findings. For example, primary and secondary visual and auditory cortices were related to fluctuations in

ISC of EEG data. Especially with regard to C_1, these findings agree with previous work using purely auditory stimulation (Cohen & Parra, 2016; Iotzov et al., 2017) and work relating fluctuations within the same component to luminance changes in a video (Poulsen et al., 2017) - replicating that both primary visual and auditory processing seem to contribute to this component. Importantly, the findings of the EEG-informed analysis revealed a broad overlap with fMRI-ISC of previous work in both sensory-perceptual and cortical midline brain regions (see Figure 3.4 and Imhof et al., 2017). However, because the data sets were collected from different samples and not using simultaneous measurements, we cannot definitely infer that EEG-ISC is originating from the indicated brain regions. Future research collecting EEG and fMRI data from the same participants would provide more conclusive evidence regarding this issue. At the same time, however, the present analysis based on independent samples precludes that relations between the two measured modalities are the result of common physiological confounds or artifacts unrelated to the stimuli, e.g., respiration or heartbeat. The ability to integrate responses to the same set of messages across multiple modalities offers a promising strategy not only for methodological integration (e.g., Haufe et al., 2018; Liu et al., 2017), but also replicates and validates the findings of enhanced ISC for strong health messages across two neuroscientific methods. This suggests that irrespective of the neuroscientific measure, neural signals are reliably entrained across viewers by health messages. As different modalities capture independent levels of information, this approach can boost our ability to identify messages that are likely to be effective at scale.

Conclusions

In summary, the present findings demonstrate the potential of EEG-based audience response measurement to differentiate between strong and weak health messages. Beyond informing basic science questions regarding the neurocognitive processes that mediate effective messaging strategies, neural metrics of audience engagement could also be used to select promising messages from a pool of candidates or to predict impact in audiences beyond the neuroscience laboratory. While not specifically designed for predicting audience impact, the observation that the degree of ISC captured by “higher-order components” was related to behavior change seems noteworthy. Given that health messages are a key strategy of public health prevention, developing neural measures as a proximal marker for health message success seems promising for a translation to applied settings.

4

Reliability of fMRI time series: Similarity of neural processing during movie viewing

Ralf Schmälzle [1], Martin A. Imhof [2], Clare Grall [1], Tobias Flaisch [2], & Harald T. Schupp [2]

[1] *Department of Communication, Michigan State University, East Lansing, USA*
[2] *Department of Psychology, University of Konstanz, Konstanz, Germany*

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Abstract

Despite its widespread use in neuroscience, the reliability of fMRI remains insufficiently understood. One powerful way to tap into aspects of fMRI reliability is via the inter-subject correlation (ISC) approach, which exposes different viewers to the same time-locked naturalistic stimulus and assesses the similarity of neural time series. Here we examined the correlations of fMRI time series from 24 participants who watched the same movie clips across three repetitions. This enabled us to examine inter-subject correlations, intra-subject correlations, and correlations between aggregated time series, which we link to the notions of inter-rater reliability, stability, and consistency. In primary visual cortex we found average pairwise inter-subject correlations of about $r = .3$ and intra-subject correlations of similar magnitude. Aggregation across subjects increased inter-subject (inter-group) correlations to $r = .87$, and additional intra-subject averaging before cross-subject aggregation yielded correlations of $r = .93$. Computing the same analyses for parietal (visuospatial network) and cingulate cortices (saliency network) revealed a gradient of decreasing ISC from primary visual to higher visual to post-perceptual regions. These latter regions also benefited most from the increased reliability due to aggregation. We discuss theoretical and practical implications of this link between neural process similarity and psychometric conceptions of inter-rater reliability, stability, and internal consistency.

Keywords

fMRI; inter-subject correlation; reliability; movie viewing; neural process reliability

Introduction

There has been an intense discussion regarding the reproducibility of research findings in functional neuroimaging (Poldrack et al., 2017) as well as science more broadly (Ioannidis, 2005; Loken & Gelman, 2017). While the debate has focused on statistical power and research practices, an important underlying topic is the reliability of the blood oxygen level-dependent (BOLD) signal. Reliability concerns the precision of brain activity measures, and a lack of reliability limits the validity and trustworthiness of results. Previous work on BOLD-fMRI reliability has primarily examined the temporal stability of task-related activations (Aron, Gluck, & Poldrack, 2006; Bennett & Miller, 2010; Brandt et al., 2013; Caceres, Hall, Zelaya, Williams, & Mehta, 2009; Chen & Small, 2007; Plichta et al., 2012; Specht, Willmes, Shah, & Jäncke, 2003; Stark et al., 2004). A complementary way to tap into this issue is via the inter-subject correlation (ISC) approach. ISC analysis assesses the similarity of fMRI time series across individuals who are exposed to the same stimulus and reveals where and to what extent the continuous brain responses concur across receivers. For example, a landmark study by Hasson and colleagues showed that individuals exposed to a 30-minute excerpt from a Western movie exhibited robustly correlated time series in brain regions devoted to visual and auditory processing as well as frontal and limbic cortex (Hasson et al., 2004). Subsequent research has confirmed inter-subject correlations in large scale brain networks across a broad range of dynamic, naturalistic stimuli (Abrams et al., 2013; Chen et al., 2017; Hasson et al., 2004; Hasson et al., 2010; Imhof et al., 2017; Kauppi et al., 2010; Schmälzle et al., 2013; Schmälzle et al., 2015).

Central to ISC analysis is the notion of similarity between functional brain responses, which relates to conceptions of reliability in measurement theory and psychology (Hasson et al., 2010). In brief, reliability refers to the quality and dependability of a measure, which encompasses different aspects of consistency and reproducibility (Shrout & Lane, 2012). One aspect of reliability is inter-rater reliability, i.e., the consensus or agreement among measures obtained from different raters. ISC analysis relates to this as it reflects the degree to which regional brain time courses from two persons who are both exposed to the same stimulus give similar „answers". Another dimension of reliability is temporal stability, typically assessed via test-retest measures. Although ISC analysis has been introduced to study inter-subject similarity, it can be easily adapted to look at intra-subject similarity as well: if a person views the same movie repeatedly, one can compare the similarity of the neural time courses across runs. Lastly, the ISC framework can be linked to the internal consistency aspect of reliability: Consistency refers to the extent to which different items proposed to „measure the same thing" will produce similar scores. This is commonly assessed by computing the inter-item covariance and related metrics, such as Cronbach's alpha (Murphy & Davidshofer, 2005). Importantly, the individual units that aim to measure the same construct do not have to be items, but can also refer to raters, in which case consistency blends with inter-rater reliability. This suggests that we may treat the measures from each individual as items that tap the common function of a region and aggregate across individuals to form more robust measures (e.g., the population-averaged response to a movie in limbic brain regions). Overall, there are obvious parallels between conceptions of reliability and the ISC approach, but except for one review article that touched on these issues (Hasson et al., 2010), empirical work remains limited.

This study examines fMRI responses during naturalistic viewing and assesses aspects of fMRI reliability. We do so by computing the inter-and intra-subject similarity of regional neural time-courses, and by demonstrating how aggregation of individuals into groups, comparable to aggregating items into scales, leads to very reliable measures of the aggregate regional response. Building upon previous research, the present study used movie clips, which are known to collectively engage widespread regions of posterior cortex. Each movie was repeated three times to enable test-retest analyses. The main analysis focuses on the primary visual cortex, the dorsal attention or visuospatial network anchored in the parietal cortex, and the anterior cingulate cortex, which is a central hub in the saliency network (Shirer, Ryali, Rykhlevskaia, Menon, & Greicius, 2012). In addition to these primary regions of interest, we report results for all additional regions that were expected to be engaged by the movie and are known as nodes of major brain networks related to vision, dorsal attention, saliency, executive control, and default mode processing (Shirer et al., 2012). Based on theoretical frameworks suggesting an information flow from primary to higher-order visual association areas, to multimodal paralimbic regions (Fuster, 2003; Mesulam, 1998; Pandya & Yeterian, 2003), we expected to see a gradient of high inter-subject correlations in primary visual regions, to medium strength in parietal regions, to lower, but still positively correlated responses in anterior cingulate cortex.

Methods

Participants

Twenty-four healthy adults (*mean age* = 23.2 years, *SD* = 2.88; range = 20 to 36 years, 13 females) with normal or corrected-to-normal vision and no history of neurological or psychiatric disease participated in this study. One additional participant was immediately replaced due to scanner artifacts. All participants provided written consent to the study protocol, which was approved by the local ethics committee. Participants received either course credit or monetary compensation.

Stimulus and Procedure

The movie clips used in this study were extracted from 75 Hollywood feature films and TV broadcasts. They consisted of positive, erotic materials depicting partly or completely naked heterosexual couples engaging in sexual activity, but they were not explicitly pornographic. The length of the erotic movie stimulus was 4 minutes and 30 seconds, comprising six concatenated short clips. The movies were shown on an MR-compatible visor system (VisualSystem, NordicNeuroLab, Inc.) with a screen resolution of 800 x 600 pixels, and timing was time-locked to the scanner triggers using Presentation software (Neurobehavioral Systems, Inc.). Participants were instructed to freely watch the clips while holding their heads still. Participants also viewed an assortment of neutral movie clips, but comparison of responses between the erotic and neutral movies is beyond the scope of this study and will be reported elsewhere. However, analysis of the neutral clips shows similar findings across levels of aggregation as reported here. Participants saw each movie three times in alternating order, randomly starting with either the positive or the neutral video assortment. After the viewing task, we acquired a high-resolution structural scan from each participant.

MRI acquisition and analysis

MRI data were acquired using a Philips Intera 1.5 90 Tesla scanner equipped with Power Gradients. BOLD data was measured using a Fast Echo Planar Imaging sequence (FFE-EPI, T2*-weighted, 90-degree flip angle, TR = 92 2500 ms, TE = 40 ms, ascending-interleaved slice order, in plane resolution of 3 x 3 mm, slice thickness of 3.5 mm, 32 slices, no gap, FOV = 240 x 240 mm). We obtained 110 functional volumes during each presentation. Structural images were obtained at the end of the experiment using a standard T1-weighted high-resolution scan with a voxel size of 1 x 1 x 1 mm (T1TFE, FOV = 256 x 256 mm, 200 sagittal slices). Field of View was adjusted in line with the AC-PC plane.

FMRI Preprocessing and Data Extraction

Data was preprocessed using SPM12 for realignment, slice time correction, and DARTEL normalization to the IXI500 template (http://brain-development.org/ixi-dataset/). Further processing was carried out in Python 2.7 using the nilearn package (Abraham et al., 2014) and custom code. Specifically, functional time courses were extracted from regions provided by the functional atlas of Shirer and colleagues (2012) (see Supplementary Figure S1 for an overview). We chose to focus on regions rather than individual voxels because regions are a common, established measurement unit in neuroimaging, and because region-level as opposed to voxel-level responses should be less sensitive to anatomical differences and allow for easier communication of results at the meso-scale (i.e., less than 100 regions vs. more than 40.000 voxels). However, the same ideas can be applied to voxel-level-analysis. In addition to the three primary regions of interest, i.e., primary visual, parietal, and anterior cingulate cortex, we also examine the results for additional regions that might be expected to be engaged by the visual stimulus (e.g., higher visual system, executive control network, default mode, see Supplementary Materials) as well as the left and right auditory cortex as control regions. Furthermore, we added subcortical regions for exploratory purposes: the bilateral thalamus, the amygdala (Tzourio-Mazoyer et al., 2002), and the ventral striatum (Tziortzi et al., 2014).

fMRI time courses were extracted from these regions, and data were filtered (0.01 - 0.12 Hz), detrended, and motion parameters were added as confounds. The first 10 volumes that might be affected by signal transients were removed, and the time courses were z-scored. Thus, we obtained a neural time course consisting of 100 samples for each of the 38 regions, from 24 participants and 3 repetitions, yielding a 100 x 38 x 3 x 24 data matrix that served as the basis for further analysis.

Data analysis

For each region, we computed Pearson correlations between the fMRI time series to capture (i) the similarity of individual regional time courses between participants (inter-subject correlation), (ii) the similarity of time courses from the same participant over repeated viewings (intra-subject correlation), and (iii) the similarity of time courses after initial averaging over multiple participants (inter-subject correlations of aggregate time-courses) (Hasson et al., 2004). For the inter-subject correlation analysis (i) we begin with the fMRI time series recorded from 24 viewers during the first viewing of the movie clips. To measure the similarity of neural responses in each region, we compute the correlation between time-series from a given region (e.g., $r_{S1V1(subject1\text{-}1st\ viewing)\text{-}vs.\text{-}S2V1(subject2\text{-}1st\ viewing)}$). This analysis is then computed for all pairs of participants (i.e. ((24 *24) -24)/2 = 276 values), and the resulting values are Fisher-*z*-transformed, averaged, and finally re-transformed to an *r*-value that represents the average similarity of time series across viewers in a given region. For the intra-subject analysis (ii), we proceed in an analogous manner but compute correlations between time courses from the same individual across the three viewings of the same movie (i.e., $r_{S1V1\text{-}vs.\text{-}S1V2}$, $r_{S1V1\text{-}vs.\text{-}S1V3}$, $r_{S1V2\text{-}vs.\text{-}S1V3}$, etc.). To compare intra-subject correlations with inter-subject correlations, we also computed inter-subject correlations also across different runs (e.g., $r_{S1V1\text{-}vs.\text{-}S2V2}$) to account for potential order effects. Finally, for the aggregated inter-subject, or inter-group analyses (iii), we average the time series from multiple viewers (e.g., from pairs, triplets, etc.) to create more reliable signals, and then assess the correlation of aggregated signals at progressive levels of aggregation. For example, we begin by taking the average time series from visual cortex for viewers A and B, and correlate this average time series against the average of neural time series from viewers C and D. Because there are multiple ways to split up the viewers into groups of two, we compute these inter-group correlations for 1000 permutations of the grouping process. This scheme is applied from average pairwise, or dyadic ISC up to the *split-half* ISC, which represents the correlation between the average time series from one half of the group against the average of the remaining half.

Results

Inter-subject correlations

We begin by examining the inter-subject correlations of neural time-series between individual viewers in the visual cortex (Figure 4.1A - left panel). Figure 4.1D shows the neural time courses from two random participants' visual cortex during the first viewing. As can be seen, viewing the same time-locked movie sequences prompts similar time courses and the inter-subject correlation for this random pair of subjects amounts to $r_{S1V1\text{-}vs.\text{-}S2V1} = 0.22$. Across all pairwise inter-subject correlations, we find an average $r_{interSC:\ pairwise} = 0.35$. Next, we start aggregating time courses of individual viewers. As a first aggregation step, we sample two random viewers, average their visual cortex time course, and compare this 2-viewer-average time course against another 2-viewer average time course from another random pair (*e.g.*, $r_{avg(S1,S2)\text{-}vs.\text{-}avg(S3,S4)}$). Figure 4.1D shows the change in correlations for example time courses averaged over two participants. Figure 4.1D (bottom left) expands this procedure to averages of 6 persons each (*e.g.*, $r_{avg(S1,S2,S3,S4,S5,S6)\text{-}vs.\text{-}avg(S7,S8,S9,S10,S11,S12)}$). As expected, averaged time courses are more similar than the individual time series, and the corresponding correlations increase to an average $r_{interSC:\ 2\text{-}person\ averages} = 0.52$ and $r_{interSC:\ 6\text{-}person\ averages} = 0.76$ across permutations. The highest aggregation step is the one that splits the dataset into two halves and measures the correlation between time course averages from two groups of twelve viewers each. As shown in Figure 4.1D (bottom right), these split-half time courses are highly similar, with an average correlation of $r_{interSC:\ split\text{-}half} = 0.87$ across permutations. Figure 4.1G generalizes this procedure to all aggregation levels and shows the evolution of ISC in primary visual cortex as we aggregate from pairwise analyses to duplets, triplets, and all the way up to split-half correlations.

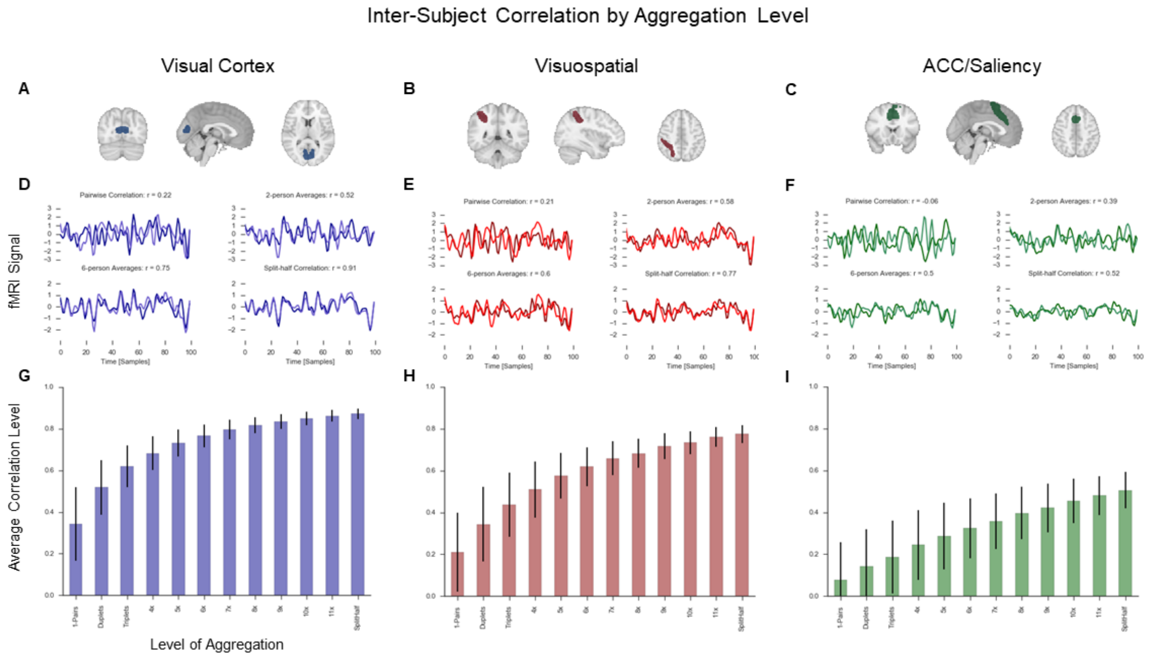

Figure 4.1 | Inter-subject correlation by aggregation level for regions involved in visual, visuospatial, and saliency processing. *A-C: The top panels of each subfigure show the anatomical location of the nodes (Shirer et al., 2012). D-F: The time series plot in the middle panel shows example time courses from two random viewers (top left), the averaged time courses from two viewers each (top right - first step of aggregation), the averaged time course across six viewers each (bottom left), and finally the averaged time courses of twelve vs. twelve viewers (bottom right: split-half correlation). G-I: The bar plots in the lowest panel illustrate the evolution of regional ISC across aggregation steps.*

The same analytical steps as described for the visual cortex were also carried out for the signals measured in the parietal and cingulate cortex (visuospatial and saliency network). As can be seen from the corresponding plots in Figure 4.1E and 1H, ISC in these regions is lower compared to the visual cortex, but still detectable to the human eye. For example, the average correlation of individual time series from the visuo-spatial network is about $r_{interSC:\ pairwise}$ = 0.2, and these correlations increase up to a level of $r_{interSC:\ split\text{-}half}$ = 0.74 through averaging.

Finally, for the saliency network, individual time series exhibit relatively weak correlations around $r_{interSC:\ pairwise}$ 0.1 (Figure 4.1I, first bar). However, as can be seen in Figure 4.1F for the example time courses at the dyadic level, we sometimes find even negative values,

suggesting relatively high noise. However, aggregation across individual viewers leads to progressively higher values up to a level of $r_{interSC}$: split-half = 0.44 for the correlation of two 12-person-averaged time series.

Intra-subject correlations

Participants in this study viewed three repetitions of the same movie clips. This allowed us to assess the similarity of regional fMRI time courses from a given viewer over repeated viewings. These intra-subject correlations can be linked to test-retest reliability, or measurement stability analysis. As can be seen in Figure 4.2 for one viewer, the visual-cortex time-series from different repetitions resembled each other and exhibited an intra-subject correlation of $r_{intraSC}$ = 0.51. Moving beyond the selected exemplar viewer, we carried out this intra-subject correlation analysis for all viewers and averaged the results: For the visual cortex, we find average intra-subject correlations of $r_{intraSC}$ = 0.33 across viewers. This value is nominally higher than the corresponding inter-subject correlations, which amount to about $r_{interSC}$: pairwise = 0.27. Of note, because intra-subject correlations necessarily compare data from different viewings, we also computed inter-subject correlations across viewings (e.g., viewer A, 1st viewing vs. viewer B, 2nd viewing) to make the measures comparable. Therefore, inter-SC values are slightly different from the results in Figure 4.1, which reflected the inter-SC during the first viewing only.

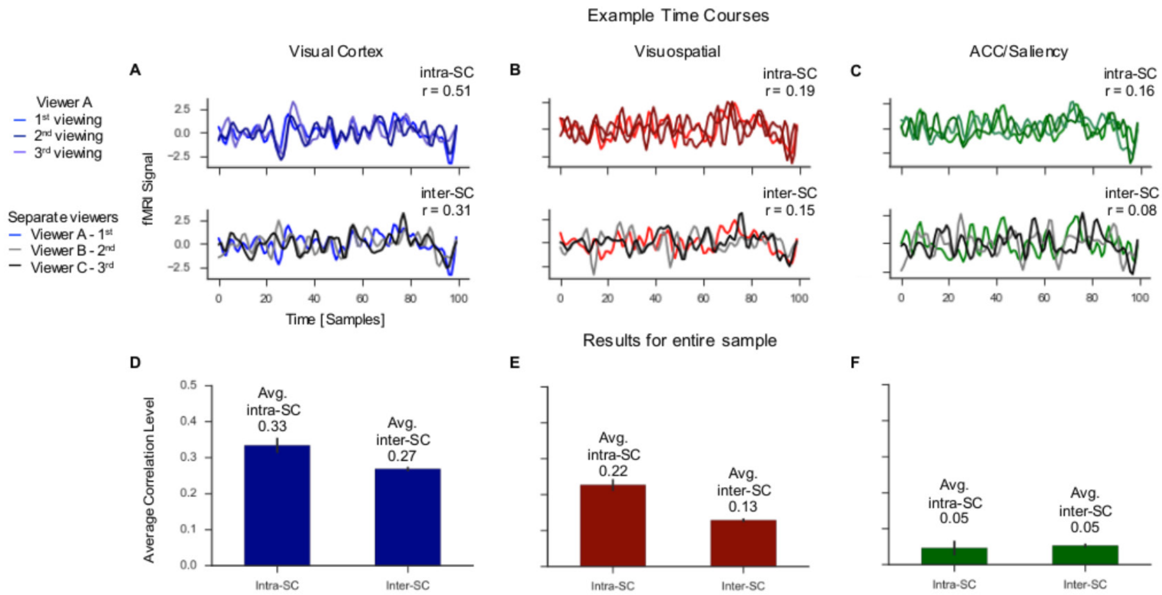

Figure 4.2 | Intra-and inter-subject correlations. *A-C. The top panels of the time series plots show data from one viewer across the three viewings, the lower panels show data from a different viewer for each viewing. D-F. The bar plots show results across all viewers. Intra-subject correlations are nominally higher for the visual and visuospatial network, but of similar magnitude for the saliency network.*

A similar pattern emerges for the visuospatial network, which again yields somewhat lower similarities compared to the visual cortex. As shown in Figure 4.2B and E, intra-SC are somewhat higher than inter-SC. Finally, for the ACC node of the saliency network (Figure 4.2C, F) we find small intra-and inter-subject correlations. Supplementary Table S1 presents results for all other regions.

Increasing inter-subject similarities through initial within-person averaging

The presence of substantial intra-subject correlations suggests that intra-subject averaging can increase the signal to noise ratio of the time series and thus provide a more robust basis for subsequent inter-subject or inter-group correlation computations. The enhancement of ISC due to this initial within-subject averaging is illustrated in Figure 4.3. For comparison, this figure also includes the corresponding inter-SC values without previous intra-subject averaging (cf. Figure 4.1C, F, I). For the visual cortex, the pairwise inter-subject correlation increases from $r_{intraSC:\ pairwise}$ = 0.35 for single-viewing to r = 0.48 across the intra-subject averages from three viewings. At the level of split-half aggregation, which exhibited a split-half correlation during first viewing of $r_{interSC:\ split\ half}$ = 0.87, this intra-subject averaging increases the split-half reliability to r = 0.93. Similarly, correlations in the visuospatial network rise from $r_{isc:\ split\ half}$ = 0.74 without intra-subject averaging to r = 0.82, and for the dACC rise from $r_{isc:\ split\ half}$ = 0.51 without intra-subject averaging to r = 0.69.

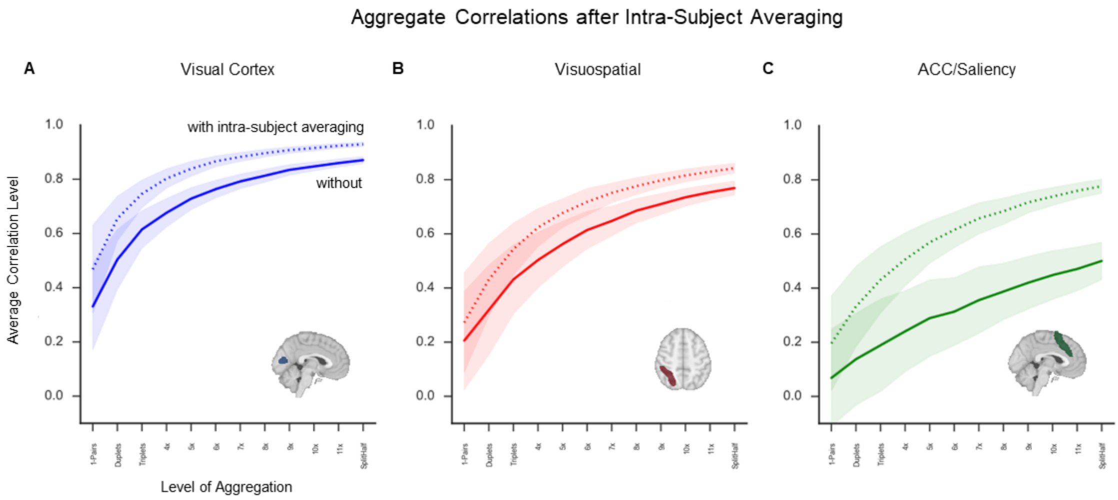

Figure 4.3 | Inter-subject correlation by aggregation level with and without previous intra-subject averaging. *The x-axis represents the level of data aggregation, ranging from pairwise time course correlations to split-half correlations. To account for randomness of the group-averaging process, all analyses are fully permuted and the results are averaged to produce point estimates for each step. Shaded areas indicate +/- 1 SD of the permuted ISC results.*

The previous analyses were carried out on three regions selected based on their location in the processing stream (Mesulam, 1998). To provide a broader picture, we carried out the same analyses for all other 35 nodes. The results, shown in Figure 4.4, parallel and expand the findings for the primary visual, visuospatial, and ACC regions. In particular, we observed a decreasing gradient of ISC as we move away from visual sensory regions, and there are strong effects of aggregation. As expected for the silent-movie stimulus, the auditory cortex showed only weakly correlated responses across participants. Also, the amygdala, the striatum, and some regions of the default and executive control network exhibit low correlations, suggesting that the selected experimental movie did not engage activity in these regions very consistently across viewers.

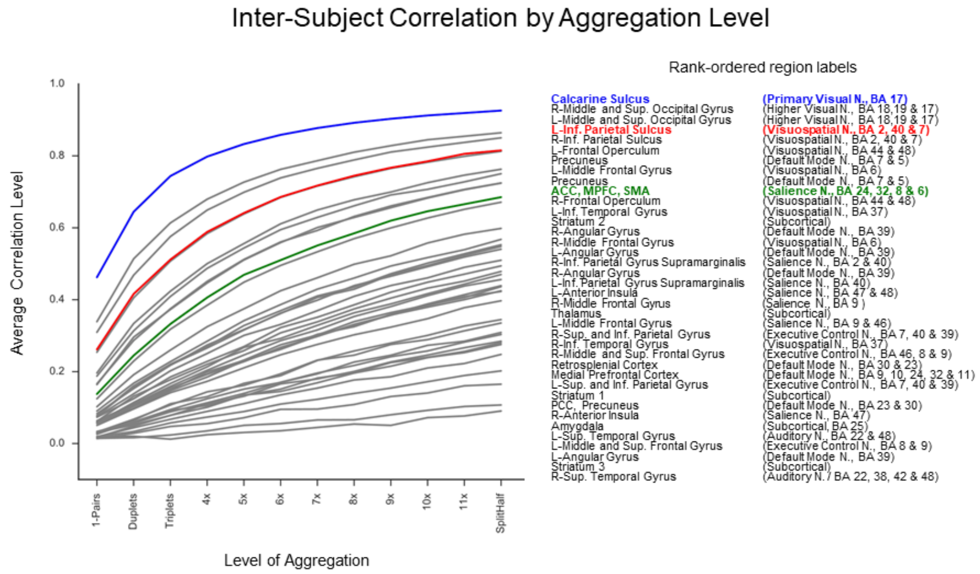

Figure 4.4 | Inter-subject correlation by aggregation level (after previous intra-subject averaging). *Text labels for the regions are ranked based on the level of ISC, ranging from highest in primary visual cortex to lowest in auditory cortex (SeeSupplementary Materials for full list and data). R = Right, L = Left, N = Network, Inf.= Inferior, Sup. = Superior.*

Discussion

The present study examined how similarly the brains of 24 participants respond during a natural movie stimulus. Similarity of neural processing was quantified via inter-and intra-subject correlation analysis. As expected, we found inter-SC to be maximal in visual cortex and lower, but still reliable across widespread brain regions implicated in higher-order processing. Intra-subject correlations were generally higher than inter-subject correlations, and inter-subject averaging as well as intra-subject averaging over repeated exposures markedly increases this similarity, particularly for regions in which similarity was not evident in pairwise correlations. These inter-and intra-subjective process similarities can be linked to inter-rater, consistency, and stability aspects of reliability, and they provide important information about the reliability of functional neuroimaging

Inter-subject correlations

The standard, pairwise inter-subject correlation analysis confirms correlated responses in visual sensory, perceptual, and higher-order regions during movie viewing. For the visual cortex, we find a robust inter-subject correlation of $r_{intraSC: pairwise}$ = 0.35 on average between the time courses from different viewers. Many other regions beyond primary visual cortex also exhibit similar processing across viewers, such as the highlighted visuospatial region, $r_{intraSC: pairwise}$ = 0.2, along with other visual-associative regions (see Table S1). The ACC, however, exhibits less strong correlations - ranging only around 0.1 at the pairwise level. This pattern of results aligns with previous ISC findings (Hasson et al., 2004; Jääskeläinen et al., 2016) and is compatible with models of neural information processing that propose a gradient of conservation from primary to associative memory structures (Fuster, 2003; Mesulam, 1998; Pandya & Yeterian, 2003). These models suggest the ACC as a region that integrates incoming external information with internal demands pertaining to motivation, emotion, and homeostasis, which could explain why it exhibits lower correlations across and within viewers. The varying strength of ISC in sensory, perceptual, and post-perceptual regions underscores that post-sensory regions do not just respond in a reflexive, stimulus-driven manner, but rather engage with the incoming stimulus based on the match between the stimulus and regional response sensitivities. In this sense, a movie provides each brain region with a time-varying landscape of action-opportunities (Gibson, 1977), and the resulting correlations of fMRI responses point to commonalities in how perceptual and cognitive-emotional systems navigate this landscape.

Based on this reasoning, we suggest that inter-SC can be understood as a neural counterpart of inter-rater agreement (Krippendorff, 2018; Riffe, Lacy, & Fico, 2014) at the level of individual brain regions, and that inter-SC of neural processes can quantify the extent to which a movie, or any other communicative signal, is successfully transmitted into a recipient's brain (Hasson et al., 2012). This naturally leads to questions about the content or nature of these reliably shared responses. While acknowledging the limits of reverse inference (Poldrack, 2006), the question seems at least partially addressable for sensory and perceptual regions: By parametrizing the movie into constituent features, one can identify how these are tracked by regional responses or can reverse-correlate from neural responses back to movie features (Naselaris, Kay, Nishimoto, & Gallant, 2011; Ringach & Shapley, 2004). For higher-order regions, however, which are less tightly coupled to immediate stimulus properties and less reliably correlated across receivers, our knowledge about the psychological interpretation of activity remains limited (e.g., dACC or default mode regions). However, inter-subject correlation methods provide unique opportunities to examine these higher-order integrative processes, for instance, by systematically varying the psychological state across or within individuals.

Intra-subject correlations

Intra-subject correlations assess the stability and individual variability of movie-evoked responses. Overall, we find intra-subject correlations to be slightly higher than inter-subject correlations whenever there is reliable inter-or intra-SC in the first place (e.g., for 15 out of 15 regions with pairwise values above 0.1). This is noteworthy for two reasons: First, we analyzed signals from relatively large regions, which should have reduced the impact of anatomical differences that might favor higher intra-subject correlations, but still found higher intra-than inter-subject responses. This points to individual differences in functional brain responses, which are a topic of ongoing research (Campbell et al., 2015; Finn et al., 2017). Second, although slightly higher, the intra-subject correlations were generally of a comparable magnitude to inter-SC (i.e., both around r = 0.3 in visual cortex). This value range may at first seem low compared to what is considered adequate in psychometrics, but we note that the underlying data are based on one single viewing. As such, the intra-subject correlations could be substantially increased by averaging across multiple trials - just as for inter-subject correlations or classical task-based studies that report higher stability (Plichta et al., 2012). A further noteworthy finding from the intra-subject analysis concerns the dACC, where intra-SCs were not even nominally higher than inter-SC (see Figure 4.2 right panel). This suggests pronounced intra-individual variability (e.g., motivation, attention, habituation) that is apparently comparable in size to inter-individual differences and poses a challenge for reliable measurement (Nord, Gray, Charpentier, Robinson, & Roiser, 2017).

One key issue for intra-subject analyses is that the underlying phenomenon might vary over time. Indeed, viewers who watched the erotic clips the second time might have started to either habituate or sensitize or form predictions. This would likely change motivational salience and cognitive control processing and thus affect intra-subject correlations, which certainly cannot result from anatomical differences. Overall, more work is needed to examine intra-subject correlations, and only few studies have begun to look more deeply into these issues, which can complement large population studies (Savoy, 2006).

Averaging across viewers to create more reliable aggregate measures

Finally, we examined the effects of aggregation on fMRI time series correlations and showed that this yields highly reliable aggregate measures. In psychometrics, it is commonplace to combine individual items that tap into a common construct into a scale. Importantly, the idea of aggregating over multiple items can be applied when raters are treated as items, which effectively blends the notion of internal consistency and inter-rater reliability. As shown in Figures 4.1 & 4.3, the similarity between averaged time courses increases markedly as we „average in" data from additional viewers. Thus, high inter-group correlations emerge for many regions for which inter-subject correlations were barely detectable. For example, the high correlation around r = 0.9 for the visual cortex shows that this procedure drastically reduces noise due to technical factors like scanner noise and non-shared signals such as individual differences.

One important benefit of this boost in reliability is related to the fact that „reliability limits validity", i.e., that the correlation between two measures will, on average, not exceed the product of their individual reliabilities. Consider, for example, a scenario in which the goal is to examine fMRI-and fNIRS responses during movie processing (Hasson, Landesman et al., 2008). In such cases, group-averaging can markedly improve the accuracy at which similarities between the measures can be assessed and thereby aid methods comparison. Perhaps more importantly, higher reliability will also improve correlations between fMRI measures and psychological variables, such as continuous attention (Nummenmaa et al., 2014), or psychological traits and other external variables (Berkman & Falk, 2013; Cohen, 1992; Poldrack et al., 2017).

Beyond better measurement, however, the issue of aggregation across individuals also raises interesting theoretical questions in their own right. If a region has no common signal to aggregate, this suggests that it is either not engaged by the stimulus in the first place (e.g., olfactory cortex during visual stimulation), that the region was not scanned reliably, or that functional anatomical or psychological factors produce variability between viewers. This latter point, together with the above discussion of intra-subject analysis, speaks to long-standing distinctions between commonality and individual differences in psychology (Lamiell, 2003). In this sense, the benefit of aggregation is that we „average in“ common signal and obtain highly reliable measures, but at the same time we „average out“ idiosyncratic information about anatomical or psychological differences; whether inter-or intra-SC analyses are to be chosen thus depends on the specific research question. Of note, this is not only an issue for aggregated ISC analyses, but is actually implicit in second level tests in the widespread statistical parametric mapping approach (Friston et al., 1994).

Implications for reliability of fMRI, limitations, and questions for future research

Studying how continuous and dynamic stimuli engage the brain is a relatively young field, and thus, a number of open questions remain. Obviously, the current study is limited to visual processing and to the specifics of the movie clips at hand. However, the observed findings regarding the pattern of reliability replicate when we perform the same analyses for a different visual movie (neutral clips), and there is first evidence that this also applies to other modalities (e.g., Lerner, Honey, Silbert, & Hasson, 2011). Second, we decided to study correlations between regional responses rather than individual voxels. The reason for this is that we are primarily interested in the level of meso-scale brain systems linked to affect and attention, which are plausible targets for media effects. Additionally, examining regional responses helps to overcome anatomical differences at smaller scales and provides a straightforward, scalable strategy. Of course, much can be learned from studying voxel-level similarities or using these for functional normalization as in Hyperalignment (Haxby et al., 2011) or shared response models (Chen et al., 2015). Third, we communicate relevant information about variability via the error bars in Figures 4.1 - 4.3, but otherwise avoid sole reliance on null-hypothesis tests. Conventional significance tests are not immediately relevant to our main points regarding inter-SC, intra-SC, their spatial distribution, and the effects of aggregation (Gigerenzer, 2004), and different types of tests with different sample sizes would be adequate for inter-SC, intra-SC, and inter-group similarity. For example, if the goal is to test whether a distribution of pairwise ISCs is significantly different from zero, then recent work by (Chen et al., 2016) provides a discussion of the statistical dependency among pairwise correlations. If one wants to test whether two individual time series - either from two viewers, viewings, or two aggregate time-series - are significantly related, then classical time-series methods are appropriate (Cochrane & Orcutt, 1949; Hamilton, 1994). Fourth, we present findings from the perspective of classical test theory (CTT) because it is intuitive, and most researchers in neuroscience and psychology are familiar with it. However, generalizability theory (Cronbach, 1972; Gao & Harris, 2012) offers an advanced framework to decompose different facets of variation (e.g., persons, items, raters, time, or setting) and assess their relative contribution. Future multi-site, multi-stimulus, multi-method, and population-level initiatives may perform G analyses to produce comprehensive neural reliability maps for different facets (Dubois & Adolphs, 2016; O'Connor et al., 2016). Related to this, the time-series correlations we report are linked and, in some cases, mathematically equivalent to intra-class correlations (ICC; Shrout & Lane, 2012). Finally, it will be interesting to expand the notion of process similarity beyond relationships among corresponding single brain regions: well-controlled movies provide an ideal tool to study similarities of dynamic functional connectivity (Bassett et al., 2011; Simony et al., 2016), or similarities of more complex network measures

(Andric, Goldin-Meadow, Small, & Hasson, 2016; Pannunzi et al., 2017; Sizemore, Giusti, Kahn, Betzel, & Bassett, 2016; Wang, Ren et al., 2017). Critically, these findings should not be taken to evaluate the reliability of fMRI as a whole. There is no such thing as the *reliability* of a measure, and a multitude of factors will affect the magnitude of correlations. For example, the relatively modest ISC in ACC should not be taken as universal, as different stimuli (e.g., a movie with shorter duration or strong negative contents), different participants (e.g., patients), or different scanning parameters could change the magnitude of the correlations. However, the outlined conceptual framework is robust to such specifics, and disentangling different facets of within and between person variation can contribute to the development of fMRI in the next decades (Dubois & Adolphs, 2016).

Summary and conclusion

This study examined inter-and intra-subject correlations during movie viewing and linked the underlying notion of neural process similarity to aspects of reliability. Especially in the era of multi-lab population neuroimaging initiatives, this approach holds great promise for probing a wider psychological repertoire in a highly reliable and controlled, but eminently scalable way (O'Connor et al., 2016). This may lead to neurometric databases of functional brain responses to movies or stories and yield important information about the distribution of normal brain function and for the diagnosis of disorders (Dubois & Adolphs, 2016). Importantly, while this paper focuses on methodological concepts, the measures of neural process similarity are of interest in their own right and offer new means to examine inter-and intra-individual neural differences in higher-order cognitive and motivational processes (Campbell et al., 2015; Hasson et al., 2009; Honey et al., 2012; Imhof et al., 2017; Naci, Cusack, Anello, & Owen, 2014; Schmälzle et al., 2013).

5

Impressions of HIV risk online: Brain potentials while viewing online dating profiles

Ralf Schmälzle [1,2], Martin A. Imhof [2], Alex Kenter [2], Britta Renner [2], Harald T. Schupp [2]

[1] *Department of Communication, Michigan State University, East Lansing, USA*
[2] *Department of Psychology, University of Konstanz, Konstanz, Germany*

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Abstract

There is an increasing trend to use online dating to meet potential partners. Previous studies in off-line contexts indicate that people may judge the risk of sexually transmitted infections based on a person's appearance. Online dating profiles commonly present profile pictures and verbal self-descriptions. To examine the integration of verbal and visual risk information, the current event-related potential (ERP) study used a simulated dating platform in which verbal-descriptive information (low vs. high verbal risk) was presented, followed by a photograph (low vs. high visual risk). Results indicated main effects of verbal and visual risk. Specifically, high-risk compared with low-risk verbal profiles elicited a relative negative shift over occipitoparietal sensor sites between 260 ms and 408 ms. Furthermore, a sustained occipital negativity (132 – 500 ms) and central positivity (156 – 272 ms) was observed for high as compared with low visual risk profiles. There was also evidence for the integration of verbal and visual risk formation, as indicated by distinct positive ERP shift occurred between 272 ms and 428 ms over anterior temporal regions when a high-risk photograph was preceded by high-risk verbal information. This suggests that verbal-descriptive information is integrated with visual appearance early in the processing stream. The distinct response for high verbal and visual information extends the notion of an alarm function ascribed to risk perception by demonstrating integration about multiple sources. Simulating online dating platforms provides a useful tool to examine intuitive risk perception.

Keywords

Online dating; risk perception; HIV; EEG; intuition; affect

Introduction

Many dates, sexual contacts, and relationships are initiated via dating websites (Rosenfeld & Thomas, 2012). Users of such websites actively browse through profiles and make consequential choices about whom to contact and potentially meet in real life (Bruch, Feinberg, & Lee, 2016; Finkel, Eastwick, Karney, Reis, & Sprecher, 2012; Heino, Ellison, & Gibbs, 2010; Lin & Lundquist, 2013). Although online dating is highly efficient for finding a partner, real and perceived risks need to be addressed. For instance, users perceive online dating as being risky in terms of contracting sexually transmitted infections (STIs) and for meeting untrustworthy individuals (Couch & Liamputtong, 2007; Couch, Liamputtong, & Pitts, 2012; Siegel, Lekas, Onaga, Verni, & Gunn, 2017). The perceived risk of dating and seeking sex partners online seems to be grounded in reality as several studies reported that using online dating services is associated with sexual risk behavior (Buhi et al., 2013; Cabecinha et al., 2017; McFarlane, Bull, & Rietmeijer, 2000; Ortiz-Martínez, Buelvas-Pérez, Martínez-Torres, Vásquez-Rada, & Carrascal-Angelo, 2018). Consequently, public health experts warn that the steady rise of online dating may facilitate the spread of STIs (Clark, 2015; Greenwood & Agarwal, 2016; Heijman et al., 2016; McFarlane et al., 2000). With regard to HIV infections, recent numbers still show only marginal declines in Western countries and increases in Eastern Europe and Central Asia (UNAIDS, 2016). The current study examines the neural correlates of how impressions of risk are formed online, focusing on the integration of information provided in verbal descriptions and visual profile pictures.

Previous research on mate choice and sexual decision making in off-line contexts suggests that people may rely on intuition to gauge “who is risky and who is safe.” Qualitative studies, survey research, and interviews with people who contracted HIV through unprotected sex point to a number of illusory control strategies that may nurture a false sense of control, as, for example, quick screenings of a partner’s personality or past sexual behavior (Gold et al., 1992; Keller, 1993; Klepinger, Billy, Tanfer, & Grady, 1993; Maticka-Tyndale, 1991; Prestage et al., 2016). Studies of the sociocognitive factors underlying these phenomena (Agocha & Cooper, 1999; Eleftheriou, Bullock, Graham, Stone, & Ingham, 2016; Fishbein, Hennessy, Yzer, & Curtis, 2004; Hennessy, Fishbein, Curtis, & Barrett, 2007) have recently been complemented by research examining the neural processes of how people evaluate HIV risk during "first sight" (Renner et al., 2015; Schmälzle, Renner, & Schupp, 2017). To shed light on implicit processes that unfold while people form impressions, functional imaging and event-related brain potentials (ERPs) have been recorded while participants were exposed to photographs of unacquainted persons. With regard to speed of processing, the data from ERP studies showed that differences between individuals subsequently judged as risky or safe emerge early in the processing stream (< 300 ms). In addition, portraits of individuals perceived as risky as compared with safe elicited significantly larger late positive potentials (LPPs), a cortical marker of affective evaluation (Renner et al., 2012; Schmälzle et al., 2011; Schupp et al., 2006). Furthermore, the hypothesis that these risk perceptions emerge spontaneously has been corroborated by studies in which participants performed a memory task unrelated to HIV, yet electrophysiological and hemodynamic responses still showed a relationship to HIV risk, which was assessed in a subsequent explicit condition (Häcker et al., 2015; Schmälzle et al., 2011). In sum, increasing evidence suggests that intuitive impressions influence HIV risk perception, which may have severe real-world consequences, reminiscent of the role first impressions play in professional, educational, and legal contexts (Ballew & Todorov, 2007; Brooks, Huang, Kearney, & Murray, 2014; Eberhardt et al., 2006; Olson & Marshuetz, 2005; Todorov, 2017; Uleman, Blader, & Todorov, 2006).

Work on how mate choice unfolds online has examined how users form impressions based on the information available in a potential partner's profile. Past research has focused predominantly on how people represent or misrepresent themselves online, how users spot deception, and which filter strategies are used during profile browsing, which has been compared to "shopping" (Bruch et al., 2016; Heino et al., 2010; Toma, Hancock, & Ellison, 2008). However, aside from general perceptions of risk associated with online dating, little is known about the underlying processes that lead to the perception of risk or safety (i.e., when people browse partner profiles). Online dating profiles typically consist of verbal information, such as demographic data and brief self-descriptions, and a visual profile picture. People must make sense of this sparse information to assess a potential partner's risk by recruiting knowledge stored in person and social world memory systems (Adams Jr., Ambady, Shimojo, & Nakayama, 2011; Gilbert, 1998; Linville & Carlston, 1994). Research in social, cognitive, and affective neuroscience has amassed a wealth of knowledge about the mechanisms of impressions based on visual appearance (Adolphs, 2003, 2009; Allison, Puce, Spencer, & McCarthy, 1999; Ambady & Rosenthal, 1992; Naumann, Vazire, Rentfrow, & Gosling, 2009; Todorov, 2017), and recent work has begun to specifically examine how verbal biographical and visual information are integrated in associative person memory (Calder, Rhodes, Johnson, & Haxby, 2011; Collins & Olson, 2014a, 2014b; Collins, Koski, & Olson, 2016). Event-related potential studies demonstrated that face processing was changed when the faces were associated in a preceding learning phase with affective as compared with neutral autobiographical information (Abdel Rahman, 2011; Baum, Rabovsky, Rose, & Abdel Rahman, 2018; Luo, Wang, Dzhelyova, Huang, & Mo, 2016; Suess, Rabovsky, & Abdel Rahman, 2015). Functional imaging studies of multiple sources of personal information point to increased activations in the anterior temporal lobe (Olson, McCoy, Klobusicky, & Ross, 2013), and intracranial recordings revealed sensitive responding to faces across multiple recording sites of the ventral stream between 100 ms and 600 ms after stimulus onset (Barbeau et al., 2008; Tsuchiya, Kawasaki, Oya, Howard, & Adolphs, 2008). However, the nexus between social cognition and health-risk perception has rarely been studied, particularly not in the context of risk perception online.

The present study examines HIV risk perception in the context of online dating, focusing on the integration of verbal-descriptive information and visual appearance of the profile picture. Thus, we created a dating platform that resembled online dating services and presented profiles that systematically varied verbal and visual information related to HIV risk (see Figure 5.1). Specifically, high-risk profiles described individuals with many sexual partners and statements indicative of carelessness and irresponsibility, which previous work identified as key elements of a high-risk stereotype (Renner & Schwarzer, 2003a).

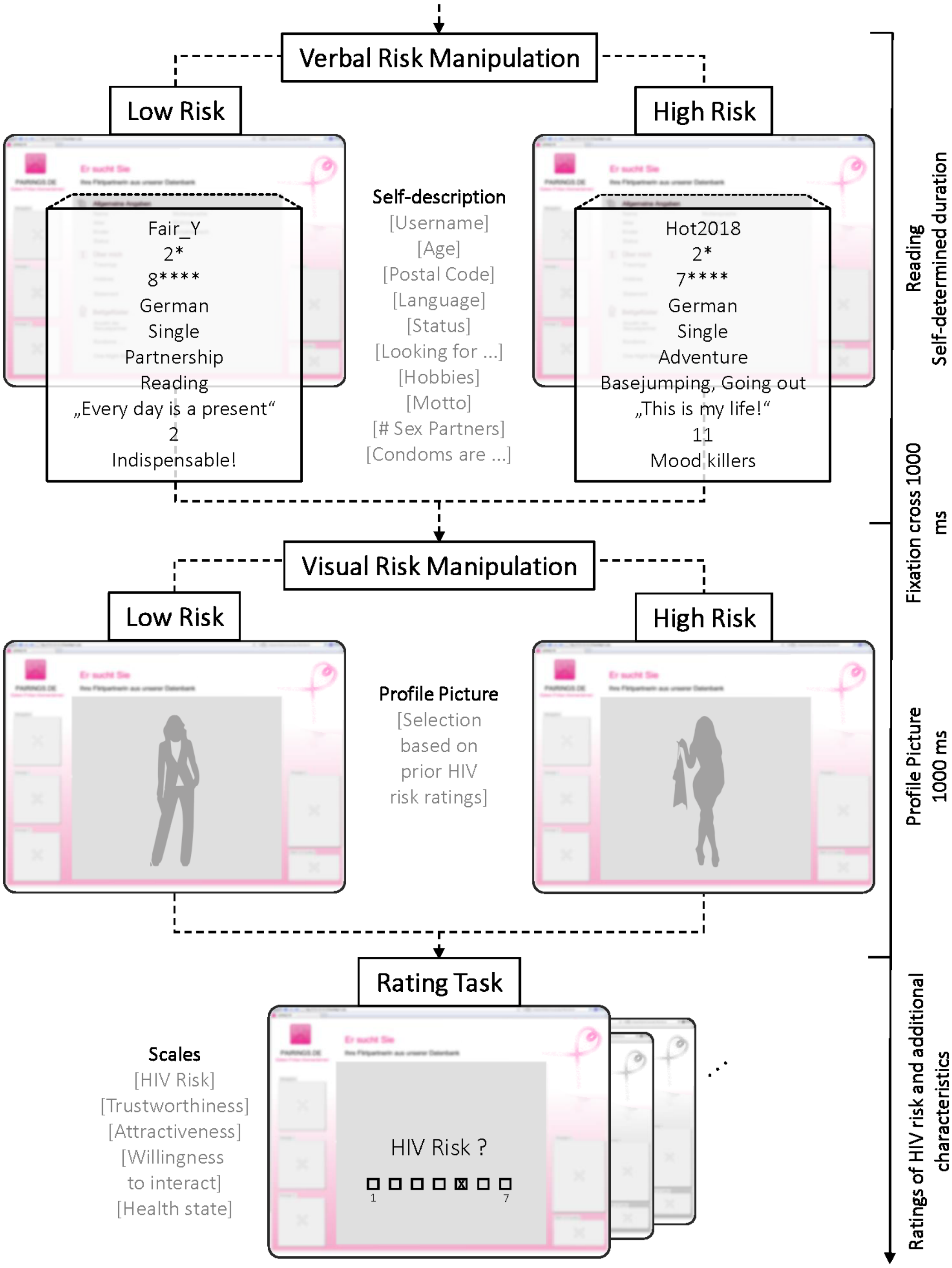

Figure 5.1 | Schematic illustration of the experimental design and timeline of an experimental trial. *Event-related brain potentials are derived relative to the onset of the profile picture. Presentation software was used to manipulate and display the verbal and visual risk information within a carefully designed website. The website included typical user interface features, such as a browser window with address bar, design features (e.g., logos), as well as buttons presumably directing to social media services. To create unique verbal profiles, the text fields were manipulated by assigning values that conveyed a low or high risk feature. Text fields included a username, demographic information, relationship status, hobbies, motto, and a rubric titled "pillow talk", which included information on sexual behavior (cf. Renner & Schwarzer, 2003a). The profile pictures were presented after the verbal information and paired with either a low or a high verbal risk profile. Assignment to the low and high visual risk categories was based on previous ratings of HIV risk. For copyright reasons, only schematic images and a redacted website design are shown. After browsing the profile and viewing the images, participants provided ratings of HIV risk as well as additional person characteristics (trustworthiness, attractiveness, willingness to interact, and health state). Two parallel versions of the website were created for male and female participants, respectively.*

This information was credibly embedded under a rubric labeled "pillow talk" and was presented alongside other relevant and irrelevant cues such as nicknames, age, location, and hobbies. The low-risk profiles, on the other hand, described individuals with cautious traits and safe past behaviors. Each dating profile also contained a picture of the person, which always succeeded the verbal information. Similar to verbal risk information, the photographs were selected to form categories of low and high HIV risk based on visual appearance, which was evaluated in previous work (Barth et al., 2013; Häcker et al., 2015; Renner et al., 2012; Schmälzle et al., 2011). Thus, the experimental design enabled us to study whether and how verbal risk information affects the subsequent neural processing of risk based on visual appearance.

Previous work suggests that risky-looking pictures elicit brain responses compatible with the hypothesized alarm function of risk perception (i.e., a fast and affective reaction; Renner et al., 2012; Schmälzle et al., 2012, 2017). Furthermore, based on the finding that face processing can be modulated by affective autobiographical information (Suess et al., 2015), one might assume that high verbal risk information affects perceptual processing in particular with regard to an occipital negativity between 200 ms and 350 ms. However, with respect to the integration of verbal and visual information, multiple types of relationships are possible. For example, if brain responses to the photographs are primarily sensitive to the consistency or inconsistency between the verbal and visual information, then conditions in which a mismatch occurs ("low verbal–high visual risk" and "high verbal–low visual risk") should lead to distinct ERP responses as compared with the matching conditions. Several ERP components have been associated with such violations of expectancy in social cognition research, including P2, N2, and P3/LPP components (Hansen, Steffens, Rakic, & Wiese, 2017; Osterhout, Bersick, & McLaughlin, 1997; White, Crites, Taylor, & Corral, 2009). Alternatively, it may be that a risky-looking photograph prompts particularly strong reactions if it matches or confirms a risky verbal description. Such a finding would be compatible with the alarm function ascribed to risk perception from a functional-theoretic perspective (Schmälzle et al., 2017; Slovic et al., 2004) and demonstrate integration of information from multiple sources early in the processing stream.

Materials and Methods

Participants

Forty-five healthy volunteers were recruited on the campus of the University of Konstanz. All participants had normal or corrected-to-normal vision. Four participants were excluded from electrophysiological analysis - one because of data acquisition failure, and three because of excessive artifacts. Thus, analysis reported are based on data from 41 participants (22 women, age: $M = 22.1$ years, $SD = 2.4$). Screening questions related to sexual behavior indicated that 19 participants were in a relationship at the time of the study. Furthermore, on average, participants reported to have had sexual intercourse with around four partners ($M = 4.3$, $SD = 4.9$), rare risky sexual behaviors ($M = 6.2$, $SD = 1.1$; scale: 1 [always] to 7 [never]) and occasional sexual intercourse without a condom ($M = 4.3$, $SD = 2.1$; scale: 1 [never] to 7 [always]). As expected, the sample showed an optimistic bias and estimated their risk as being lower compared with an average peer of the same age and sex ($M = 2.2$, $SD = 1.1$; scale 1 [significantly below average] to 7 [significantly above average]). Participants received either monetary reward or course credits for participation and provided written consent to the study protocol, which was approved by the Ethics Review Board of the University of Konstanz.

Experimental paradigm

In order to examine the impact of personal risk information on the viewing of opposite sex photographs, we created an experimental paradigm that emulated an authentic online dating platform. Specifically, Presentation software was used to display a carefully designed and visually appealing website that included typical user interface features, such as a browser window with address bar, logos, social media buttons (e.g., Twitter, Facebook), user statistics, as well as advertisements (see Figure 5.1).

Verbal risk information

This simulated dating website first displayed a screen providing verbal information about a potential partner (see Figure 5.1). Participants controlled the duration of the verbal profile and continued the trial via a mouse click. The verbal profile provided information such as user name, relationship status, hobbies, a motto statement, and relationship wishes. Furthermore, under a rubric titled “pillow talk“, information about sexual history (i.e., number of sex partners and number of one-night stands), as well as attitudes towards condom use (e.g., “Never without” or “Condoms are unromantic”) was embedded. A total of 160 different risk profiles were created for males and females separately by systematically varying the risk for contracting HIV and sexually transmitted infections. Specifically, informed by previous research on HIV risk (Renner & Schwarzer, 2003a), 80 high-risk profiles described a person with many sexual partners, infrequent condom use, and attributes of carelessness and irresponsibility, while another 80 profiles presented-low risk information (i.e., consistent condom use, no one-night stands, trustful and responsible). The spreadsheet with the unique feature values for each low-risk and high-risk variable was created by the first author and refined using a team of research assistants matching the target audience (available at github.com/nomcomm/RiskProfiles_CABN). For each participant, unique high-risk and low-risk profiles were created by randomly drawing from the pool of high-risk and low-risk exemplars of each profile variable (i.e., user name, relationship status, hobbies, etc.) of the respective gender.

Visual risk information

After a delay of 1 second displaying a fixation cross, the photograph of an opposite-sex person was presented for 1 second. Two sets (male and female) of 160 photographs each were used. These photographs have already been evaluated in terms of HIV risk in previous studies by opposite-sex raters and were retrieved with permission from public databases (Barth et al., 2013; Häcker et al., 2015; Renner et al., 2012; Schmälzle et al., 2011; Schmälzle, Hartung et al., 2019). To closely resemble real dating platforms, the photographs showed portraits varying in attire, socioeconomic status cues, and situational context features. Furthermore, to be representative of the study target population’s age and race, only photographs of Caucasians between 18 and 35 years were included. At the time the study was conducted, the database consisted of 240 male and 240 female photographs, along with HIV risk ratings from at least 40 opposite-sex raters per image. From this pool, we selected 80 male and 80 female photographs with highest HIV risk ratings, and 80 male and 80 female images with lowest HIV risk ratings.

Experimental design

Verbal and visual risk information were combined to form four experimental conditions consisting of 40 trials each (i.e., 40 low verbal/low visual risk, 40 low verbal/high visual risk, 40 high verbal/low visual risk, and 40 high verbal/high visual risk). The order of trials varied randomly, and each participant received a unique pairing of verbal and visual risk information, controlled by a MATLAB script that generated individual scenarios pairing verbal profiles (high/low verbal risk, individually assigned from the spreadsheet categories) with visual images (high/low visual risk, as defined by ratings of HIV risk from prior studies).

Self-report measures

Following the picture display, participants provided ratings of their impression about the potential partner on perceived HIV risk, trustworthiness, attractiveness, willingness to interact, and perceived health on scales ranging from 1 to 7. The order of rating scales varied randomly across trials.

Procedure

To increase credibility of the online dating platform, participants were told that the computer would choose randomly among different versions and layouts of online dating services that were to be compared. Specifically, a dynamic intro sequence was created "connecting" to the dating platform. Two practice trials served to familiarize the participants with the profile and photograph presentation as well as the self-report measures. The experiment then displayed the 160 experimental trials (see example in Figure 5.1), which lasted about 50 minutes, including two breaks. Presentation software (Neurobehavioral Systems, Inc., Berkeley, CA) was used to present the stimuli and to synchronize EEG acquisition. Stimuli were shown on a 21-in.' computer screen (1,024 × 768 resolution) located at a distance of approximately 100 cm from the participants, and the photographs that were embedded into the dating website spanned a visual angle of about 18 × 13 degrees. After navigating the dating platform, participants completed questionnaires that assessed sexual history as well as behavior and beliefs concerning HIV. At the end of the study, they were debriefed and informed that the profile information was fictitious.

EEG data acquisition and analysis

Electrophysiological data were collected from the scalp using a 257-lead HydroCel Geodesic Sensor Net (EGI: Electrical Geodesics, Inc., Eugene, OR). The EEG was recorded continuously with a sampling rate of 250 Hz, with the vertex sensor as reference electrode, and online filtered from 0.1 Hz to 100 Hz using Netstation acquisition software and EGI amplifiers. Impedances were kept below 50 kΩ, as recommended for this type of amplifier. Off-line analyses were performed using BESA (BESA GmbH) and EMEGS (Peyk, Cesarei, & Junghöfer, 2011) software packages and in-house MATLAB code (The MathWorks, Inc.). Processing steps included low-pass filtering at 40 Hz, artifact detection, bad sensor interpolation, baseline - correction for prestimulus (100 ms) ERP activity, and conversion to an average reference (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). Trials with blinks were discarded, and eye-movement artifacts were corrected using the adaptive artifact correction approach implemented in BESA (Ille, Berg, & Scherg, 2002).

Single-sensor waveform analyses were used to determine statistically significant effects for the processing of the pictures as a function of experimental condition. Specifically, the data from each time point and sensor were submitted separately to a repeated-measures ANOVA, including the within factors verbal risk (low verbal, high verbal) and visual risk (low visual, high visual). To account for the multiple comparisons problem, a cluster-based permutation test (Maris & Oostenveld, 2007) with N = 1,000 permutations was performed as implemented in the EMEGS package. Sensor clusters were considered meaningful if they reached a single sensor inclusion threshold of $p < .05$ and a cluster-level threshold of $p < .05$, corrected for multiple comparisons (see Appendix for EGI sensor numbers forming significant clusters). For descriptive reasons, interaction effects were followed up by dependent *t*-tests using Bonferroni-adjusted significance criterion (i.e., $p < .05/4$).

Results

Self-report data

Perceived HIV risk varied as a function of verbal risk information, $F(1,40) = 134.7$, $p < .001$, partial $\eta^2 = .77$, as well as visual risk information, $F(1,40) = 56.5$, $p < .001$, partial $\eta^2 = .59$. As shown in Figure 5.2, both high-risk verbal and visual information was associated with increased HIV risk perception compared with low-risk information. The interaction of verbal and visual risk information was not significant, $F(1,40) = .00$, ns.

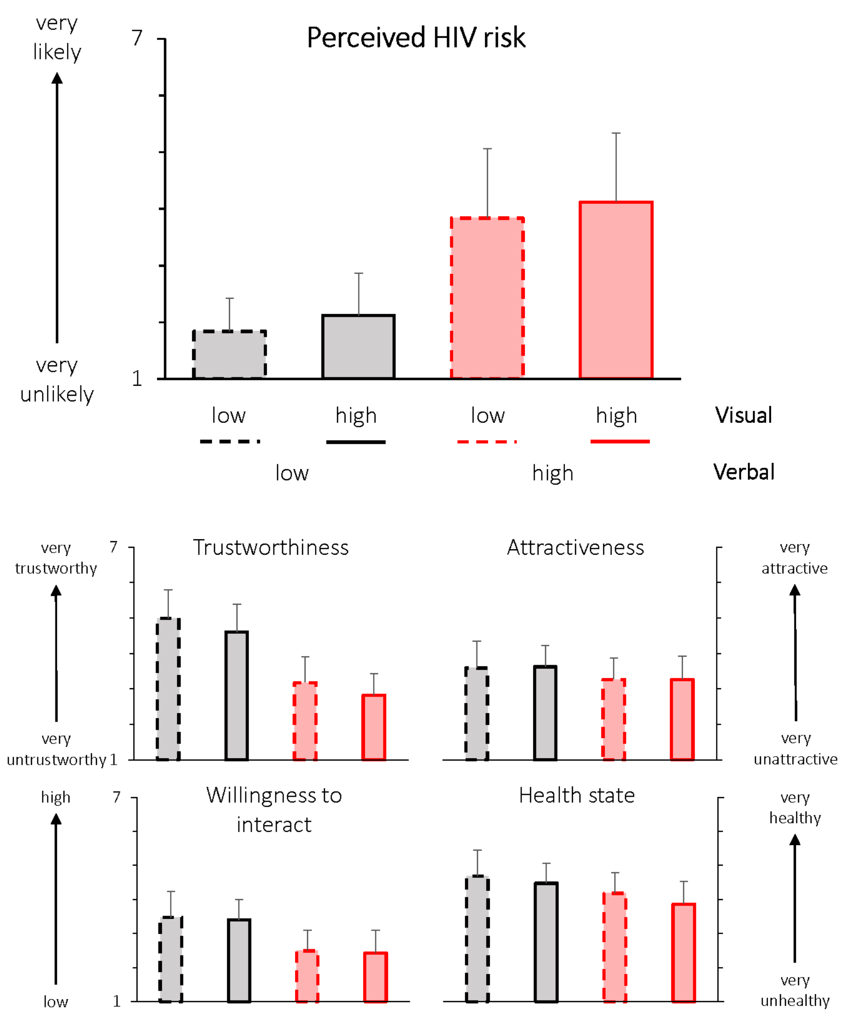

Figure 5.2 | *Top panel: Mean judgments of perceived HIV risk for the combinations of visual and verbal risk categories. Lower panels: Mean judgments of perceived trustworthiness, attractiveness, willingness to interact, and health state. Error bars represent standard deviations.*

As expected, a mirroring pattern of results emerged for the analysis of trustworthiness ratings, verbal risk, $F(1,40) = 140.2$, $p < .001$, partial $\eta^2 = .78$; visual risk, $F(1,40) = 68.1$, $p < .001$, partial $\eta^2 = .63$. For both main effects, high-risk information was perceived as less trustworthy, and vice versa. Attractiveness ratings were modulated by verbal risk information, $F(1,40) = 24.5$, $p < .001$, partial $\eta^2 = .38$, with low-risk profile individuals being perceived as more attractive. Neither the main effect of visual risk, $F(1,40) = .9$, ns, nor the interaction of verbal and visual risk was significant, $F(1,40) = .01$, ns. Similarly, willingness to interact was significantly larger for individuals associated with a low-risk as compared with a high-risk verbal profile: verbal risk, $F(1,40) = 62.6$, partial $\eta^2 = .61$. Neither the main effect visual risk, $F(1,40) = .04$, ns, nor the interaction of verbal and visual risk was significant, $F(1,40) = .5$, ns. Perceived health was higher for both low verbal, $F(1,40) = 36.9$, $p < .001$, partial $\eta^2 = .48$, as well as low visual risk information, $F(1,40) = 42.2$, $p < .001$, partial $\eta^2 = .51$, with both factors showing an interaction, $F(1,40) = 5.6$, $p = .02$, partial $\eta^2 = .12$.

Event-related potentials

Single-sensor waveform analysis served to identify effects associated with the processing of verbal and visual risk information. As shown in Figs. 5.3 and 5.4, differential processing of high-risk compared with low-risk information was indicated by significant ERP cluster effects for both verbal and visual risk information. Furthermore, a significant interaction of verbal and visual risk information appeared with distinct topography, polarity, and latency. This interaction effect was primarily driven by the condition in which the verbal profiles containing high-risk information were followed by a high-risk photograph (see Figure 5.5).

Main effect of "verbal risk"

Verbal profiles indicating high as compared with low sexual risk information affected the processing of the upcoming photograph independent from the risk status of the photograph. Specifically, a significant main effect of verbal risk was observed over occipitoparietal sensor sites in a time interval between 260 ms and 408 ms (see Figure 5.3). Inspection of the cluster ERP waveforms and the difference scalp map showed that high verbal risk information is associated with a relative negative shift as compared with low verbal risk information.

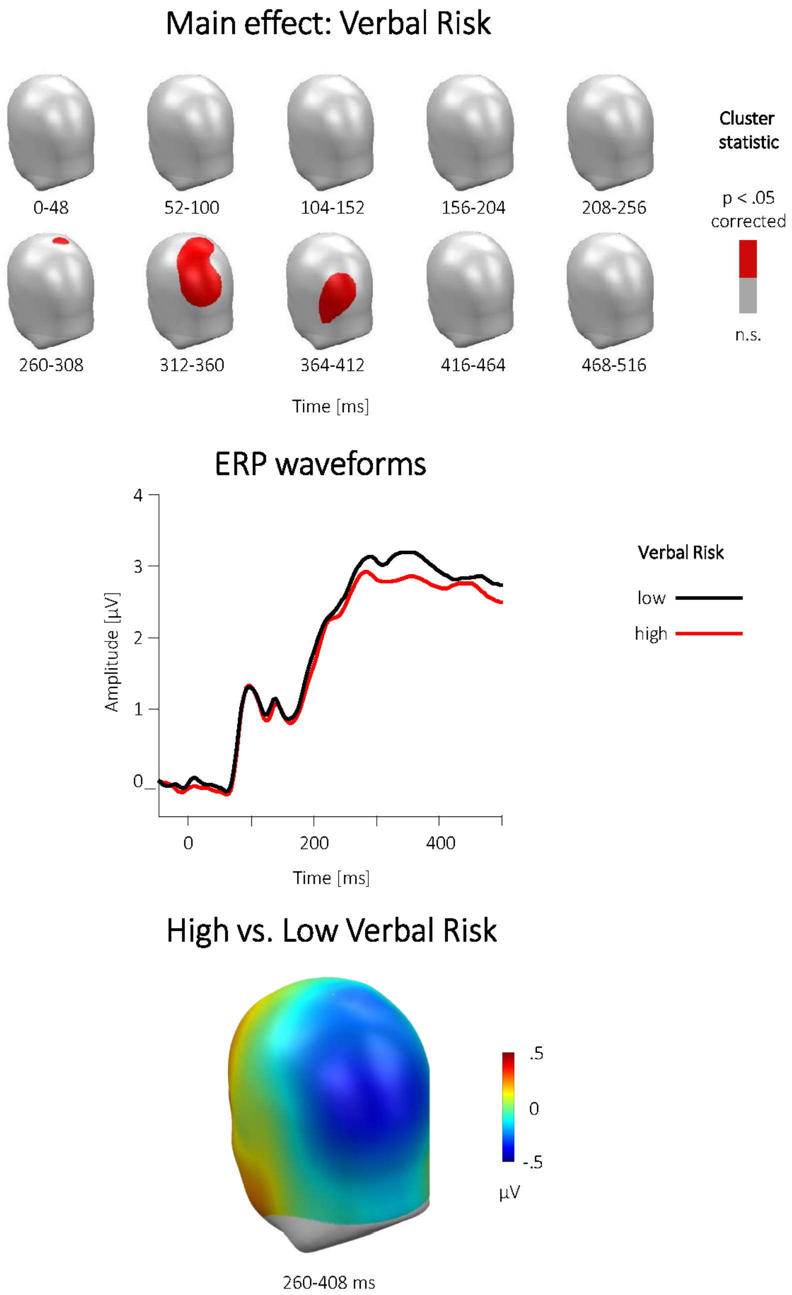

Figure 5.3 | Main effect for verbal risk. *Top panel: Results of the single sensor waveform analysis. Images show significant cluster effects, thresholded at p < .05 for the sensor and cluster level, collapsed across time bins of 48 ms, and shown on a back view tilted 30° to the left and 30° backward for the occipitoparietal effect. Middle panel: ERP waveforms of the occipitoparietal sensor cluster, separately for low and high verbal risk. Bottom panel: Topographical map of the ERP difference between high and low verbal risk.*

Main effect of "visual risk"

Two significant ERP cluster effects were observed comparing the processing of high and low visual risk photographs. As shown in Figure 5.4 (left column), the first and stronger cluster effect occurred over right occipital sensor sites between 132 ms and 500 ms. Similar to the main effect of verbal risk, high-risk information was associated with a relative negative potential as compared with low-risk information. The second main effect of visual risk was observed in a bilateral centrally located cluster between 156 ms and 272 ms, and the visual risk effect occurred with reversed polarity (i.e., high visual risk was associated with an increased positivity; Figure 5.4, right column).

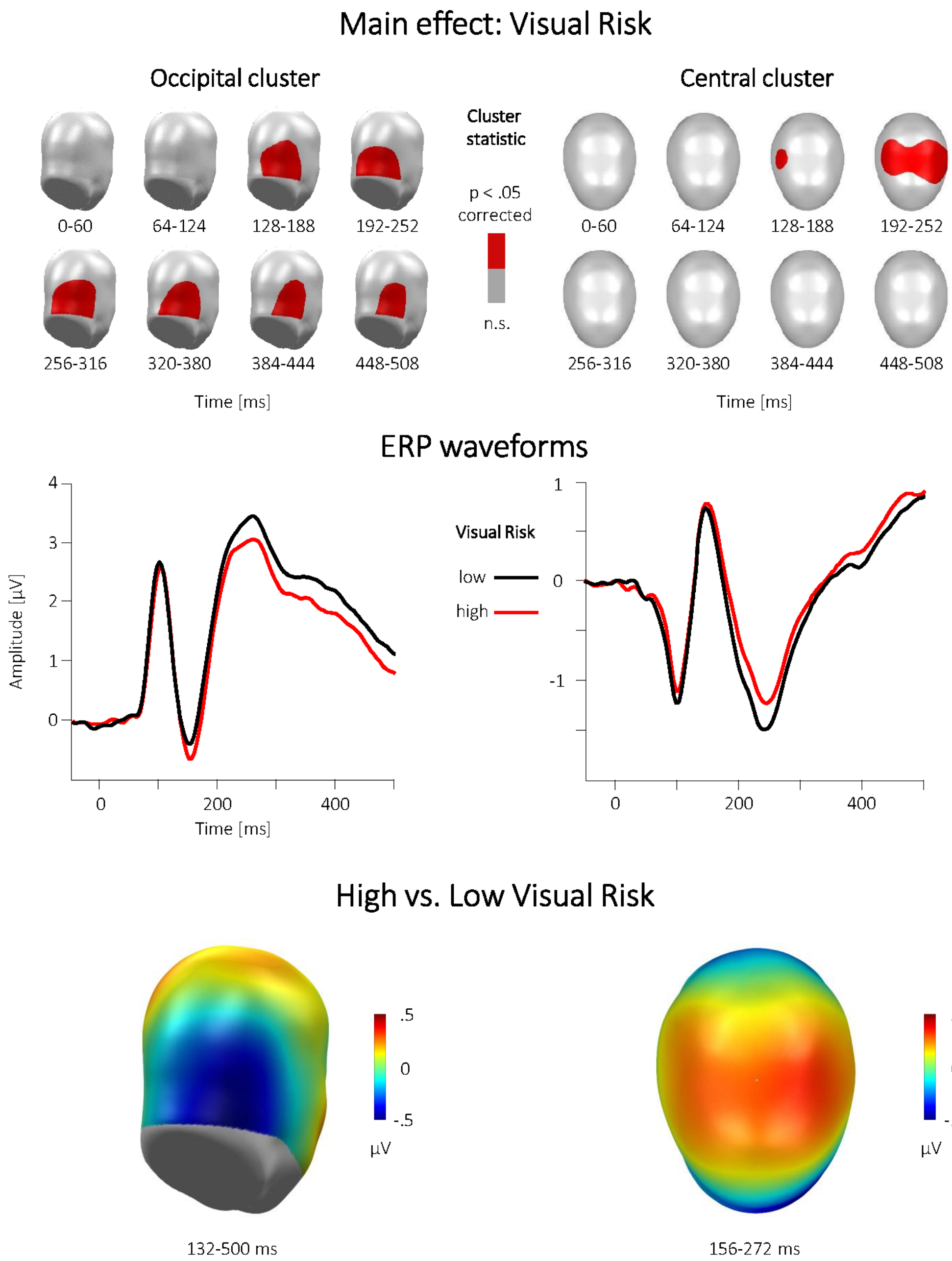

Figure 5.4 | Main effect for visual risk. *Top panel: Results of the single sensor waveform analysis. Images show significant cluster effects, thresholded at p < .05 for the sensor and cluster level, collapsed across time bins of 60 ms, and shown on a back view tilted 30° to the right for the occipital effect, and a top view for the central effect. Middle panel: ERP waveforms of the occipital (left) and central (right) sensor cluster, separately for low and high visual risk. Bottom panel: Topographical maps of the ERP difference between high and low visual risk showing the occipital (left) and central (right) effects.*

Interaction effects of "verbal and visual risk"

A significant interaction of verbal and visual risk was observed in a right[1] anterior temporal cluster in a time interval from 272 ms to 428 ms (see Figure 5.5).

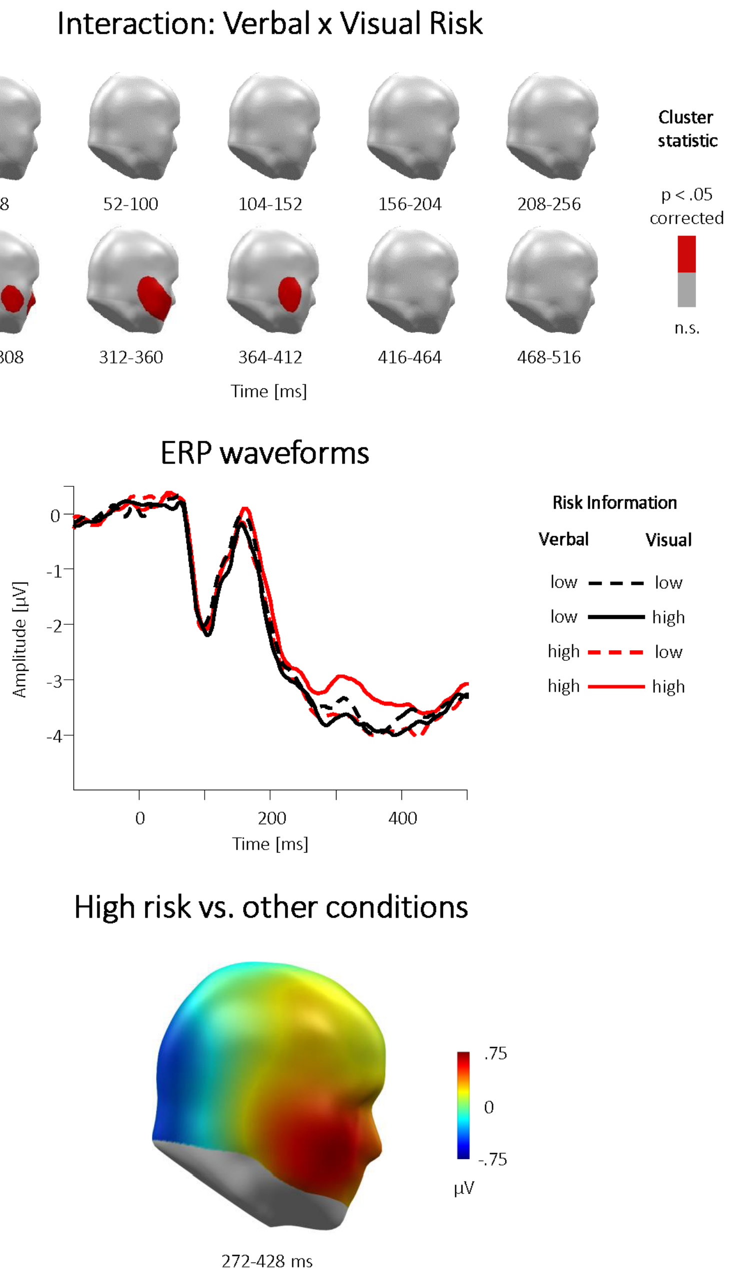

Figure 5.5 | Verbal × Visual Risk interaction effect. *Top panel: Results of the single sensor waveform analysis. Images show significant cluster effects, thresholded at p < .05 for the sensor and cluster level, collapsed across time bins of 48 ms, and shown on a right view tilted 20° to the left for the anterior temporal effect. Middle panel: ERP waveforms of the anterior temporal sensor cluster, separately for the four conditions. Bottom panel: Topographical map of the ERP difference between high visual/high verbal risk and the three other conditions.*

[1] While the cluster statistic was not significant over corresponding left hemispheric sensor sites, we conducted an exploratory analysis over the left hemisphere (EGI sensor numbers 241, 244, 245,246, 248, 249, 250, 252, 253, 254; time window 280–400 ms), revealing a relative positive shift for the high verbal and visual risk condition compared with the three other conditions, t's(40) > −2.0, p < .05

For descriptive reasons, the interaction was followed up for both sources of risk (i.e., verbal and visual) separately. Towards this end, mean amplitudes were extracted for this cluster across all sensors and time points contributing to the effect, separately for the four conditions. The processing of high visual risk information elicited a significant relative positive potential shift when preceded by high compared with low verbal risk information, $t(40) > -3.24$, $p = .002$. Similarly, when preceded by high verbal risk information, high as compared with low visual risk was associated with a relative positivity, $t(40) > -3.02$, $p = .004$. The complementary *t*-tests for low-risk conditions were not significant in both cases, t's(40) < 1.9, ns.

Exploratory analysis: Gender differences

Post hoc analyses were conducted to explore possible gender differences in processing and evaluating HIV risk. With regard to HIV risk ratings, 2 (verbal risk) × 2 (visual risk) × 2 (gender) ANOVAs revealed no significant interaction involving the factor gender (*F*s < 1.6, $p > .2$). To parallel the self-report analyses with ERPs, mean amplitudes for significant main and interaction effects were extracted across all sensors and time points contributing to the effect. For the main effect of verbal risk, the 2 (verbal risk) × 2 (gender) ANOVA indicated no significant interaction with gender, $F(1,39) = .05$, ns. Similarly, for the main effect of visual risk in the occipital cluster, the 2 (visual risk) × 2 (gender) ANOVA showed no significant interaction effect, $F(1,39) = 1.1$, ns. However, there was a significant Visual Risk × Gender interaction for the centrally located sensor cluster, $F(1,39) = 5.1$, $p = .029$, partial $\eta^2 = .12$. Although follow-up tests confirmed the effect for both genders, the effect appeared larger in men than in women, $F(1,18) = 16.9$, $p < .001$, and $F(1,21) = 4.6$, $p < .05$, respectively. With regard to the interaction effect, a significant three-way interaction of Verbal Risk × Visual Risk × Gender was observed, $F(1,39) = 4.6$, $p = .038$, partial $\eta^2 = .11$. Follow-up analyses showed the effect for women, $F(1,21) = 14.8$, $p = .001$, but not for men, $F(1,18) = .4$, ns. Together, these exploratory analyses of gender differences suggest largely similar effects with an interesting gender difference in the anterior temporal cluster where verbal and visual risk information interacted. However, given the sample size and experimental design, which was not optimized to reveal gender differences, these findings await replication in future research.

Discussion

Online dating profiles consist of verbal and visual information, and mate-seeking users must integrate both sources to form a coherent overall impression (Bruch et al., 2016; Finkel et al., 2012). The present study examined how verbal-descriptive information about the riskiness of a person affects spontaneous processing of a person's visual appearance as measured by event-related brain potentials. Three main findings emerged: First, the processing of the photograph was affected by the preceding verbal risk information independent from the risk status of the photograph. Specifically, high-risk verbal profiles elicited a relative negative shift over occipitoparietal sensor sites between 260 ms and 408 ms. Second, photographs from the high as compared with the low visual risk category were associated with a sustained negative shift between 132 ms and 500 ms over occipital sensor regions and a positive shift over central sensor sites between 156 ms and 272 ms, similarly pronounced for low and high verbal risk conditions. Third, after reading the profile of a person matching a high-risk HIV stereotype, viewing a photograph from the high-risk category prompted an early (~270 ms) anterior-temporal positive ERP shift compared with the three other conditions. This work extends previous research on intuitive risk perception to a potentially consequential real-world setting and establishes a platform to examine health risk perception and social impression formation in a use-inspired basic science approach (Stokes, 2011).

A main finding of the present study is that verbal risk information affects the processing of the upcoming photograph. This finding resonates with previous ERP research examining the impact of affective personality information on face processing (Abdel Rahman, 2011; Baum et al., 2018; Luo et al., 2016; Suess et al., 2015). This line of research relies on a learning phase in which negative, neutral, and positive autobiographical information is repeatedly paired with faces. Notably, in the testing phase, ERPs were collected to face processing in a variety of task conditions, such as, for instance, a gender task that did not require participants to recollect the autobiographical information. The findings indicate that faces associated with negative and positive compared with neutral autobiographical information elicited a larger relative negativity over posterior sensor regions between ~200 ms and 400 ms (Abdel Rahman, 2011; Luo et al., 2016; Suess et al., 2015). Acknowledging differences in experimental methodology, the similarity in findings is striking in that high verbal risk profiles elicit an ERP modulation similar in polarity, topography, and latency to emotional autobiographical information. Overall, providing information about sexual risk behavior, the present findings add further evidence to the notion that autobiographical knowledge about a person affects the processing of the visual appearance of the person.

Prior work using only photographs found that viewing high-risk photographs prompted a relatively negative deflection over occipital sites (Renner et al., 2012; Schmälzle et al., 2011), and the relative occipital negativity towards risky looking profile pictures corroborates this effect. However, within the current work, negativity emerged earlier (~132 ms) and lasted longer (~500 ms). Furthermore, it seems possible that the relative shift associated with high-risk photographs over central sensor regions reflects polarity reversal, a hypothesis awaiting future research. Methodological differences between the current and previous work may explain differences in the appearance of early modulation effects. Previous research dealt with visual appearance only and did not include verbal risk information. Task set and instruction can have profound effects on speed of processing. For instance, research on the processing of natural scenes revealed that the recognition of a single picture as compared with a higher-order semantic classification task speeded the onset latency of ERPs by ~30–40 ms (Delorme, Rousselet, Macé, & Fabre-Thorpe, 2004). One may speculate that methodological differences, in particular the activation of risk-related knowledge structures by the verbal profile (cf. Collins & Olson, 2014a, 2014b), account for the observed differences in the latency of the occipital negativity elicited by risky-looking persons. This reasoning could also account for another difference between the current findings and previous work: Previous studies found that LPP amplitudes increased with higher ratings of HIV risk (Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012), whereas no such effect was seen in the current data. In sum, the main effect of visual risk provides further evidence for the notion that HIV risk impressions appear to be embedded in a stereotypical set of beliefs about negative personality attributes (Renner & Schwarzer, 2003a), which are activated during first sight.

Beyond the main effects of verbal and visual risk, a novel finding is revealed by the significant interaction of both factors, reflected by an ERP difference over anterior-temporal sites between 272 ms and 428 ms. Critically, this effect was specific to the condition conveying high verbal and high visual risk—that is, the maximum risk information possible. Although the effect reached significance over the right hemisphere, a similar pattern of ERP modulation was seen over corresponding left hemispheric sites at the same latency in exploratory analysis. Evidence from anatomical, lesion, animal, and functional imaging studies points to the anterior temporal lobe as critical for social cognition and person memory (Olson et al., 2013), and as a "switchboard for conceptual knowledge" (Lambon Ralph, Jefferies, Patterson, & Rogers, 2017; Wang, Collins et al., 2017). Specifically, functional imaging studies revealed activation of the anterior temporal regions in conditions in which multiple pieces of information had to be integrated, and facial identity was linked to semantic, biographic, and emotional knowledge (Olson et al., 2013; Wang, Collins et al., 2017). Furthermore, intracranial recordings in epileptic patients indicate ERPs over anterior temporal regions to faces, peaking around 350 ms after stimulus onset, with larger amplitudes to famous compared with unknown faces (Barbeau et al., 2008; Trautner et al., 2004). Viewed from this perspective, reading a dating profile with name, hobbies, and sexual behavior may create a transient person representation, which is then integrated with the incoming visual information early in the processing stream. Although integration of verbal and visual information is needed in all four conditions, it was specifically the condition in which both sources of information implied high risk that elicited a distinct positive shift in the ERP waveform, suggesting a tagging of the highest risk condition. This is compatible with the notion that the role of intuitive processes in risk perception is to implement a monitoring and alarm system (Schmälzle et al., 2017; Slovic et al., 2004). Consistent with this notion, fMRI studies (Häcker et al., 2015) revealed increased activation in the saliency network (Medford & Critchley, 2010; Menon & Uddin, 2010), and ERP studies point to early, affect-based, and incidental judgments (Schmälzle et al., 2011; Schmälzle et al., 2012). The picture that emerges is one in which the hypothesized risk perception system detects sources of risk and triggers an alarm signal, which in turn can regulate attention processes and generate feelings of risk reflected in explicit judgments (Loewenstein et al., 2001; Slovic et al., 2004).

The notion of stereotype consistency provides a different perspective on the integration of risk information across multiple sources. The profile information about biographical, behavioral, and other risk-relevant data was selected to correspond to the low and high-risk stereotype identified in previous research using verbal methods (Renner & Schwarzer, 2003a). The activation of stereotypes creates expectations about visual appearance (Hansen et al., 2017; Kunda & Sherman-Williams, 1993; Kunda & Thagard, 1996; Littlejohn & Foss, 2009), which then match or clash with fast impressions driven by visual appearance (Willis & Todorov, 2006). Thus, it seems possible that the consistency of verbal and visual risk information would predict ERP response patterns. However, although the differentiation between low and high visual risk following high verbal risk information is compatible with the stereotype consistency hypothesis, the lack of a differentiation for visual risk (low vs. high) in the low verbal risk conditions does not support this hypothesis. Thus, an explanation based on an expectancy violation account would require auxiliary assumptions - for instance, a negativity bias (i.e., stronger weighting of negative risk information; Cacioppo, Cacioppo, & Gollan, 2014; Rozin & Royzman, 2001). Overall, although future research needs to determine the integration of risk information across a broader array of experimental manipulations, the current pattern of findings is in favor of the risk sensitivity hypothesis.

The high temporal resolution of EEG is ideal for studying visual impressions, but the limited spatial resolution demands further research using fMRI to reveal the neural structures implicated in the integration of verbal-descriptive and visual information. In particular, more work is needed to substantiate the notion that the anterior temporal lobe is involved in integrating verbal and visual information, and to detail its relationship to structures of the salience network, that is, the amygdalae, anterior cingulate, and insular cortices. Other methodological modifications, such as presenting the visual information first and then analyzing neural responses to subsequent verbal statements, or using process-tracing methods to uncover sequential information sampling strategies, would help to provide a deeper understanding of how people “screen” potential partners. Such an approach would also help to further the understanding of different effects observed for ERPs and HIV risk ratings. Compared with ERP findings, self-report data were particularly sensitive to verbal risk information and did not show an interaction of visual and verbal risk. This may reflect, in part, the experimental design - that is, ERPs and self-report were measured at different times, or indicate different functions and sensitivities of physiological and self-report data (cf. Lang, 1968). Importantly, neither the current findings nor previous ones make a claim about the validity of the HIV risk stereotypes and visual impressions. Rather, reliance on feelings of risk has been dubbed as illusory control strategy providing ineffective protection against sexually transmitted infections. To our knowledge, only one study directly examined the ability to detect HIV positive individuals by presenting pictures and short vignettes from HIV-positive and HIV-negative people (Thompson, Kyle, Swan, Thomas, & Vrungos, 2002). Participants were, on average, at chance in detecting HIV risk. Interestingly, receiving corrective feedback in this task as part of a broader intervention design was associated with increased condom use in a 3-month follow-up. Thus, with the increasing number of online dating users, simulation online platforms may provide novel means for an experiential mode of experience, making visible the shortcomings of the strategy to gauge the riskiness or safety of potential partners on unreliable and superficial cues. Furthermore, including neural measures as well as ecological momentary assessment would allow insight on the processes underlying these judgments and to follow the dynamic of risk perception and behavior in everyday life.

Summary

Public health experts warn that online dating could escalate the spread of STIs because it is used by millions and creates conditions under which intuitive impressions are likely to emerge. Specifically, if people rely on intuitive impressions about a potential partner’s risk as opposed to effective protection strategies, they are at risk for contracting HIV or STIs more broadly. In the present study, we took a novel approach to shed light on the processes involved in HIV risk perception online. We find that explicit verbal risk information altered brain processes of person perception specific to the condition signaling highest risk (i.e., high verbal and visual risk) relatively early in the processing stream (~ 270 ms). These findings demonstrate how implicit processes associated with riskiness based on visual appearance can be contextualized and shaped by explicit biographical information about a person. Overall, simulating online dating platforms creates an experimental petri dish to study how multiple sources of biographical information are integrated and lead to intuitive impressions of risk.

6

Visual cues that predict intuitive risk perception in the case of HIV

Ralf Schmälzle [1,2], Freda-Marie Hartung [2,3], Alexander Barth [2], Martin A. Imhof [2], Alex Kenter [2], Britta Renner [2], Harald T. Schupp [2]

[1] *Department of Communication, Michigan State University, East Lansing, USA*
[2] *Department of Psychology, University of Konstanz, Konstanz, Germany*
[3] *Department of Communication & Environment, Hochschule Rhein-Waal, Kamp-Lintfort, Germany*

Author notes

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Abstract

Field studies indicate that people may form impressions about potential partners' HIV risk, yet lack insight into what underlies such intuitions. The present study examined which cues may give rise to the perception of riskiness. Towards this end, portrait pictures of persons that are representative of the kinds of images found on social media were evaluated by independent raters on two sets of data: First, sixty visible cues deemed relevant to person perception, and second, perceived HIV risk and trustworthiness, health, and attractiveness. Here, we report correlations between cues and perceived HIV risk, exposing cue-criterion associations that may be used to infer intuitively HIV risk. Second, we trained a multiple cue-based model to forecast perceived HIV risk through cross-validated predictive modeling. Trained models accurately predicted how "risky" a person was perceived (r = .75) in a novel sample of portraits. Findings are discussed with respect to HIV risk stereotypes and implications regarding how to foster effective protective behaviors.

Introduction

Merely looking at another person, people spontaneously form impressions about fundamental personality characteristics such as trustworthiness, competence, and attractiveness (Asch, 1946; Kleisner et al., 2013; Linke, Saribay, & Kleisner, 2016; Todorov et al., 2015). Such snap judgments have been shown to influence real-world decisions in many contexts, including political voting, sentencing, leadership, or online dating (Brooks et al., 2014; Eberhardt et al., 2006; Olivola et al., 2014; Todorov et al., 2005; Zebrowitz & McDonald, 1991). Less known, however, snap judgments seem also to play a role in the context of sexually transmitted infections (STIs) (Swann Jr et al., 1995; Thompson et al., 1999) where people draw inferences about potential partners and make decisions about whether to use effective protection.

Research shows that people report that they often „just know“ whether a person is risky or safe—even when they do not know much about the respective person's past sexual behavior or personality (Gold et al., 1992; Klepinger et al., 1993). For example, many people who contracted HIV during unprotected sexual intercourse report they had assumed their partners were safe–and that they regret being wrong (Crowell & Emmers-Sommer, 2001; Masaro, Dahinten, Johnson, Ogilvie, & Patrick, 2008). Focus groups on HIV prevention point to a related phenomenon: participants often express trust in their ability to detect potentially risky sex partners based on their appearance, even though research suggests that they cannot (Thompson, Anderson, Freedman, & Swan, 1996; Thompson et al., 2002). Impressions of partner safety or risk based on intuitive snap judgments may thus influence reliance on effective protection strategies (i.e., condom use), particularly during „hot“ sexual encounters that impair deliberation and make impulsive decisions more likely (Ariely & Loewenstein, 2006; Epstein, 1994; Hofmann, Friese, & Wiers, 2008; Loewenstein et al., 2001).

Intuitions about riskiness may not only influence sexual risk behavior, but may also come into play in the medical context, for instance, when paramedics or nurses approach patients or victims and need to decide on the spot whether or not to wear protective gloves (see Mattarozzi, Colonnello, Gioia, & Todorov, 2017for a similar argument). Furthermore, a recent study indicated that a mismatch between patients' personal profile and the stereotypical risk factors for HIV resulted in delayed diagnosis of HIV by doctors (Schwartz, Block, & Schafer, 2014). Not only did the participants report surprise at their diagnosis, indicating that people without the stereotypical risk factors for HIV fail to make the connection between their behaviors and risk of HIV, but medical experts made the same error: The participants reported having seldom been offered HIV tests despite visiting physicians over a period of years with HIV symptoms, i.e., weight loss, persistent infections, swollen lymph nodes, suggesting that the stereotypes of who is at risk of contracting HIV are also present in the medical community.

The intuitive nature of risk perception has been strongly supported by a series of studies relying on neuroscientific measures. Event-related potential (ERP) studies revealed that ERP responses to risky as compared to safe individuals diverged early in the processing stream (< 300 ms). This speed precludes systematic reasoning about health risk and thus supports the notion of intuitive processing (Slovic & Peters, 2006). Moreover, ERP differences between intuitively risky and safe partners emerged at the level of the late positive potential (LPP), an ERP component known to respond to affective significance (Schupp et al., 2006). Portraits of risky-looking individuals prompted larger LPPs, which may serve as an intuitive alarm signal for attentive processing (Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012). This interpretation was corroborated by a subsequent fMRI study that found increased activation toward individuals later judged as risky within the saliency network, a set of brain regions involved in attention and relevance detection (Häcker et al., 2015). Perhaps the strongest support for the intuitive nature of HIV risk perception comes from studies which revealed similar ERP and fMRI correlates of risk processing for implicit and explicit conditions (Häcker et al., 2015; Schmälzle et al., 2011). Together, these findings indicate that people are highly sensitive to cues of riskiness and rapidly and spontaneously form impressions about HIV risk.

To tap into the nature of the associative memory representation underlying HIV risk stereotype, several studies related HIV risk perceptions to a broader set of person characteristics. Across different stimulus sets, a strong inverse association of HIV risk perception with ratings of trustworthiness and responsibility emerged (Barth, Schmälzle, Hartung, Renner, & Schupp, 2015; Renner et al., 2012). This is consistent with work suggesting that trustworthiness and responsibility lie at the core of a high HIV risk stereotype in young adults (Renner & Schwarzer, 2003a). Interestingly, and compatible with the ERP findings, research on person perception indicates that inferences about trustworthiness are formed spontaneously and based on the information available in short glances (Bar et al., 2006; Willis & Todorov, 2006). For example, judgments of traits like trustworthiness or health state have been linked to facial features, shape, and color (Jones, Batres et al., 2018; Kleisner et al., 2013). These findings show that humans form impressions - whether about risk or trustworthiness - with ease, but they do not imply that the inferences are reliable or accurate. Additionally, both commonalities and differences have been found for cue-based judgments across cultural backgrounds, highlighting the importance of possible cross-cultural differences (Kleisner et al., 2017; Tan, Tiddeman, & Stephen, 2018). In sum, an extant literature in evolutionary psychology and face perception has identified that such cues matter in a wide array of judgments, such as trustworthiness, attractiveness, and health (Frost, Kleisner, & Flegr, 2017; Jones, Kramer, & Ward, 2012; Russell et al., 2016; Tan et al., 2018). Furthermore, there is a robust literature in social psychology regarding personality impressions based on thin slices of information (Ambady & Rosenthal, 1992), part of which also focuses on underlying cues (Borkenau & Liebler, 1992; Gosling, Ko, Mannarelli, & Morris, 2002; Naumann et al., 2009).

The current study examined this issue using portraits that were similar to how people present themselves on social media and dating websites, creating ecologically valid conditions for the study of HIV risk impressions. Thus, our research focuses on early stages of HIV infection, which are not reliably associated with visible signs of illness or health deterioration. The research design consisted of two independent sources of rating data: First, the entire stimulus set was evaluated according to a list of specific cues deemed relevant to person perception. Towards this end, a list of perceivable cues was derived from the literature and via focus groups, resulting in a set of over sixty cues and general impressions (see Table 6.1 and Figure 6.1). Each portrait was then rated on all cues to measure the extent that a cue was present. Second, an independent group of raters evaluated the depicted persons according to HIV risk as well as further person characteristics of trustworthiness, health, and attractiveness. These additional characteristics were assessed to determine the relationship of HIV risk perception to fundamental person characteristics brought out by previous research on trust (Kleisner et al., 2013; Linke et al., 2016; Todorov, 2008), health (Jones et al., 2012; Jones, 2018), and attractiveness (Agocha & Cooper, 1999; Kleisner et al., 2017; Stephen & Perera, 2014).

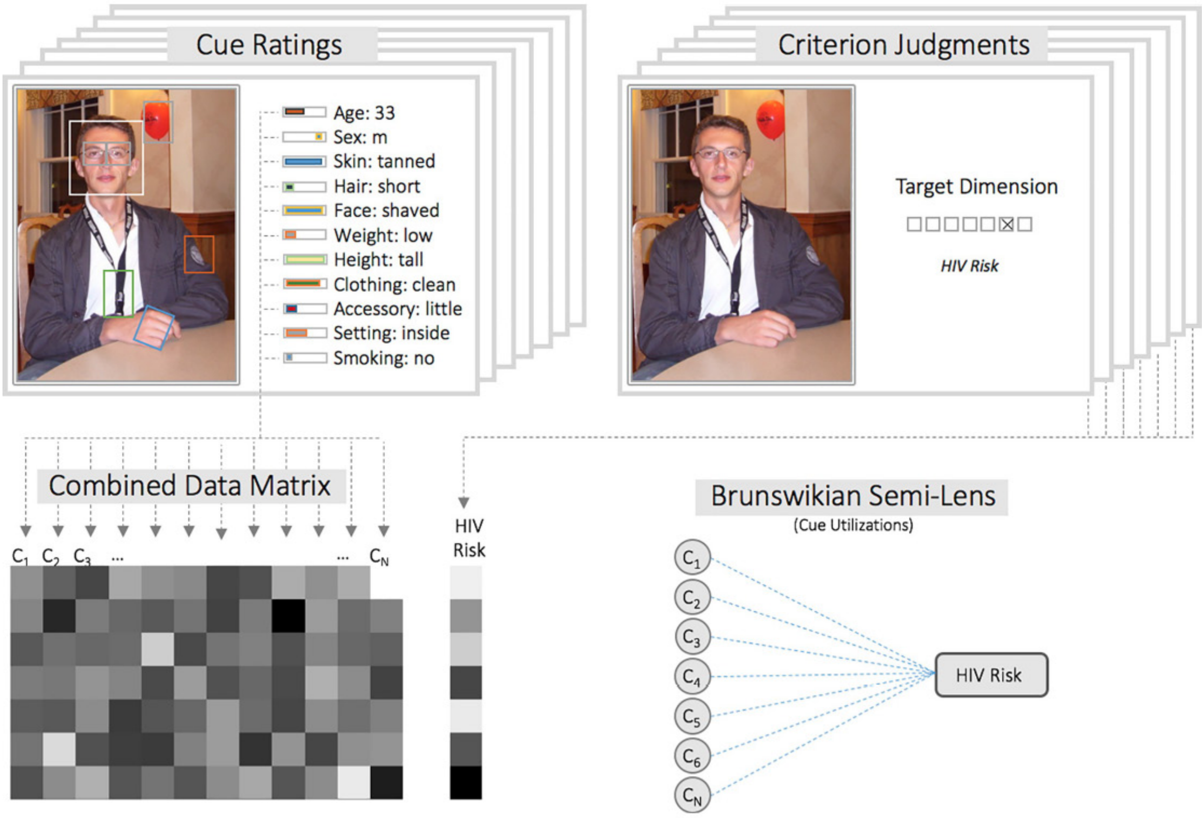

Figure 6.1 | Schematic overview of the current study and example stimuli. *Ratings for observable cues and criterion ratings (HIV riskiness, as well as other impressions) are collected from independent groups of raters for a large set of target photographs. Averaged cue and criterion ratings are then combined and correlations are assessed between each individual cue vector and the HIV risk criterion judgments. This strategy identifies cues that may be utilized to infer HIV risk and thus comprise a „Brunswikian Semi-Lens".*

We first report the intraclass-correlation to support the notion that perceived riskiness is reliably measured and shared among participants. Secondly, we adopted a Brunswikian Lens Model perspective to study the relationship between perceivable cues and

HIV riskiness ratings (Brunswik, 1955). In brief, Brunswik's Lens Model serves as framework for the relationship between the environment and perception, which is mediated probabilistically by cues that are used to form impressions (Brunswik, 1955; Gosling et al., 2002; Hartung & Renner, 2011; Jones, 2018; Naumann et al., 2009). Critically, we do not consider the relationship between cues and the objective external variable, i.e., „actual HIV status", called cue-validity coefficients, but rather focus on the psychological impression of „perceived HIV risk" or intuitive riskiness, i.e., the *cue-utilization* coefficients (see Figure 6.1). Next, we test whether a model based on multiple cues can be trained to predict HIV risk impressions in new data. Lastly, to reveal the relationship between cue-based models of HIV risk and models of trustworthiness, and their distinctiveness to models of attractiveness, we test whether cue-models trained to predict one variable can predict another (e.g., whether a cue-model that accurately predicts trust can be used to predict risk and vice versa).

Method

Participants

The cue-ratings of 60 cues and 13 additional general impressions (cf. Tables 6.1 & 6.2) were collected within small groups of 8 - 12 participants aged between 18 and 35 in the context of an introductory psychology practicum. Participants received course credit whether they participated or not and provided oral consent as this was an anonymous survey. The criterion ratings of perceived HIV risk were obtained from previous studies of HIV risk perception, which accumulated criterion ratings across several separate studies (Barth et al., 2015; Häcker et al., 2015; Renner et al., 2012; Schmälzle et al., 2011). For each photograph, criterion ratings of HIV riskiness were obtained from 40 opposite-sex judges, who were between 20 and 32 years old. Participants were recruited for a study of first impressions on the local campus and participated in individual sessions. Criterion raters provided written consent to take part in the study and received either credit towards research participation requirements or monetary reimbursement. The research design and consent approach were approved by the IRB of the

University of Konstanz. All procedures were in accordance with local guidelines and the principles expressed in the Declaration of Helsinki.

Cue judgment methods

Selection of cues

Each photograph was evaluated according to general personality characteristics and a large set of perceivable cues. General personality impressions are listed in Table 6.2 and were selected based on previous research on person perception (Borkenau & Liebler, 1992; Gosling et al., 2002; Hartung & Renner, 2011; Naumann et al., 2009; Sutherland et al., 2015). In order to implement a Brunswik's Lens Model perspective, it is crucial to represent the possible features and characteristics underlying snap judgments in the list of cues. Towards this end, in a first step, a large set of possible cues and impressions was identified by an extensive literature search of the relevant literatures on personality impressions and person perception (Borkenau & Liebler, 1992; Funder, Furr, & Colvin, 2000; Hartung & Renner, 2011), which included journals from social and personality psychology, face perception and vision, health psychology as well as human medicine textbooks. From these diverse sources, we compiled a large list of several hundred possible cues and conduced a focus group consisting of the two lead-Postdocs, two doctoral students and several research assistants to: (i) Identify additional potential cues for HIV risk impressions, that were not listed in the literature ("identify the white space"). (ii) Classify the cues across the spectrum from concrete (e.g., "cigarette visible") - semi-abstracted (e.g., "smile"), - abstracted (e.g., "trustworthy"). (iii) Form broader categories along which the cues can be clustered (e.g., facial cues, adornment, setting). (iv) Reduce redundant or synonymous cues (e.g., "torn clothing" instead of "torn shirt and torn shorts") and (v) Remove cues that were not possible to rate with the present stimulus set (e.g., cues that are not visible, such as skin conditions of covered body-parts). The final list consisted of 60 perceivable cues, which were sorted into ten higher-order categories of face and body appearance and setting (see Table 6.1) as well as 13 general impressions (see Table 6.2).

Stimuli

The stimulus set consisted of 240 photographs of persons in daily life scenes and was the same as in previous research (Barth et al., 2013; Renner & Hartung, 2004; Renner et al., 2012; Schmälzle et al., 2011). To have high ecological validity, stimuli were selected based on the following six criteria: (i) A colored photo of a (ii) single person located in the foreground, with (iii) their face clearly visible. In terms of age and race, only photographs of (iv) young (18-35 years old) (v) European descent were included. To resemble natural conditions and to facilitate impression formation, only (vi) portraits of individuals in which context features beyond the face itself were visible, such as attire, clothing, or aspects of the situation in which the picture was taken. Half of the pictures depicted male and female targets, respectively. The photographs were retrieved with permission from a popular online photo-sharing community (www.flickr.com).

Cue rating procedure

Booklets for collecting ratings were distributed across the groups with 8 - 10 cues or general impression rating scales for each participant. The study was conducted by an experimenter who presented 60 target photographs on a projector screen and participants provided their ratings for a given cue in booklets. Each participant rated all 60 photographs on one cue and then viewed them again with the instruction to rate the next cue. With this procedure, which lasted about 45 minutes per group, we obtained cue-ratings from eight judges per cue (Gosling et al., 2002). The study was presented as a general inquiry of person perceptions. Specifically, participants did not know that cue-ratings would be related to criterion judgments of HIV risk or other personality characteristics.

Criterion judgment methods: HIV risk

Stimuli and procedure

Criterion ratings were obtained for the same stimulus set as in the cue rating study. These ratings were obtained by aggregating data from previous studies in order to obtain a ratio of 40 criterion judgments per image from opposite-sex raters (Renner et al., 2012; Schmälzle et al., 2011). Each participant was tested individually and the rating procedure was operated by a computer running Presentation software (Neurobehavioral Systems Inc., Berkeley, CA). Each picture was shown for 2 s followed by the presentation of the rating scales. The order of rating scales was randomized for each image, and the order of the picture stimuli was determined randomly for each participant. Perceived HIV risk was assessed by the question „How likely do you think is it that this person is HIV-positive?“ (translated from the German "Für wie wahrscheinlich halten Sie es, dass diese Person HIV-positiv ist?") on a 7-point likelihood rating scale ranging from „very unlikely“ (1) to „very likely“ (7). In addition to perceived HIV risk, participants also provided ratings of perceived trustworthiness, health, and attractiveness for each image (Agocha & Cooper, 1999; Renner et al., 2012). In order to determine the relationship of visual cues and risk perception, it is necessary to demonstrate that the stimulus materials actually varied in their ascribed HIV risk. Thus, risk ratings were calculated across participants for each individual picture. Indicating substantial variation in risk, mean risk ratings increased linearly from very low risk (*min* = 1.83) to very high risk (*max* = 5.93; *M* = 3.7; *SD* = .86). Similar findings emerged for trustworthiness (*min* = 1.63; *max* = 6.25; *M* = 4.1; *SD* = .82), attractiveness (*min* = 1.35; *max* = 6.45; *M* = 3.67; *SD* = 1.16), and health (*min* = 2.12; *max* = 6.3; *M* = 4.4; *SD* = .83).

Data analysis

We first examined the reliabilities of aggregate ratings and computed associations between individual cues and the criterion ratings of HIV risk. Next, we combined cues into a multiple regression model. Specifically, we used regularized LASSO regression with 10-fold cross-validation as implemented in scikit-learn (Pedregosa et al., 2011; Tibshirani, 2011). Thus, within each fold, a training model of cue-criterion relationships was constructed based on a subset of the data. To validate the model, the coefficients from the training model were then applied to the held-out set of photographs that were not used for training. In other words, multiplying the cue-values for novel photographs with the trained model coefficients, the model generates cue-based predictions of HIV risk. These are then compared against the actual HIV risk ratings (see Figure 6.1) and predictive accuracy is measured using R^2 and the standard error of the estimate, and averaging them across folds. Code to reproduce these analyses is posted online at http://github.com/nomcomm/RiskCues_PlosOne.

Results

Reliability measures

We first assessed the reliabilities of the cue-ratings among the eight raters who evaluated to what extent each cue was expressed on the images (intraclass correlations, two-way random, absolute). Across the set of cues, the average ICC was 0.84 (see S1 Table for results for individual cues). As for the cues, we assessed the reliability for the criterion ratings. HIV risk had an ICC of .92, and similar values were obtained for ratings of trust, health, and attractiveness (all ICC = .91).

Relationships between individual cues and perceptions of HIV risk

The cue-utilization correlations in Table 6.1 indicate the relationships between each cue and perceptions of HIV risk. As can be seen, multiple cues, mostly showing low-to-moderate effect sizes, are related to perceived riskiness/safeness. For instance, if a person wears lots of body adornment, has an unconventional appearance, or appears tired-looking, then independent judges will regard this person as having higher HIV risk. Furthermore, the visibility of cigarettes, provocative clothing, and a facial expression signaling negative emotional states (angry, exhausted, serious, or worried) are also linked to heightened HIV risk.

Table 6.1 | Descriptives for cue ratings, correlations between cues and perceived HIV risk ("cue utilization coefficients"), and regression model coefficients.

Cue	HIV Risk Mean *(SD)*	$r_{\text{Cue-HIV Risk}}$	$\text{coef}_{\text{Lasso}}$
Face: Eyes			
Dark (vs. no dark rings under eyes)	3.27 (0.87)	0.21	0.04
Reddened (vs. no reddened eyes)	2.85 (0.78)	0.33	0.12
Dark (vs. bright eyes)	4.3 (1.28)	0.23	0
Face: View			
Coquettish (vs. no coquettish gaze)	3.49 (1.22)	0.13	0.12
Averted (vs. front facing gaze)	3.42 (2.06)	0.14	0.01
Tired (vs. alert gaze)	3.45 (1.03)	0.28	0
Face: Hair			
Ungroomed (vs. groomed hair)	3.34 (0.87)	0.19	0.04
Long (vs. short hair)	3.31 (1.33)	0.19	0
Fashionable (vs. unfashionable hairstyle)	3.64 (1.03)	0.06	0
Dark (vs. bright hair)	4.63 (1.59)	0.22	0.03

continued ...

Table 6.1 | continued

Cue	HIV Risk Mean *(SD)*	$r_{Cue\text{-}HIV\ Risk}$	$coef_{Lasso}$
Face: Mouth			
Smile (vs. no smile)	3.62 (1.56)	-0.33	0
Full (vs. narrow lips)	3.8 (0.93)	0.29	0.07
Face: Skin			
Unhealthy (vs. healthy skin)	3.41 (0.9)	0.14	0
Pale (vs. tanned skin)	4.24 (0.94)	-0.06	0
Pimply (vs. pimple free skin)	3.02 (0.84)	0.1	0
Many (vs. few skin folds)	2.49 (0.68)	-0.05	0
Spotty (vs. spot free skin)	2.74 (0.89)	0.1	0
Greasy (vs. dry skin)	4.31 (0.71)	-0.01	0.02
Lots of (vs. no skin visible)	4.65 (1.36)	-0.1	0
Facial Configuration			
Babyish (vs. mature face)	4.01 (0.97)	-0.09	0
Feminine (vs. masculine face)	4.16 (1.09)	-0.06	-0.03
Round (vs. narrow face)	3.6 (1.09)	-0.25	-0.01
Worn (vs. fresh face)	3.53 (0.96)	0.33	0.2
Ugly (vs. beautiful face)	3.93 (1.05)	0.01	0.02
Red (vs. pale cheeks)	4.03 (1.06)	-0.13	0
Narrow (vs. full jaws)	3.81 (1.19)	0.26	0.02
Average (vs. unusual face)	4.33 (0.77)	-0.42	-0.08
Reddened (vs. no reddened face)	3.93 (1.38)	-0.09	0.01
Symmetric (vs. unsymmetric face)	4.37 (0.77)	-0.01	0
Facial Expression			
Happy (vs. sad expression)	4.43 (1.5)	-0.33	0
Exhausted (vs. powerful expression)	3.7 (0.95)	0.24	0
Worried (vs. unworried expression)	3.26 (1.19)	0.31	0.06
Serious (vs. blithely expression)	3.72 (1.37)	0.35	0
Angry (vs. cheerful expression)	3.4 (1.08)	0.22	0
Friendly (vs. grumpy expression)	4.34 (1.39)	-0.35	-0.03
Body: Figure			
Musculous (vs. not musculous stature)	4.18 (0.89)	-0.09	-0.04
Overweight (vs. underweight)	3.7 (0.93)	-0.28	-0.11
Well (vs. badly proportioned stature)	4.69 (1.09)	0.23	0.07
Tall (vs. low height)	4.33 (0.81)	-0.13	-0.09
Tense (vs. relaxed posture)	3.76 (0.91)	0.16	0
Body: Appearance			
Ungroomed (vs. groomed appearance)	3.22 (1.04)	0.18	0.02
Lot of (vs. no body adornment)	2.96 (1.11)	0.43	0.14
Worn out (vs. intact clothes)	2.45 (0.81)	0.07	0
Provocative (vs. reserved clothes)	4.09 (1.23)	0.23	0.06
Unconventional (vs. conventional appearance)	3.49 (0.74)	0.54	0.31
Fashionable (vs. unfashionable appearance)	4.25 (1.08)	0.2	0.06
Dark (vs. bright clothes)	4.08 (1.6)	0.06	0.03
Clean (vs. dirty clothes)	4.38 (1.02)	-0.03	0
Setting			
Pallid (vs. colorful background)	3.96 (1.41)	0.15	0.04
Unorganized (vs. organized background)	3.74 (1.14)	0.07	0.05
Alcohol (vs. no alcohol visible)	0.12 (0.29)	0.09	0
Picture taken inside (vs. outside.)	7.47 (0.46)	0.08	0
Picture taken in nature (vs. civilization.)	0.25 (0.37)	-0.18	0
Cigarettes (vs. no cigarettes visible)	7.05 (0.15)	0.17	0
Food (vs. no food visible)	7.14 (0.27)	-0.08	0
During sports activities (vs. not.)	5.91 (2.4)	-0.06	-0.02

Conversely, lower HIV risk - or a safer impression - is associated with having positive emotional expressions (smiling, friendly, or happy), an average face, and with persons who are observed within nature scenery.

Predicting HIV risk impressions from visual cues

We used a linear regression model to capture the relationship between cue-ratings and HIV impressions and to test whether and to what degree a trained model could predict HIV risk ratings in unseen data based on the learned cue-criterion relationships. Specifically, we used regularized LASSO regression with 10-fold cross-validation as implemented in scikit-learn (Géron, 2017; Pedregosa et al., 2011; Tibshirani, 2011). We found that the model performed substantially above chance, explaining on average more than half of the variance, with an $R^2 = .56$ and a *standard error of the estimate* = .57. Figure 6.2 shows the correlation between predicted and actual HIV risk ratings, which amounts to $r = .75$ ($t(238) = 17.5$, $p < .0001$). Thus, a model trained to predict HIV risk solely from visual cues can accurately predict HIV impressions for new pictures.

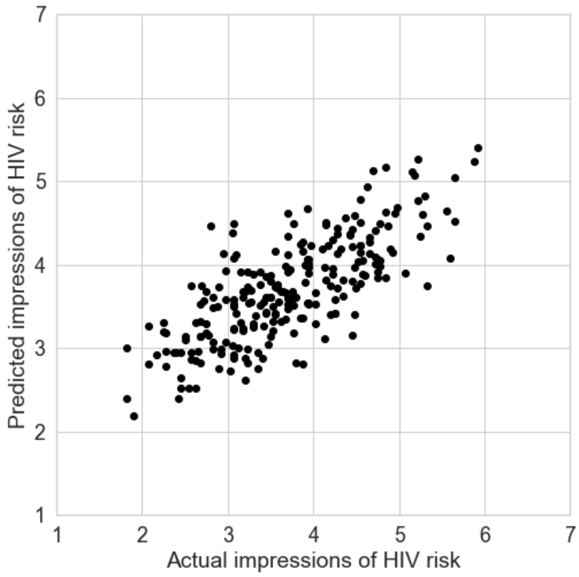

Figure 6.2 | Relationship between actual impressions of HIV risk and model-based predictions. *The model was trained using LASSO-Regression and cross-validated using a 10-fold strategy. We then compare the model-based predictions against actual perceptions of HIV risk obtained from different raters, finding that the model learned to successfully predict HIV risk based on cues (r = 0.75). See text for details.*

Notably, even when confining the set of predictive cues to concrete ones (e.g., dark vs. bright clothes) and disregarding more abstract inferences (such as "conventional vs. unconventional appearance"), the predictive model still performed remarkably well ($r = .61$; $t(238) = 11.9$,

$p < 0.0001$, $R^2 = .35$, *standard error of the estimate* = .69). Also, applying conventional linear instead of LASSO regularized regression did not meaningfully change these findings. Together, these findings suggest that intuitive inferences about HIV risk - rather than being unknowable and random - are systematically related to visual cues.

How does HIV risk perception relate to general person impressions?

Impressions about HIV risk are likely embedded in a network of various other social dimensions that might also be inferred from short glances (Renner et al., 2012; Sutherland et al., 2015). To gain insight into these relationships, we also obtained ratings for all images on 13 more general impressions. Table 6.2 lists correlations between each general impression and perceived HIV risk. As shown, perceived low responsibility is most strongly associated with perceived HIV risk. This is consistent with previous research on HIV risk (Renner & Schwarzer, 2003a; Renner et al., 2012) and with recent work on social impressions (Todorov, 2011), where this dimension also ranks first for impressions of trustworthiness. Further, risky-looking people are seen as rather uneducated and selfish, and as less cautious, less likable, and less popular.

Table 6.2 | Descriptives for ratings of general impressions.

General Impression	Mean (*SD*)	$r_{\text{Cue-HIV Risk}}$
Irresponsible (vs. responsible)	3.6 (1.02)	0.6
Uneducated (vs. educated)	3.55 (0.9)	0.55
Selfish (vs. unselfish)	4.06 (1.1)	0.48
Ill-looking (vs. healthy-looking)	3.59 (1.23)	0.18
Scruffy (vs. kempt)	3.7 (1.1)	0.17
Southern (vs. nordic) type	3.31 (0.98)	0.34
Homosexual (vs. heterosexual)	0.15 (0.17)	0.13
Attractive (vs. unattractive)	3.93 (1.33)	0.1
Sporty (vs. unsporty)	4.39 (1.19)	0.04
Self-confident (vs. not)	4.6 (1.04)	-0.01
Popular (vs. unpopular)	4.07 (1)	-0.16
Cautious (vs. risk-seeking)	4.01 (1.03)	-0.36
Likeable (vs. unsympathetic)	4.28 (0.96)	-0.41

Notes. The middle column shows, for each impression, the average impression rating and the standard deviation. The right column lists the relationship between each general impression and perceived HIV risk.

The relationship between impressions of HIV risk to perceptions of trust, health, and attractiveness

The same methods used to examine and forecast ratings of HIV risk can also be applied to other criterion ratings, such as trust, health, and attractiveness. Specifically, the correlation between predicted trust and actual trust ratings was $r = .75$, for health $r = .84$, and $r = .89$ for attractiveness (all $p < 0.001$). This suggests that for each of these characteristics, the overall impression of a given person can be predicted with relatively high accuracy from a set of cues. Importantly, the trained model based on trust was able to significantly predict HIV risk ratings, with lower trust ratings being associated with higher HIV risk ($r = -0.64$, $p < 0.001$). In contrast, the health and attractiveness models did not predict ratings of HIV risk very well, $r = -0.23$ for health and $r = .06$ for attractiveness.

Discussion

Sexually transmitted infections are a great burden at the individual and societal level, with more than 1 million of STIs being acquired per day (Newman et al., 2015; World Health Organization, 2016). Major health organizations consistently report and warn against a knowledge-behavior gap in HIV prevention. Specifically, while knowledge about effective HIV prevention is high, levels of protective behavior are low (World Health Organization, 2016). The reliance on ineffective rather than effective strategies to prevent infection may help to explain the knowledge-behavior gap (Thompson et al., 2002). Specifically, basing HIV perception on the appearance or trustworthiness of the partner may give people the feeling of risk control while not providing effective control. In order to further understand appearance-based HIV risk perception, we reveal in the present research how visible cues in photographs of persons - similar to the ones used in online dating - relate to impressions of HIV risk, how impressions of HIV risk can be predicted from the cues alone with relatively high accuracy, and how impressions of HIV risk relate to broader impressions of trust, health, and attractiveness.

Perhaps the most notable finding of this study is that „how risky“ a novel person will be evaluated on average can be predicted by their appearance. By linking the cue-ratings to the criterion judgments through cross-validated predictive modeling, the trained model significantly predicted HIV risk ratings for new target photographs. Importantly, all that is „fed in“ to this model are the cue-measures for each image, which are then weighed by the learned coefficients to yield predictions of HIV risk. In particular, we found that cue-based models can explain about half of the variance in perceived HIV risk and that this finding is robust to specific modeling choices. These numbers are surprisingly high considering that (i) cues and criterion reflect consensus ratings not considering individual variation in appearance-based risk perception, (ii) measurement errors in the assessment of cues and criterion, and (iii) that additional relevant cues may not have been incorporated in the model. Inspection of the model coefficients revealed the most important cues for riskiness or safety. The top five risk-enhancing cues were „unconventional appearance“, a „worn face“, „lots of body adornment“, a „coquettish gaze“, and „reddened eyes“. In contrast, cues associated with more safety were a „friendly expression“, a „musculous stature“, an „average face“, a „tall body” and „overweight”. Of note, as some of these cues are themselves abstractions (e.g., „unconventional appearance“), we also inspected top-ranking cues in the models that were reduced to concrete-only cues. In that model, additional top cues for HIV risk were „alcohol visible“ and „spotty skin“, whereas lowered risk was predicted by „picture taken in nature“, „food visible“, and „pimply skin“. Overall, when it comes to judgments of HIV risks at zero acquaintance, information contained in a fairly small set of visible cues is systematically related to the consensus among perceivers about what constitutes „HIV riskiness“.

The present findings close a gap of knowledge in the understanding of the processes leading to intuitive decisions to engage in risky sexual behaviors. We proposed previously that riskiness is judged according to a stereotype of HIV (Renner et al., 2012; Schmälzle et al., 2011). This reasoning builds upon the findings that distrust and lack of responsibility are key features of a high HIV risk stereotype (Renner & Schwarzer, 2003a), that HIV risk ratings are negatively associated with ratings of trust and responsibility (Renner et al., 2012; Schmälzle et al., 2011), and evidence that trust is perceived intuitively (Todorov et al., 2015). According to this reasoning, HIV risk and trustworthiness are assumed to rely on common cues. The observed cue-utilization coefficients strongly support this notion. Specifically, a model trained on cues for trustworthiness was able to significantly predict lowered perceptions of HIV risk, and the model trained on HIV was able to predict perceived trustworthiness. Further insight into the nature of the suggested HIV risk stereotype can be gleaned by inspecting the relationship between HIV risk and ratings of 13 other general impressions. The strongest association emerged between HIV risk and a perceived lack of responsibility, followed by the perception that the depicted person was uneducated, selfish, and generally less likable (see Table 6.2). This replicates previous findings obtained using verbal procedures to elicit stereotypic associations (Renner & Schwarzer, 2003a; Renner et al., 2012). Overall, adopting a Brunswikian Lens Model perspective supports the notion that intuitive HIV risk perception may reflect the activation of the high HIV risk stereotype utilizing cues associated with trust and responsibility.

While the present study specifically focused on the cue-utilization process, it has to be noted that the cues utilized in intuitive risk perception are presumably not valid. To our knowledge, only one study directly examined the ability to detect early-stage HIV positive individuals by presenting pictures and short vignettes from HIV-positive and HIV-negative people (Thompson et al., 2002). Participants were at chance level in detecting HIV risk, which suggests that relying on snap judgments of HIV risk is ineffective. This finding is consistent with the analysis of the conditions leading to good or bad intuitions (Hogarth, 2010). Specifically, the low base rate and the lack of corrective feedback were identified as main conditions leading to bad intuitions, which apply to the present case, i.e., judging HIV risk on person appearance. Thus, even if some cues were statistically associated with actual HIV risk status, reliance on such cues would still provide an ineffective strategy to prevent sexually transmitted diseases. From this perspective, studying how visible cues systematically affect HIV risk ratings may provide the basis for new kinds of public health interventions in which participants can make direct experience with the fallacies of relying on appearance-based risk perception to prevent infection with sexually transmitted diseases. Furthermore, targeting intuitive HIV risk perception may also have implications regarding discrimination of certain individuals given the robust literature on the stigmatization of HIV positive people (Bishop, Alva, Cantu, & Rittiman, 1991; Herek, Capitanio, & Widaman, 2002; Schwartz et al., 2014).

To relate the current findings to previous research in health psychology and psychophysiology, the present study examined the intuitive perception of HIV risk. However, from a public health perspective, it is relevant to determine in future research whether the current findings are specific to HIV or extend to other sexually transmitted diseases. While base rate of HIV is comparably low, chlamydia, gonorrhea, syphilis, and trichomoniasis are STIs with much higher prevalence rates, i.e., an estimated 500 million people becoming infected each year (World Health Organization, 2016), and, similar to HIV, a person can be infected with chlamydia or trichomoniasis without presenting visible symptoms. There is first evidence that the risk stereotype associated with chlamydia is highly similar to the stereotype associated with HIV (Renner et al., 2008). Thus, it seems possible that the current findings are not specific to HIV and may generalize to other STIs. However, there is evidence that perceptions of HIV risk can be separated from leukemia risk, which is equally a life-threatening disease with no initial visible signs, but not contagious (Barth et al., 2013; Bishop, 1991; Skelton, 2006). Compared to leukemia, which is viewed as affecting "innocent people by fate", HIV is, at least on average, associated with more negative attitudes, greater attribution of irresponsibility, and stigma (Bishop, Alva et al., 1991; Herek et al., 2002; Schwartz et al., 2014; Skelton, 2006). Interestingly, contrasting HIV and leukemia risk perception revealed a pronounced dissociation in event-related brain potential responses associated with high and low risk for both diseases (Barth et al., 2013). This finding implies at least some specificity of intuitive HIV risk perception rather than a generic response to all kinds of diseases. However, a more comprehensive assessment of intuitive risk perception associated with a range of STIs and other diseases is needed to assess the memory representations accessed by intuition for key characteristics of illness representation, i.e., contagiousness and seriousness (Bishop, 1991).

The current research is rooted in the health psychological and public health literature on HIV risk behavior in young adults (Maticka-Tyndale, 1991; Swann Jr et al., 1995; Thompson et al., 1999). However, a highly relevant, but henceforth largely unconnected line of research exists on the topic of face perception in social and evolutionary psychology regarding impressions of health (Jones et al., 2012), attractiveness (Rhodes & Zebrowitz, 2002), and social impressions more broadly (Sutherland et al., 2013; Todorov et al., 2015). We found that HIV risk shows a small to medium association with how “ill-looking” the depicted persons are perceived ($r = 0.18$ for HIV risk to ill-looking), which is substantially lower than, e.g., the correlation to responsibility ($r = 0.6$). We interpret this as evidence that people seem to judge HIV risk more based on personality characteristics and less on cues for health. However, several cues that emerged in the cue-utilization analysis, such as „reddened eyes“ or „spotty skin“, are compatible with cue-utilizations reported for health (Jones, Porcheron, Sweda, Morizot, & Russell, 2016; Jones, Batres et al., 2018; Tan et al., 2018). More abstracted cues, such as an „exhausted“ or „sad“ facial expression were also related to judgments of HIV risk, and such cues have also been reported in the literature on health and disease perception based on facial appearance (Jones, Batres et al., 2018).

The relationship of attractiveness and HIV risk perception is less clear, although there is evidence that physical attractiveness drives sexual interest, which can influence partner selection, and may play a role in the context of HIV risk (Agocha & Cooper, 1999; Blanton & Gerrard, 1997; Dijkstra, Buunk, & Blanton, 2000). In principle, both a positive or a negative relationship between attractiveness and HIV risk seem possible: A positive relationship might arise based on the idea that attractive people have more sexual opportunities and thus are likely more at risk. On the other hand, the „what-is-beautiful-is-good stereotype“ (Eagly, Ashmore, Makhijani, & Longo, 1991) suggests that more attractive people should have lower risk, and the same prediction arises from the notion that attractiveness „advertises“ health (Jones et al., 2001). In the current dataset, the correlation between HIV risk and attractiveness is low, and the cue-models trained to predict attractiveness were not able to predict ratings of riskiness, and vice versa. Overall, while the relationship of attractiveness may vary with the attractiveness of the models and experimental methodology (Eleftheriou et al., 2016; Hennessy et al., 2007), we observed no robust relationship of attractiveness and perceived HIV risk in our stimulus set.

Future research should examine how these impressions relate to broader notions of disease avoidance (Curtis, Barra, & Aunger, 2011; Schaller, 2011) and to general models of person impressions (Sutherland et al., 2013; Todorov et al., 2015). Over the past years, researchers have made great advancements in modeling facial appearance (Blanz & Vetter, 2003; Walker, Schönborn, Greifeneder, & Vetter, 2018) and understanding interactions between cues and higher-order judgments for real-world outcomes (Eberhardt et al., 2006; Jones, Batres et al., 2018; Linke et al., 2016; Mattarozzi et al., 2017; Olivola et al., 2014; Stephen & Perera, 2014), renewing the interest in the structure of social impressions and their predictability from photographs (Park & Judd, 1989; Rosenberg, Nelson, & Vivekananthan, 1968; Vernon, Am Sutherland, Young, & Hartley, 2014; Wang & Kosinski, 2018). Recent research suggests a 2- or 3-factor model of social trait impressions (Sutherland et al., 2013) comprising approachability/trustworthiness, dominance/masculinity, and youthfulness/attractiveness. Although our work differs with respect to the stimuli used (faces vs. more naturalistic photographs of persons) as well as regarding the concrete traits studied, previous findings using similar factor-analytic techniques found a comparable organization in which a factor comprising trustworthiness, responsibility, and risk was dissociable from a factor for attractiveness, health, and willingness to interact (Renner et al., 2012). To comprehensively position "HIV risk" within this social trait space requires studying a broader variety of images and the assessment of more traits (Renner & Hartung, 2004). Interestingly, in the domain of trust, recent research demonstrated that different images of the same person are associated with different ratings of trust (Todorov & Porter, 2014). Presenting multiple images of the same person in future research may not only provide further insight into the association of risk perception with the key characteristics of the HIV risk stereotype but would also reveal the extent to which risk perception varies with situational context.

The present study has limitations with regard to the stimulus materials as well as the examined cues and person characteristics. While our stimulus materials were selected to represent naturalistic person presentations on social media, a larger number of stimuli would be desirable. Related to the issue of stimulus sampling, future work should extend our findings to different cultural contexts, and vary both the observers and targets. Extending our work beyond the „western“ setting in which our study was conducted could provide insights into commonalities and differences of social inferences across cultures (Henrich et al., 2010). Additionally, in recent work, we found differences in HIV risk ratings based on both the gender of the person that is to be judged as well as the raters' gender (Barth et al., 2015). Within the current work, the entire cue-criterion-correlation vector for males and females showed a large correlation (r = 0.72, p < 0.001). Future work might examine possible gender commonalities and differences systematically using larger sample sizes. Furthermore, while we undertook considerable effort to include relevant cues to person perception based on literature research and focus group discussions, it is always possible that the inclusion of additional cues would result in larger cue-utilization coefficients. However, the strong association between riskiness and multiple cues may be considered as evidence that our cue selection covered most obvious aspects. We also note that the ratings of HIV risk, as well as other characteristics, are inherently relative and should be interpreted with respect to the current set of stimuli and questions. Furthermore, it would be helpful to see how HIV risk impressions relate to additional person characteristics, including, for instance, competence, warmth, or intelligence (Fiske, Cuddy, & Glick, 2007; Todorov et al., 2015). Additionally, assessing measures of confidence in the perceived person characteristic may provide valuable information on the association between trust, responsibility, and HIV risk ratings. Such work may also point to subtle differences when moving from general to more specific person characteristics.

Summary and conclusion

This study reveals visual cues that are systematically linked to snap judgments about a person's HIV risk. HIV risk impressions appear to be embedded in a stereotypical set of beliefs about negative personality attributes. Knowing only a handful of cues is sufficient to predict perceptions of HIV risk. These findings provide insight into the phenomenon of intuitive risk perception and can be used to design health campaigns and interventions aimed at reducing the burden of HIV and sexually transmitted infections.

7

General Discussion

Humans are surrounded by risk information about threats to their health. Human health can be improved by adopting a healthier lifestyle, such as stopping to smoke, reducing alcohol use, adopting safe sex practices, or decreasing sedentary behavior. Nevertheless, initiating changes in health behavior is challenging (see, e.g., Institute of Medicine, 2001 - for an overview). A fundamental variable in major theories on health behavior is risk perception. Recognizing to be personally at risk is assumed as a precondition for behavior change (Brewer et al., 2007; Ferrer & Klein, 2015; Loewenstein et al., 2001; Portnoy et al., 2014; Renner & Schwarzer, 2003b; Renner & Schupp, 2011; Renner et al., 2015; Weinstein, 2003). Meta-analytic findings show robust effects of risk perception on intentions and behavior, corroborating the existence of a behavior-motivation link (Sheeran et al., 2014; Webb & Sheeran, 2006). Based on the assumption that risk perception is central to influence behavior change, the overarching aim of the dissertation was to advance knowledge on health-related risk perception and communication. The present dissertation addressed the following research questions to reach this aim:

- What are the mechanisms underlying intuitive social risk perceptions?
- How does real-life risk communication unfold its effects among recipients?
- Can we link neuroscientific measures of risk communication to later behavior change?

A shared aspect across these questions is the identification of variables that influence the transition from general to personal risk perception and, ultimately, to healthier behavior. The present dissertation builds upon an interdisciplinary approach, influenced by health psychology, communication science, and affective neuroscience, to capture the mechanisms underlying health-related risk perception and communication. Furthermore, the dissertation takes a specific focus on the potential of neural measures to assess the perception of risk and effective risk communication. Two common risk behaviors were used as model systems that illustrate the gap between knowledge and behavior: sexually transmitted infections and risky alcohol use.

Intuitive risk perception in the context of sexually transmittable infections

Social risk perception is relevant in every situation in which humans decide whether to interact and meet with an unknown person or not. Recently introduced safety features in online dating apps, which now also incorporate a digital "alert button", illustrate the timeliness of this problem (Tinder, 2020). Field studies and focus groups revealed that people often do not rely on rational criteria when judging whether a partner is risky or safe concerning an STI. Instead, people reported to "just know" whether a partner is safe, even in cases without knowledge about a person's sexual history (e.g., Gold et al., 1992; Keller, 1993; Swann Jr et al., 1995). These findings led to the notion that intuitive processes might be crucial to understand STI risk perceptions.

Two studies of this dissertation extended previous work regarding the first research question, "What are the mechanisms underlying intuitive social risk perceptions?". In previous work, photographs of unacquainted others were presented to participants, followed by a question, such as "How risky is this person?". The studies showed early differences in the EEG signal between portrait pictures of individuals deemed risky in terms of HIV compared to individuals deemed safe (Barth et al., 2013; Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012). Moreover, the ERP analyses revealed additional differences between individuals perceived risky and individuals perceived safe at the level of an ERP component known to respond to the affective significance of stimuli and signaling attentive processing (Schupp et al., 2006). The converging picture from this self-report and neuroscientific evidence - based on visual information - is that STI risk perceptions involve characteristics of intuitive judgments. These characteristics are a fast mode necessitating almost no effort or conscious insight (Hogarth, 2010), as well as the involvement of affect (Slovic & Peters, 2006). Thus, intuitive processes have been ascribed a key role for STI-related social risk perceptions (Schmälzle et al., 2017).

In real-life, judgments about a person's riskiness or safeness involve not only visual information but also other sources of information. For example, intuitions about a partner's riskiness are derived from information on personality, biography, or past sexual behavior (Gold et al., 1992; Keller, 1993). Consequently, we aimed to detail further the mechanisms underlying intuitive social risk perceptions using ERP analyses. Within Chapter 5, we extended the previous paradigm by including verbal-descriptive biographical information (Schmälzle, Imhof, Kenter, Renner, & Schupp, 2019). We used a simulated online dating platform to investigate how verbal information is integrated with visual information. Participants saw either low or high-risk verbal-descriptive information in a text profile, followed by a low or high-risk portrait picture. The main finding of the subsequent ERP analyses was an interaction of verbal and visual risk information, observed over anterior-temporal sensor sites between 270 and 430 ms. These findings show that risk information from multiple sources about a person, such as verbal and visual information, is integrated early in the processing stream. This early integration precludes deliberative reasoning and supports the notion that social risk judgments are formed intuitively.

The picture that arises from the findings is one in which verbal information, provided by a dating profile, may form a transient person representation. The visual information contained in the picture is then integrated into this person representation. This reasoning builds on previous literature that highlighted the anterior temporal lobe's importance for integrating multiple pieces of social knowledge. For example, differences in neural activation were seen in these regions during the integration of multiple sources of information, or while facial identity was linked to semantic, biographic, and emotional knowledge (Collins & Olson, 2014a; Collins et al., 2016; Lambon Ralph et al., 2017; Wang, Collins et al., 2017). While the finding is in concert with previous literature on person perception and semantic cognition, one has to be cautious about spatial inferences using EEG. However, the experimental paradigm is transferable to an fMRI setting, which could validate the role of anterior-temporal brain regions for integrating multi-modal social risk information.

Verbal and visual information was integrated during all four experimental conditions. The condition mainly contributing to the ERP effect, however, was the one in which the maximum risk information was integrated. Specifically, dating profiles revealing high verbal and high visual risk seemed to mainly contribute to the effect. This finding added to previous work, which interpreted larger ERP differences for risky-looking individuals as related to affective significance and enhanced attention (Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012). Overall, the findings are in concert with the assumption of a neural system that processes potential risks. Considering the present finding in light of the previous work, the tagging of high-risk information may be interpreted as an alarm function leading to risk perception.

Chapter 6 provides an in-depth view of this putative risk perception system. The goal was to identify the bases of stereotypes underlying social risk perceptions on HIV (Schmälzle, Hartung, Barth, Imhof, Kenter, Renner & Schupp, 2019). Previous work indicated that risk perceptions in the context of HIV seem to rely on stereotypes, often evolving around trustworthiness and responsibility (Renner & Schwarzer, 2003a; Renner et al., 2012). The specific features that underlie these stereotypical notions of riskiness, however, remained unclear. In Chapter 6, we thus used a correlational approach to reveal cues that are used to infer ratings of riskiness. Using a Lens Model approach (Brunswik, 1955), we characterized the relationship between environmental features, the so-called “cues“, and perceived riskiness. These cue-criterion associations revealed which cues are used to infer HIV risk intuitively. While people lack insight into the specific features that give rise to their risk perception (e.g., Renner et al., 2012), the cue assessments revealed a high inter-rater agreement. Importantly, however, this agreement does not imply that these intuitive judgments are accurate. In sum, the first main result was that people seem to use a systematic set of cues when asked to evaluate the perceived HIV risk and trustworthiness of a person.

People seem to implicitly rely on a shared set of cues to judge HIV risk and trustworthiness. This finding led to the hypothesis that impressions of person characteristics can be predicted based on visual cues. Further analyses tested this hypothesis and revealed that a model solely based on visual cues can be used to predict perceived riskiness within a new set of portrait pictures. Similar results were obtained when predicting perceived riskiness using a model based on visual cues for trustworthiness. Previous work suggested that trustworthiness and responsibility are inter-related with perceptions of HIV risk, forming a dimension that may underlie stereotypical perceptions of high-risk persons (Barth et al., 2015; Renner & Schwarzer, 2003a; Renner et al., 2012; Schmälzle et al., 2011). We added to this work by revealing that visual cues can be used to predict perceived riskiness. Moreover, we substantiated the assumption that impressions of HIV risk are related to perceived trustworthiness.

A neural risk perception system

From a broader perspective, Chapters 5 & 6 indicate that verbal and visual information about the riskiness of a person is integrated via a fast and intuitive mode. Persons revealing risky attributes, be it verbal or visual, presumably receive preferential processing, related to enhanced attention and affective significance (Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012). In two studies, this preferred mode of processing was also seen implicitly, that is, during an implicit viewing task without mentioning HIV risk (Häcker et al., 2015; Schmälzle et al., 2011). An fMRI study about social risk judgments based on visual information found increased activation to individuals judged risky in the anterior insulae and medial frontal cortices (Häcker et al., 2015). In recent work, we replicated this finding in the anterior insulae for persons perceived as risky, that is, HIV-positive. Crucially, in this work, the real HIV status of the depicted persons was known, and participants subsequently received feedback on their decisions. During feedback on infected persons, a similar pattern of increased activation emerged within the anterior insulae, medial prefrontal cortex, and the amygdalae (Imhof, Flaisch, Renner, & Schupp, in preparation). The anterior insulae and medial frontal regions are assumed to form a saliency network, which is involved in “tuning” attention to internal or external information and shifting working-memory resources (Leech & Sharp, 2014; Menon & Uddin, 2010; Raichle, 2015; Seeley et al., 2007). Considering the current findings together with this work, we suggest that risk information is processed by a neural risk perception system that detects sources of risk and triggers an alarm signal (Renner et al., 2012; Schmälzle et al., 2011; Schmälzle et al., 2012, 2017). The findings of Chapters 5 & 6 add to the evidence that social risk perceptions are made intuitively and based on multi-modal information. Two relevant sets of brain regions for the processing of this risk information are the saliency network and cortical midline regions.

Stereotypical screenings of social risk information

The proposed screening of the social environment for potential risk signals might be seen as a “first line of defense“, which triggers avoidance behavior against potential health threats (Schaller & Park, 2011; Schaller, 2011). This concept of a behavioral immune system assumes that humans are highly sensitive to cues that reveal pathogens in others. The resulting avoidance can be advantageous as it renders an energetically expensive immune response to pathogens unnecessary, which represents the second line of defense. In the case of STI risk decisions, however, such intuitive control strategies are dangerous as they are made in a “wicked environment”. Such environments are characterized by a lack of valid feedback, which leads intuitions astray (e.g., Hogarth, 2010; Kahneman & Klein, 2009). STIs are usually not associated with overt signs. Hence, while relying on the first line of defense might be adaptive for observable illnesses, intuitive judgments on STIs represent an illusory control strategy that does not provide protection.

Providing feedback might be one way to change the reliance on illusory control strategies. Thompson and colleagues (2002) revealed that participants were at chance level when making judgments about HIV status. In a recent study, we gathered information on the actual HIV status of the persons depicted on the pictures that were presented in the laboratory. Using this set of pictures, we were able to reproduce the findings of Thompson and colleagues (Imhof et al., in preparation). Moreover, we were able to provide participants with “real” feedback on their decisions. This feedback about the failure of their inferences could be one way to provide valid information and experiences, which are otherwise missing in STI risk decisions. Theories in health psychology suggest that a feeling of being susceptible or personally at risk is central to motivating changes in behavior (Ferrer & Klein, 2015; Loewenstein et al., 2001; Renner & Schupp, 2011; Renner et al., 2015; Slovic & Peters, 2006;

Weinstein, 2003). Being exposed to feedback may present one way to experience failure and could help to undermine reliance on illusory control strategies. These insights can inform interventions aimed at reducing STIs. Specifically, relying on intuitive risk perception can be targeted as illusory control strategies, and actual strategies, such as consistent protective behavior, could be highlighted.

Risk communication in the context of risky alcohol use

Based on the assumption that risk perception is central to influence behavior change, it is imperative to advance knowledge on the mechanisms underlying health-related risk perception. From an applied perspective, on the other hand, it is highly relevant to reveal how risk perception can be effectively influenced to lead people to adopt a healthier lifestyle. The second part of the dissertation expands the study focus from intuitive risk judgments to the perception of health-related risk communication. Mass media messages are a key strategy to promote public health by reaching millions with messages about risks and desired behaviors (e.g., Rice & Atkin, 2013). Media influences on risk perception, though, are not a simple sender-receiver relation, and many questions remain about how messages affect recipients (e.g., Kasperson, 2012; Wåhlberg & Sjöberg, 2000). By using real-life video health messages, we assess health-related risk perception using ecologically valid stimuli (Chapters 2 & 3). However, these stimuli are also highly dynamic with regard to their physical properties and their content. These properties necessitate the use of a data analysis approach that can cope with complex, naturalistic stimuli. Consequently, we used the inter-subject correlation (ISC) analysis to address the second research question, "How does real-life risk communication unfold its effects among recipients?".

Previous work - mostly using fMRI – has revealed that ISC can reveal the neural response to naturalistic stimuli, such as movies or narratives (Golland et al., 2007; Hasson et al., 2004; Hasson, Landesman et al., 2008; Hasson et al., 2010; Honey et al., 2012; Jääskeläinen et al., 2008; Lerner et al., 2011). However, these studies also showed that response reliability, as measured by ISC, varied with the length of the presented stimuli. Especially ISC in higher-order brain areas depended on information that unfolded over a longer time scale of up to 40 seconds (Hasson et al., 2010; Lerner et al., 2011). Real-life health messages often rely on short videos less than a minute in length. Thus, it is essential to detail the robustness of fMRI-ISC in use with short videos. The findings of Chapter 4 indicate that ISC offers a reliable measure of neural response similarities in use with short video segments and group sizes similar to those of Chapters 2 & 3. Furthermore, brain regions revealing ISC while viewing video segments were not restricted to sensory-perceptual regions and extended to post-perceptual brain regions (Schmälzle, Imhof, Grall, Flaisch, & Schupp, preprint). In sum, the findings suggest the approach as a useful tool to assess the dynamic processing of real-life risk information.

In Chapter 2, we used fMRI to examine how the brains of young adults "tune in" to real-life health messages about risky alcohol use that varied in perceived message effectiveness (Imhof et al., 2017). The main finding of the study was that strong messages, evaluated to be more effective, commanded enhanced ISC within widespread brain regions. This finding suggests that these messages had greater "neural reach" across the brains of an audience. Enhanced ISC was seen in brain regions that included the dorsomedial prefrontal cortex, the insulae, and the precuneus. The cortical midline regions and the insula have previously been related to narrative engagement, self-relevance, and attention towards salient stimuli (Adolphs, 2003; Ferstl et al., 2008; Gusnard et al., 2001; Mar, 2011; Menon & Uddin, 2010; Northoff et al., 2006; Raichle, 2015; Schmitz & Johnson, 2007; Uddin, 2015). Overall, we suggest that effective health messages lead to enhanced engagement of the audience, which is reflected within shared brain responses in the aforementioned regions. This engagement is presumably based on psychological variables, such as saliency or personal relevance. Based on the findings, the ISC approach offers a promising strategy for tracking the neural effects of health communication.

In Chapter 3, we expanded the experimental approach to EEG to examine the processing of risk communication with high temporal resolution and a second target group (Imhof, Schmälzle, Renner, & Schupp, in press). The results replicated the differentiation between strong and weak messages seen in the fMRI study in terms of both self-reported effectiveness and ISC differences. Using the EEG data, we identified four distinct components that revealed ISC across the new target group. Three of the components revealed stable differences, with almost all participants revealing enhanced ISC during strong messages. In further analyses, we took an approach that connected EEG-ISC with fMRI data to identify candidate brain sources of the spatially distinct correlated components. In this approach, fluctuations in EEG-ISC are used as a parametric regressor in fMRI-GLM analyses. We revealed that EEG-ISC in the second audience co-varied with the fMRI signal of the first audience in a meaningful pattern of brain regions. EEG-ISC was not only related to signal in brain regions related to sensory-perceptual processing but also with the signal in the precuneus, the insula as well as the posterior and dorsal anterior cingulate extending to the medial prefrontal cortex. Thus, distinct correlated components seem to be related to post-perceptual brain regions. The extension of the ISC approach to EEG is promising as it may provide a more accessible marker to quantify the impact of health messages within the brains of a target audience.

We found marked parallels between the fMRI-ISC results reported in Chapter 2 and possible neural generators of EEG-ISC in Chapter 3. Thus, the multi-methods approach enabled replication and validation of the measure with respect to previous findings and across two imaging modalities. The results also underline the potential of the ISC approach to measuring similarities across neuroscientific methods (e.g., Haufe et al., 2018; Liu et al., 2017; Nastase et al., 2019). The picture emerging from the two chapters is that irrespective of the neuroscientific measure, neural responses are reliably entrained during the perception of health messages and across two independent target groups. The findings indicate that ISC of both fMRI and EEG data can differentiate messages that are strong or weak in terms of perceived effectiveness. ISC thus seems suited as a tool to gauge the “neural reach” of health communication in small groups. Given that different neuroscientific modalities capture independent levels of information, this approach may boost our ability to identify messages that are effective at scale.

Communication neuroscience: From brain mapping to prediction of behavior

Based on the assumption that neuroscientific measures can contribute to understanding the effects of communication, an interdisciplinary field of "communication neuroscience" is emerging (Falk, 2010; Schmälzle & Meshi, 2020). Both EEG (Potter & Bolls, 2012) and fMRI (Cacioppo et al., 2018; Weber et al., 2018) have been used to extend the understanding of communication-related phenomena. Many studies from the field have treated "brain measures" as a dependent variable. In other words, these studies map where in the brain neural activity changes in response to a manipulation of an independent variable, such as health information. For example, in Chapters 2 & 3 of this dissertation, we used ISC to assess differences in neural processing for strong as compared to weak messages. Similarly, in Chapter 5, we used ERP analysis to compare the responses to high and low-risk information (see Figure 7.1a).

More recent work points to a so-called "brain as predictor" logic. In this logic, the brain is used as an independent variable and acts as a mediator, moderator, or a direct predictor of an outcome (see Figure 7.1b; Berkman & Falk, 2013; Falk et al., 2015). For instance, the hypothesis can be tested that a brain region's signal allows predicting behavior change. Crucially, the choice of a brain region should be governed by previous knowledge (Falk et al., 2015). For example, Falk, Berkman, and colleagues (2010) used fMRI data from an a priori ROI in the mPFC during viewing risk communication advocating sunscreen use. Brain activity in this ROI was then related to changes in sunscreen use in the following two weeks. Activation was able to explain variance above and beyond intentions and attitudes measured by self-report. That mPFC-activity in response to health messages can predict behavior change has been repeatedly replicated and extended, e.g., to smoking or physical activity (Chua et al., 2011; Cooper et al., 2015; Doré et al., 2019; Falk, Berkman et al., 2010; Falk et al., 2011; Kang et al., 2018). Gaining the capability to improve predictions of outcomes, e.g., compared to self-report or task performance, is essential. This capability allows testing hypotheses and may improve understanding of psychological processes (for an overview, see Gabrieli et al., 2015).

As can be seen in Figure 7.1, the trajectory from the brain as a dependent variable to using brain measures as an independent variable is reflected in the present dissertation. In Chapter 3, we used both a brain mapping and a brain-as-predictor approach. Specifically, we addressed the third research question, "Can we link neuroscientific measures of risk communication to later behavior change?". A follow-up questionnaire four weeks after exposure to the health messages revealed reductions in the amount and frequency of drinking compared to baseline measurements. To explore the potential of EEG-ISC to predict subsequent behavior change, we assessed the relationship between ISC and drinking behavior at follow up using a regression model. The model included drinking at baseline, self-reported risk perception, and intentions, as well as ISC during strong messages. In this model, ISC of components related to higher-order brain regions was a significant predictor of drinking amount at follow up. This finding suggests a link between ISC during processing effective health risk information and subsequent behavior change. Furthermore, the study is one of the first that used EEG-ISC to predict changes in health behavior.

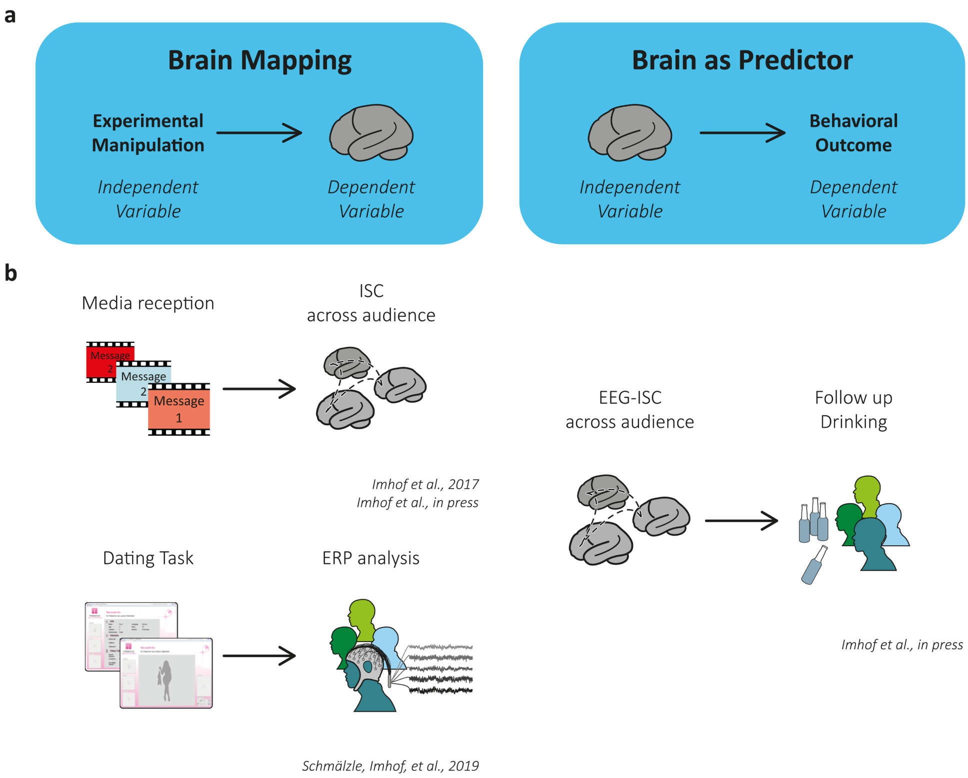

Figure 7.1 | A conceptual overview of ways that neuroimaging data is used to assess neural processes associated with health-related information. *a) Schematic overview of designs used in communication neuroscience. b) Examples of the work in the current dissertation illustrate the approaches using exemplary, simplified study designs.*

There is evidence that the brain as a predictor approach is extendable to an out of sample prediction (Chan, Smidts, Schoots, Dietvorst, & Boksem, 2019; Dmochowski et al., 2014; Falk et al., 2012; Falk et al., 2016). For example, Falk et al. (2016) were able to predict the population-level success of an e-mail campaign against smoking on the population level by using brain activity of a small "neural focus group" captured during the perception of the images used in the campaign. However, no metrics related to population-level effectiveness were available for the set of health messages used in Chapters 2 & 3. Thus, taking a population-level perspective was not possible with the current data. Exploring whether messages achieving broader "neural reach" in a focus group, will also have enhanced mass reach through EEG seems promising for future research (e.g., Barnett & Cerf, 2017; Dmochowski et al., 2014). Given the advantage of ISC to capture neural responses to content-rich audiovisual media, expanding on the work in this dissertation may lead to an identification of neural signatures of message effectiveness. Based on the work of Chapters 2 & 3, it seems feasible that future work may forecast whether new messages will reach an audience. By capitalizing on "neural focus groups", population effects might be predicted by the neural response of small-scale target audiences.

A hierarchy of brain regions related to the perception of health risk information

Within the present dissertation, we found reliable entrainment of neural responses during the perception of health messages in both sensory-perceptual and post-perceptual brain regions. A model that can explain these ISC findings is informed from animal and neurological research and assumes a cortical hierarchy within the human brain. As visualized in Figure 7.2a & 7.2b, the model suggests an information flow from primary sensory, unimodal brain regions via higher-order unimodal and heteromodal association regions, to paralimbic and limbic regions (Fuster, 2003; Mesulam, 1998; Pandya & Yeterian, 2003). The processing of incoming information, however, is not restricted to bottom-up processing. Regions higher in the hierarchy can also influence their predecessors in a top-down fashion (Fuster, 2003; Mesulam, 1998).

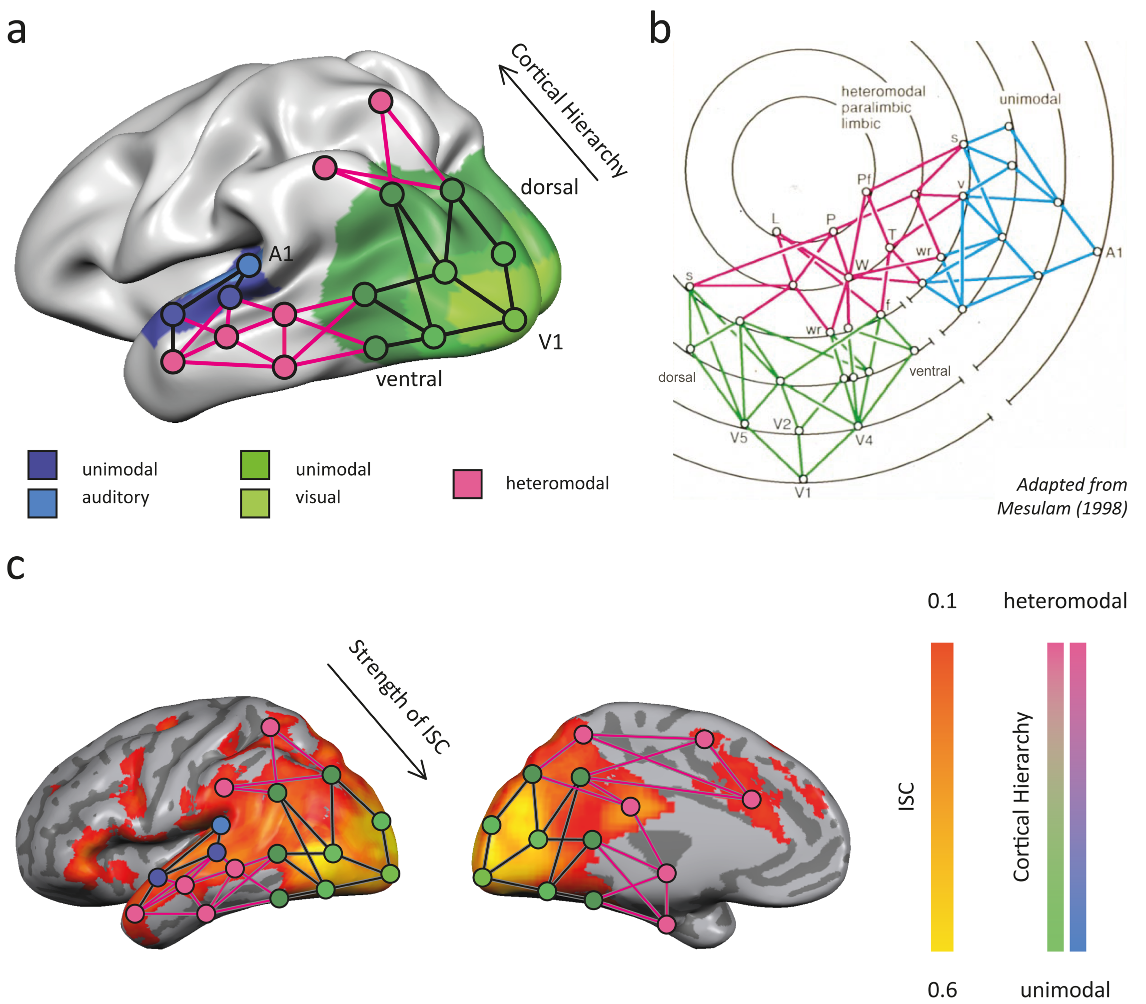

Figure 7.2 | A cortical hierarchy is reflected in a gradient of inter-subject correlation. *a) Hypothetical cortical hierarchy from primary visual (green) and auditory regions (blue), to unimodal association areas, to heteromodal association areas, and higher-order post-perceptual brain regions (magenta).*
b) Schematic mapping of cortical hierarchy: Visual and auditory pathways extend from unimodal primary visual, and auditory cortices to higher-order limbic and paralimbic heteromodal association areas. Dorsal and ventral streams are indicated for the visual modality. Circles represent cortical areas ("nodes"). Concentric rings visualize synaptical connections between nodes at the same hierarchical level. Gaps in rings illustrate the absence of connections between unimodal visual and auditory nodes.
Abbreviations: A1 = primary auditory cortex; f = face encoding area; L = hippocampal-entorhinal / amygdaloid components of limbic system; P = posterior parietal cortex; Pf = lateral prefrontal cortex; s = spatial location encoding area; T = lateral temporal cortex; v = individual voice pattern identifying area; V1 = primary visual cortex; V2 / V4 / V5 = additional visual areas; W = Wernicke's area; wr = word-form encoding area).
The figure section 7.2b is adapted from Mesulam (1998). Republished with permission of Oxford University Press, from "From sensation to cognition" by Mesulam, M.-M., published in Brain: A Journal of Neurology, 121(6), 1998; permission conveyed through Copyright Clearance Center, Inc.
c) Average ISC results (r-values) during viewing strong health messages (Imhof et al., 2017) are overlaid on a rendered anatomical volume and overlaid by a hypothetical, cortical network.
Please note that all anatomical labels and connections are approximate and only for illustrational purposes. Anatomical volumes are inflated, Talairach-normalized renderings of the Colin27 Average Brain (Holmes et al., 1998).

Considering the findings of the two model systems in this dissertation from a broader perspective, we suggest that health-related risk information and risk communication engage this hierarchy of brain regions. Previous work revealed that fMRI-ISC shows a gradient across different levels of the cortical hierarchy with ISC decreasing from primary sensory to higher-order regions (Abrams et al., 2013; Golland et al., 2007; Hasson et al., 2004; Hasson, Yang, Vallines, Heeger, & Rubin, 2008; Hasson et al., 2010; Jääskeläinen et al., 2008; Jääskeläinen et al., 2016; Lerner et al., 2011; Wilson et al., 2008). The fMRI-ISC findings in Chapters 2 & 4 similarly revealed a cortical hierarchy during the perception of video segments, with ISC decreasing from primary sensory to higher-order brain regions (see Figure 7.2c). Previous work has shown that the entrainment of brain regions across viewers also depends on the meaning transported in the media stimulus (Honey et al., 2012) or shared risk perception of the viewers (Schmälzle et al., 2013). The results underline the notion that integrative, post-perceptual regions seem not just to respond in an automatic, stimulus-driven manner. Instead, they seem to engage with the incoming stimulus based on meaning and personal relevance.

The EEG-ISC findings in Chapter 3 agree with this assumption by revealing a similar hierarchy during the perception of video health messages, but in use with EEG data. Specifically, the results show a distinction between correlated components mostly relatable to either primary sensory or higher-order brain regions. The picture that arises based on the current findings (Chapters 2 & 3) and previous work (Schmälzle et al., 2015) is that ISC across an audience is consistently enhanced during strong messages. Importantly, the enhancement is seen not only within stimulus-driven brain regions but also within regions related to higher-order processing - such as assessing personal relevance, affective evaluation, and directed attention. By showing this enhancement irrespective of the neuroscientific measure, the present dissertation extended previous work that used fMRI-ISC. Capitalizing on correlated EEG components related to higher-order processes appears especially promising to allow inferences about the effectiveness of health messages in future work.

Higher-order brain regions seen in this dissertation are foremost cortical midline regions, i.e., dorsomedial prefrontal cortex (dmPFC), the anterior and posterior cingulate cortex, as well as the precuneus and the insula. Functional neuroimaging research has linked the cortical midline regions to a broad set of processes surrounding personal relevance, social and memory-related tasks, as well as affective evaluation (Apps et al., 2016; D'Argembeau et al., 2010; Etkin et al., 2011; Murray et al., 2012; Qin & Northoff, 2011; Raichle, 2015; Schmitz & Johnson, 2007). The findings of Chapter 5 indicated anterior-temporal regions during the integration of verbal and visual risk information. While this region likely is not directly processing “social risk“, it may provide integrative, risk-processing regions with accumulating sensory evidence (for a similar concept, see Heekeren, Marrett, & Ungerleider, 2008). The regions seen during the processing of risk information in this dissertation partly align with meta-analytic findings on the neural underpinnings of risk perception during decision-making under uncertainty, which indicated the anterior insula, the thalamus, dorsolateral and dorsomedial prefrontal, as well as parietal regions (Mohr, Biele, & Heekeren, 2010). From a broader perspective, the findings of the current dissertation suggest that risk perception is not represented in a dedicated “risk brain region”. A hierarchical framework within the human brain could explain the current findings during the processing of dynamic health-related risk information. A common denominator of the identified brain regions seems to be the response to salient, affective, and personally relevant information.

Directed attention through personal relevance

Within this dissertation, we exposed participants to ecologically valid risk information with the goal to elicit and assess personal risk perception, which in turn, may act as a prerequisite for behavior change (Renner et al., 2015). A shared finding in response to the risk information used in this dissertation seems to be a modulation of attention. In Chapter 2, fMRI-ISC effects for more effective health messages were additionally seen in occipital and parietal brain regions, revealing overlap with the dorsal and ventral attention networks (Corbetta & Shulman, 2002; Fox et al., 2006). In Chapter 3, fluctuations of EEG-ISC were related to fMRI signal in sensory-perceptual and visual-associative regions. Enhancement of ISC in these regions could likewise reflect increased visual attention. Chapter 5 revealed an early, sustained ERP differentiation depending on the visual risk status of the presented person’s picture. However, there was no difference seen in the late positive potential, which has been observed reliably in studies that probed person portraits perceived high in risk (Barth et al., 2013; Renner et al., 2012; Schmälzle et al., 2012). Different task modalities might explain this divergence. Taken together, the findings from electrophysiological and functional neuroimaging in this dissertation agree with research from affective neuroscience showing ERP modulations (Schupp et al., 2006) as well as increased activations in visual-associative regions towards emotional stimuli (Junghöfer et al., 2005; Lang & Bradley, 2010; Sabatinelli et al., 2005). Acknowledging the limits of reverse inferences (Poldrack, 2006), a common feature across the studies of this dissertation might be the attentional tuning towards salient information, presumably related to higher-order brain regions. Health-related risk information may represent such salient, personally relevant information. In models from communication science, the ability to direct attention is a critical feature of a communication campaign. This ability is seen as a pre-condition for effectiveness and determines whether other variables that are conditional on attention can exert their influence (McGuire, 1989). The finding that neural measures might reveal this attentional tuning is promising for understanding the effects of health communication on a neural level.

Personal relevance is one variable that may influence how risk information is processed. The elaboration likelihood model of persuasion (ELM) postulates that changing an attitude can happen through either a central or a peripheral route, depending on a person's current ability and motivation to process a piece of information (Petty & Cacioppo, 1986; Petty et al., 2009). According to the model, personal involvement or relevance is among the variables which prompt more elaborate message processing. In Chapters 2 & 3, enhanced ISC was seen in cortical midline regions using fMRI and in correlated EEG components related to the same brain regions. These findings support the idea that messages that promote a sense of personal relevance, risk perception, or related psychological processes appear to be the ones that lead to enhanced ISC. Research showing stronger activity in the mPFC and precuneus for self-tailored compared to less or untailored anti-smoking and safer sex messages supports the suggested role of personal relevance for effective messages (Chua et al., 2009; Chua et al., 2011; Wang et al., 2016). While it is tempting to interpret heightened ISC in dmPFC as purely driven by self-relevance, ISC may rise through other factors, such as affective or narrative information.

Thus, a many-to-one relationship seems plausible. In light of theories on media effects and persuasion, however, the findings of the current dissertation agree with the notion that personal relevance is a promising factor for prevention media. Neural measures may present one way to elucidate how this relevance can be achieved.

Persuasion theories assume that selective attention and elaborated processing of a message are crucial for changing attitudes or behavior. Attention and elaborated processing, in turn, can be brought out by issue involvement, personal relevance, emotion, or immediacy of an adverse effect in time (e.g., Greenwald & Leavitt, 1984; McGuire, 2013; Petty & Cacioppo, 1986; Petty et al., 2009). The "risk as feelings" approach similarly assumes that affective reactions depend on factors such as the immediacy of a risk, its vividness, bodily states, or current mood (Loewenstein et al., 2001). Within health communication, fear appeals are a prominent strategy to provoke such affective reactions, targeted at changing behavior (Maddux & Rogers, 1983; Witte, 1992). Solely focusing on affect and personal relevance, however, might not be sufficient. Meta-analytic findings on fear appeals showed that effectiveness increased when a message included efficacy statements (Tannenbaum et al., 2015; Witte & Allen, 2000). Similarly, major models on health behavior change indicate that aspects other than personal risk perception, such as self-efficacy, are equally relevant to change behavior (Renner & Schwarzer, 2003b; Schwarzer, 2008). Health communication likely also needs to focus on resources to initiate and maintain healthy lifestyles in order to be successful. Overall, models on persuasion and health behavior change support the idea that information that promotes a sense of personal relevance can lead to elaborated processing, risk perception, and ultimately – behavior change.

The potential of neural measures for effective health risk communication

The translational potential of EEG-ISC seems especially promising for formative research. Mobile EEG provides an accessible and scalable measure that could be integrated into message pre-testing. For example, first studies adopted EEG laboratory research to natural contexts, such as classroom interactions or cinemas (see Figure 7.3a - Barnett & Cerf, 2017;

Dikker et al., 2017; Poulsen et al., 2017). As shown in Chapters 2 & 3, ISC can reveal if and how health messages prompt a shared signal across a target audience. By exploiting this relation with mobile EEG, the measure may serve as a proximal marker of health message success in more realistic settings. The portable nature and cost-effectiveness of mobile EEG enhance its scalability and allow the assessment of more diverse groups and to make samples "less weird" (Burns et al., 2019; Henrich et al., 2010).

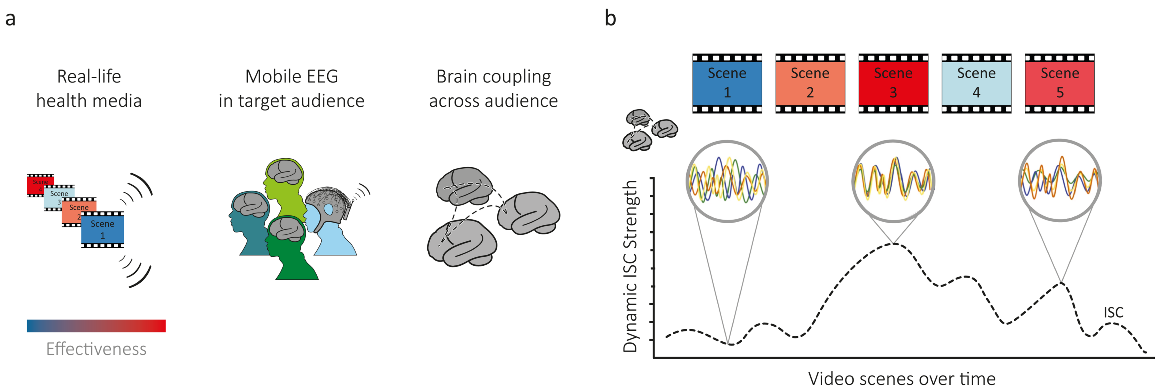

Figure 7.3 | Envisioned experimental paradigms. *a) To increase ecological validity and generalizability, EEG-ISC is assessed across different target groups using mobile EEG. b) A dynamic ISC over time approach allows identifying key features or scenes that specifically "resonate" within an audience.*

A natural step forward from this dissertation is to exploit the temporal resolution of EEG. Due to the short video durations in the current studies, ISC was calculated on a video-by-video base, thereby "integrating" over similarities across the whole video. This approach suffers from a lack of temporal resolution, especially with fMRI data, where brain activity is collected about every two seconds. In fast-paced media, such as short narratives used in health messages, two seconds can be the difference between a love and a crime scene. A scene-by-scene measure may identify critical moments in the video leading to peaks in ISC (see Figure 7.3b & Schmälzle & Grall, 2020). In this respect, the results of Chapter 3 are promising as EEG provides the temporal resolution needed for this analysis. This approach can provide a direct and unobtrusive measure of which key moments "resonate" the most within an audience, which in turn, could signal risk perception and persuasion.

Conclusion

The present dissertation represents a perspective influenced by health psychology, communication science, and affective neuroscience to assess how the human brain processes health-related risk information. We used two ecologically valid model systems to get a window onto the pathways through which health-related risk information motivates behavior change, that is, sexually transmitted infections and risky alcohol use.

The first part showed that risk information about a person from different modalities seems to be combined fast and in an intuitive mode. Persons in our environment that reveal high-risk features presumably receive a preferential mode of processing. These findings corroborate the notion of a neural risk perception system that detects sources of risk and triggers an alarm signal. The assessment of risk likely involves stereotypical perceptions based on a reliably shared set of features. For STIs, however, these intuitive perceptions present a dangerous illusory control strategy.

The second part has shown that methods from affective neuroscience can reveal how target groups perceive health-related risk communication. The reception process of such dynamic messages is difficult to observe using traditional analysis methods. Importantly, measures of inter-personal neural synchronization distinguished video health messages based on their effectiveness. The ISC approach thus offers a promising strategy for tracking the neural effects of health communication. By capitalizing on “neural focus groups”, the effects of health communication might be predicted using the neural responses of small-scale target audiences.

To inform models of health message reception, a systematic study of “how” risk information is processed, of “what” constitutes compelling risk information, and within “which” group of receivers is needed. The results of this dissertation suggest that a neuroscientific perspective can offer tools to answer these questions. Specifically, neural measures allow a glimpse of how risk information shapes risk perception and changes in behavior. A better understanding of these mechanisms can lead to better strategies for communicating health risks and, ultimately – healthier behavior.

Author contributions

The articles in the present dissertation were realized in cooperation with Prof. Harald T. Schupp (HS), Prof. Dr. Britta Renner (BR), Dr. Ralf Schmälzle (RS), Dr. Tobias Flaisch (TF), Clare Grall (CG), Alex Kenter (AK), Prof. Dr. Freda-Marie Hartung (FMH), and Dr. Alexander Barth. In the following, contributions of the author (MI) and the authors mentioned above are detailed based on the criteria suggested by the International Committee of Medical Journal Editors (ICMJE; http://www.icmje.org/).

Chapter 2: How real-life health messages engage our brains: Shared processing of effective anti-alcohol videos

MI and RS designed the study with important intellectual input from BR and HS. MI and RS carried out data collection. MI conducted data analysis under the supervision of RS and HS. MI, RS, and HS conceptualized the manuscript draft. The manuscript was written and revised by MI, RS, BR, and HS.

Chapter 3: Strong health messages increase audience brain coupling

MI designed the study with important intellectual input from RS, BR, and HS. MI carried out data collection. MI conducted data analysis under the supervision of RS and HS. MI, RS, and HS conceptualized the manuscript draft. The manuscript was written and revised by MI, RS, BR, and HS.

Chapter 4: Reliability of fMRI time series: Similarity of neural processing during movie viewing

RS and MI designed the study with important intellectual input from HS. MI and RS carried out data collection. RS conducted data analysis. RS prepared the manuscript draft with important intellectual input from MI, CG, and HS. The manuscript was written and revised by RS, MI, CG, TF, and HS.

Data of this chapter has been used within separate analyses and with different research objectives in Imhof, M. (2014). Emotion-associated brain synchronization induced by naturalistic stimuli: An fMRI study using the intersubject correlation analysis. *Unpublished Master Thesis.*

Chapter 5: Impressions of HIV risk online: Brain potentials while viewing online dating profiles

RS designed the study with important intellectual input from HS and BR. RS carried out data collection. HS, RS, MI, & AK conducted data analysis. HS prepared the manuscript draft with important intellectual input from MI and RS. The manuscript was written and revised by RS, MI, AK, BR, & HS.

Chapter 6: Visual cues that predict intuitive risk perception in the case of HIV

RS designed the study with important intellectual input from FMH, AB, BR & HS. RS, FMH, MI, & AK carried out data collection. RS conducted data analysis. RS prepared the manuscript draft with important intellectual input from BR, and HS. The manuscript was written and revised by RS, FMH, AB, MI, AK, BR, and HS.

Danksagung

“If we knew what it was we were doing,

it would not be called research, would it?” *

Diese letzten Sätze in meiner Muttersprache möchte ich nutzen um allen zu danken, ohne die diese Dissertation nicht zustande gekommen wäre.

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* often attributed to Albert Einstein, but not verified.

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