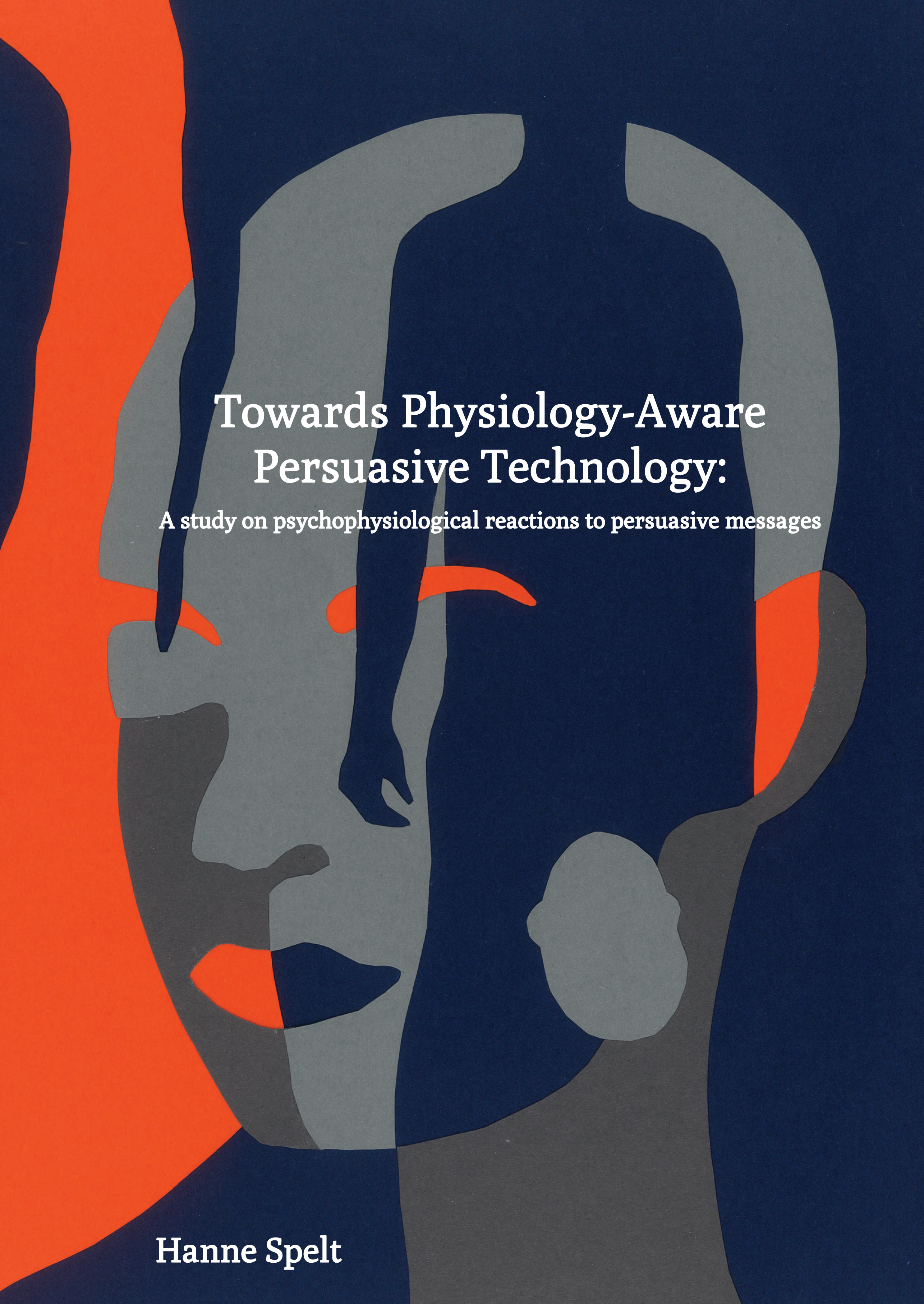
Towards Physiology-Aware Persuasive Technology



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A study on psychophysiological reactions to persuasive messages

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Cover: The front cover illustrates the interrelation between the body and the mind. This psychophysiological relation is, however, not always that evident or understood in detail. A literature search, four empirical studies and some perseverance enabled the creation of this four-colored persuasive image. Cover design by Elianne Koolstra.

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PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus prof.dr.ir. F.P.T. Baaijens, voor een commissie aangewezen door het College voor Promoties, in het openbaar te verdedigen op dinsdag 2 maart 2021 om 13:30 uur

door

Hanne Adriana Alijda Spelt

geboren te IJsselstein

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Het onderzoek of ontwerp dat in dit proefschrift wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

Contents

Chapter 1

General introduction

Unhealthy lifestyle behavior can contribute to ill health, cause human suffering, and impose high costs on individuals and society (World Health Organization, 2018). Lifestyle behaviors that affect a person's health are for example snacking, smoking, or insufficient physical activity. Therefore, changing health-related behaviors can be essential. *Persuasive Technology* (PT) can assist in (health-related) behavior change (IJsselsteijn, de Kort, Westerink, de Jager, & Bonants, 2006; Karppinen et al., 2018; Nelson, Verhagen, & Noordzij, 2016; Win, Roberts, & Oinas-Kukkonen, 2019). PT systems are intentionally designed to change a person's attitude and/or behavior (IJsselsteijn, de Kort, Midden, Eggen, & van den Hoven, 2006, p. 1). PT comes in many forms, for example mobile phone applications, wristbands, smart lights, or computers, and can operate in various contexts, such as health care, education, or environmental sustainability (Masthoff, Grasso, & Ham, 2014). People voluntarily use PT because it can provide support in their pursuit to change their behavior into a direction they wish to achieve.

Changing a person's attitude or behavior, better known as *persuasion*, can be an interactive process (Petty & Cacioppo, 2018), and achieved using a variety of strategies (Armstrong, 2010; Michie et al., 2013; Rhoads, 2007). Attitudes and behaviors differ from person to person (Petty & Cacioppo, 2018). Therefore, attempts at persuasion are most effective when personalized to the user (Markopoulos, Kaptein, De Ruyter, & Aarts, 2015; Meschtscherjakov, Gärtner, Mirning, Rödel, &

Tscheligi, 2016). For instance, messages are more persuasive when their framing as a gain or as a loss is adapted to the receiver's personality traits (Hirsh, Kang, & Bodenhausen, 2012). In personalized PT systems, input about the user is used to adapt system features to the users' emotional, cognitive or behavioral characteristics (Markopoulos et al., 2015), for example by sending an authority-based message to a user that self-reported a high susceptibility to the persuasion principle of authority (Cialdini, 2007; Kaptein, De Ruyter, Markopoulos, & Aarts, 2012).

1.1 Scope of this thesis

In this thesis, it is argued that psychophysiological assessment can advance Persuasive Technology by providing further understanding of persuasion-related processes and informing personalization of persuasive interventions. It is clear that people can have emotional and cognitive reactions to an attempt at persuasion (Cialdini, 2007; Miron & Brehm, 2006; Perloff, 2008). Moreover, physiological activity is known to reflect emotional and cognitive processes (Kreibig, 2010; Picard, 1995), potentially also persuasion-related processes. Therefore, an approach that can inform persuasion is physiological assessment.

Considering a person's physiology – together with subjective reports – is expected to help with detecting, and potentially also further understanding of persuasion-related processes. If so, these insights could perhaps be used to optimize persuasive interventions and persuasive technology by allowing physiology-contingent selection and tailoring of persuasive content. Therefore, more knowledge about the psychophysiological signature of persuasion is needed. This thesis sets out to address this with the following interrelated questions:

How does physiology reflect persuasion
and can this knowledge be used to personalize Persuasive Technology?

This thesis will consider several aspects of these two questions. First, physiological activity during attempts at persuasion will be examined multiple times. Next to exploring the (absence of) change in physiology, I will also study the meaning of physiological activity in terms of the effectiveness of the persuasion attempt. That is, does physiological activity in exposure to persuasive information indeed relate to persuasion? In unsuccessful persuasion attempts, a person can become motivated to reject the attempt, which might influence physiology as well. Therefore, also processes of psychological reactance will be considered in the empirical studies of this thesis.

Furthermore, a myriad of strategies can be used to achieve persuasion (e.g. Cialdini, 2007; Orji, Vassileva, & Mandryk, 2014). Possibly these strategies elicit different persuasion-related processes, each perhaps associated with its own physiological signature. In similar vein, the findings might be controlled by differences between people's states and traits. A person's personality, susceptibility to persuasion or current motivations might influence how he or she perceive an attempt at persuasion (Kaptein, 2012; Meschtscherjakov et al., 2016), and thereby potentially also their physiology. I will try to identify whether certain persuasive strategies or individual characteristics correspond to specific psychophysiological reactions to attempts at persuasion.

At the same time, it is important to consider how such psychophysiological knowledge can be applied to systems employing PT. That is, how should a physiology-aware persuasive system function? For this, I will first review contemporary personalization methods. Next, I will present two ways in which a system can adapt its' persuasive features to the user's physiology, and explore the ethics involved. With this approach, I hope to learn whether physiological measures can facilitate further personalization of persuasive interventions.

1.2 Research approach

This thesis takes a psychophysiological research approach. Psychophysiology can be defined as "the scientific study of social, psychological, and behavioral phenomena as related to and revealed through physiological principles and events in functional organisms" (Cacioppo, Tassinary, & Berntson, 2007, p. 4). Psychophysiology is a subfield of psychology and thus seeks to explain human behavior and experiences in the physical and social environment. However, a psychophysiology researcher will try to link a psychological phenomenon to changes in physiology. The latter can be captured using parameters of the central, autonomic, or somatic nervous systems (Cacioppo et al., 2007).

Various laboratory experiments will be performed to investigate the research questions. The benefit of a laboratory environment is that all presumed causes of a psychological phenomenon can be incorporated, while all interferences can be minimized. It permits a controlled presentation of the persuasive stimuli, followed by a targeted analysis of their impact. Furthermore, it allows within- and between-subject comparison and potential replication of results (Webster & Sell, 2014, pp. 10–11). This artificial character of laboratory experiments is favorable when trying to establish a psychophysiological relationship.

In these experiments, *persuasion* will be operationalized as a change in related motivations, that is attitudes or intentions, or a change in the target behavior after the intervention. Therefore, it is important that all persuasive stimuli advocate a clear objective and the participants have room for that change: People to whom the target objective seems relevant, but who do not yet comply with it. For finding these participants, I will utilize recruitment channels providing access to interested citizens, as well as students, thus deliberately covering a range of personal characteristics. These individual differences are expected to impact persuasion and physiological processes, and I will account for them by using subject-specific analyses.

1.3 Outline of this thesis

The work presented in this thesis aims to provide answers to the research questions in six chapters:

In *Chapter 2*, I will draw on existing literature to analyze the possibilities of physiology-aware PT. For this, I will review related literature in the field of persuasion, (personalized) PT and psychophysiology as well as model two possible physiology-based adaptations of current PT.

The following four chapters describe the empirical work done to validate a part of this model.

Chapter 3 describes an explorative study that investigates psychophysiological reactions to persuasive information and whether those are affected by individual differences in motivations.

In *Chapter 4*, I focus on psychophysiological measures of reactance to persuasive messages. These insights might help to differentiate between persuasion and psychological reactance.

In *Chapter 5*, I explore whether susceptibility to specific persuasive principles reflects in physiology when exposed to messages deploying those principles. Thereby, it narrows the scope of this research to distinct strategies for achieving persuasion.

Chapter 6 investigates if physiology predicts persuasion effectiveness in terms of motivational state as well as of subsequent behavior. Additionally, it sets out to quantify the information yielded by physiology that was not represented in other predictors of persuasion.

Finally, in *Chapter 7*, I reflect on the contribution of this thesis' findings to understanding of persuasion-related processes, implications for design as well as ethics of future persuasive technology, and formulate conclusions.

1.4 Main contributions

This thesis integrates knowledge and methods from various disciplines to explore psychophysiology as personalization input of persuasive technology. With this multidisciplinary approach, I intend to contribute to several research fields: First, this research contributes to the field of psychophysiology by probing the presence of physiological activity patterns in the context of persuasion. Second, this research contributes to the field of persuasion by adopting a new experimental approach, which is physiology, to create insights in underlying mechanisms of persuasion, and thereby optimize persuasive interventions. Third, this research contributes to the field of human-computer interaction and persuasive system design by adding physiology to an overview of well-known personalization methods, and presenting two ways to personalize systems iteratively using physiological data. Fourth, a discussion on the implications of real-time physiology-aware PT systems adds to both the fields of persuasive system design as well as ethics.

Chapter 2

Persuasive Technology

The purpose of this chapter[1] is to present the possibility of physiology-aware Persuasive Technology (PT). The chapter begins with an introduction of PT and the psychology of persuasion. It proceeds with a review of contemporary personalization methods, followed by the introduction of physiology as a measure of persuasion-related processes. Physiological measurement is compared to traditional self-report and behavior measures of persuasion. Next, I propose two types of physiology-based PT adaptations and model a PT deploying these two physiology-based adaptations as well as self-report and behavior adaptations. Lastly, I discuss the meaning of physiology-contingent personalization for persuasive systems design.

[1] Part of this chapter has been submitted for publication to the journal User Modeling and User-Adapted Interaction as Spelt, H.A.A., Westerink, J.H.D.M., Frank, L.E., Ham, J., & IJsselsteijn, W.A., Physiology-based personalization of Persuasive Technology: A user modeling perspective. *User Modeling and User-Adapted Interaction*.

2.1 Introducing Persuasive Technology

Originally, persuasion specified the process by which one person tried to influence a second person (Perloff, 2008). Persuasive approaches have been effectively used to change the perspectives on topics such as health behaviors (Perloff, 2008), shopping (Cialdini, 2007), or politics (Brader, 2005). Since people attribute social characteristics to personal information systems (e.g. computers or mobile phones) (Fogg, 2003; Nass & Moon, 2000), persuasion can also occur via a technology-human interaction (Meschtscherjakov et al., 2016; Mitchell, Fondazione, Kessler, & Mamykina, 2020). This resulted in the rise of *Persuasive Technology* (PT), which is "a computerized software or information system designed to reinforce, change or shape attitudes or behaviors or both without using coercion or deception" (Oinas-Kukkonen & Harjumaa, 2008b).

Recent technological developments have changed attempts at persuasion from mass to personalized influence, since they enable a more complex, subtle and calculative form of persuasive communication (Perloff, 2008). Persuasion attempts to promote health behavior have come a long way from crusades against binge drinking in the 1800's (Perloff, 2008, p. 5) to contemporary mobile phone applications with push-notifications (Kaptein et al., 2012; Maimone, Guerini, Dragoni, Bailoni, & Eccher, 2018; Van Dantzig, Bulut, Krans, Van Der Lans, & De Ruyter, 2018). Contemporary PT comes in many forms, that is computers (Vroege et al., 2014; Wijsman et al., 2013), wrist bands (Westerink et al., 2014), mobile phone applications (Garnett, Crane, West, Brown, & Michie, 2019), ambient lighting (Maan, Merkus, Ham, & Midden, 2011), or even in virtual reality (Chionidis & Powell, 2020). It can be used for various objectives, for example, stimulating users to take a small break during computer work (Ham, Schendel, Koldijk, & Demerouti, 2011), encouraging physical exercise (Herrmann & Kim, 2017; Vroege et al., 2014; Wijsman et al., 2013; Win et al., 2019), promoting healthy eating (Kaptein et al., 2012; Maimone et al., 2018; Orji et al., 2014), conserving energy (Ham & Midden, 2014), supporting waste management (Nkwo, 2019), promoting weight-loss (Karppinen et al., 2018), supporting self-management of type 2 diabetes (Kim et al., 2019), or reducing alcohol intake (Garnett et al., 2019).

It is likely that PT will continue to evolve. Contemporary PT is to a great extent shaped by the role and development of modern information systems in the last few decades (IJsselsteijn, de Kort, Midden, et al., 2006). Information systems have become omnipresent in our society (Iyengar, Oinas-Kukkonen, & Win, 2018), and most people see their personal information systems, such as a smart phone or a computer, as indispensable or even as an extension of themselves. The technology behind these devices enabled a growth in the number of persuasive communications with messages travelling faster than ever before (Iyengar et al., 2018; Perloff, 2008). For instance, Natural Language Generation has been used to automate the creation of personalized persuasive messages on a large scale (Guerini, Stock, & Zancanaro, 2007; Maimone et al., 2018; Pan & Zhou, 2014). The recent trends of applying artificial intelligence to information systems (Iyengar et al., 2018) and reliable biosensors to wearable technology (van Lier et al., 2020) further expand PT's potential, for example, by creating an immersive, all-round experience with continuous dialogues.

2.2 Psychological processes related to persuasion

Persuasion, the main goal of PT, is a communicative process in which an entity (e.g. a computer, poster or television) influences a person to change his or her perspective on a particular subject or their behavior, while the person still has a free will to do or think otherwise (Perloff, 2008). Traditionally, persuasion is defined as the "an active attempt by an individual, group or social entity to change a person's beliefs, attitudes or behaviors by conveying information, feelings, or reasoning" (Cacioppo, Cacioppo, & Petty, 2017, p. 1). In this thesis, however, we make a distinction between an attempt at persuasion, persuasion-related processes, and persuasion. An *attempt at persuasion* or a persuasive appeal concerns an effort that tries to persuade someone, for example a sales pitch or a message. *Persuasion-related processes* are the psychological processes evoked by that attempt, irrespective of the success of the attempt. Persuasion-related processes comprise all evoked thoughts and feelings, both fast and autonomous as well as controlled and deliberate. *Persuasion* itself is when attitudes, intentions and/or behaviors are successfully changed by an attempt at persuasion. We believe that distinction is important, because successful and unsuccessful persuasive attempts can bring about substantially different mechanisms. Either case – being persuaded or not – is relevant to investigate.

In the influential *Elaboration Likelihood Model* (ELM),[2] attempts at persuasion target attitudes and/or intentions (Briñol, Petty, & Guyer, 2019; Petty & Cacioppo, 1986, 2018). *Attitudes* are evaluative feelings about an issue, person or object (Petty & Cacioppo, 2018), and *intentions* are motivational drivers for behavior (Ajzen, 1991). The recipient does not have to be aware of the attempt at persuasion for it to be successful or persistent. The ELM describes how persuasion can be achieved via direct and indirect pathways (Figure 2-1). If the recipient is motivated and able to consider the attempt at persuasion, the direct or central pathway will likely predominate. Attitude change through this pathway is achieved by influencing related beliefs (Petty & Cacioppo, 2018). The direct pathway is characterized by conscious processing of the information, and is considered to have a more persistent impact: Elaborating on all relevant facets of the subject before forming the attitude will make it stronger and more durable. In the indirect pathway, the person is not likely to elaborate on arguments, but is subject to peripheral cues in the persuasive context, such as likability or authority of the source (Kitchen, Kerr, Schultz, McColl, & Pols, 2014; Petty & Cacioppo, 1986). For example, when a person adopts a product promoted by their favorite celebrity, without actively weighing the pros and cons of that decision.

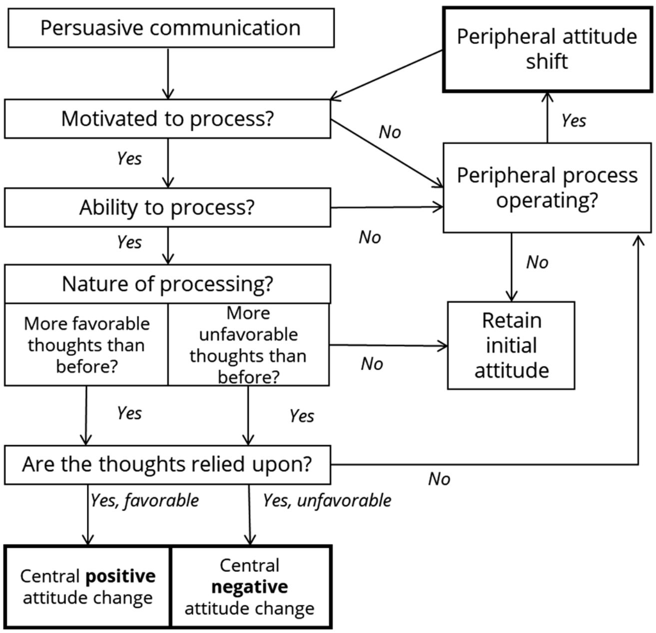

Figure 2-1 The Elaboration Likelihood Model of persuasion based on Petty & Cacioppo (1986). The left side illustrates the central or direct pathway, while the peripheral or indirect pathway is shown on the right side.

[2] A similar dual-process model of persuasion is the heuristic-systematic model (Eagly & Chaiken, 1993).

Attempts at persuasion can also evoke psychological processes that do not lead to persuasion. Even if a person is motivated and able to process the persuasion attempt, it can be unsuccessful if the person strongly disagrees with it. This response is known as *psychological reactance* (Brehm, 1966). In psychological reactance, people become motivated to "regain a freedom after it has been lost or threatened" and it "leads people to resist the social influence of others" (Steindl, Jonas, Sittenthaler, Traut-Mattausch, & Greenberg, 2015, p. 205). The level of reactance can depend on, among others, the importance of the threatened freedom (Rains, 2013), the magnitude of the threat (Steindl et al., 2015), the legitimacy of the threat (Sittenthaler, Steindl, & Jonas, 2015), or the social agency of the messenger (Roubroeks, Ham, & Midden, 2011). These characteristics are related to current motivations and behaviors, for example, which freedom a person perceives to be important is a belief that attributes to motivation (Miron & Brehm, 2006).

It is hypothesized that there are various ways to influence this process of achieving persuasion. For example, by ensuring that someone will elaborate on the persuasive message, or by hampering this elaboration while thickening the affective associations and simple inferences tied to persuasion context. Researchers have classified these approaches in various tactics (Rhoads, 2007), strategies (Dal Cin, Zanna, & Fong, 2004), and principles (Armstrong, 2010; Cialdini, 2007), some of which we will discuss in the following chapters of this thesis. One way to increase the likelihood of persuasion effectively is adapting the attempt to the personality characteristics of the receiver, also known as personalization.

2.3 Personalizing persuasion

There is no one-size-fits-all approach to successful persuasion. Differences in susceptibility to persuasive appeals come from dispositional characteristics (i.e. a person's state, trait, or demographic characteristics), and can vary over situations (e.g. a person's susceptibility to persuasive appeals can change depending on characteristics of the person's situation). Firstly, personality traits like need for cognition (Cacioppo, Petty, Koa, & Rodriquez, 1986), behavioral motivation (Hirsh et al., 2012; Sherman, Mann, & Updegraff, 2006), or the big five characteristics (Alkiş & Taşkaya Temizel, 2015), influence people's susceptibility to specific persuasive strategies. Similarly, demographic variables such as age or educational level can also affect susceptibility to persuasive information in general (Orji, Mandryk, & Vassileva, 2015). Secondly, a person has to be motivated and able to perceive and process a persuasive attempt for it to be effective (Petty & Cacioppo, 1986). This process can be restricted by emotional (DeSteno, Wegener, Petty, Rucker, &

Braverman, 2004; Rosselli, Skelly, & Mackie, 1995) or situational states (Kitchen et al., 2014; Petty & Cacioppo, 1986). For example, persuasion attempts may fail when there is no time to process the cue or if the receiver's mind is occupied with personal issues. The momentary context can influence people's susceptibility to a persuasive attempt: Someone might be more receptive to follow the orders of a police officer when being pulled over on the highway than during a night out with his friends.

The idea behind personalization[3] is that when the persuasive information does not fit with the state of the user, this causes the likelihood of persuasion to decrease. This can be mitigated with a better comprehension of the user and their context. Therefore, technologies that try to persuade should adapt themselves to the user with, among others, *self-report, behavior* or *contextual measures* (Markopoulos et al., 2015; Oinas-Kukkonen & Harjumaa, 2009). Table 2-1 presents an overview of known measures and adaptable system-features for the personalization of PT.

Self-report measures often take the form of questionnaires prompted by the PT interface. They are used to predict susceptibility to persuasive strategies or measure how a user feels or perceives his/her own behavior. Behavior measures monitor overt behavioral change over time using sensors, and can link this change to PT features in retrospect (Markopoulos et al., 2015). Thereby, they measure direct target behavior via the intensity of the behavioral response, but potentially also indirect representations of mental processes, for example longer dwell times or a higher click-through number both hint at engagement (Barral et al., 2016; Moshfeghi & Jose, 2013). Contextual measures, such as time or location, can reveal the activities that the user is engaged in, and thereby how the context might influence the person - either directly or through changing the person's susceptibility to persuasive appeals. The use of physiological measures for these purposes will be elaborated in the next sections. Information from all these measures can be used to adapt features of the system, such as persuasive strategies, end-goals, content of the messages, and timing of the prompts (Table 2-1). Adapting these system-features to user-characteristics fosters persuasion (Hirsh et al., 2012).

[3] Although both aim at increasing the likelihood of persuasion, personalization differs from tailoring. Tailoring involves feature adaptation on group level, whereas personalization involves feature adaptation on individual level (Karppinen et al., 2018; Oinas-Kukkonen & Harjumaa, 2009).

Table 2-1 Overview of measures and adaptable system-features for the personalization of Persuasive Technology.

	Descriptor	Explanation	Examples
Personalization measures	Self-report measures	Questionnaires can be used to obtrusively measure (Markopoulos et al., 2015): • Demographic state, which can influence users' motivations, opportunities, and abilities to perform a certain behavior (Michie, van Stralen, & West, 2011; Orji et al., 2015). • Personality traits, which relate to the user's tendency to comply with distinct persuasion strategies (Alkiş & Taşkaya Temizel, 2015; Cacioppo et al., 1986; Hirsh et al., 2012; Kaptein et al., 2012; Sherman et al., 2006). • Reflections on the user's own affective or cognitive state, which can influence motivation and ability to comply (DeSteno et al., 2004; Kitchen et al., 2014; Petty & Cacioppo, 1986; Rosselli et al., 1995). • Self-reported (target) behavior.	• Age, gender, education • Big-Five, need for cognition • PANAS • Food diary
	Behavior measures	Behavior measures can be used to unobtrusively measure: • The target behavior in relation to persuasive features, which can reveal susceptibility to those persuasive features (Markopoulos et al., 2015). • Expressions of user states in behavioral responses (Barral et al., 2016; Moshfeghi & Jose, 2013).	• Accelerometers, energy usage, user-system interaction • Keystroke force, dwell time, click-through
	Context measures	Contextual measures can reveal the context a user is involved in to assure that a persuasive prompt is delivered when the user is receptive, can process it and there is room for action.	Geolocation, calendar, time
	Physiological measures	Physiological activity holds information about the emotional and cognitive states of a person (Cacioppo et al., 2007). Physiological state can reveal whether the user is in a receptive mood, whereas physiological reactivity reveals the impact of a persuasion attempt.	Heart rate, heart rate variability, respiration rate, skin conductance level, facial muscle activity
Personalization features	Persuasive strategy	Various strategies can be used to achieve persuasion (Cialdini, 2007; Michie et al., 2011; Rhoads, 2007).	Authority, action-planning, gain-framing, controlling language
	End-goals	People use a PT to achieve a preferably self-set goal. The system determines several measurable sub-goals adapted to the users capabilities to help achieve that goal.	Active minutes per day, calorie intake, screen time
	Content	Persuasive messages that include user-specific information are perceived as more personal. User-system interaction improves when the system's interactions are in line with characteristics of the user.	Nicknames, behavioral history, culture, age,
	Timing	Attempts at persuasion are most effective when delivered just in time. Prompts can have different functions, such as reminding or motivating, depending on the time at which the user receives it (Fogg, 2009).	Spark prompts, facilitator prompts, signal prompts

2.4 Physiology during persuasion-related processes

Recently researchers have found an additional measure of persuasion-related processes in the form of physiology (Barraza, Alexander, Beavin, Terris, & Zak, 2015; Cacioppo et al., 2017; Correa, Stone, Stikic, Johnson, & Berka, 2015; Falk & Scholz, 2018). It is known that certain mental states correspond with an activation of physiology, for example, heart rate and skin conductance change 20 minutes before a person becomes aggressive (Looff et al., 2019). This might also be the case in persuasion-related processes. An attempt at persuasion is likely to influence someone's mental state: A person goes through several experiences before the exposure to the persuasive cue is translated into actual change of motivations or behavior. For example, the processing of persuasive information requires attention and further compliance asks for self-regulation. In addition, a person can have a range of feelings, such as annoyance or frustration when it is not easy to comply or if the message feels confrontational. We can also expect a drive and determination when someone is eager to comply. As psychological and physiological processes interact (Cacioppo et al., 2007), the mental processes activated by a persuasion attempt might result in varying levels of physiological activity. Studying these variations in physiological activity can therefor generate insights in the psychological mechanisms of persuasion. Moreover, if physiology indeed reflects persuasion-related processes, physiological assessment could serve as additional adaptation input in personalized persuasive technology (Table 2-1).

Therefore, some background on how psychological mechanisms can produce physiological responses is provided: Psychological states and processes activate brain areas, such as the prefrontal cortex, limbic system or thalamus (Gazzaniga, Irvy, & Magnun, 2009; Posner, Russell, & Peterson, 2005). In turn, these brain areas can further activate the nervous system (Fairclough, van der Zwaag, Spiridon, & Westerink, 2014; Jänig, 2003; Kreibig, 2010; Picard, Vyzas, & Healey, 2001; Thayer & Lane, 2009). The autonomic nervous system innervates bodily processes via its sympathetic and parasympathetic branches. Via the sympathetic branch the body is activated and prepared for action (sometimes in response to an emotional experience), whereas the parasympathetic branch is responsible for relaxation. The interplay between the two branches determines the activity in the various peripheral physiological subsystems (Cacioppo et al., 2007; Jänig, 2003), such as the *cardiovascular*, *electrodermal*, *respiratory* and *facial muscle systems*. As such these systems are known to reflect different parts of emotional (Jänig, 2003; Kreibig, 2010; Picard et al., 2001) and cognitive processes (Boucsein, 2012; Fairclough & Mulder, 2011). Changes in the cardiovascular, electrodermal and respiratory systems are predominantly associated with arousal level,[4] ranging from calm to excited, whereas facial muscle activity can reflect valence, ranging from negative to positive emotions (Boxtel, 2010). The studies in this thesis focus on peripheral physiology, which comprises all parts of the nervous system outside the brain and spinal cord, as these changes are often easily measurable with wearable technologies and thereby incorporable in PT. These subsystems, their main functions and measurable features are presented in Table 2-2 (see Jänig, 2003; Kreibig, 2010 for a full review).

Since emotion- or cognition-related brain activity can influence physiology via the nervous system, changes in physiology are taken to have psychological meaning. These physiological changes become especially meaningful when considering the timing of the physiology change in the process, which is pre-persuasion attempt, during the persuasion attempt, during the evoked persuasion-related processes, during new behavior, and after new behavior. The specifics of the psychophysiological relationship in persuasion are not yet clear. Among others, it is not known whether persuasion consists of one or a mix of psychological processes, and which physiological parameters covary with the phenomenon. This latter issue is part of the *multi-mapping problem* (Cacioppo et al., 2007, Chapter 1; Fairclough, 2009): Cacioppo et al. (2007, p. 11) also describe how one specific physiological reaction can connect to a specific (set of) psychological phenomena (one-to-many specificity).

[4] Recent studies indicated that cardiovascular and electrodermal activity can be related to certain affective states as anger or stress (Brouwer et al., 2018; Looff et al., 2019).

Table 2-2 Main functions, important measurable features and interpretations of activity changes of the cardiovascular, electrodermal, respiratory and facial psychophysiological systems.

Physiological subsystem	Measurable features	Psychological meaning
Cardiovascular system is responsible for blood flow throughout the body. Its main functions are the supply of oxygen and disposal of waste. The system is under hormonal and nervous system control (Cacioppo et al., 2007).	*Heart rate (HR)* is measured as the number of beats per minute. Sympathetic and parasympathetic activity can increase and decrease HR, respectively (Camm et al., 1996).	*HR* increases in states with a higher arousal levels, for example joy, fear, or cognitive demands. It decelerates in passive emotions and resting states, such as affection, or contentment (Jänig, 2003; Kreibig, 2010; Looff et al., 2019).
	Heart rate variability (HRV) reflects the beat-to-beat variability in HR and thereby the interplay between the sympathetic and parasympathetic nervous systems.	*HRV* indicates adaptive emotion regulation in both pleasant and unpleasant emotions. Reduced HRV indicates emotional dysregulation, such as anxiety, stress, or depression (Jänig, 2003; Kreibig, 2010).
Electrodermal system involves sweat gland activity. The system is solely innervated by the sympathetic branch of the nervous system (Boucsein, 2012; Cacioppo et al., 2007).	*Skin conductance level (SCL)* is the tonic component of skin conductance.	Electrodermal activity can reflect affect, attentional reactions or effort. *SCL* elevates during experiences that call for action or evoke stress (Brouwer et al., 2018).
	Skin conductance responses (SCRs) are rapid phasic components. SCRs are measured as the number or magnitude of the skin conductance peaks.	*SCRs* can arise in response to a stimulus and their magnitude reflects emotional levels independent of the valence of the stimuli. The presence of SCRs can indicate reward focus or decision-making.
Respiratory system consists of all organs involved in breathing. Its primary task is oxygen supply and carbon dioxide depletion. Breathing can occur both automatically and intentionally (Cacioppo et al., 2007).	*Respiration rate (RR)* can be measured via mechanical movement of the diaphragm and rib muscles	Changes in *RR* relate to cognitive demands, for example high task difficulty or working memory load, as well as emotional processing, for example breathing rate is faster in disgust or sadness, slower in relief, and stops in surprise.
Facial muscles are skeletal muscles on the face and used to control conscious and unconscious facial expressions (Boxtel, 2010).	*Zygomaticus major (EMG-ZM)* activity is measured from the muscles located between the cheekbones and lip-corners.	*EMG-ZM activity* causes the lip-corners to go up. This is known as smiling and associated with psychological states of positive valence.
	Corrugator supercilii (EMG-CS) activity is measured from the muscles located at the medial end of the eyebrows.	*EMG-CS activity* causes frowning and associates with negative emotions, for example anger or sadness. Frowning also occurs with increased cognitive demands, for example reading or thinking.

Nevertheless, to date, several studies indicated that this psychophysiological relationship holds for some parts of the persuasion process. Neuroscientific studies describe different neural correlates for message-induced persuasion (Cascio, Scholz, & Falk, 2015; Chua et al., 2011; Falk et al., 2015; Falk & Scholz, 2018), perceived persuasiveness (Cacioppo et al., 2017) and persuasion-induced behavior change (Cooper et al., 2018; Falk, Berkman, Mann, Harrison, & Lieberman, 2010; Falk & Scholz, 2018; Pegors, Tompson, O'Donnell, & Falk, 2017; Vezich, Katzman, Ames, Falk, & Lieberman, 2017). Cardiovascular and electrodermal arousal can indicate success of narrative persuasion, namely heart rate variability lowered and skin conductance level and number of responses increased in persuaded participants (Barraza et al., 2015; Correa et al., 2015). Peripheral physiology can also reveal psychological reactance to a persuasive message (Lewinski, Fransen, & Tan, 2016; Sittenthaler et al., 2015), that is when person becomes motivated to reject it. Furthermore, insights from neuroscience studies indeed suggest that persuasion consists of several sub-processes that demand or trigger different psychophysiological resources (Cascio et al., 2015): The exposure to (and potentially valuation of) persuasive information, the integration of the persuasive information into one's self-image, and the performance of persuasion-aligned behavior. These earlier findings indicate that to some extent persuasion-related cognitive and affective processes are reflected in physiology.

2.5 Measures for the personalization of persuasion attempts

That physiology might be used as measure of persuasion-related processes brings important benefits for the personalization of PT. This is mainly due to how physiological measures relate to the contemporaneous measures of self-report and behavior.[5] This section reports a comparison of important characteristics of the three measurements (Table 2-3) and describes how the measurements complement each other when personalizing PT.

[5] Contextual measures are not discussed in this analysis, as context-aware coaching in persuasive systems (Van Dantzig et al., 2018) is a relatively new phenomenon.

Table 2-3 Characteristics of self-report, behavioral and physiological measurements used for personalization of Persuasive Technology.

	Self-report measures	Behavior measures	Physiological measures
Representation	User's conscious reflections on affective and cognitive states (constructs)	Consequences of affective and cognitive states (behavior)	Derivatives of conscious and unconscious affective and cognitive processes (physiology)
User control	Overt controlled responses	Overt semi-controlled responses	Covert uncontrollable responses
Nature	Retrospective, obtrusive	Continuous, unobtrusive	Continuous, unobtrusive
Pitfalls	Introspection, non-response, (short-term) illness, signal loss	Faulty usage, illness, signal loss	Physical exercise, situational stressors, (short-term) illness, signal loss
Function	- Predictive: helps narrow down PT features that increase susceptibility for this user - Success assessment: measures whether user's behavior & underlying motivations have changed	- Process tracking: tracks changes in user behavior - Success assessment: tracks whether behavior reached set goals	- Predictive: helps identify which timing, strategy & content is most appropriate for this user - Process tracking: tracks user's reactions to PT prompts

For personalization, the system needs to understand the state of the user, as this state is decisive for the perception and thereby the success of an attempt at persuasion. Each personalization measure captures a different facet of this user state. Self-report measures aim at capturing the user's experience in the form of conscious reflections on psychological activity. Behavior measures demonstrate the consequences of psychological activity. And physiological measures present immediate derivatives of psychological activity (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000; Cacioppo et al., 2007).[6] The measures try to apprehend the process at different moments in time, that is during (physiology), shortly before and after (self-report) or later in time (behavior). This has consequences for when they can be used to measure persuasion effectiveness. As remarked before, persuasion is a complex, often multi-phased, process (Oinas-Kukkonen & Harjumaa, 2009): Various mental steps or even persuasive attempts might be needed to affect behavior. Asking for self-reports after each and every step in the process of being

[6] Roughly speaking physiology comprises uncontrollable bodily responses innervated by the autonomic nervous system, such as increased heart rate via (nor-)epinephrine release or brain activation via neurotransmitter release, whereas behavioral responses are all bodily changes innervated by the somatic nervous system that a person is or can be aware of, such as physical activity or posture.

persuaded or for each persuasive message is annoying. Especially since the (targeted) behavior is only expected to change after a cascade of persuasive messages, and not after a single message. With physiology, however, the reaction to each individual message can be interpreted. This yields data with a high temporal resolution, and in a continuous data trace even small changes in physiology might be meaningful. Physiology thus can be used for event detection (Maimone et al., 2018), and captures an instantaneous psychology-related reaction that can be used for real-time adaptation of the PT-user communication.

In addition, these measures differ in the extent to which the user is aware of the measurement and/or the responses being captured. To start, physiological measures collect information without the need to disturb the user. This unobtrusiveness results in direct and unhindered information related to the user's mental state. Although at the start the user might be aware of the system that performs the physiological or behavioral measurements, the user might forget it as time progresses. In contrast, completing a questionnaire cannot remain unnoticed: the user must deliberately answer and knows which answers were given (Maimone et al., 2018). As for behavior, whether or not the user was aware of the mental processes that activated it, the user can be aware of the behavior itself. Obtrusive questionnaires might reduce the persuasiveness of the system, as it can reveal the persuasive strategies that the system aims to use. A physiological sensing device might pick-up hidden states or reactions which a behavior or self-report measure might have missed (Picard, 1995). Additionally, people have no control over their physiological responses, as they are under autonomic nervous system control, which contrasts with self-report and to some extent with behavior measures. In theory, physiological measurement enables the analysis of mental states before the user notices them or even if the user never becomes consciously aware of them. Maybe precisely because the user is often unaware of physiological responses and has no control over them, they can function as an implicit measure of the mind (Picard, 1995).

Each measure has its own pitfalls (Table 2-3). Persuasion-related processes can happen automatically and outside of the user's awareness making them difficult to capture with traditional measures (Falk & Scholz, 2018). The traditional measures are often limited to conscious introspection, thereby lacking measurement of potentially relevant unconscious processes. Physiology has a wider range of possible inconveniences for assessing persuasion effectiveness: One difficulty is signal quality. The development of biosensors is ongoing. Currently, the quality of a measurement can vary between people or situations. It is important that analyses only include reliable points in a physiological trace for responsible personalization of the system. Future research must indicate which methods can assure sufficient quality of the physiological signal.

Additionally, inter-personal physiological activity levels can vary depending on static characteristics as age, gender or health (Shaffer & Ginsberg, 2017), but are less relevant in subject-specific systems employing PT. In addition, dynamic influences on intra-personal physiological activity levels, such as exercise, situational stressors, or illness, could lead to false positives and be detrimental for the efficiency of PT. For example, the system might interpret a sudden change in physiological activity as a reaction to a persuasive feature of the system, whereas in reality the user's love interest walked in at the exact same moment. This issue however becomes less problematic as time progresses due to repeated exposure: The encounter with a love interest and a persuasive feature will not always coincide.

Considering the information in this section thus far, we conclude that self-report, behavior and physiological measures each have their own function when personalizing PT systems. Self-report measures can be predictive by assessing relevant susceptibility traits before an attempt at persuasion even starts, in order to help select successful persuasive features and estimate the success of an intervention by checking whether underlying motivations (or observed behaviors) have changed. Behavior measures can show whether the attempt at persuasion is persistent, that is to what extent did the user reach his/her behavioral goal. Physiology might reveal the presence of a persuasion-related process and part of its impact on the user. As none of these measures provides a complete representation, the ultimate personalized PT system will likely combine them. Physiological data on its own might reveal the mental state and arousal of a person, but not why the person is aroused. The other measures can serve to frame the physiological activity, as emotions and cognitions do not stand on their own but evolve in specific situations (Picard, 1995).

2.6 Physiology and Persuasive Technology design

When adding physiological measures to PT, it is good to take into account generic guidelines for designing persuasive systems, as created by various researchers (Fogg, 2003; Oinas-Kukkonen & Harjumaa, 2009; Torning & Oinas-Kukkonen, 2009). Opening the research domain of PT in the previous century, Fogg (1998, 2003, p. 25) distinguished three potential functions for information systems that each bring their own persuasive affordance: An information system as a tool, a medium or a social actor. First, an information system as a tool can increase the user's capabilities, which makes it easier to comply with the persuasion objective. To illustrate, the spelling suggestions in Microsoft Word have persuaded me to write this thesis in proper English. Second, an information system as a medium can provide an experience as motivation. That is, the chefs on YouTube inspired my partner to improve his cooking skills (for which I am grateful). Third, an information system can behave as a social actor to create a relationship. In this case, a computer tries to trigger emotions and cognitions through communications, just as a person would (Fogg, 2003, Chapter 2).[7] This illustrates how an information system can be persuasive depending on its function.

Physiology measures have the potential to increase the persuasive affordance of information systems by supporting parts of this functional triad (Fogg, 1998). For instance, one persuasive technology tool is what Fogg defined as tailoring; "a computing product that provides information relevant to individuals to change their attitudes or behavior or both" (2003, p. 37). Fogg has detailed how information can be tailored to a person's needs or interests. These needs and interests might be subject to a person's emotions or cognitions, and physiology can also provide information about a person's emotional and cognitive state. In similar vein, a person's emotions and cognitions in itself might be worth to adapt to. Especially when the systems behaves like a social actor (third function). For successful communication, the system should not only display social cues, but also be able to understand the social cues of the user. Research has indicated that this *emotional intelligence* can be derived, amongst other sources of user information, from physiology (Pantic & Rothkrantz, 2003). [8] As described before in section 2.4, physiological measures might inform the system about the user's emotions and cognitions.

Fogg's functional triad has been followed up by a well-used model for the design of PT: The *Persuasive Systems Design model* (PSD) by Oinas-Kukkonen and Harjumaa (2009). The PSD distinguishes three phases in persuasive systems development as presented in Table 2-4 (Oinas-Kukkonen & Harjumaa, 2008a, 2009). We argue that physiological measurement can be used to create insight into various elements in the PSD model: In the first phase, in which the designer understands key issues

[7] Although equally effective, research did indicate different interaction patterns in human versus automated coaching. People have longer conversations with human coaches. People are more proactive to contact their automated coach and respond faster to their messages (Mitchell et al., 2020).

[8] Emotional intelligence is defined as "the ability to recognize, express and have emotions, coupled with the ability to regulate these emotions, harness them for constructive purposes, and skillfully handle the emotions of others" (Pantic & Rothkrantz, 2003, p. 1370).

behind PT systems, postulates 1 and 4 highlight that "information technology is never neutral" and "persuasion is often incremental". Indeed physiological measures can monitor the user's psychology and might inform the system about changes in the user's preferences, needs or goals during the incremental process of achieving persuasion. With today's biosensors, this can be done unobtrusively without disturbing the user. This aligns with Postulate 6, which states that "persuasive systems should aim at unobtrusiveness".[9] Physiological measures might also be able to detect a violation of Postulate 2, which is "people like their views about the world organized and consistent". Research seems to indicate that inconsistencies between attitudes and behaviors relate to changes in physiology, that is the psychophysiology of cognitive dissonance (Harmon-Jones, Amodio, & Harmon-Jones, 2009; McGrath, 2017).

Table 2-4 Phases of Persuasive Systems Development formulated by Oinas-Kukkonen & Harjumaa (2009).

Phases	
Understanding key issues behind persuasive systems	Design postulates: 1. Information technology is never neutral. 2. People like their views about the world to be organized and consistent. 3. Direct and indirect routes are key persuasion strategies (Figure 2-1). 4. Persuasion is often incremental. 5. Persuasion through persuasive systems should always be open (the designers bias should be transparent). 6. Persuasive systems should aim at unobtrusiveness. 7. Persuasive systems should aim at being both useful and easy to use.
Analyzing the persuasion context	The situation of the system under development needs to be understood in terms of the intent, the event and the strategy. 1. For the *intent*, one should consider who is persuading the user and what type of change is effectuated. 2. The *event* focusses on the use context, the user context and the technology context. 3. The message and the direct or indirect route characterize the *strategy*.
Designing system features	The last phase considers the design of system features. 28 design guidelines are categorized in: 1. Primary task support* 2. Dialogue support 3. System credibility support 4. Social support

Note. The design guideline primary task support was informed by Fogg's functional triad (1998).

Furthermore, in the second phase of the PSD, the designer analyses the context, and views the user as a "human information processor" that actively needs to consider the new information to be persuaded (Oinas-Kukkonen & Harjumaa, 2009, p. 489). This perspective underlines the advantages of using physiological measures in the

[9] But see our ethical discussion in section 7.5.

actual design of the PT in the third phase: First, physiology is known to reflect mental effort and can thus reveal whether the user is processing (Cacioppo et al., 2007; Fairclough & Mulder, 2011). Second, physiological measures might detect when emotions hamper this information processing (DeSteno et al., 2004), as different emotional states correspond with different physiological signatures (Cacioppo et al., 2000; Kreibig, 2010).

2.7 Biocybernetic loops in Persuasive Technology

Now that the potential benefit of the physiological assessment of persuasion-related processes has been identified, this section reports on physiology-based approaches for PT personalization. Adapting a system based on physiology is known as *physiological computing*. The core component in physiological computing is the *biocybernetic loop* (Fairclough, 2009). The loop aims at extracting user states from physiology using biosensors and providing (real-time) system adaptations. Physiological computing applications are used in various context, such as military task performance (John, Kobus, Morrison, & Schmorrow, 2004), mental workload (Fairclough, 2009), vitality (Westerink et al., 2014), or gaming (Mandryk & Atkins, 2007; Tijs, Brokken, & IJsselsteijn, 2008).

PT systems can potentially function as biocybernetic loops as presented in Figure 2-2. The interface could be any type of device that communicates with the user, for example a mobile phone, a wristband, a computer, or a smart lamp. The user employs the system to achieve a self-set or advised behavior change. The sensors register overt and covert user reactions using bio- and behavior sensors. The core is an algorithm that chooses the persuasive features that will increase the likelihood

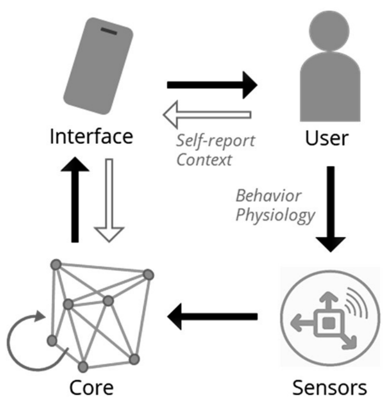

Figure 2-2 Hypothetical Persuasive Technology system involving a biocybernetic loop in black. Figure based on Fairclough (2009).

of persuasion. User information is fed to the core via the interface (white arrows) or the sensors (black arrows). The core analyzes this information and adapts the interaction accordingly, which closes the loop.

2.7.1 Physiological state and reactivity as personalization input

The interaction between the core and biosensors can be discussed in more detail when considering two types of physiological information relevant for personalization; *physiological state* and *physiological reactivity* (Figure 2-3).

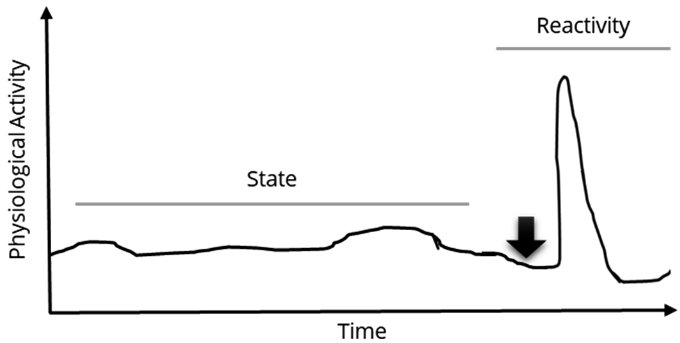

Figure 2-3 A visual representation of physiological state (left) and physiological reactivity (right) following a persuasive message (arrow). Physiological state can vary from low to high. Reactivity levels can vary between no reactivity and high levels of reactivity.

In a certain *physiological state* activity is relatively stable for a brief period. It can reflect emotional or cognitive states, such as relaxation or anxiety (Picard et al., 2001). This information is relevant for PT as a user's emotions can change the perception of a message and influence the likelihood of persuasion (DeSteno et al., 2004; Picard, 2003; Rosselli et al., 1995). For example, people in fearful or anxious states are more susceptible to the frightening information in fear appeals (DeSteno et al., 2004; Rogers, 1983). Emotions can also dissuade. For example anger leads to a lower level of information processing and thereby to no or a less persistent change in attitude (Brehm, 1966; Petty & Cacioppo, 1986). Moreover, emotions can influence effectiveness of persuasion attempts even when they are incidental and do not relate to the persuasion objective (DeSteno et al., 2004; Petty & Cacioppo, 1986). Even if feelings of anger were evoked by something unrelated to the persuasive attempt itself, the attempt's effect is still limited due to lower levels of information processing. In general, messages with an emotional framing that is in line with the state of the user are most persuasive (DeSteno et al., 2004): Rational messages, for example, are more effective in neutral than positive moods (Rosselli et al., 1995). Therefore, knowing the physiological state of the user and having insight into their emotions before the PT acts might increase the likelihood of persuasion.

Physiological reactivity is the second type of relevant information for PT personalization (Figure 2-3). Physiological reactivity can indicate a rapid change in activity following (or during) exposure to something (Cacioppo et al., 2007). The magnitude of these activity changes can reveal information about the user's psychological reaction to this something. A sudden change in cardiovascular, electrodermal, or respiratory activity often indicates arousal (Cacioppo et al., 2007), whereas facial muscle activity can be related to valence (Boxtel, 2010). A classic example of this phenomenon is the startle response (Lang, Bradley, & Cuthbert, 1990), where the sudden increase in arousal reveals how shocked a person is by what he/she just saw. Reactivity can therefore be insightful in case of an attempt at persuasion. For example, a message might engage the user, resulting in a distinct physiological pattern with elevated heart rate and skin conductance levels. In addition, physiological reactivity might reveal the success rate of a persuasive appeal: high levels of reactivity can relate to active processing and elaborating on information (Thayer, Hansen, Saus-Rose, & Johnsen, 2009), potentially resulting in behavior change. However, it can also indicate that the person is feeling reactant to the message (Sittenthaler et al., 2015). No or low levels of reactivity could hint at indifference of the user.

2.7.2 Physiology-based adaptation

We argue that physiological state and reactivity information enable two types of physiology-contingent adaptation in PT; *state and reactivity adaptation*. In state adaptation, the system adapts to the stable physiological state of the user. In reactivity adaptation, the user's physiological reactivity to a message is used to adapt the system. Figure 2-4 presents these adaptations in the biocybernetic loop as determined by the core on the basis of input of biosensors.[10] The next sections discuss both types of adaptations in detail.

[10] Traditional motivational state adaptation (red lines in Figure 2-4) is not explained further in the main text as this is considered out of the scope of this thesis. It basically consists of linking the presentation of a persuasive message with its impact in terms of (the absence of) a change in motivational state and/or behavior to generate knowledge.

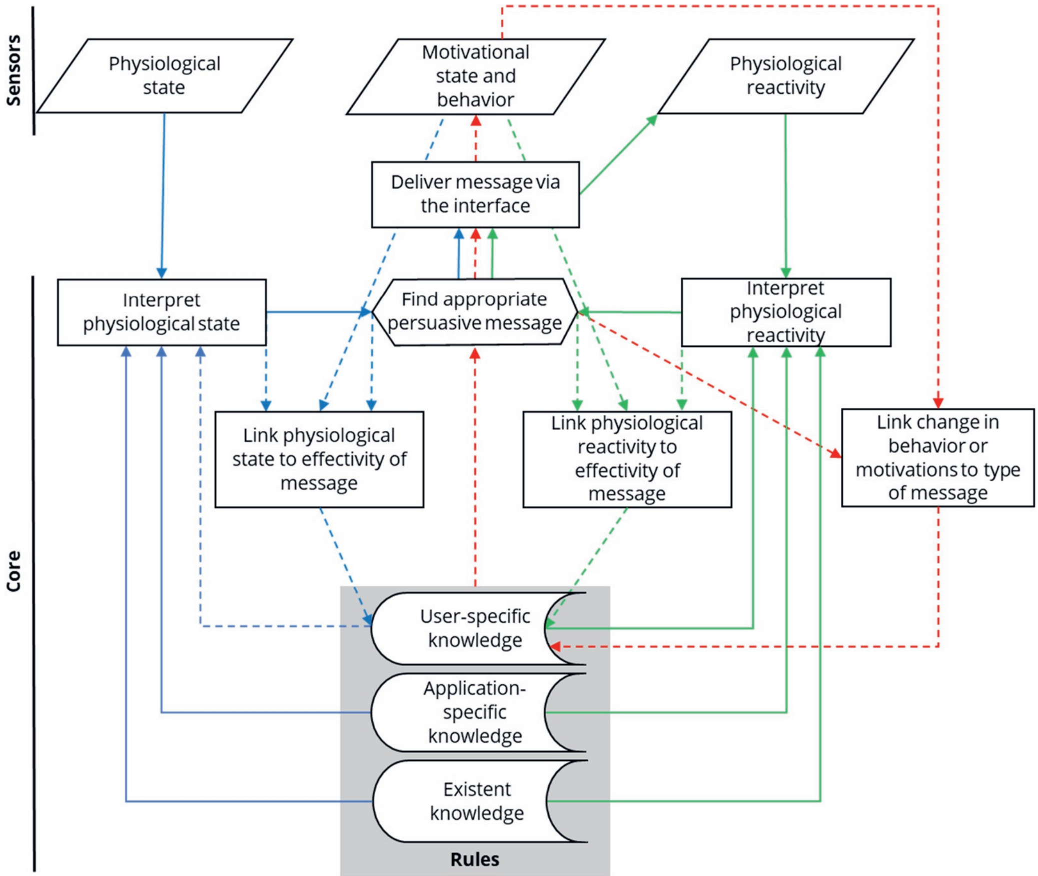

Figure 2-4 Architecture and detailed steps of three types of PT system adaptation: physiological state (blue), physiological reactivity (green), and motivational state or behavior adaptation (red). Each box depicts a different process; a parallelogram stands for data, a hexagon marks a preparation phase, and a half cylinder indicates storage of rules based on knowledge. The dashed lines and steps in italic apply only to systems that can monitor motivational state and/or behavior.

State adaptation starts with a measurement of the person's physiological state using biosensors (see the blue path in Figure 2-4). The core of the system filters the physiological data, interprets the psychophysiological state and finds appropriate persuasive features that will increase the likelihood of persuasion in this particular state. For these steps, the core can use existent knowledge from literature or potentially application-specific knowledge from extensive testing with the system. Existent knowledge consists of, among others, which type of messaging is suited for an emotional state (DeSteno et al., 2004; Van Den Broek, Schut, Tuinenbreijer, & Westerink, 2006). For example, users with a low arousal state might be served best with a message triggering a moment of reflection, while during high arousal an energetic persuasive appeal might be an extra motivational push. System features subject to state adaptation could include persuasive strategy, content, and timing. For example, using kind words when the user is tired.

After the state-adapted messages have been sent, their effects on the motivations and behavior of each individual user can be measured via self-report or, if possible, behavioral sensors. Linking physiological states with persuasive features and persuasion effectiveness can result in user-specific insights on which new rules can be defined. Activity levels and their accompanied psychological states may affect the persuasive impact of an appeal differently depending on the user. Even when activity patterns appear to reflect a distinct state, the degree of susceptibility to a persuasive cue depends on the person's appraisal of the situation.

Next, *reactivity adaptations* can be done based on physiological reactivity to a persuasive message (see green paths in Figure 2-4). The biosensors can measure the magnitude of the reactivity response. The core can interpret the (absence of a) reaction in terms of susceptibility based on existent knowledge in literature or on application-specific knowledge and decide whether to send a second message or use similar messaging in the future. Optionally this step can be repeated for the second message. In that sense, reactivity responses can be used to fine-tune PT-user interaction and predict the success rate of a message. Reactivity information becomes even more meaningful when linked to consequent behavior or motivational state. Sensors can monitor consequent changes in motivational state and behavior. This information can then be used to further specify rules based on user-specific knowledge and optimize future interactions.

To find appropriate messages, physiological state and reactivity can be quantified in terms of valence and arousal (Bradley & Lang, 1994; Russell, 1980). This quantification can be deciphered in terms of psychology, for example low arousal means relaxation. Alternatively, this quantification can be related to (a change in) behavior directly, for example low arousal and high valence indicates susceptibility to a message. The system might start with psychology labels in order to use existent persuasion knowledge and prevent a cold start,[11] while it moves towards linking physiology directly to behavior. Persuasive processes are individually dependent, meaning that not all knowledge will apply to each user. How to interpret physiological reactions to persuasive features in terms of a specific user's susceptibility to them is something the PT can learn: Over time, the system can gain

[11] The phrase 'cold start' has been used for situations where a system has to start making recommendations, while knowing very little of the user (Schein, Popescul, Ungar, & Pennock, 2002).

user-specific insights by reinterpreting physiological states and their impact on susceptibility as measured by motivation and/or behavior change. Perhaps, the systems network can function as a black box or use machine learning and adapt to the user's feedback to personalizing its models. Therefore, it is important to characterize message features and analyze the user's reactions to those features multiple times. This will ensure that differences in physiological reactivity found are indeed related to the messages presented, and thereby circumvents the multi-mapping problem (Cacioppo et al., 2007, Chapter 1). These iterations ensure that the right conclusions are drawn about the persuasiveness of a specific message in a particular state or the meaning of reactivity in terms of susceptibility. Consequently, the PT can be personalized based not only on physiological activity, but also on user-specific inferences from that physiological activity. This approach of combining physiological with self-report and behavior measures could enable optimal persuasion in PT by delivering the right message, at the right time, with the right content (Fischer, 2001; Fogg & Eckles, 2007).

The use of physiology as input for personalization is not new. Various scholars have created personalized music players that use physiological state to coach people towards certain moods (Janssen, Broek, & Westerink, 2012; Van Der Zwaag, Janssen, & Westerink, 2013) or fitness level (Oliver & Kreger-Stickles, 2006). The target objective, for example mood or fitness level, was represented by a certain physiological state. These systems recommended a song with an energy just above or below current physiological state of the user (Janssen et al., 2012; Oliver & Kreger-Stickles, 2006; Van Der Zwaag et al., 2013). In that sense, these systems describe state adaptation where physiology serves as both the input signal as well as the target state. The system described in the current work differs from previous user-modeling research on three points: 1) This system is focused on persuasion, 2) the objective is to change behavior or motivational state, and 3) this system accounts for both slow and fast changes in physiology, that is state and reactivity adaptation. Importantly, this research contributes to persuasion research by comparing various persuasion principles and using psychophysiology to integrate the attained insights in a holistic domain-independent model.

In summary, we presented physiology as a measure of persuasion-related processes. This is because an attempt at persuasion induces psychological processes, which may provide measurable physiological activations. Using physiological measures, the presence of persuasion-related processes and their impact might be localized real-time. This knowledge might support designers of persuasive system. Physiological measures, combined with contemporary measures, can perhaps be used to personalize attempts at persuasion. There are two types of physiological information that can inform a PT system, that is physiological state and reactivity. We modeled a system that – in addition to subjective and behavioral measures – adapts to the user's physiological state and reactivity. The remainder of this thesis will mainly focus on the possibility of reactivity adaptations. To this end, we will investigate whether there are certain physiological patterns during attempts at persuasion.

Chapter 3

Exploring psychophysiological reactions to persuasive information

Before a Persuasive Technology (PT) system can make physiology-contingent adaptations, a better understanding of the psychophysiological nature of persuasion is needed. This thesis makes a start by validating assumptions for reactivity-based adaptation (the green loop in Figure 2-4), namely that physiological reactivity is informative of the persuasion process. I will study people's physiological reactivity in exposure to persuasive information in a series of experiments. In this first empirical chapter,[12] a myriad of persuasive strategies were combined to create a powerful persuasive stimulus. My supervisors and I often referred to this chapter as 'the sledgehammer' in our discussions. This coarse approach is our first attempt at identifying *if* people have a physiological response when being persuaded.

[12] This chapter has been submitted as a separate article to the journal Behavior & Information Technology as Spelt, H., Asta, L., Kersten-van Dijk, E., Ham, J., IJsselsteijn, W., & Westerink, J., Exploring psychophysiological reactions to persuasive information. *Behavior & Information Technology*.

3.1 Introduction

Attempts at persuasion try to change attitudes and behaviors (Perloff, 2008). Persuasive interventions, that is technologies striving to persuade someone (Fogg, 2009; IJsselsteijn, de Kort, Midden, et al., 2006), have the ability to efficiently support people to change their behavior (Chua et al., 2011). The rapid development of persuasion techniques and digital technologies in the past century have enabled the growth of personalized persuasive interventions (Markopoulos et al., 2015). These types of interventions can adapt to a specific user, which will foster persuasion (Markopoulos et al., 2015). That is, personalized approaches have proven to outperform universal approaches (Chua et al., 2011; Lacroix, Saini, & Goris, 2009). For instance, current behaviors and motivations can affect susceptibility to persuasion, and are therefore a good basis for personalization.

Studying physiological responses can further enhance our understanding of the underlying mechanisms of persuasion (Chua et al., 2011; Schneider, Rivers, & Lyons, 2009). Peripheral physiological measures such as heart rate or sweating can correlate with, and therefore be proxies or predictors of behavior and experience, since these measures reflect deeply rooted physiological reactions of the nervous system (Cacioppo et al., 2007). Insights from physiology might thus enrich our comprehension of persuasive processes. In addition, the psychophysiological knowledge gained could be deployed to use peripheral physiology as an extra input in the personalization of persuasive interventions (i.e. by means of physiological computing (Fairclough, 2009)). Thus, this study investigates if and when physiology changes during an attempt at persuasion. Moreover, it focuses on individual aspects such as current behavior and motivations in relation to psychophysiological responses to persuasive information.

3.1.1 Physiology as indication of persuasion-related processes

During persuasion[13] people change their behaviors, preferences or attitudes by conforming to a message that encourages this change (Falk & Scholz, 2018; Perloff, 2008). A well-known model of persuasion is the *elaboration likelihood model (ELM)* (Petty & Briñol, 2014; Petty & Cacioppo, 1986), which centers around the probability that someone will consider a message along one of two routes of processing. This

[13] As defined in Chapter 2, we make a distinction between persuasion, an attempt at persuasion and persuasion-related processes. An attempt at persuasion concerns the effort that tries to persuade someone, for example a message or video. Persuasion-related processes are the related psychological processes evoked by that persuasion attempt. Persuasion is when attitude, intentions and/or behavior are successfully changed by an attempt at persuasion.

model proposes that if the person is motivated and able to consider the message, the central route will establish more durable attitude change, while persuasion is less persistent when based on simple inferences and affective associations via the peripheral route. Researchers have exploited these routes to achieve persuasion (Carpenter, 2015; Cialdini, 2004) and found evidence supporting this model. Critics however judged the ELM and related dual-process models as descriptive and failing to pinpoint underlying psychological mechanisms (Kitchen et al., 2014; O'Keefe, 1990).

One method to gain further understanding of such mechanisms underlying persuasion is psychophysiology. The psychophysiological research tradition posits that all mental states have a physiological substrate (Andreassi, 2007; Cacioppo et al., 2007). When experiencing emotions or cognitions, parts of the brain become activated (Gazzaniga et al., 2009; Posner et al., 2005). Via the *autonomic nervous system* (ANS), brain areas can influence bodily states (Fairclough et al., 2014; Jänig, 2003; Kreibig, 2010; Neafsey, 1991; Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012). The ANS is the control system responsible for retaining the body in optimal condition for it to deal with, sometimes unexpected, external demands (Jänig, 2003; Porges, 2007). Via its sympathetic and parasympathetic branches, the autonomous nervous system can control organ activity by respectively increasing or decreasing arousal (Cacioppo et al., 2007; Jänig, 2003; Kreibig, 2010). These arousal changes can be measured via amongst others *heart rate* (HR) and *heart rate variability* (HRV) in the cardiovascular system (Camm et al., 1996; Shaffer & Ginsberg, 2017),[14] or *skin conductance level* (SCL) and *responses* (SCRs) in the electrodermal system (Boucsein, 2012) (see also Table 2-2).[15] Especially HR and SCL seemed to be indicative for changes in arousal (Cacioppo et al., 2007). Due to this brain-body connection, changes in features of peripheral physiology relate to psychological meaning, for example heart rate acceleration can indicate mental effort (Fairclough & Mulder, 2011). Research indicates that peripheral physiology can partially reflect emotions (Appelhans & Luecken, 2006; Koelstra et al., 2012; Kreibig, 2010) and cognitions (Fairclough & Mulder, 2011; Segerstrom & Nes, 2007; Thayer et al., 2009).

[14] The cardiovascular system is responsible for the supply of oxygen and depletion of waste by blood flow. Heart rate (HR) is the number of heartbeats in a minute, and heart rate variability (HRV) the variability in the time between those beats. Two commonly used HRV measures are standard deviation of normal-to-normal peaks (SDNN) and root mean square of successive differences (RMSSD) (Berntson et al., 1997; Cacioppo et al., 2007).

[15] The electrodermal system varies with sweat gland activity and is a sensitive indicator of both psychological and physiological arousal. Skin conductance level (SCL) is the tonic level of electrodermal activity, and skin conductance responses (SCRs) are the number of rapid arousal increases within a time range (Boucsein, 2012).

Thus, potentially also the mental states associated with persuasion-related processes are measurable in peripheral physiology. That is, an attempt at persuasion can influence emotional or cognitive states and these states might reflect in peripheral physiology. For example, an attempt at persuasion might result in increased cognitive effort when elaborating on a message (Petty & Cacioppo, 1986) or negative emotions when being confronted with a discrepancy between your own and the advocated behavior (Cialdini & Goldstein, 2004; Festinger, 1989). Neuroscience studies revealed several neural underpinnings of persuasion-related processes by analyzing concurrent brain activation (Bartra, McGuire, & Kable, 2013; Falk et al., 2015; Falk & Scholz, 2018; Vezich et al., 2017). The brain areas associated with persuasion-related processes, for example ventromedial prefrontal cortex and anterior ventral striatum (Bartra et al., 2013; Falk & Scholz, 2018), were also associated with peripheral physiological activity, for example by influencing cardiovascular arousal resulting in fluctuations of heart rate, blood pressure and flow (Bartra et al., 2013; Gianaros et al., 2005; Shoemaker & Goswami, 2015; Thayer et al., 2009). Moreover, heart rate variability was implicated in persuasion-related processes such as appraisal (Bartra et al., 2013; Thayer et al., 2012), social threats (Okruszek, Dolan, Lawrence, & Cella, 2017), and mentalizing (Denny, Kober, Wager, & Ochsner, 2012; Okruszek et al., 2017). Similarly, electrodermal activity was associated with energy regulation and highly responsive to social interactions (Cacioppo et al., 2007, p. 172), potentially also persuasion.

Earlier research indeed hinted at a link between persuasion-related processes and peripheral physiology: Electrodermal and cardiovascular activity predicted the effectiveness of narrative persuasion (Barraza et al., 2015; Correa et al., 2015) and psychological reactance to a message (Steindl et al., 2015). Threatening messages evoked more systolic blood pressure reactivity compared to control messages (Schneider, Rivers, & Lyons, 2009). Also, facial muscle activity (Lewinski et al., 2016) and body posture (Briñol & Petty, 2008) appeared to offer insights into persuasion-related processes. The current research aims to extend this knowledge.

3.1.2 Subject-specific motivations affect psychophysiological responses to persuasion

To date, research into the psychophysiology of persuasion has mainly focused on the effects caused by persuasive strategies, that is narrative vignettes (Barraza et al., 2015; Correa et al., 2015), threat or challenge message framing (Schneider et al., 2009), or fear appeals (Wegener & Carlston, 2014). However, irrespective of the strategy used, persuasion and its accompanying physiological processes might also differ between people. Attempts at persuasion will not be equally effective for everyone due to differences in, for example, personality (Cacioppo et al., 1986; Oyibo, Orji, & Vassileva, 2017; Perloff, 2008) or initial beliefs and motivations (Cialdini & Goldstein, 2004). Next to differences in stable characteristics or traits, persuasive effectiveness can also differ due to the momentary state of a person: Mood can influence the perception of a persuasive cue (DeSteno et al., 2004; Rosselli et al., 1995) and situational constraints on time or resources can hamper the elaboration on a persuasive cue (Petty & Cacioppo, 1986). This is why personalized approaches are more likely to achieve persuasion than generic interventions.

What people inherently think about the topic targeted by a persuasive message affects the relative persuasiveness of it, and potentially also the physiological responses to it. People have beliefs and motivations that steer behavior or behavior change (Ajzen, 1991; Michie et al., 2011). To illustrate, the theory of planned behavior stipulated beliefs about the (desirability) of the behavioral outcomes, social norms and perceived control (Ajzen, 1991). These beliefs result in motivations[16] to perform – or not perform – a behavior: The overall evaluation of the targeted behavior results in an *attitude towards the behavior*, social pressures result in *injunctive and descriptive norms*, and people's confidence to perform a behavior is defined by *perceived behavioral control* (Ajzen, 2002). As changing motivations can be a way to change behavior, these motivations are often the target of persuasion.

Importantly, the motivations to behave in a certain way are unique to an individual and can influence the process of persuasion. The decision (not) to comply with a persuasive message is based on the perceived value of the communicated information (Brinol & Petty, 2009; Carpenter, 2015; Cialdini & Goldstein, 2004): A message is more compelling if it concerns a subject considered important by the receiver and/or their social surroundings. This importance is reflected in the strength of relevant motivations. Thus, the alignment between the advocated information and the current motivations affects the persuasiveness of the message: People are susceptible to persuasive information that is slightly misaligned with their current motivations and behaviors. Misalignment between their own and the advocated motivations and behaviors can cause discomfort or stress, partly because

[16] Other behavior models define motivations broader, such as "all those brain processes that energize and direct behavior, not just goals and conscious decision-making. It includes habitual processes, emotional responding, as well as analytical decision-making" (Michie et al., 2011, p. 4). For practical reasons, this study limits itself to constructs of the demarcated and validated theory of planned behavior.

social approval is essential for human survival (Cialdini & Goldstein, 2004). This discomfort can motivate actions in line with compliance (Festinger, 1989; Harmon-Jones & Harmon-Jones, 2007). Completely aligned messages are not persuasive, as they cannot change motivations. However, if the conflict is too large the attempt is likely to backlash or elicit a counter-reaction. This response is known as *psychological reactance* (Brehm, 1966).[17]

There is reason to believe that the increased persuasiveness of motivation-misaligned messages is reflected in peripheral physiological responses.[18] Differences in valuation or conflict detection due to initial alignment of motivations with the advocated persuasive message can influence brain activation during persuasion-related processes (Cascio et al., 2015; Falk & Scholz, 2018; Klucharev, Hytönen, Rijpkema, Smidts, & Fernández, 2009), and thereby potentially also peripheral physiology. Due to the positive correlation of conflict detection and valuation with brain activation (Cascio et al., 2015), we expect that greater misalignment will result in more peripheral physiological activity. As such, more physiological activity during persuasion-related processes can be expected in people whose current motivations are less aligned to the advocated goal compared to people whose motivations are more aligned. In the current research, we study these possible effects of individual differences in initial beliefs and motivations on psychophysiological reactions to persuasive information in order to eventually accommodate personalized attempts at persuasion using physiology.

3.1.3 Study aim and hypotheses

This study intends to determine *if* people's physiology changes due to persuasion. It investigates whether analysis of peripheral physiological reactions creates insight in the underlying process of persuasion. In particular, it probes whether physiological activity during a persuasion attempt differs based on the strength of the current behaviors or related motivations in question.

We do this by persuading people to limit their meat consumption. Nowadays meat consumption is determined by cultural-oriented values such as masculinity, nutrition and hedonism (de Bakker & Dagevos, 2012). Plant-based alternatives have

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[17] Reactance is the topic of investigation in Chapter 4.

[18] Notably, the motivational state of psychological reactance can also activate a person's physiology (Miron & Brehm, 2006; Sittenthaler et al., 2015; Steindl et al., 2015). Because people often feel angry, hostile or uncomfortable during reactance (Brehm, 1966; Steindl et al., 2015), this state is expected to provoke a rapid emotional response. The link between psychological reactance and physiology will be discussed in detail in the next chapter.

become largely available. Meat consumption is a voluntary behavior that has a high potential for change (Zur & Klöckner, 2014). Many people both care for animals/the environment and enjoy eating meat. This inconsistency is better known as the meat paradox (Bastian, Loughnan, Haslam, & Radke, 2012; Loughnan, Bastian, & Haslam, 2014). This makes meat consumption a useful subject for persuasion research.

This chapter describes an explorative study. As it is unclear *if* physiology reflects part of persuasion-related processes, a broad spectrum of physiological features is studied in exposure to an extensive set of persuasive interventions. Furthermore, research has identified a variety of beliefs that may contribute to the reduction of meat consumption (i.e. moral considerations, health aspects and environmental impact), and a tool to capture the underlying motivations that lead to consumption behavior (Zur & Klöckner, 2014). We will investigate whether the degree of alignment between a person's current behavior and the topic of vegetarianism predicts physiological responses to an attempt at persuasion on this topic. Therefore, people with medium or high current meat consumption patterns will be exposed to a persuasive video advocating limited meat consumption. Considering the above, we formulate the following hypotheses: 1) Physiology changes due to an attempt at persuasion. 2) Physiological reactivity to an attempt at persuasion relates positively to persuasion-induced motivation change. 3) Individual differences in current behaviors and motivations can affect psychophysiological reactions to persuasive information – a greater misalignment is expected to evoke more physiological reactivity to the attempt at persuasion.

3.2 Methodology

3.2.1 Design

This study investigated the relationship between physiological responses to an attempt at persuasion and related behaviors and motivations. It had a between-subject design, distinguishing people with medium and high meat consumption. Peripheral cardiovascular and electrodermal physiology was measured while participants watched a persuasive video that deployed various persuasion strategies and urged to limit meat consumption. Participants' motivations to limit meat consumption were measured one week before the study, as well as immediately after the video to establish the persuasive impact of the video.

3.2.2 Participants

Recruitment occurred via the University participant database. Seventy people without (a history of) cardiovascular disease and with sufficient English language skills participated in this study. Participants were included if they reported to eat meat in any of their meals (breakfast, lunch, diner) at least five days a week. They were divided in two experimental groups; group M (medium meat consumption) included people that reported to eat meat five or six times per week (N = 36, 13 women, M_{age} = 29, SD_{age} = 16), while group H (high meat consumption) included daily consumers of meat (N = 34, 10 women, M_{age} = 25, SD_{age} = 6).

3.2.3 Manipulation

The persuasive video included fragments from the documentary "*Cowspiracy: the sustainability secret*", which discusses the adverse consequences of animal product consumption on society and the environment (Anderson & Kuhn, 2014). The persuasive video had a total duration of 9:35 minutes and employed various persuasive strategies, including rational arguments (O'Keefe, 2013), authority (Cialdini, 2004), clear forceful language (Miller, Lane, Deatrick, Young, & Potts, 2007), fear appeals (Rogers, 1983), repetition (Michie et al., 2013), and new information (Armstrong, 2010).

To indicate when a certain persuasive strategy was active, the video was split in 19 epochs of 30 seconds. Two independent raters scored active persuasion principles per epoch. For this, a subset of relevant principles from the persuasion principle index were selected (see Armstrong, 2010, p. 387 for the full persuasion principle map). Table 3-1 presents how the selected persuasion principles were applied to our video. Table 3-2 indicates when both raters agreed in categorizing a certain principle in the features shown during that epoch. The video started with the current state of animal agriculture and its effects on the environment, as discussed by experts from different fields, that is general practitioners, dairy farmers, sustainability scientists, and conservation scientists. It presented quotes such as "animal agriculture is the number one contributor to human-caused climate change" and "raising animals for food costs one third of the planets freshwater, occupies 45% of the earth's land, is responsible for 91% of the amazon destruction and is a leading cause of species extinction and ocean dead zones". The information provided was supported with easily understandable stories, metaphors, and visual representations (see Figure 3-1a). The video emphasized that by adopting a vegan/vegetarian diet participants could lessen the burden on the earth's resources (Figure 3-1b). Only in the end, the video implied that the viewer could be part of the solution of the meat consumption problem, as the video ended with a clear call for action to "make the change".

Table 3-1 Subset of relevant principles from the persuasion principle index (Armstrong, 2010; Green, Armstrong, Du, & Graefe, 2016) with explanation for the raters of the video.

Persuasion principle		Explanation
Influence	Reason	Does the epoch provide (strong) reasons to support the claim? Reasons should be logical and relevant.
	Social proof	Does the epoch show that the behavior is widely performed?
	Authority	Does the epoch use support from an authority to enhance believability?
Emotion	Guilt	Does the epoch evoke self-awareness or encourage the viewer to anticipate their guilt if they ignore reasonable advice?
	Fear	Does the epoch convey a threat related to likely or sever consequences that can be eliminated?
	Provocation	Does the epoch includes shocking information and a selling point that helps resolve the incurred shocked feeling?
Overcoming resistance	Stories	Does the epoch include a story to put things into context?
	Perspectives	Does the epoch provide new perspectives?
Acceptance	Problem solution	Does the epoch describe a problem AND show how the limited meat consumption can solve it?
	Evidence	Does the epoch provide quantitative evidence?
	Data presentation	Does the epoch present substantial amounts of data in simple tables or graphs?
	Refutation	Does the epoch respond to negative claims about limiting meat consumption?
	Repetition of claims	Does the epoch repeat important claims?
	Clear call for action	Does the epoch involve a clear and specific call for action?
Message	Rational argument	Does the epoch only involve strong arguments?
	Forceful text	Does the epoch use specific words in active voice?
	Metaphors	Does the epoch involve a metaphor to show the benefit?
	Informative illustration	Does the epoch show illustrations that support the basic message?
Motion media	Spokesperson	Does the epoch use a credible spokesperson that is similar to the customer on relevant traits?
	Music/sound	Does the epoch use sound or music that is relevant to the story?

Table 3-2 Active Persuasion Principles for each 30-second epoch of the persuasive video.

Persuasion principle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Influence																			
Reason			■	■	■								■					■	■
Social proof																			
Authority	■	■					■	■		■									
Emotion																			
Guilt																			
Fear	■	■																	
Provocation																			
Overcoming resistance																			
New perspectives					■														
Stories									■										
Acceptance																			
Problem and solution																			
Evidence						■	■	■										■	■
Data presentation			■	■															
Refutation																			
Repetition of claims																	■		
Clear call for action																			■
Messages																			
Rational argument	■	■					■	■				■			■		■		■
Forceful text														■					
Metaphors																			
Informative illustration			■	■					■		■		■						■
Motion media																			
Spokesperson					■							■	■						
Music/sound						■													

Note. Persuasion principles were validated in previous research (Armstrong, 2010; Armstrong, Du, Green, & Graefe, 2016; Green et al., 2016). Each main principle consists of several sub principles (Armstrong, 2010). Gray shading indicates the presence of the specific persuasion principle during that epoch according to two independent raters. Epochs last 30 seconds each.

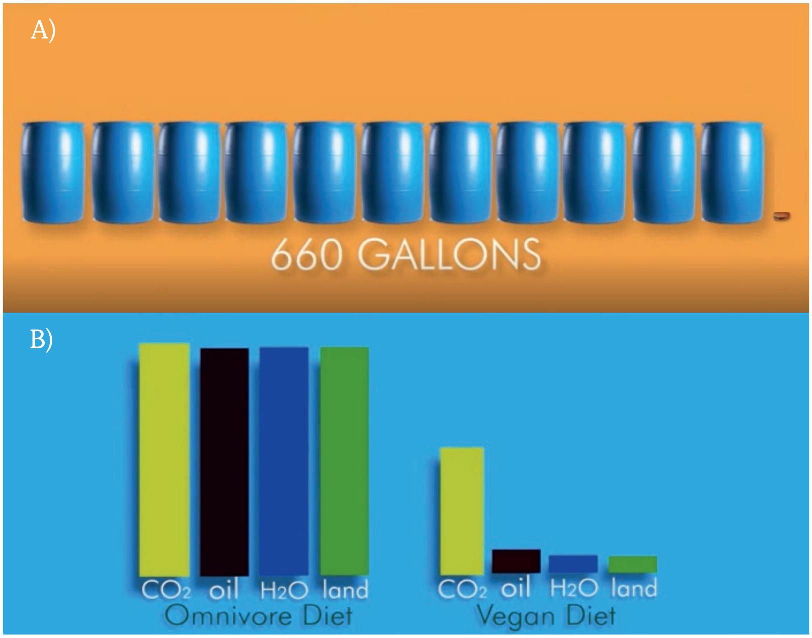

Figure 3-1 Informative illustrations from Andersen & Kuhn (2014): A) A visual representation of the amounts of water it takes to make a quarter-pound hamburger versus the actual hamburger. B) How much materials relatively can be saved by adopting a vegan diet compared to an omnivore diet.

3.2.4 Measurements

3.2.4.1 Self-report measures

In addition to demographic questions about age, gender and education, current behavior was assessed with one item asking average weekly meat consumption ranging from 'never' to 'daily'. To determine the participant's motivation to limit meat consumption, a validated questionnaire identified related intentional and habitual processes, as well as situational constraints (Zur & Klöckner, 2014). The underlying latent variables were perceived behavioral control, injunctive norm, descriptive norm, health beliefs, moral beliefs, attitude, reduction intention and habits. Apart from attitude, descriptive norm and reduction intention, all items were answered on a 7-point scale ranging from 'completely disagree' to 'completely agree'. Attitude was measured by asking whether participants thought 'introducing vegetarian dishes in my diet would be… pleasant – unpleasant' on a 7 point Likert-scale (Zur & Klöckner, 2014). Descriptive norm was quantified as the number of people with a vegetarian or meat-light diet in the social network of the participant. Reduction intention was measured on a 4-point ordinal scale with 1 = 'no intention to reduce', 2 = 'intention to reduce', 3 = 'intention to become vegetarian', and 4 = 'intention to become vegan'. In addition, a control questionnaire with three questions tested whether the participant had paid attention to the video and one question probed the novelty of the information presented.

3.2.4.2 Physiological measures

A Mobi physiology-recording device, sampling at 1029.5 Hz, with three Kendall H124SG electrodes in Lead II placement and two dry electrodes with Velcro straps on the fingertips of index and middle fingers was used to measure cardiovascular (ECG) and electrodermal (EDA) activity, respectively. Physiology was measured during the complete laboratory experiment.

3.2.5 Procedure

One week before the laboratory session, the participants completed an online survey checking their applicability, and gathering their demographic information, current meat-eating behavior, as well as motivations to limit meat consumption. Then, the participants were divided into two groups based on current medium or high meat consumption: either 5 or 6 days per week (group M), or every day of the week (group H). The experimental procedure was the same for both groups. Participants were instructed to refrain from drinking caffeinated drinks in the 2h preceding the laboratory session. Upon arrival in the laboratory, the participants received an explanation and signed an informed consent. Then, they were attached to the physiological-recording device and seated in front of a computer screen. On a desktop, custom OpenSesame software with a Legacy-backend (Mathôt, Schreij, & Theeuwes, 2012) executed the experiment by script. It started with a 5-minute neutral sea-life video with classical music (Piferi, Kline, Younger, & Lawler, 2000), during which a baseline recording of physiological activity in rest was performed. Afterwards, the 9:35-minute persuasive video was displayed on the computer screen. Finally, the participant completed a survey again assessing motivations to limit meat consumption as well as control questions.

3.2.6 Signal processing

Answers on the questionnaire measuring motivations to limit meat consumption were analyzed as instructed (Zur & Klöckner, 2014). The difference between initial and final motivational state scores served as measure of the persuasive impact of the movie.

A 50 Hz notch filter was applied to all physiological signals. In the ECG signal, R-peaks were detected to calculate inter-beat intervals (IBIs) and manually checked. IBIs outside 0.4-1.4s range or three times the standard deviation from the mean were checked and interpolated if the value seemed to be an artefact (Norris, Larsen, & Cacioppo, 2007). The EDA signal was converted from a resistance to a conductance signal and down sampled to 5 Hz. A 0.5 Hz low-pass Butterworth filter was applied to the log transformed conductance signal (Boucsein, 2012).

The next step was parameter extraction for each experimental segment (baseline, video, survey). From IBI data, mean heart rate (HR) was computed, as well as heart rate variability (HRV) by means of standard deviation of the normal-to-normal peaks (SDNN) and root mean square of successive differences (RMSSD) (Camm et al., 1996, Berntson et al., 1997). From the filtered EDA signal, mean skin conductance level (SCL) and the number of skin conductance responses per minute (SCRs) per experiment segment were calculated. The SCRs were calculated by counting positive to negative zero crossings in the first time-derivative of the filtered EDA signal (Boucsein, 2012). As HRV parameters are time dependent, a fixed time range was used to calculate mean values for each experiment segment, that is physiological baseline, persuasive video and survey completion. The time range was set to 4.5 minutes in order to ensure equal-length physiology traces in each experiment segment. In the baseline segment, we sampled a physiological trace during the last 4.5 minutes. Since the persuasive video was 9:35 minutes, two samples were created; one sample over the last 4.5 minutes of the first half of the video, and one sample over the first 4.5 minutes of the last half of the video. The physiological parameters between both samples did not differ significantly, thus the average of the physiological parameters during both samples eventually served as parameter values. Lastly, parameter extraction during the survey concerned the first 4.5 minutes of the segment. Next, physiological activity values with a Mahalanobis score larger than 25 were replaced as missing value (Yuan & Zhong, 2008). The Mahalanobis score is a multivariate distance measures that rescales variables based on their eigenvector to remove covariance and calculates the distance from the matrix mean. Physiological reactivity was calculated by subtracting the value in rest state (baseline) from value during the video, that is HR reactivity $_{\text{(video)}}$ = HR $_{\text{(video)}}$ – HR $_{\text{(baseline)}}$, and likewise for the survey segment. Furthermore, the physiological trace during the video was sampled in 19 epochs of 30 seconds, as this is the shortest period for calculating reliable HRV features (Lewis, Furman, McCool, & Porges, 2013). Again, physiological parameter values were extracted for each epoch and checked for outliers. For signal processing, R Studio (RStudio Team, 2016) was used with packages *Psych* (Revelle, 2017), *Tidyverse* (Wickham, 2017), *Signal* (Carezia et al., 2015), and *Zoo* (Zeileis & Grothendieck, 2005).

3.2.7 Statistical analyses

First, we verified whether the video was indeed persuasive for both consumption groups. Multiple within-between ANOVA's with motivations as dependent, and time (before/after) as well as group (Medium/High meat consumption) as independent variables tested whether the persuasive video affected motivations and if this differed based on initial consumption patterns. Dependent motivation variables tested were moral beliefs, health beliefs, perceived behavioral control, attitude, and reduction intentions. Injunctive and descriptive norms as well as habits were not tested, as they cannot change over the short course of the experiment.

Next, we checked if and when physiological activity was evoked in our experimental procedure (hypothesis 1). Physiological reactivity was tested with multiple linear mixed models with experiment segment (video/survey) and participant as random factor. This was done separately for each physiological reactivity parameter of interest as dependent variable, that is HR, RMSSD, SDNN, SCL and SCRs. This approach enabled us to create subject-specific models, account for missing data, and characterize the unexplained or residual variation in the response on multiple levels (Bates, Mächler, Bolker, & Walker, 2015; Venables & Ripley, 2003). We also investigated changes in physiology during the persuasive video and if those changes relate to specific persuasion principles (Green et al., 2016). We singled out the persuasion principles that were active in the epochs that evoked more activity compared to the preceding and following epoch, that is higher HR, SCL, or SCRs values and lower SDNN or RMSSD values. As our sample size does not allow for enough power for statistical tests on this purpose, these results were described qualitatively.

To check whether physiology is related to change in motivation (hypothesis 2), a multivariate correlation was performed between physiological reactivity values, that is HR, SDNN, RMSSD, SCL and SCRs, and the change in motivational state, that is moral beliefs, health beliefs, perceived behavioral control and reduction intentions. To investigate whether current behavior and motivation affect physiology (hypothesis 3), physiological reactivity was tested with multiple linear mixed models with experiment segment (video/survey), experimental group (M/H), and initial motivations, that is moral beliefs, health beliefs, perceived behavioral control, attitude, injunctive norm and reduction intention, as fixed factors, and participant as random factor. This was done separately for each physiological reactivity parameter of interest as dependent variable, that is HR, RMSSD, SDNN, SCL and SCRs. To avoid overfitting, we started with a simple model and compared a series of increasingly complex fits using the Akaike Information Criterion (AIC) (Venables & Ripley, 2003): Our simple model included only experiment segment as fixed factor and participant as random factor. One by one, a variable of initial motivation was added to the model and evaluated. The added variable was only retained when it significantly explained more variance and added predictive power to the model based on AIC weights (Wagenmakers & Farrell, 2004). For analysis, R Studio (RStudio Team, 2016) was used with packages *Car* (Fox & Weisberg, 2019), *Psych* (Revelle, 2017), *lme4* (Bates et al., 2015), and *lmerTest* (Kuznetsova, Brockhoof, & Christensen, 2017).

3.3 Results

Incorrect timestamps led to the exclusion of datasets of two participants. Insufficient conductance properties of the skin led to an additional exclusion of electrodermal activity values for 14 participants. This left 54 complete and 14 incomplete datasets for analysis.[19]

3.3.1 Self-report data

The self-report data had no outliers, but only perceived behavioral control was normally distributed. As data transformations, that is Log, Square Root, Cube Root, or Tukey's Ladder of Powers, did not improve normality of the other scales, we used un-transformed data. Because 68 is considered a reasonable sample size we continued our analysis with parametric tests (Norman, 2010). Levene's test revealed homogeneity of variance for all self-report scales. Cronbach's alpha indicated sufficient internal reliability for all scales except for initial injunctive norm. Table 3-3 depicts descriptive statistics for both groups.

[19] Although 14 datasets did not have EDA values, we only excluded those sets from the correlational analysis, as linear mixed model can handle missing data (Venables & Ripley, 2003).

Table 3-3 Descriptive statistics of motivational state one week before and immediately after the persuasive video for both intervention groups.

				Median meat consumers		High meat consumers		
Scale	Time	# items	α	*Mean*	*SD*	*Mean*	*SD*	
Attitude	Before	1	-	5.056	1.330	4.471	1.212	
	After	1	-	4.722	1.446	4.588	1.559	
Moral Beliefs	Before	5	0.636	4.811	1.032	4.659	0.801	♦
	After	5	0.579	5.489	0.825	5.494	0.806	
Health Beliefs	Before	2	0.700	4.528	1.336	4.191	1.451	
	After	2	0.787	4.708	1.518	4.324	1.440	
Perceived Behavioral Control	Before	4	0.568	4.792	1.039	4.507	1.074	♦
	After	4	0.665	5.285	0.932	4.993	1.031	
Reduction Intention	Before	4	0.584	0.910	0.364	0.713	0.262	♦,●
	After	4	0.642	1.097	0.415	0.897	0.332	●
Injunctive Norm	Before	4	0.472	2.604	0.983	2.397	1.015	
Descriptive Norm	Before	5	0.650	34.194	11.222	34.294	21.274	
Habits	Before	3	0.808	4.58	1.367	5.431	1.304	

Note. α = Cronbach's alpha, *SD* = standard deviation, ♦ = this variable was significantly affected by time (before/after video), ● = this variable was significantly different between groups (M/H). Descriptive and injunctive norms, as well as habits were not measured after the intervention, as they cannot change over the short course of the experiment.

Six within-between ANOVA's with Benjamini & Hochberg' correction for multiple testing were conducted to compare the video's effect on the motivational state components, that is moral beliefs, health beliefs, perceived behavioral control, reduction intentions, and attitude, of medium and high meat consumers. There was a significant effect of time (before/after video) on moral beliefs ($F(1, 136) = 26.014$, $p < 0.001$), perceived behavioral control ($F(1, 136) = 8.063$, $p = 0.021$) and reduction intention ($F(1, 136) = 9.899$, $p = 0.008$), as well as a significant effect of consumption patterns (M/H) on reduction intention ($F(1, 136) = 11.280$, $p = 0.004$), but no interaction effects between consumption patterns and time. Post-hoc comparisons using the Tukey HSD test revealed that scores before the video were lower than after for moral beliefs, perceived behavioral control, and reduction intention (all p's < 0.009). It also revealed lower reduction intention of High meat consumers compared to Medium meat consumers both before and after the video (see both p's < 0.05 in Table 3-3).

3.3.2 Physiological data

HR and SDNN reactivity values were normally distributed. Normal distribution was achieved for SCRs reactivity using a Square root transformation. Normal distribution for SCL and RMSSD reactivity values could not be achieved with any standard data transformation, for example Log, Square Root, Cube Root, or Tukey's Ladder of Powers. Figure 3-2 depicts average physiological activity for each experiment segment and both experimental groups.

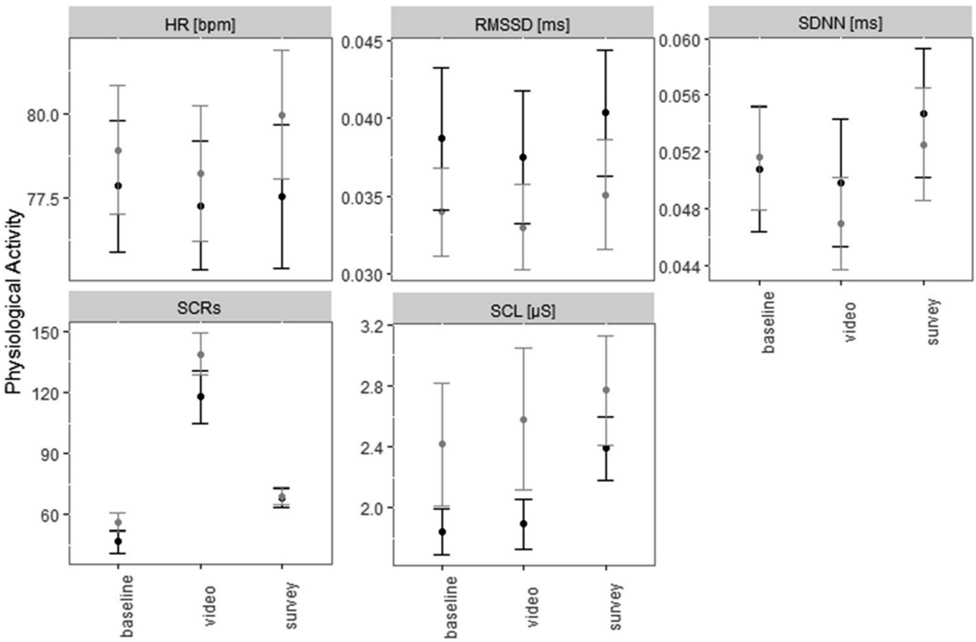

Figure 3-2 Average physiological activity per segment for each experimental group with error bars representing standard errors of the mean. Black = group of Medium meat consumers, grey = group of High meat consumers.

The results of various linear mixed models indicated that SDNN and SCRs reactivity during exposure to the video was significantly different from zero, that is SDNN was lower and number of SCRs were higher during the video than during baseline. Additionally, reactivity to the survey was significantly different from reactivity to the video for HR, SDNN, RMSSD, SCL and SCRs (Table 3-4).

Table 3-4 Summary results of the mixed linear models for reactivity of Heart Rate (HR), Root Mean Square of Successive Differences (RMSSD), Standard Deviation from Normal-to-Normal intervals (SDNN), Skin Conductance Level (SCL) and number of Skin Conductance Responses (SCRs) per experiment segment (video, survey).

	HR		RMSSD • 100		SDNN • 100		SCL		SCRs	
Predictors	*Est.**	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
Persuasive video (Intercept)	-0.56	0.148	-0.13	0.171	-0.30	**0.030**	0.09	0.391	76.06	**<0.001**
Survey	1.22	**0.004**	0.24	**0.020**	0.52	**<0.001**	0.51	**<0.001**	-62.29	**<0.001**
Random Effects										
Subject variance	5.55		0.35		0.65		0.16		1344.26	
ICC	0.45		0.45		0.50		0.48		0.08	
N	68 pnr		68 pnr		68 pnr		54 pnr		54 pnr	
Obs.	134		134		134		104		104	
R^2 / Cond.R^2	0.036 / 0.467		0.023 / 0.464		0.050 / 0.522		0.092 / 0.778		0.402 / 0.450	
AIC	682.426		312.007		403.251		214.699		1062.790	

Note. *Est.* = estimated difference in units of the physiological parameters, *p* = p-value (presented in bold if significant), *ICC* = intra-class correlation coefficient, *Obs.* = Observations, R^2 = Marginal r-squared statistics, *Cond.* R^2 = conditional r-squared statistics, *AIC* = Akaike Information Criterion

Per 30-second epoch, we calculated average physiological activity for each parameter (Figure 3-3). Epochs with an increase in physiological activity compared to the epoch before (10-50% of the physiological activity range, marked light grey) are considered interesting, especially when the increase in activity is substantial (>50% of the range, marked dark grey). Higher HR, SCL or SCRs values and lower SDNN or RMSSD values indicate arousal. Visual inspection of the average physiological activity values in Figure 3-3 indicates a clear arousal increase for most of the physiological activity parameters. Figure 3-3 shows that the most notable fluctuation in physiology occurred at the end of the video in epoch 19,[20] when the viewer is presented with the call for action to "make the change". Three of the five

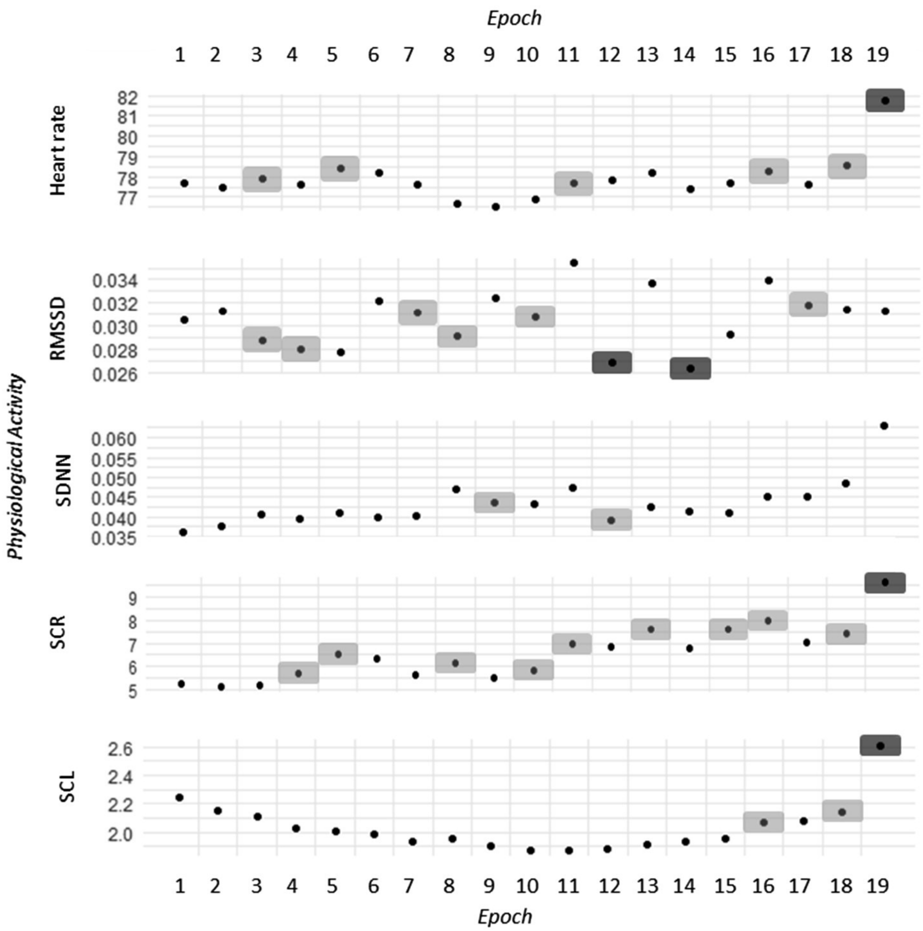

Figure 3-3 Average physiological activity for each 30-second epoch with light grey markers indicating a small increase in activity (10-50% of the range) and dark grey markers indicating a notable increase in activity (>50% of the range).

[20] Please note that in epoch 19 SDNN was impacted by the rapid change in heart rate.

physiological parameters indicate an increase in arousal during epochs 16, 18 and 19. Two of the five physiological parameters showed increased reactivity during epochs 3, 4, 5, 8, 10, 11, 12, 13, 15, 16, 18 and 19. We calculated for each persuasion principle (Table 3-2) whether its usage generally, that is more than 50% of the times, coincided with these increases in arousal. This was 6 times out of the 6 epochs that used reason, 1 out of 1 for new perspectives, 3 out of 5 for evidence, 2 out of 2 for data presentation, 1 out of 1 for a clear call for action, 4 out of 6 for rational arguments, 5 out of 6 informative illustrations and 3 out of 3 for the use of a spokesperson.

3.3.3 Relation between self-report and physiological data

Multiple Spearman correlations tested the relation between physiological reactivity parameters (for the video segment) and change in moral beliefs, health beliefs, perceived behavioral control and reduction intention. After Holm correction for multiple testing, no significant relations were found.

3.3.4 Mixed model approach for individual differences in psychophysiological responses

The results of various linear mixed models showed that for some parameters physiological reactivity during the video was significantly different from zero, as indicated by lower RMSSD and SDNN values and more SCRs (Table 3-5). During the survey HR, RMSSD, SDNN and SCL were higher than during the video, while there were less SCRs. Various factors of initial motivation explained variance in physiological reactivity, except for SDNN reactivity. The subject-specific null model including experiment segment as fixed factor best explained SDNN reactivity. Results show that HR increases 0.92 bpm per unit of initial moral beliefs and decreases with 2.44 bpm per unit of initial reduction intention. Higher initial reduction intention also related to higher RMSSD values. SCL was 0.06 μS higher for people with a unit higher initial injunctive norm. The inclusion of initial attitude and initial injunctive norm in respectively the SCL and SCRs model lowered overall AIC, although these factors seemed to not significantly explain variance. Group (M/H) did not explain variance in physiological activity. Except the model for SCL, these models have lower AIC than the models presented in section 3.3.2, suggesting a better fit.

Table 3-5 Summary of the best mixed linear model fits for reactivity of Heart Rate (HR), Root Mean Square of Successive Differences (RMSSD), Standard Deviation from Normal-to-Normal intervals (SDNN), Skin Conductance Level (SCL) and number of Skin Conductance Responses (SCRs) in relation to initial motivations.

	HR		RMSSD • 100		SDNN • 100		SCL		SCRs	
Predictors	*Est.**	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
Persuasive video (Intercept)	-2.90	0.088	-0.58	**0.009**	-0.30	**0.030**	-0.02	0.840	60.11	**<0.001**
Survey	1.24	**0.003**	0.24	**0.020**	0.52	**<0.001**	0.09	**<0.001**	-62.31	**<0.001**
Initial moral beliefs	0.92	**0.009**								
Initial reduction intention	-2.44	**0.010**	0.55	**0.024**						
Initial attitude							-0.03	0.063		
Initial injunctive norm							0.06	**0.005**	7.15	0.094
Random Effects										
Subject variance	5.55		0.35		0.65		0.01		1341.26	
ICC	0.38		0.42		0.50		0.69		0.06	
N	68 pnr		68 pnr		68 pnr		54 pnr		54 pnr	
Obs.	134		134		134		104		104	
R^2 / Cond.R^2	0.141 / 0.466		0.076 / 0.464		0.050 / 0.522		0.228 / 0.761		0.418 / 0.451	
AIC	675.395		308.859		403.251		-134.537		1060.121	

Note. *Est*. = estimated difference in units of the physiological parameters, *p* = p-value (presented in bold if significant), *ICC* = intra-class correlation coefficient, *Obs*. = Observations, R^2 = Marginal r-squared statistics, *Cond.* R^2 = conditional r-squared statistics, *AIC* = Akaike Information Criterions

3.4 Discussion

Physiology might reflect parts of persuasion-related processes. Therefore, this study investigated whether peripheral physiological responses to an attempt at persuasion increase our understanding of the underlying psychological process. Potentially, insights obtained from physiological measurements can increase the effectiveness of current persuasive interventions. Additionally, by adapting to physiological responses, interventions could be further adapted to a specific user (i.e. personalization). The relationship between persuasion-induced motivation change and physiological reactivity was investigated. We specifically researched to what extent individual differences in initial behaviors and motivations affect physiological reactivity to persuasion attempts. Psychophysiological responses from people with medium and high meat consumptions habits were collected while they viewed a persuasive video advocating vegetarianism. Physiological responses of the cardiovascular and electrodermal systems were related to the changes in motivations to limit meat consumption, in specific attitude, reduction intention, perceived behavioral control, health and moral beliefs. We expected a positive relationship between physiological reactivity and persuasion-induced motivation change, but our results did not support this. We also expected more physiological reactivity in people with initial behaviors and motivations that were less aligned with the advocated message, and our results supported this hypothesis. Our findings are discussed in detail in the following sections.

3.4.1 A persuasive video motivates behavior change for all

Before testing our hypotheses, we checked whether the manipulation had the anticipated effect - did the video persuade our participants? The results confirm that the video indeed increased participants' motivations to limit their meat consumption. After viewing the video, participants found eating meat to be more immoral, thought they had more control over their own consumption behavior, and had higher intentions to reduce their meat consumption. Generally, the video did not affect participants' attitude towards introducing vegetarian dishes in one's diet, nor did it affect their health beliefs. For attitude, this finding is surprising and may originate in the fact that in the validated questionnaire (Zur & Klckner, 2014) attitude was measured with a single scale, while previous research recommends a set of scales with instrumental and experiential components (Ajzen, 2002). Furthermore, the focus of the video on the environmental consequences of animal product consumption explains why we did not find a change in health beliefs.

The persuasive effects of the video on motivations were the same for participants with medium or high meat consumption habits. Although the intentions to reduce meat consumption turned out to be higher among the medium consumers (both before and after the video), we did not find the expected interaction effect between consumption group and time. From this, we conclude that the video was no more persuasive for people whose initial behaviors were more in line with the message in the persuasive video. However, it could also be that the high meat consumption group was more reluctant to (report a) change in motivation. In that sense, an increase from 1 to 2 in the high meat consumption group might be more meaningful than from a 4 to 5 in the medium consumption group. Another explanation for not finding the anticipated result is that, besides reduction intentions, the two groups did not differ in motivational aspects at baseline. Thus, the difference between the groups may have been not large enough to result in a different increase in intentions to reduce meat consumption.

3.4.2 Physiological responses to a persuasion attempt

The video as a whole did not clearly arouse the participants (hypothesis 1). Participants had lower average SDNN and RMSSD as well as more SCRs in exposure to the persuasive information compared to rest state. But there was no apparent change in HR or SCL, while these are the parameters that are most often measured as arousal indicators. Therefore, although physiological reactivity was clearly present, this experiment did not yield a clear demonstration of overall arousal due to the persuasive information. Part of the results also seemed to indicate that on average participants were more aroused while completing the survey compared to watching the persuasive video, as suggested by higher average HR and SCL values. In contrast, however, SDNN, RMSSD and SCRs results hint at less arousal during the survey. The contradiction between these findings is currently not understood. One explanation for the increased HR and SCL activity involves a difference in self-related processing between watching a movie and self-reporting one's experience. Watching a movie is a passive activity that does not ask for reflection on the information regarding one's self-image. In contrast, it is possible that during the survey the participants more actively integrated the persuasive information into their own situation, which may have resulted in higher salience of the potential conflict between the information provided in the video and their own habits and behaviors. Self-related processing and conflict detection might have caused arousal in HR and SCL, which is consistent with previous neuroscientific research (Cascio et al., 2015; Pegors et al., 2017; Vezich et al., 2017).

We also looked whether short-term changes in physiology are related to specific persuasion principles (Green et al., 2016) using physiology measures for 19 epochs of 30 seconds. The most pronounced arousal increases coincided with the presentation of the use of reason, informative illustrations or a spokesperson, the presentation of new perspectives, evidence or rational arguments, and especially a clear call for action. This seems to provide some first evidence that the exposure to some persuasion principles might indeed influence physiology, but not all. This finding should be further investigated with a counter balanced design. We also found a considerable rise in arousal towards the end of the video. One possibility for this increase might be that only then the viewer felt addressed and part of the problem, which resulted in increased arousal. Possibly, this increase in HR, SCRs, and SCL arousal was associated to self-related processing (Vezich et al., 2017). As we found a similar response during the survey, we encourage further research on the relationship between physiology and self-value integration during persuasion. Given that the video continued for another five seconds after the last epoch, we do not think that the increase in physiological activity related to physical movement. Nevertheless, we cannot entirely exclude the possibility that towards the end of the video, cues that the video was 'wrapping up' were present, and viewers may have become more restless and/or prepared for the next step in the experiment.

3.4.3 Relating persuasion-induced physiology to motivational change

Our second hypothesis stated that the mental states associated with processing a persuasion attempt are measurable in physiology: We expected a positive relation between persuasion-induced motivation change and physiological reactivity to the persuasive video. However, our results did not confirm this hypothesis. We did not find a significant relation between change in moral beliefs, health beliefs, perceived behavioral control, attitude, or reduction intentions on the one hand and HR, SDNN, RMSSD, SCL or SCRs reactivity on the other. Considering that our manipulation did persuade people to change their motivations, this appears to indicate that physiology and persuasion-induced change in motivational state are not correlated in this way.

However, various alternative explanations are possible. Firstly, although our manipulation was confirmed to be persuasive, it might not have been persuasive enough. Our participants increased their moral beliefs, perceived behavioral control and reduction intentions after the video, but on average with less than 1 point on a 7-point Likert scale (Table 3-3). If the video would have been more persuasive, this might have resulted in a more salient change in physiological activity during the video. One reason for the lower persuasive power of the video could be that the participants had already relatively high motivations at baseline (>4 on a 7-point Likert scale), indicating a potential ceiling effect. Another explanation could be that an attempt at persuasion does not elicit one single delimited psychological process, but a mixture of emotions and cognitions. The existence of many validated persuasion strategies (Cialdini, 2007; Green et al., 2016; Rhoads, 2007) illustrates the many potential routes to achieve persuasion. Different routes to persuasion are associated with different underlying psychological processes, at the same time affecting various associated physiological processes as well. Another explanation for the lack of a significant association between self-reported mental states and psychophysiology could be large individual variations in psychophysiological responses in the current study design.

3.4.4 Individual differences in physiological responses to a persuasion attempt

For our third hypothesis, possible effects of individual differences in current behaviors and motivations on physiological reactions to persuasive information were investigated. We expected that greater misalignment between current behaviors and motivations with the advocated information would evoke more physiological reactivity to the persuasion attempt. This reasoning did not become evident in differences in physiological activity between high and medium meat consumers. However, people with motivations more aligned with the advocated behavior did have less arousal compared to people with less aligned motivations: Except for SDNN, arousal in all physiological parameters during the persuasive video and completion of the survey was explained by initial motivations (Table 3-5). Specifically, higher initial attitudes towards becoming vegetarian and intentions to reduce meat consumption related to lower arousal (lower HR and SCL, and higher RMSSD reactivity), whereas higher initial moral beliefs and injunctive norms increased physiological reactivity. In sum, participants experienced more arousal when their initial motivation was less aligned with the advocated behavior, or when they live up to relatively high moral beliefs and injunctive norms. This seems logical, as people will have a harder time reaching the persuasion objective when their motivations lie further away from it. These results suggest that the initial motivations towards a certain behavior relate to physiological reactivity in exposure to an attempt at persuasion concerning that behavior.

Thus, while the results of this study do not present a clear relationship between persuasion-induced motivation change and physiological reactivity to persuasive information, it appears that initial motivations are related to physiological reactivity in exposure to persuasive information. This implies that not so much the change in motivations, but the alignment of the person's initial motivations with the persuasive information caused physiological arousal when contemplating persuasion-aligned behavior. This seems to indicate that physiological data can hold subject-specific information relevant for persuasive interventions. These interventions can potentially use this information to adapt their persuasion attempts to that specific user in order to foster persuasion.

3.4.5 Limitations and future research

Based on the limitations of the current study, we pose several avenues for future research: First, a limitation of the current study was the lack of difference in motivations between the experimental groups. Future research might benefit from recruiting participants with more extreme differences in behaviors and motivations, for example vegetarians versus daily meat consumers. A greater difference in initial behaviors might help powerful persuasive stimuli like the "*Cowspiracy*" excerpt (Anderson & Kuhn, 2014) to uncover physiological relations with persuasion.

Second, persuasion might consist of several sub-processes that ask for or trigger different psychophysiological resources. The current study was not designed to analyze psychophysiological responses to each part of the persuasion process (Cascio et al., 2015) including the exposure to the persuasion attempt followed initially by an emotional response and then by a cognitive valuation of the persuasive information, as well as the integration of the persuasive information into one's self-image, and the performance of persuasion-aligned behavior. Different steps in the persuasion process may involve different psychophysiological resources, as for instance suggested in Table 3-4 by the differences in physiological reactivity during video (exposure/valuation) and survey (self-image integration). Recent neuroscience research endorses this idea and describes different neural correlates for message-induced persuasion, perceived persuasiveness and behavior change (Cacioppo et al., 2017). Future research would benefit from making a clear distinction between the different parts of the persuasion process to increase understanding of the psychophysiological responses.

3.5 Conclusion

Taken together, this study did not find a correlation between physiological responses to an attempt at persuasion and persuasion-induced changes in motivation. However, this study's findings do indicate that studying psychophysiological responses to an attempt at persuasion can indeed increase our understanding of the processes at play. Variance in physiological reactivity to persuasive information was better understood using initial motivations: People with motivations more aligned with the persuasive message had less physiological arousal than people with misaligned motivations. All in all, these findings encourage further psychophysiological persuasion research.

Chapter 4

Physiology and reactance to persuasive messages

Our first results did not show the expected positive relationship between physiology and persuasion-related processes. The findings do indicate that people with motivations less aligned with the advocated behavior have more physiological arousal. This chapter[21] describes a study investigating a related mechanism that might have caused the physiology increase of people with motivations less aligned with the advocated behavior, namely psychological reactance. When a person becomes motivated to reject to a persuasive message, this may affect physiology. Recognizing this state of psychological reactance can be valuable for PT adaptation, as persuasive interventions can lose their effectiveness when a person becomes reactant.

[21] This chapter has been published as Spelt, H. A. A., Kersten-van Dijk, E. T., Ham, J., Westerink, J. H. D. M., & IJsselsteijn, W. A. (2019). Psychophysiological Measures of Reactance to Persuasive Messages Advocating Limited Meat Consumption. *Information*, 10(10), 320–332. https://doi.org/10.3390/info10100320

4.1 Introduction

Persuasive technology can help people to change their behavior to become healthier or more pro-environmental by presenting persuasive information or indicating opportunities for change. However, a persuasive message may also evoke psychological reactance. In that case the user is motivated to reject the advocacy, thereby limiting the desired impact of the persuasive technology on behavior (Miron & Brehm, 2006). The motivational state and the negatively valenced emotions associated with psychological reactance are likely—as any emotions—to be reflected in psychophysiological signals (Kreibig, 2010; Picard et al., 2001; Sittenthaler et al., 2015). Physiological reactions might then be used to detect whether a persuasive message is evoking resistance (Steindl et al., 2015). As such, physiology could be an objective measure of persuasion effectiveness. Physiology-based selection of persuasive content would enable unobtrusive personalization of persuasive technology, minimizing the occurrence of reactance. In theory, such biocybernetic-loop systems (Fairclough, 2009) facilitate user-specific adaptation and help to improve long-term behavior change interventions within and across individuals, contexts and time. Biocybernetic-loop systems could then contribute to the field of personalized persuasive technology. This study investigates the physiological patterns in the cardiovascular and electrodermal systems that occur when people respond to persuasive messages that can give rise to psychological reactance.

4.1.1 Psychological reactance is situation specific

Persuasive messages aim at convincing people to change their attitudes, intentions and behaviors (Dillard & Shen, 2005), but can also be perceived as a threat to or restriction of certain freedoms (Dillard & Shen, 2005; Rains, 2013), for example due to the use of controlling or forceful language (Steindl et al., 2015). In that case, people experience *psychological reactance* in which a motivation is aroused to reject the advocacy and reestablish their threatened freedom (Sittenthaler et al., 2015). Psychological reactance is a reactive phenomenon—it occurs when a person responds to a situation containing a specific threat to a specific freedom and is best described as a mix of negative cognitions and emotions towards this threat (Dillard & Shen, 2005; Miron & Brehm, 2006). The negative emotions and cognitions aroused depend on these situational characteristics (Dillard & Shen, 2005). To overcome feelings of reactance, a person may engage in freedom restoration behaviors with a state of motivational arousal (Brehm, 1966; Miron & Brehm, 2006; Sittenthaler et al., 2015).

Differences between people and/or the strength of threats can influence the level of the reactant response. Individual differences arise from the perceived importance of the freedoms that are threatened (Brehm, 1966). The beliefs that shape perceived importance rely on underlying motivations, such as social norms (Miron & Brehm, 2006) or intentions (Ajzen, 2002; Steindl et al., 2015). A second determinant for the magnitude of reactance is the nature and strength of the threat, which can depend on the content but also on the formulation of the message (Ghazali, Ham, Barakova, & Markopoulos, 2018; Miller et al., 2007; Rains, 2013). Generally, *high controlling language* (HCL) is more likely to arouse reactance than *low controlling language* (LCL): HCL has a powerful and directive nature due to the use of many imperatives. It tends to be short, clear and efficient (Miller et al., 2007). In LCL, the intentions of the sender are more ambiguous. LCL emphasizes self-initiation and choice. Consequently, it is perceived to be more polite and less forceful (Miller et al., 2007). Usage of HCL increases the probability that the recipient perceives the messages as a threat, will reject the message, and experiences psychological reactance (Miller et al., 2007).

4.1.2 Measuring the psychophysiology of reactant responses

Earlier research indicates that it is difficult to measure the presence and intensity of reactant responses and its effects and on people's experiences (Miron & Brehm, 2006; Rains, 2013). Several surveys have been developed for this purpose (Miron & Brehm, 2006; Rains, 2013; Steindl et al., 2015), but their validity is an ongoing debate (Rains, 2013; Steindl et al., 2015). Most surveys measure trait characteristics of reactance, while reactance is a situational response (Miron & Brehm, 2006). A well-used survey is by Dillard and Shen (2005) and focuses on the person's *perceived threat to freedom* and *feelings of anger*. Nevertheless, researchers have proposed physiological measures as an additional measure of reactance accounting for direct affective responses (Miron & Brehm, 2006; Steindl et al., 2015). Physiological activity can give information about the mental state of a person and can thereby function as an implicit measure of the mind (Cacioppo et al., 2000; Picard, 1995). Therefore, analyzing psychophysiological responses might yield essential additional insights into psychological reactance.

For our argumentation, it is important to realize that the motivational state of reactance has energizing properties, which can be reflected in the physiological system (Miron & Brehm, 2006; Steindl et al., 2015). That is, cortical responses reflecting the negative emotions and cognitions specific to reactant responses can influence peripheral physiology as well (Kreibig, 2010). Peripheral physiology is influenced by the sympathetic, 'fight-or-flight', and parasympathetic, 'rest-and-digest', branches of the nervous system. These influences are measurable, among others, using features of the cardiovascular and electrodermal system (Cacioppo et al., 2007; Jänig, 2003). Thus, the negative emotions and cognitions that arise in reactant responses might reflect in cardiovascular and electrodermal activity (Shoemaker, Norton, Baker, & Luchyshyn, 2015; Thayer et al., 2012). To draw psychophysiological inferences from cardiovascular and electrodermal activity we have to review the function of both systems.

The cardiovascular system is responsible for blood circulation and, thereby, transportation of blood cells, oxygen, nutrients, waste, and hormones through the body (Cacioppo et al., 2007). Easily measurable features of the cardiovascular system are *heart rate* (HR), that is the number of heart beats per minute, and *heart rate variability* (HRV), that is the variability between those beats resulting from the interplay between the sympathetic and parasympathetic nervous system (Camm et al., 1996). Sympathetic influences increase HR and decrease HRV, and can hint at high arousal emotions, such as fear or joy, and increased cognitive demands. HR decreases and HRV increases under parasympathetic control, often indicating resting states or passive emotions (Kreibig, 2010; Thayer & Lane, 2009). Electrodermal activity, on the other hand, comprises sweat gland activity and is under only sympathetic control. Electrodermal arousal can increase in actionable emotional experiences and cognitive demands, such as decision-making. Measurable features of electrodermal arousal are the tonic component, namely *skin conductance level* (SCL), and the number of rapid phasic responses per minute, called *skin conductance responses* (SCRs) (Boucsein, 2012).

Results from several studies indeed indicated that psychological reactance can be seen as a state with motivational, emotional and cognitive components (Jonas et al., 2009; Rains, 2013; Sittenthaler, Jonas, & Traut-Mattausch, 2016; Sittenthaler et al., 2015; Steindl et al., 2015), such as anger, which is both motivational and affective (Steindl et al., 2015), and negative cognitions (Rains, 2013). Earlier research has shown that reactant responses are indeed associated with heightened sympathetic activity as reflected in elevated epinephrine and norepinephrine neurotransmitter levels (Miron & Brehm, 2006). Only a few studies have linked peripheral physiological activity with psychological reactance (Sittenthaler et al., 2016, 2015; Steindl et al., 2015). These studies analyzed reactance in specific contexts and only for HR and SCL. Other features of cardiovascular and electrodermal activity such as HRV or SCRs are even more sensitive to sympathetic and parasympathetic changes (Cacioppo et al., 2007), and thereby might reveal further insights in psychological reactance. Evoking reactance in other contexts can also produce extra insights, as situational aspects might determine psychophysiological activity during reactance, for example, the topic, the severity of the threat, the perceived importance of the freedom, or specific determinants of freedom.

4.1.3 Study aims and hypotheses

This study investigates whether psychological reactance is reflected in peripheral physiology. Additionally, we want to gain more insight in what predicts psychological reactance, especially the potential role physiological activity. We build on previous work on reactance to an attempt at persuasion (Dillard & Shen, 2005) by using a similar experiment set-up with persuasive content differing in high or low controlling language and self-report measures of reactance (Dillard & Shen, 2005; Rogers, 1983), but now also measure cardiovascular and electrodermal activity. Doing so, previously researched (Sittenthaler et al., 2016, 2015) and new features of the cardiovascular and electrodermal system will be analyzed in relation to psychological reactance. To induce reactant responses, we will use the issue of meat eating, because earlier research suggested people consume meat as a way to express their identity (Loughnan et al., 2014) and that reactance occurs more easily for high involvement issues (Ghazali et al., 2018). Based on earlier research we expect 1) that the motivational arousal and negative feelings in reactance increase arousal, as reflected by HR acceleration, decreased HRV, elevated SCL and more SCRs compared to rest state, 2) that this increased activity positively correlates with self-report measures of reactance, and 3) that this psychophysiological relationship explains part of the reactant responses.

4.2 Methodology

4.2.1 Participants

We recruited participants using the University database, which contains mainly students and a few adults. Fifty-nine people with a relatively high meat consumption (>5 times per week) and without (a history of) cardiovascular diseases participated in this study. Sufficient English language skills and willingness to sign the informed consent were required. Participants received 10 euros or student credits as compensation. Participants were divided into two manipulation groups (group 1: $N = 31$ (19 women), $M_{age} = 23.3$, $SD_{age} = 5.5$, and group 2: $N = 28$ (16 women), $M_{age} = 24.5$, $SD_{age} = 6.7$. The internal ethical board at the Eindhoven University of Technology reviewed and approved the study.

4.2.2 Manipulation

This study had a between-subject repeated-measures design in which participants watched a persuasive video advocating limited meat consumption in either high controlling (HCL) or low controlling language (LCL) for group 1 and 2 respectively. Based on previous research (Dillard & Shen, 2005; Rogers, 1983), the video consisted of a threat-to-health/environment component (202 words) and a recommendation for action (Table 4-1, HCL: 226 words, LCL: 224 words). The first part emphasized the negative consequences of behavior, whereas the second part regulated the strength of the threat. Both videos had comparable content but differed in framing. Besides using more imperatives, the HCL video pressed participants to do a certain action, that is become vegetarian, whereas the LCL video emphasized the choice for action. Especially for the group that saw the HCL video, the intervention tried to evoke psychological reactance.

Table 4-1 A subset of sentences from the manipulation video advocating limited meat consumption.

Segment	Subset of Sentences
Threat-to-health/environment (202 words, presented to both groups)	Eating meat has consequences for your health and the environment. People who eat meat have a higher body mass index and blood pressure than non-meat eaters. […], eating meat increases your risk of heart disease, diabetes and various types of cancer. […], eating meat poses several serious long-term risk to your health. […] Meat production uses up many of the earth's resources. […] About 15% of the global greenhouse gasses come from livestock production. […] This makes livestock production a bigger contributor to global greenhouse gasses than all the world's planes, trains and automobiles put together. […] Around 70% of global freshwater consumption is used in agriculture. […]
Recommendation in HCL (226 words, presented to group 1)	As any sensible person can see, there is really no choice when it comes to consuming meat: you simply have to stop. […] The scientific evidence showing a link between cardiovascular risks and meat consumption is so overwhelming that only a fool would possibly argue with it. […] If you have been reducing your meat consumption, do it even more. […] If you haven't been reducing your meat consumption, right now is the time to start. Today. […] Set a goal for yourself to stop and commit to it. Stop eating meat.
Recommendation in LCL (224 words, presented to group 2)	Most people agree that reducing your meat consumption is a good idea; nevertheless, the choice to do so is completely up to you. […] You are the boss of your own body and you make the rules. What you consume is your own decision. […] If you have been reducing your meat consumption, we support your decision. And if you haven't been reducing your meat consumption, we support your decision. […] You are free to do as you want.

4.2.3 Procedure

One week before the laboratory session, the participant completed an online pre-survey assessing demographic information, meat consumption, and initial motivational state towards limited meat consumption. The participant was instructed to refrain from caffeinated drinks in the 2 hours preceding the laboratory session. Prior to the experiment segments, the participant received a short introduction, signed the informed consent and was attached to the physiological measurement equipment. Then, the participant was seated in front of a computer screen to start the experiment. The computer asked the participant to describe his/her favorite dish to increase awareness of their consumption freedom (Figure 4-1). A baseline measurement of physiology was conducted twice while the participant viewed 3- and 5-minute sea-life movies (Overbeek, van Boxtel, & Westerink, 2012). A 4.5-minute factual video with neutral information about the consequences of meat consumption on the environment and health followed the first baseline. The factual video ensured that all participants had similar topic-specific knowledge. After the second baseline, the persuasive messages were presented. Both the HCL and LCL messages had a total duration of 3 minutes. After the persuasive messages, participants had the opportunity to restore their freedom by filling out questions in the post-survey while reflecting on the video. In this post-survey, a reactance questionnaire as well as control questions were asked in addition to questions assessing motivational state towards limited meat consumption.

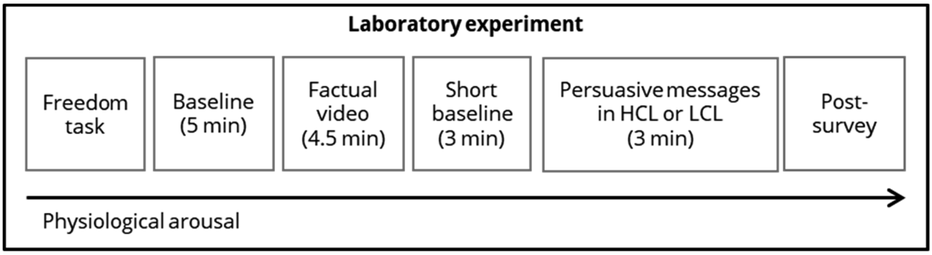

Figure 4-1 Experimental procedure during the laboratory experiment starting with a freedom exercise followed by a baseline measurement of physiology in rest, a factual movie about the consequences of meat consumption on health and environment, a second baseline, persuasive messages using high or low controlling language and a post-survey.

4.2.4 Measurements

4.2.4.1 Subjective data

Self-report measures included demographic information such as age, gender and educational level. Following the theory of planned behavior (Ajzen, 2002), participants' motivational state to limit meat consumption was asked using questions about attitude towards and intention to perform the advocated behavior, as well as subjective and injunctive norms. The five attitude items focused on the instrumental, for example 'worthless–valuable', and affective, for example 'good–bad', nature of limiting meat consumptions with scale end-points counterbalanced. Intention was assessed using three items on intentional effort. Subjective norms measured the perceived expectations of other people's behavior (3 items), whereas injunctive norms represented people's ideas of the participants own behavior (3 items). These items used a 7-point Likert scale ranging from 'strongly disagree' to 'strongly agree'.

Table 4-2 Items for the reactance scales: Feelings of Anger and Perceived Threat to Freedom.

	Feelings of Anger	Perceived Threat to Freedom
1	I was irritated	The video tried to make a decision for me
2	I was angry	The video tried to manipulate me
3	I was annoyed	The video tried to pressure me
4	I was aggravated	The video threatened my freedom to choose

In the post-survey, four items per scale concerning *feelings of anger* and *perceived threat to freedom* (PTTF) checked if participants were reactant towards the video. These questionnaires were answered on 5-point Likert scales ranging from 'completely disagree' to 'completely agree' (Table 4-2) (Dillard & Shen, 2005). In addition, a control survey consisted of one question on the newness of the information and three multiple-choice questions to test if participants paid attention to the video. The questions were presented in English. With exception of the control questions, all questionnaires in this study were validated in previous research and analyzed as instructed (Ajzen, 2002; Dillard & Shen, 2005) using various packages in R studio (Revelle, 2017; RStudio Team, 2016; Wickham, 2017).

4.2.4.2 Physiological data

We used a Mobi physiology-recording device with gel electrodes in Lead II placement for ECG measurement, and dry electrodes with Velcro straps on the fingertips for skin conductance measurement (Boucsein, 2012), sampling at 1029.5 Hz. Physiological features were measured during the complete laboratory experiment. In the ECG signal, we calculated inter-beat intervals (IBIs) and verified them by manually checking the R-peaks. IBIs below 0.4 s or above 1.4 s were interpolated (Zeileis & Grothendieck, 2005). This procedure was seldom needed. From the filtered IBI data, mean heart rate (HR), standard deviation from normal-to-normal peaks (SDNN), and root mean square of successive differences (RMSSD) for the middle three minutes of each experiment segment were calculated. Electrodermal activity (EDA) was down-sampled to 2 Hz and filtered with a 0.5 Hz low-pass Butterworth filter. From the filtered EDA signal, mean skin conductance level (SCL) and the number of skin conductance response peaks per second (SCRs) were calculated for the middle 3 minutes of each experiment segment (Cacioppo et al., 2007). The difference between the physiological values during the factual video, persuasive messages, or survey and those of the preceding baseline served as measure of physiological reactivity to each experiment segment, for example $reactivity_{(messages)} = arousal_{(messages)} - arousal_{(short\ baseline)}$. Several R packages were used for the preprocessing of physiological data (Carezia et al., 2015; Wickham, 2017; Zeileis & Grothendieck, 2005).

4.2.5 Analyses

First, we verified if the two groups were statistically similar with respect to demographic information and motivational state using an independent t-test. As manipulation check, an independent t-test was applied to check whether HCL evoked more reactance than LCL. Additionally, a within-between MANOVA on attitudes and intentions checked whether the video was persuasive.

To answer hypothesis 1, a linear mixed model was applied for each physiological reactivity variable with experimental segment and manipulation condition as fixed and subject as random effects. In linear mixed models, fixed effects are variables constant over measurements, while random effects can vary per measurements. This approach enabled the analysis of physiological reactivity during different experiment segments, while accounting for individual differences and missing data (Venables & Ripley, 2003).

To answer hypotheses 2 and 3, we evaluated the fit of multiple linear models with psychological reactance as dependent variable. To yield only one dependent variable, reactance was calculated by adding anger and PTTF scores. The best predictors of variance in psychological reactance were established by evaluating four models, 1) a null model, 2) a state model, 3) a message-reactivity model, and 4) a full model. The null model included no predictors. The state model evaluated all self-reported scores that determined initial motivational state to limit meat consumptions; attitude, intention, subjective and injunctive norms before the manipulation. The message-reactivity model evaluated HR, SDNN, RMSSD, SCL and SCRs reactivity to the persuasive messages—that is the rise in physiological activity from the short baseline to the persuasive messages for each parameter. Lastly, the full model evaluated all physiological reactivity and initial motivational state variables. Only significant models were presented and only including those variables that improved predictive power of the model by explaining extra variance in reactance based on AIC weights (Wagenmakers & Farrell, 2004). Eventually, the fit of the four models was evaluated using Akaike Information Criterion (Wagenmakers & Farrell, 2004). This evaluation reveals which combination of predictor variables predicts variance in psychological reactance best. In these relational analyses, the effect of manipulation was not considered relevant. Analyses were carried out using several R Studio packages (Bates et al., 2015; Revelle, 2017; RStudio Team, 2016; Wickham, 2017).

4.3 Results

The final data set contained subjective and physiological data of 56 participants. Three datasets had to be excluded due to incompleteness. Data for intention, descriptive norms, and PTTF were not normally distributed and transformation did not effectuate normal distribution, that is log, log+1, Tukey's Ladder of Powers, Cube root nor square root transformation. There were no significant differences between the demographic characteristics or initial motivational state of the two groups, that is attitudes, intention, subjective norms and descriptive norms.

As a persuasion check, a within-between MANOVA with Bonferroni–Holm correction was conducted to compare the main effects of condition and time, and the interaction effect between manipulation and time on attitudes and intentions towards limited meat consumption. Both the main and the interaction effects were not significant; attitudes and intentions did not change over the course of the experiment in either condition.

As a manipulation check, an independent sample one-tailed Mann–Whitney U t-test with Bonferroni–Holm correction revealed that the HCL condition indeed evoked significantly more anger and perceived threat to freedom than the LCL persuasive messages (Table 4-3).

Table 4-3 Descriptive statistics of both reactance scales and results of a one-tailed Mann–Whitney U test comparing the two conditions (high controlling language (HCL) > low controlling language (LCL)).

Condition		HCL		LCL			
Scale	*α*	*Mean*	*SD*	*Mean*	*SD*	*U*	*p*
Anger	0.91	3.45	1.35	2.84	1.12	280	**0.034**
PTTF	0.92	4.20	1.43	2.70	1.45	164	**0.002**

The results of multiple linear mixed models with experiment segment and manipulation condition as fixed effects and subject as random effect showed physiological reactivity differed significantly between experimental segments for HR, SDNN, and RMSSD (Table 4-4). On average, SDNN and RMSSD were 89 and 36 ms lower, and HR 1.30 bpm higher during the persuasive messages compared to the short baseline. During the factual video, HR reactivity was 1.03 bpm lower than during the persuasive messages, whereas SDNN reactivity was 54 ms higher (see also Figure 4-2). With the exception of number of skin conductance peaks, the difference in experiment segments explains between 32.7% and 44.9% of the variance in physiological reactivity based on the conditional R^2 , that is based on both fixed and random effects (Bates et al., 2015). There was no significant effect of manipulation on physiological reactivity.

Table 4-4 Summary results of the mixed linear models for reactivity of Heart Rate (HR), Heart Rate Variability (root mean square of successive differences (RMSSD) and standard deviation from normal-to-normal peaks (SDNN)) and Electrodermal (skin conductance level (SCL) and responses (SCRs)).

	HR		RMSSD·100		SDNN·100		SCL		SCRs	
Predictors	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
Persuasive messages (Intercept)	1.30	**.001**	−0.36	**.040**	−0.89	**<.001**	0.06	0.294	−4.56	0.190
Factual video	−1.03	**.018**	0.04	.829	0.54	**.038**	−0.06	0.317	−0.32	0.948
Survey	−0.60	.165	0.13	.519	0.50	.058	0.10	0.112	4.74	0.330
Random Effects										
σ²	5.25		1.10		2.26		0.11		639.99	
ICC	0.43		0.33		0.37		0.31		0.03	
Obs.	171		171		171		164		165	
R^2/Cond. R^2	0.025 / 0.449		0.001 / 0.336		0.010 / 0.376		0.028 / 0.327		0.008 / 0.040	
AIC	847.072		563.667		692.645		163.913		1549.650	

Note. *Est*. = estimated difference in units of the physiological parameters, *p* = p-value (presented in bold if significant), σ^2 = subject variance, *ICC* = intra-class correlation coefficient, R^2 = Marginal r-squared statistics, *Cond.* R^2 = conditional r-squared statistics, *Obs.* = number of observations, *AIC* = Akaike Information Criterion

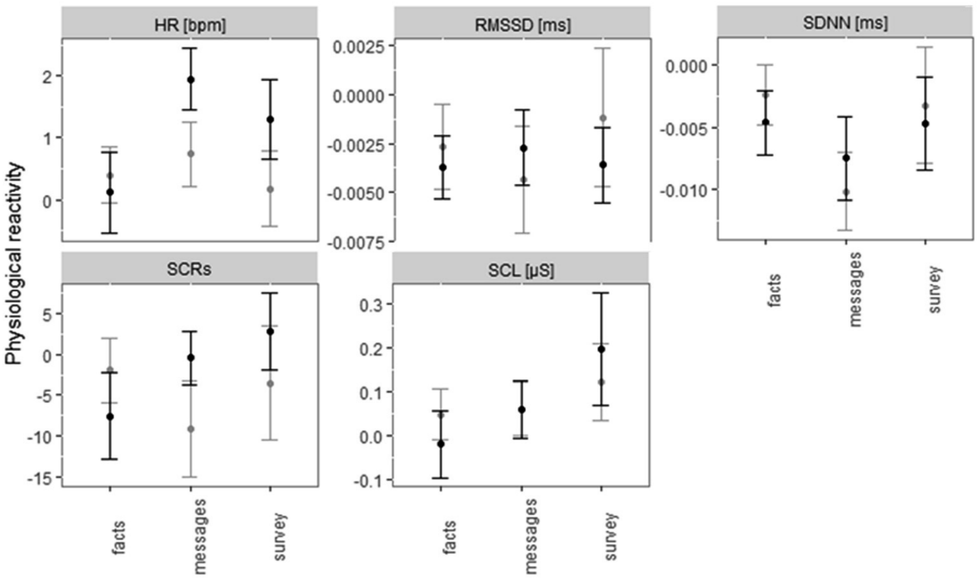

Figure 4-2 Average physiological reactivity per segment for each experimental group with error bars representing standard errors of the mean. Black = group that received LCL, red = group that received HCL.

Results of various linear models with reactance as dependent variable and physiological reactivity and/or initial motivational state as predictor variables for the main analysis are presented in Table 4-5. Out of the four possible models (Section 4.2.5) only three models had a significant fit; the null, state, and full model. The null model includes no predictors and the significant intercept reveals that on average the participants experienced reactance. Results from the state model reveal that from all initial motivational state factors, for example attitude, injunctive and subjective norms, only intention to limit meat consumption explains variance in reactance; reported reactance drops 0.54 on a 1–14 point scale with each unit rise of initial intention. We did not find a significant fit for the message-reactivity model, suggesting a minor role of the physiological reactivity variables in explaining variance in reactance. However, the full model was significant, not only including a relationship between reactance and initial motivational state, but also with physiological reactivity. Results of the full model reveal that on average people report 8.73 experienced reactance on a 1–14 scale. Higher initial intentions to limit meat consumption lower the reported reactance by 0.58 per step on the intention scale. Although the physiological reactivity variables were non-significant on their own, they did yield a model with higher predictive power when combined with intention than the state model. Physiological reactivity to the persuasive messages also lowers reactance by 0.23 and 0.52 for each bpm rise in HR and millisecond rise in RMSSD, respectively. In comparison to the null and state models, the full model has the best fit based upon the lowest AIC. The full model explains around 20.1% of variance in self-reported reactance in our sample based on R^2.

Table 4-5 Results of three linear models explaining variance in reactance.

	Null Model		State Model		Full Model	
Predictors	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
(Intercept)	6.63	**<0.001**	8.47	**<0.001**	8.73	**<0.001**
Intention to limit meat consumption			−0.54	**0.012**	−0.58	**0.006**
HR reactivity to persuasive messages					−0.23	0.056
RMSSD reactivity to persuasive messages					−0.52	0.055
Observations	56		56		56	
R^2 / Adjusted R^2	0.000 / 0.000		0.112 / 0.095		0.201 / 0.155	
AIC	262.250		257.627		255.693	

Note. *Est*. = estimated difference in units of the physiological parameters, *p* = p-value (presented in bold if significant), R^2 = Marginal r-squared statistics, *AIC* = Akaike Information Criterion

4.4 Discussion

Use of psychophysiological reactions could be an objective approach to personalize persuasive interventions, for example trying to avoid reactance. Therefore, we studied psychophysiological reactance to persuasive messages that used high controlling (HCL) or low controlling language (LCL). The messages tried to persuade people with a relatively high meat consumption, that is >5 days per week, towards a more vegetarian diet. Psychological reactance to these messages was assessed with self-reported feelings of anger and perceived threat to freedom (PTTF). A factual video preceding the messages ensured that all participants had akin topic-specific knowledge. Motivations to limit meat consumption were measured one week before and immediately after the experiment. Physiological reactivity was measured during the factual video, the persuasive messages, and the closing survey, using features of the cardiovascular and electrodermal system.

4.4.1 Controlling messages evoke reactance and sympathetic physiology

We found that neither the HCL nor LCL messages persuaded participants to limit their meat consumption (further), as indicated by equal attitude and intention levels before and after the experiment. While for the HCL condition this finding was in line with our expectations, we expected the LCL messages to increase motivations to limit meat consumption. As both groups report some level of reactance (at least 2.7 PTTF on a 7-point scale), this might have limited the persuasiveness of the messages. Importantly, participants were more reactant in the HCL condition by experiencing higher feelings of anger and greater perceived threat to freedom compared to participants that received the LCL condition. Therefore, we can assume that, despite the lack of attitude change, our manipulation was successful.

During the persuasive messages, participants had heightened sympathetic physiological activity as indicated by cardiovascular arousal compared to activity during rest state, that is the short baseline. On the other hand, during the factual video, we found decreased heart rate and increased heart rate variability. Because the action performed by the participant was similar during the factual video and the persuasive messages, namely watching an informative video, this finding cannot be attributed to a difference in general information processing or attention. In addition, both the factual video and the persuasive messages were concerned with the context of meat consumption. Generally heart rate decelerates with increased attention (Cacioppo et al., 2007), whereas during our persuasive messages the opposite occurs. This finding, therefore, seems to suggest that elevated cardiovascular reactivity is indeed caused by the content of the persuasive messages. We did not find a different effect of the HCL and LCL framing on cardiovascular or electrodermal reactivity. One reason for the lack of this finding could be that the manipulation conditions were not distinct enough in their psychological effects; both conditions were not persuasive and both evoked some level of reactance.

4.4.2 Psychological reactance is explained by self-report and physiological measures

Further analyses reveal a relationship between psychological reactance and initial motivations to limit meat consumption; people with higher intention to limit their meat consumption experienced lower reactance. This finding is not surprising. As the intentions of these people were in line with the advocated appeal, the messages were probably less threatening to them and, thus, evoked lower levels of reactance. Interestingly, adding cardiovascular measures significantly improved this explanatory model. Both an increase in HR and SDNN reactivity appear to lower the reported reactance in this study. These findings are somewhat surprising as increased HR indicates arousal, whereas increased SDNN indicates relaxation. As this is contradictory, future research is needed to replicate this cardiovascular relation. Despite this ambiguity, the combination of initial intention with cardiovascular measures did explain almost twice as much variance in reactance than initial intentions alone, that is 20.1% versus 11.2% as indicated by the R^2 in Table 4-5. This underlines our idea that psychological reactance might have a psychophysiological nature. It surely invites the combination of subjective self-report with objective physiological measures in future reactance research.

4.4.3 Limitations and future research

This study has an explorative nature and, thereby, comes with limitations. Since the study was limited to the context of meat consumption and concerns only people that have a high meat consumption patterns (>5 days per week), the findings cannot be generalized. Eating animals is seen as a moral dilemma between the aversion to animal suffering and the desire to eat meat (Loughnan et al., 2014). The moralization of vegetarianism is driven by strong affective responses, such as disgust and guilt (Rozin, Markwith, & Stoess, 1997). Additionally, the formation of these beliefs depend on other attributes, that is experiences, characteristics, objects, than health behaviors. (Ajzen, 1991). Thus, the psychology of morality is wired differently than health beliefs. Therefore, it could be that similarly framed persuasive messages concerning other contexts produce different or no physiological markers. Further work is required to establish if this relation also holds in other contexts, for example climate change, energy saving.

Another limitation might come from the manipulation not being strong enough, explaining the similar effects of both conditions. Although the spread in reactance scores enabled correlational analyses, it could be that too few people experienced high enough levels of reactance to evoke physiological reactivity. Previous research (Dillard & Shen, 2005) reported anger and PTTF scores between 0.45–1.44 and 2.31–3.11 on a 0–4 scale, while we found an average anger score of 3.45 and PTTF score of 4.20 on a 1–7 scale in the HCL condition. The scores are relatively high, but not extreme. This could be one reason for not finding a stronger psychophysiological relationship in reactance. Future research should find out whether higher levels of reactance do reflect in physiology or whether such a robust relationship does not exist at all.

Lastly, personality traits were not considered in this study, while they might have explained some of our results. As mentioned in the introduction, reactant responses are determined by the perceived importance of the freedoms that are threatened (Brehm, 1966). These perceptions may differ based on personality traits. These traits can therefore mediate the reactance response, but they can also influence the physiological response. For example, trait characteristics such as approach-avoidance motivation are associated with other nervous system activity patterns (Balconi, Falbo, & Brambilla, 2009), novelty seeking correlates negatively with low frequency HRV and LF/HF ratio (Takahashi et al., 2005) and cardiovascular arousal relates to neuroticism and agreeableness (Koelsch, Enge, & Jentschke, 2012). As our main finding indicates that HRV parameters explain variability in self-reported reactance, personality traits should also be considered in future research.

Despite its limitations, the study adds to our understanding of persuasive messages and their effects on physiology. Future research should try to replicate and extent these findings to different contexts, types of communication, and people. If an evident physiological marker for psychological reactance is found, it could have considerable implications for personalized persuasive technology, that is indicating which messages are (not) effective for the user. It could set up the use of built-in biocybernetic loops regulated by physiological, affective, and behavioral interactions in human–technology interaction. Thereby, it would enable physiology-based adaptation as a personalization technique for persuasive technology.

4.5 Conclusion

We did not find clear psychophysiological responses related to reactance. Nevertheless, the results do encourage further research because the present findings indicate more cardiovascular arousal during persuasive messages — although most likely not linked to reactance or attitude change. Further research should not only consider the strategy to evoke reactance but also types of freedom and underlying psychological processes that are targeted.

Chapter 5

Physiological reactions to messages deploying persuasion principles

Physiological responses and reactance to an attempt at persuasion do not only depend on a person's current motivational state (Chapters 3 and 4), but might also depend on other parameters. For instance, personality traits also influence susceptibility to an attempt at persuasion in general and for specific persuasion principles. The explorative results in Chapter 3 appeared to indicate that exposure to some persuasion principles can influence physiology, but not all. As such, physiological responses to an attempt at persuasion may be affected by personality, specific persuasion principles and/or an interaction between the two. In this chapter,[22] I will examine psychophysiological responses to messages deploying a number of specific persuasion principles, namely authority, scarcity, commitment and consensus.

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[22] This chapter has been published as Spelt, H. A. A., Westerink, J. H. D. M., Ham, J., & IJsselsteijn, W. A. (2019). Psychophysiological Reactions to Persuasive Messages Deploying Persuasion Principles. *IEEE Transactions on Affective Computing*, 1–13.
Part of this chapter has been published as Spelt, H. A. A., Westerink, J. H. D. M., Ham, J., & IJsselsteijn, W. A. (2018). Cardiovascular Reactions During Exposure to Persuasion Principles. In *Persuasive Technology* (Vol. 10809, pp. 267–278). Waterloo: Springer International Publishing.

5.1 Introduction

Despite good intentions, most people struggle with changing their behavior towards a healthier or more sustainable lifestyle. A considerable body of research has therefore emerged around behavior change interventions, which provide support for people when trying to change their behavior. One way to increase effectiveness is by tailoring the intervention (Hirsh et al., 2012; Kaptein, 2012; Lacroix et al., 2009; Matz, Kosinski, Nave, & Stillwell, 2017) to specific characteristics of the individual. For this approach, understanding the psychological processes underlying persuasion is essential for the success of tailored interventions (Markopoulos et al., 2015).

Currently, the effects of an attempt at persuasion on human experience and behavior are analyzed using self-report measures and observational data (Kaptein, 2012). However, there are additional ways to gain insight, for instance using psychophysiology. As some psychological events cause changes in one's physiology (Cacioppo et al., 2007), psychophysiological variables and their relationship with psychological events might tell us something about mental processes underlying persuasion. Psychophysiological measures can help in explaining behavior and human experience, reflecting deeply rooted physiological reactions as triggered by the nervous system. Thus, they can serve the same goal as self-report measures, but are less subject to biases that are inherent to self-report introspection processes (Calvo, D'Mello, Gratch, & Kappas, 2015). Moreover, in comparison to self-report, psychophysiological measures have the advantage that they can be applied without interrupting the user and can be used continuously throughout a persuasive intervention. This may thus yield a measure that has higher temporal resolution, potentially picking up on subtle changes in experience in-the-moment, which might be missed using a retrospective summary measure such as self-report. Importantly, real-time measures of physiology could be applied to adaptive and personalized interventions, as the interactive application may take such psychophysiological indicators explicitly into account (see for example physiological responses in affective loops improving dynamic game balance (Tijs et al., 2008)). Psychophysiological information could therefore enhance behavior change interventions by allowing physiology-contingent selection and tailoring of persuasive content, and unobtrusive optimization of persuasion interfaces.

Thus far, only few studies have investigated the psychophysiology of persuasion (Cacioppo et al., 2017; Correa et al., 2015; Falk & Scholz, 2018) and a firm link between persuasion-related processes and physiology has not yet been established. This chapter will give a brief overview of previous literature on psychophysiological processes during persuasion. The next section will describe the psychological processes of persuasion. Then we discuss the meaning of physiological reactions and their link to psychology. Next, we explain why a link between bodily processes and psychological susceptibility to an attempt at persuasion is expected. The remaining part of the chapter discusses a study exploring physiological reactions of the peripheral nervous system to messages employing various persuasion principles.

5.2 Related research

5.2.1 Overall processes of persuasion

Changing behavior involves a complex interaction of internal and external motivations. An attempt at persuasion is an external motivator with the goal to change one's intention and attitude towards a certain topic, while still having the free will to think or do otherwise (Perloff, 2008). If the attempt at persuasion is successful, the resulting change in attitude and intention can potentially change behavior (Ajzen, 2002). A way to model the impact of persuasion attempts on intention and attitude is the elaboration likelihood model (ELM, (Petty & Briñol, 2014)). This model centers on the probability that a person considers the communicated message. Therefore, the impact of persuasive cues can vary in correctness, motivation and elaboration of a person (Petty & Briñol, 2014). These variations result in the prevalence of either a central or a peripheral route during persuasion: The *central route* provides conscious evaluations of the communication, whereas the *peripheral route* is based on simple inferences and affective associations tied to the persuasion context (Cacioppo et al., 1986). If both motivation and ability to process the message are high, the central route is more likely to prevail than the peripheral route (Perloff, 2008; Petty & Briñol, 2014).

Given this, the prevailing processing route can be manipulated, for example hampering one's awareness of being persuaded by realizing situations where persons are not able to process a cue via the central pathway due to time constraints (Falk & Scholz, 2018). Professional persuaders use this in their benefit. Cialdini's *persuasion principles* describe six manipulations of this kind (Cialdini, 2007):

- The *authority principle* implies that people comply more when the source is a legitimate authority.
- The *reciprocity principle* suggests that people feel obliged to return a favor or have the norm to do so.

- The *scarcity principle* describes how scarce things become more valuable.
- The *commitment and consistency principle* denotes people's tendency to follow pre-existing commitments and relates to the cognitive dissonance theory.
- According to the *social proof* or *consensus principle*, people tend to use others as an example when they are uncertain.
- The *liking principle* explains peoples' tendency to behave more positively to what they know or like.

Cialdini's principles effectuate persuasion via the peripheral route by manipulating peripheral cues, for example source credibility, instead of argument quality (Cialdini, 2007).

5.2.2 Individual differences in susceptibility to persuasion attempts

Although these principles have, on average, positive effects on compliance with persuasive requests, not every principle is equally effective for everyone (Cialdini, 2007). Previous research indicates that individual differences in traits such as need for cognition (Cacioppo et al., 1986) and involvement (Markopoulos et al., 2015; Perloff, 2008) induce diverse compliance to persuasive strategies. For example, people scoring high in need for cognition and involvement are more likely to be persuaded via the central route than via the peripheral route (Cacioppo et al., 1986). This explains the differences in persuasion route effectiveness among different persons. These individual differences are used in personalized behavior change interventions to increase effectiveness (Hirsh et al., 2012; Markopoulos et al., 2015).

Besides differences in susceptibility to persuasive strategies, there are also differences in susceptibility to distinct persuasion principles that can be used for personalization (Kaptein, 2012; Kroeze, Werkman, & Brug, 2006). Kaptein et al. (2012) developed a *susceptibility to persuasion scale* (STPS), measuring individual differences in susceptibility to Cialdini's persuasion principles. Doing so, these individual differences can be used as a relative advantage to persuade instead of a liability. The scale successfully profiles the expected compliance to a request when formulated by specific persuasion principles and enables personalized use of persuasion principles (Kaptein, 2012). However, by explicitly assessing these persuasion profiles, the person has to consent with filling in the questionnaire. Therefore, he or she will be aware of the measure and might be able to imagine its influence on the intervention. Despite the successful use of meta-judgmental measures to tailor persuasion principles, there is controversy in literature about the precise underlying mechanisms (Markopoulos et al., 2015). Thus, although differences in susceptibility to an attempt at persuasion are measurable and usable for personalization, other, and specifically implicit, ways to measure the impact of various persuasion strategies may yield additional insight in underlying psychological mechanisms. In the future, this knowledge may be used to tailor persuasive interventions further with implicit profiles.

5.2.3 Psychophysiology in persuasion research

The psychophysiological research domain is based on the observation that our experiences and physiology are integrated (Cacioppo et al., 2007). In other words, various cognitive or affective states are distinguishable in physiology, which makes psychophysiology an implicit measure of the mind, considering both conscious and unconscious psychological processes (Cacioppo et al., 2000, 2007). An attempt at persuasion aims at changing psychological states such as intentions and attitudes that could result in behavior change (Perloff, 2008). For a person, it might not be easy to comply with persuasive cues, as changing behaviors and habits requires high levels of self-control, self-regulation, effort and attention. This strong appeal on a person's resources activates the prefrontal cortex (Falk & Scholz, 2018) and potentially induces negative emotions. When being confronted with their 'wrong' behaviors people might experience feelings, such as frustration or annoyance, which might lead to psychological reactance (Brehm, 1966; Eagly & Chaiken, 1993; Roubroeks et al., 2011). Therefore, persuasive messages might change a person's valence and arousal states. As affective states have physiological correlates (Kreibig, 2010), these states caused by an attempt at persuasion might also result in detectable physiological signs.

Indeed, earlier research indicated changes in cardiovascular arousal due to narrative persuasion, that is successful persuasion was characterized by lower heart rate variability (Correa et al., 2015). This indicates that psychophysiological metrics during persuasion-related processes might reflect the effects of persuasive cues. Furthermore, there is a growing amount of papers on the neural correlates of persuasion-related processes (Cacioppo et al., 2017; Falk & Scholz, 2018; Yomogida et al., 2017), of which some claim that neural correlates indeed predict the effectiveness of an attempt at persuasion even better than self-report measures (Falk et al., 2010; Yomogida et al., 2017). Since the same neural correlates also relate to peripheral physiology such as cardiovascular arousal (Shoemaker et al., 2015; Thayer et al., 2009; Thayer & Lane, 2009), this again appears to hint at a psychophysiological impact of persuasion. However, a direct link between distinct persuasion strategies and the peripheral nervous system has not yet been established. Therefore, this chapter sets out to assess this link by exploring reactions of the peripheral nervous system to different persuasion principles.

5.2.4 Physiology of affective states

As the relation of psychophysiological parameters with persuasion-related processes is still unknown, we took the broadly established valence-arousal framework as a research basis, also known as the circumplex model of affect (Russell, 1980). The model states that emotions are not discrete singular states, but come from complex interactions between cognitions and neural structures emerging from two independent neurophysiological systems (Posner et al., 2005): 1) The valence-neural circuit finds it basis in the mesolimbic system linked to dopamine release when processing valenced emotions, for example negatively valenced anger or positively valenced joy. 2) The arousal-neural circuit regulates the arousal level of the central nervous system through its connection with the limbic system and the thalamus, for example low arousal levels during boredom versus high arousal levels during anger (Russell, 1980). The prefrontal cortex interprets and acts upon the signals from the valence and arousal circuits and, thereby, facilitates conscious emotions (Posner et al., 2005).

The valence-arousal framework connects affective states to neurophysiological systems (Posner et al., 2005). Affective states have also been linked to changes in the peripheral nervous system (see Kreibig, 2010 for a full review). As these peripheral parameters are easily accessible with wearables (van Lier et al., 2020) and incorporable in persuasive technology, this chapter focuses on responses of the autonomic and somatic nervous system. In the autonomic system, reactivity of the *cardiovascular system* (CVS), the *electrodermal system* (EDS) and the *respiratory system* (RPS) predominantly indicates arousal, and reactivity of the somatic nervous system *facial muscle activity* indicates valence. Each subsystem provides different information about cognitive and emotional processes. The main functions, important parameters, and the meaning of activity changes for the physiological system are described briefly in Table 5-1.

Table 5-1 Main functions, important measures and interpretations of activity changes for psychophysiological systems of interest.

Cardiovascular system (Cacioppo et al., 2007; Camm et al., 1996) provides blood flow to all the tissues in the body, thereby, ensuring the supply of oxygen and depletion of waste. Both hormonal and autonomic systems regulate blood flow, making the CVS highly responsive to neurobehavioral processes.

- *Heart rate (HR)* is the number of R peaks (heartbeats) within a minute. Increased heart rate indicates a state of higher arousal.
- *Standard deviation normal-to-normal peaks (SDNN)* reflects all cyclic components responsible for variability in the time between heartbeats (interbeat interval, IBI) in the fixed whole period of recording. Decreased SDNN reflects prolonged higher states of physical and emotional arousal.
- *Root mean square of successive differences (RMSSD)* is the variability in IBI differences, thus filtering out lower frequency variability. High frequency HRV is an index of parasympathetic cardiac control. It reflects sudden changes. Decreased RMSSD reflects sudden higher states of physical and emotional arousal.

Electrodermal system (Cacioppo et al., 2007; Van Den Broek et al., 2010) focuses on the sweat glands, as skin conductance varies with sweat gland activity. Activity in the sympathetic nervous system results in increased electrodermal activity. Skin conductance is sensitive indicator of both psychological and physiological arousal.

- *Skin conductance level (SCL)* is the tonic component of the skin conductance.
- *Skin conductance responses (SCR)* are rapid phasic components.

Respiratory System (Cacioppo et al., 2007) has as primary task to supply oxygen and deplete carbon dioxide in the blood. Automatic regulation operates via the brainstem. Voluntary regulation involves different cortical areas.

- *Respiration rate (RR)* is measured via mechanical movement of the diaphragm and rib muscles. Changes in RR relate to task difficulty and cognitive problems. Higher respirations rates indicate increased arousal.

Facial muscle activity (Boxtel, 2010; Lapatki et al., 2010) can provide quantitative information about affective states and expression. Activity is measured with electromyography where the waveform of the signal reflects the contributions made by all active muscle motor units in the area of interest.

- *Zygomaticus major (EMG-ZM)* muscle is located in the cheek and activity associates with psychological states of positive valence.
- *Corrugator supercilii (EMG-CS)* muscle is located in the eyebrow and activity associates with psychological states of negative valence.

Earlier findings in psychophysiological persuasion research can be linked to the valence-arousal model: effective narrative persuasion resulted in lower heart rate variability (HRV) compared to absence of an attempt at persuasion (Correa et al., 2015). Activity in the medial prefrontal cortex (mPFC) correlates positively with behavior change (Cacioppo et al., 2017; Falk et al., 2010; Falk & Scholz, 2018; Pegors et al., 2017). Research also indicated that activation of the mPFC can lead to decreased HRV and increased HR (for detailed information see Shoemaker et al., 2015; Thayer & Lane, 2009). These findings suggest an increase in cardiovascular and neural activity during persuasion, but proof for a specific persuasion valence-arousal pattern is still thin. Not all earlier results can be easily compared, as different persuasion strategies might have different effects, for example empathetic narrative persuasion (Correa et al., 2015) does not elicit the same psychological response as gain/loss-framed messages (Falk & Scholz, 2018). In similar vein, different persuasion principles will probably not elicit the exact same degree of valence and arousal. In addition, individual differences in susceptibility might also reflect in physiological reactions, for example someone with higher susceptibility to a certain principle will have a different valence-arousal pattern than someone with lower susceptibility to the same persuasion principle. By analyzing physiological reactions during persuasion-related processes in perspective of the valence-arousal model, it might be possible to classify and/or group the impact of various persuasion principles. This could create extra insight in the underlying processes of persuasion.

5.2.5 Study Aims and Hypotheses

This chapter investigates whether physiological reactions to persuasive messages provide additional insights into the individual susceptibility to an attempt at persuasion in general and to various persuasion principles specifically. It aims at finding a relation between scores on self-reported susceptibility to persuasion attempts and physiological activity during exposure to persuasion principles. Most earlier studies do not consider individual differences and compare results between groups of participants (Correa et al., 2015; Falk et al., 2010), even though comparison of reactions to different persuasion principles within one individual is equally informative. Especially when individual differences in physiological reaction reflect differences in individual susceptibility to persuasion principles, it might be possible to make implicit persuasion profiles based on psychophysiological data. If it is established how the cardiovascular, electrodermal and respiration system respond to different persuasion principles and what this represents in terms of susceptibility to persuasion, this information can be used to implicitly profile and further personalize future persuasive interactions, and thereby enhance behavior change interventions (Markopoulos et al., 2015).

Given the background described in the introduction, we formulated the following hypotheses: 1) There is a difference in physiological responses in exposure to persuasion principles compared to rest state. 2) Different persuasive principles elicit different physiological patterns, as the principles target different psychological aspects. 3) The difference in physiological responses during attempts at persuasion relates to self-reported susceptibility to persuasion – higher susceptibility to a certain principle is expected to evoke more physiological activity in exposure to that principle.

5.3 Methodology

5.3.1 Design

This study has a within-subject design with persuasive manipulations employing four (out of six) persuasion principles, as formulated by Cialdini (2007); scarcity, authority, commitment and consensus. Liking and reciprocity proved to be difficult to implement in our non-interactive setting (Kaptein, Markopoulos, De Ruyter, & Aarts, 2010). The persuasive messages promoted oral care by increased tooth brushing behavior, since this is a preventive health behavior associated with considerable general health indices (Kandelman, Petersen, & Ueda, 2008). Participants' individual susceptibility to persuasion was measured to predict the effectiveness of the persuasive cues and relate it to physiological responses. The study has six blocks - one baseline of physiological state, four randomized persuasive manipulation blocks and an acoustic startle. The difference in physiological activity between baseline and startle illustrates the range of participants' physiological reactions and helps interpret the differences in physiological reactions to the persuasion principles applied in the study. Physiological arousal and valence will be assessed by different parameters of the nervous and affective system - the cardiovascular, electrodermal, respiration and facial motor system.

5.3.2 Participants

Sixty healthy participants (M_{age} = 48, SD_{age} = 9.6, range = 18 – 60), who indicated to usually brush their teeth less than 2 minutes per session, participated in a 1-hour experiment. Individuals with a history of cardiovascular diseases and pregnant females were excluded from participation. To enhance commitment to the study, participants were led to believe they would participate in a 1-week trajectory to improve their oral care, starting with a laboratory study.

5.3.3 Manipulation

The four blocks of the manipulation were based on the persuasion principles scarcity, authority, commitment and consensus (Cialdini, 2007). Per principle, 14 messages aiming at increasing teeth brushing time were constructed (see examples in Table 5-2). Messages were based on earlier research employing persuasion principles (Cialdini, 2007; Kaptein, 2012) and presented in the native language of the participants (Dutch) to control for language biases. Important parts of the sentences appeared in bold. Each block consisted of an equal number of messages directly focusing on the behavior to change, such as “dentists advise to brush your teeth two minutes per session”, and messages containing peripheral cues effecting behavior change, for example “dentists advise to participate in his study”. Based on several pilot trials, exposure to a single message lasted 8 seconds to standardize the speed of information processing across participants. Messages were alternated with a fixation point lasting 3 seconds. Participants were exposed to all messages in each block. Block and message order was randomized by OpenSesame software (Mathôt et al., 2012). Each block lasted around 3 minutes (Figure 5-1).

Table 5-2 Subset of persuasive messages deploying persuasion principles.

Principle	Message
Authority	Try brushing your teeth well. According to **the College of Dental care,** this is an easy way to lead a healthy life.
Authority	**Doctors** say that dental health relates strongly to your overall health. Therefore, participate in this experiment.
Scarcity	Changing your oral care habits in the future will not reverse teeth decay. **Now is your chance** to work on healthy teeth.
Scarcity	Your dentures give you **a unique appearance**. Do not ruin this and brush your teeth twice a day for two minutes. Starting now.
Commitment	Try to achieve your goal to live a healthier lifestyle by brushing your teeth twice a day for two minutes. **Stay committed!**
Commitment	You participated in this study to improve your oral care. **Finish what you started** and give your teeth the care they need.
Consensus	**Everyone agrees:** Brushing your teeth twice a day for two minutes improves multiple aspects of your life in terms of health and appearance.
Consensus	You are not alone: **95% of the preceding participants of this study** have already increased their healthy brushing behavior.

5.3.4 Measurements

5.3.4.1 Self-report measures

In addition to questions about demographics, participants’ relation to oral health care was assessed with questions regarding past behavior and attitude. Past behavior focused on the quantity and quality of teeth brushing. Based on the theory of planned behavior, five questions reflecting the observed quality and instrumental nature of the behavior provided insight in the participant’s attitude towards the targeted behavior (Ajzen, 2002). Furthermore, the Ten-Item Personality Inventory (TIPI), a 10-item measure of the Big Five personality dimensions, was administered (Gosling, Rentfrow, & Swann jr, 2003). To determine participants’ individual susceptibility to persuasion, the Susceptibility To Persuasion Scale (STPS) by Kaptein et al. (2012) was administered. The STPS is a self-report measure assessing susceptibility to each distinct persuasion principle (all six principles were included, including the two we did not use as manipulation). The scale has 26 items fitting the underlying latent variables (7-point scale ranging from ‘completely disagree’ to 'completely agree'). All questionnaires in this study were validated in previous research and were analyzed as instructed (Ajzen, 2002; Gosling et al., 2003; Kaptein, 2012).

5.3.4.2 Physiological measures

For cardiovascular measures, three sticky Kendall H124SG ECG electrodes measured electrocardiography (ECG): one electrode on the right side of the torso below the collarbone, a ground electrode on the left side below the collarbone, and one electrode on the left side of the torso underneath the ribs. Two dry electrodes fastened on the thenar eminences of the palms measured electrodermal activity (EDA) (Cacioppo et al., 2007, p. 163). Respiration rate (RR) was measured with a piezoelectric belt transducer around the chest (Cacioppo et al., 2007). Facial electromyographic (EMG) measures consisted of four reusable Ag/AgCl surface electrodes attached with disposable adhesives to the skin on top of the zygomaticus major (EMG-ZM) and corrugator supercilii (EMG-CS) (Boxtel, 2010). The physiological parameters of interest were recorded simultaneously using a NeXus-10, that is a multi-channel ambulatory system with bipolar electrophysiological inputs and a maximum sample rate of 1024 Hz.

5.3.5 Procedure

Participants were instructed to refrain from drinking caffeinated beverages in the 2 hours preceding the experiment. To enhance engagement, instructions emphasized that the lab task prepares the participants for a successive week in which oral health care would be monitored and coached. Participants were attached to the NeXus-10, seated in front of a computer screen and given a closed headset. Custom OpenSesame software with a Legacy-backend (Mathôt et al., 2012) executed the experiment by a script starting with the self-report measures, excluding the STPS. While a recording of their physiological activity was performed as a baseline measure, participants watched a 5-minute fragment of the neutral sea life video 'Coral Sea dreaming' with classical music, since a relaxing video is known to lower physiological activity (Overbeek et al., 2012). Afterwards, the manipulations were displayed on the computer screen. Alternating the four manipulation blocks, different 3-minute emotionally neutral sea life videos were put on display allowing the physiological system to return to baseline levels prior to each manipulation (see Figure 5-1). Each stimulus block lasted around 3 minutes to allow HRV analysis (Camm et al., 1996). To evoke a startle response, a loud unexpected 1000 Hz sine tone and white noise mix accompanied with a big red cross appeared after the last block.

The STPS was taken at the end just before debriefing to eliminate the possibility that its questions would influence participants' perception of the manipulation.

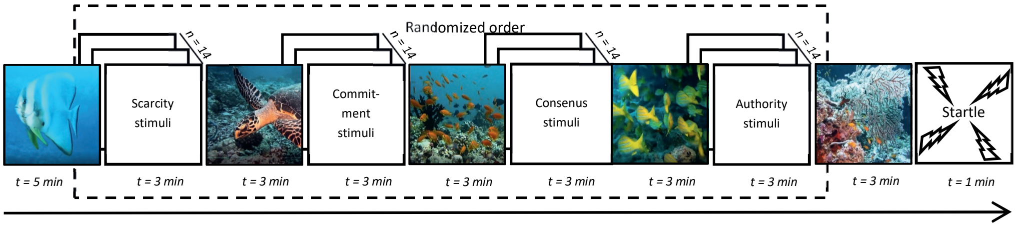

Figure 5-1 Visual representation of the experiment conditions. Each manipulation condition consisted of 14 messages and lasted 3 minutes. The manipulation conditions occurred in randomized order alternated with short sea life clips. A longer clip was presented at the beginning for baseline recordings and a short acoustic startle was presented at the end to elicit a maximum range of physiological values.

5.3.6 Signal processing

The first step to signal processing of the psychophysiological data was signal quality enhancement by elimination of those observations that are artifacts or outliers. A 50 Hz notch filter was applied to all signals. R-peaks in the ECG signals were detected using EDFBrowser (van Beelen, 2017), and inter-beat intervals (IBIs) were derived. Inter-beat intervals outside 0.4-1.4s were manually checked and interpolated if the value seemed an artifact. EDA was filtered with a 0.5 Hz low-pass Butterworth filter. The signal was down sampled to 2 Hz. A low pass cutoff frequency of 0.5 Hz was applied to the respiration signal. EMG outliers were removed using a limit of 10^{-4} mV on a normalized histogram. Both EMG signals were filtered with a 20 Hz high-pass filter. The full-wave EMG signal was rectified (Boxtel, 2010).

The second step was parameter extraction from filtered data for each experimental condition: baseline, manipulation blocks, rests in between blocks and startle response. From filtered IBI data, mean heart rate (HR) was computed as well as heart rate variability (HRV) by means of standard deviation of the normal-to-normal peaks (SDNN) and root mean square of successive differences (RMSSD) (Camm et al., 1996) for each segment. From EDA, mean skin conductance level (SCL) and the number of skin conductance response peaks per second (SCRs) were calculated. The mean rectified voltage of the EMG in the zygomaticus major (EMG-ZM) and corrugator supercilii (EMG-CS) were calculated. Respiration rate (RR) was determined as the number of respiration cycles per minute (Cacioppo et al., 2007). Each of the above-mentioned parameters was calculated per segment or condition. Reactivity was quantified as the parameter value during a manipulation block minus the average of parameter values during the preceding and successive rest-phases. As there was no rest-phase after the startle stimulus, startle reactivity was calculated by subtracting the value during the last minute of the rest-phase preceding the startle stimulus from values during the startle stimulus. For all parameters, three times the standard deviation was operated as cut-off point.

5.3.7 Statistical analysis

The third step is statistical analysis with a multivariate approach. To answer hypothesis 1) and 2), a repeated measure MANOVA was used to find if reactivity in physiological parameters during persuasion attempts was different from zero and between experiment parts. For hypothesis 3), a multivariate correlation was performed between susceptibility self-report measures, that is the subscales and total score on the STPS, and physiological reactivity during exposure to the (matching) persuasion stimuli. In addition, linear mixed models were used to assess the interplay between subjective and physiological data taking into account individual differences. For analysis, R Studio (RStudio Team, 2016) with packages *Tidyverse* (Wickham, 2017), *Psych* (Revelle, 2017), and *lme4* (Bates et al., 2015) was used.

5.4 Results

The final dataset contained self-report and physiological reactivity data of 56 participants, since four sets had to be discarded due to insufficient conductance properties of the skin.

5.4.1 Self-report data

Self-report data had no outliers and was normally distributed with the exception of brushing quality and quantity. Considering our recruitment criteria, this was in accordance with expectations. Most participants reported to brush their teeth at home for a duration of 1 - 1.5 minutes per session. Their attitude towards brushing was relatively positive (M = 5.11 on a 7-point Likert scale, SD = 1.21, range = 3.2 – 6.4). Descriptive statistics of the TIPI and STPS subscales and the overall STPS score were calculated (Table 5-3). Based on the observed alpha-values, the STPS items are considered to have sufficient internal reliability, in line with previous research (Hirsh et al., 2012), except for Liking. However, this is not a real problem, since we did not present a matching persuasive message. The insufficient internal reliability of the TIPI subscales is not surprising since the number of items is small.

Table 5-3 Descriptive statistics of the susceptibility to persuasion scales and the ten-item personality inventory.

Scale	*Mean*	*SD*	α	# items
Authority	3.82	1.10	0.76	4
Scarcity	3.91	1.10	0.67	5
Liking	5.17	0.84	0.32	3
Commitment	5.49	0.86	0.74	5
Reciprocity	4.90	0.99	0.77	5
Consensus	4.21	1.03	0.61	4
overall STPS	4.58	0.61	0.82	26
Agreeableness	4.33	0.96	0.26	2
Conscientiousness	5.28	1.17	0.49	2
Emotional stability	4.88	1.27	0.49	2
Extraversion	4.58	1.35	0.75	2
Openness	5.27	1.12	0.63	2

5.4.2 Physiological data

In the physiological reactivity dataset, only HR data was normally distributed. Various data transformations, that is log, log10 () + 1, Cube root and Tukey's Ladder of Powers, did not improve normality. We proceeded to analyze without data transformation, since 56 participants is a reasonable sample size. Reactivity for all conditions is visually represented in Figure 5-2. To test if people's physiology reacted to the startle response, multiple t-tests compared the reactivity parameter values during the startle stimulus to zero. RMSSD and SDNN were omitted as the startle response was recorded for only 60 seconds (Camm et al., 1996). Results indicate that almost all parameters were significantly different from zero ($p < .05$, $d = 0.427 – 0.882$), indicating a physiological reaction to the startle stimulus, and proper measurement of physiological activity. Only EMG-CS was not significantly different from zero ($p = 0.058$).

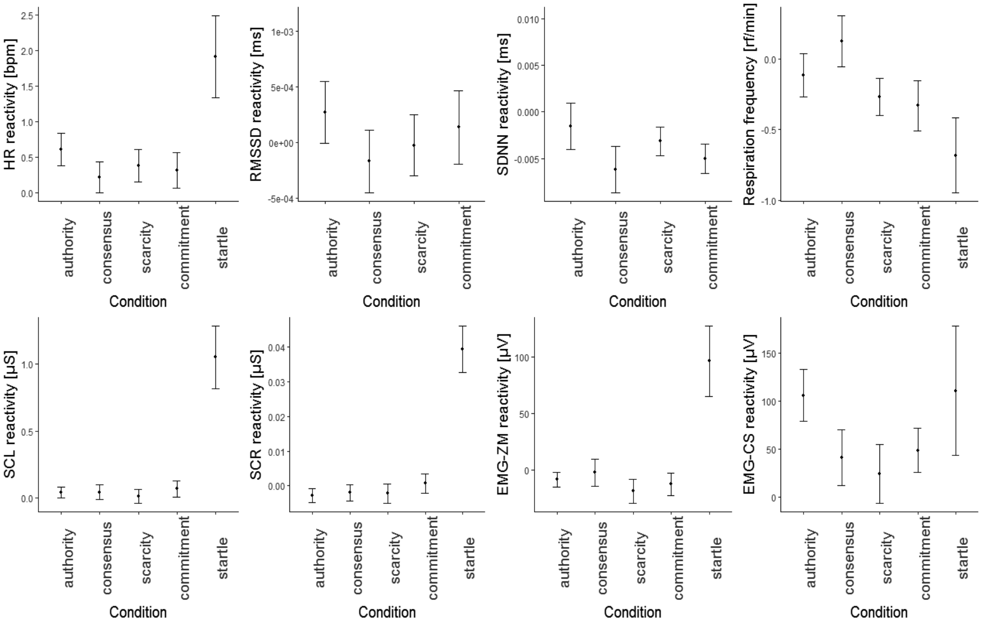

Figure 5-2 Physiological reactivity per condition with error bars representing standard errors of the mean. Reactivity during persuasion stimuli was significantly different from zero for heart rate, SDNN, SCR, and facial muscle activity in the corrugator supercilii and zygomaticus major. Startle data for RMSSD and SDNN were omitted, as the response was recorded for only 60 seconds.

Intercept terms of the one-factor Pillai's trace MANOVA with Bonferroni correction revealed that average reactivity to persuasion attempts was significantly different from zero in multivariate statistics (F (1,143) = 6.376, p < .001, η^2 = 0.044) and univariate statistics for HR (F (1,143) = 8.987, p = .003), SDNN (F (1,143) = 14.752, p < .001), SCR (F (1,143) = 8.676, p = .004), EMG-CS (F (1,143) = 11.648, p < .001) and EMG-ZM (F (1,143) = 5.589, p = .020). Univariate reactivity intercepts for RMSSD, breathing rate, and SCL were not significantly different from zero. There was, however, no significant effect on reactivity of the factor condition (4 levels: authority, scarcity, commitment, and consensus).

5.4.3 Relation between self-report and physiological data

Five multivariate Pearson correlations, with Benjamini & Hochberg' correction for multiple testing, calculated the relationship between physiological reactivity and self-report data, that is one test per STPS subscale and one for overall susceptibility. Self-reported susceptibility to the scarcity principle (scarcity subscale) proved not to be correlated to physiological reactivity during the block with persuasive messages deploying the scarcity principle. In a similar way, no significant correlations were found for the other three persuasion principles, nor for the correlation between overall STPS susceptibility and physiological reactivity during all persuasive blocks.

5.4.4 Mixed model approach

In addition to above-mentioned statistics, we performed a linear mixed effects analysis to understand the relationship between self-report measures and physiological reactivity. Mixed models consist of fixed and random effects. Fixed effects are constant across measurements, whereas random effects vary for example due to individual differences. This approach enabled us to create subject-specific models, account for missing data, and characterize the unexplained or residual variation in the response on multiple levels (Bates et al., 2015; Venables & Ripley, 2003). To avoid overfitting, we started with a simple model and compared a series of increasingly complex fits using the Akaike Information Criterion (AIC) (Venables & Ripley, 2003). Only if the added factor significantly explained more variance and added predictive power to the model, this effect was retained. Parameter specific *p*-value estimations were based on conditional *t*-value with the Satterthwaite approximation for denominator degrees of freedom (Venables & Ripley, 2003). In the dataset, the first level are the individual participants and the second level are the repeated measures of physiological reactivity to the four persuasion principles within the subject. The first fit (model A) consisted of manipulation condition as fixed effect and subject as grouping variable. In the second fit (model B), the overall STPS score was added as fixed effect. The third fit (model C), contained scores on the STPS subscales related to physiological activity during the corresponding manipulation as fixed effect. As fourth (model D), the different factors of the TIPI, that is extraversion, emotional stability, conscientiousness, openness, and agreeableness, were added as fixed effects and evaluated one by one in model D. This iterative model-building process was performed separately for each physiological response parameter.

Results indicated that for most physiological parameters the fixed effects of overall STPS or STPS subscale, did not significantly explain variance. In other words, model A, a subject-specific model focusing on reactivity of physiological outcome parameter based exclusively on manipulation condition, was the best fit for HR, RMSSD, SDNN, and RR reactivity. Exceptions are SCL and EMG-CS reactivity, for which the overall STPS scores significantly explained more variance in physiological responses to the persuasive manipulations. Consequently, model B proved to be the best fit for SCL and EMG-CS (Table 5-4). Higher overall STPS scores indicated lower reactivity and vice versa. Results show EMG-CS values drop 44.67 mV with higher overall STPS score. However, a large amount of variance in EMG-CS reactivity is still unexplained. For SCR, a model containing both overall and subscale STPS scores in addition to manipulation as fixed effect and subject as grouping variable proved to be the best fit. Similarly, higher overall STPS scores indicated lower reactivity and vice versa. In contrast, higher STPS subscale scores indicated higher reactivity. Probably the effect of average scale score is influenced strongly by the psychophysiology of commitment, as this scale has a larger, negative relationship with SCR reactivity than consensus and scarcity. A version of model D with a fixed effect of manipulation and as random effect TIPI subscale extraversion was the best fit for EMG-ZM reactivity. Results show EMG-ZM values rise with 9.53 mV with higher scores on TIPI subscale extraversion.

Table 5-4 Summary of the best mixed linear model fit for skin conductance level, skin conductance response, and electromyographic activity in the corrugator supercilli and zygomaticus major.

	SCL		SCR · 100		EMG-CS		EMG-ZM	
	Est.	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
Fixed Parts								
Intercept (authority)	0.58	**.017**	1.26	.241	299.11	**.007**	-52.15	**.026**
manipulation (commitment)	-0.01	.920	-0.29	.332	-45.45	.154	-8.55	.379
manipulation (consensus)	-0.03	.644	-0.08	.749	-65.73	**.042**	-0.80	.935
manipulation (scarcity)	-0.03	.593	-0.20	.408	-88.18	**.007**	-10.35	.286
STPS total	-0.12	**.024**	-0.53	**.043**	-44.67	.053		
STPS subscales			0.23	**.045**				
TIPI Extraversion							9.53	**.041**
Random Parts								
σ^2	0.092		1.243		26058.294		2489.606	
$ICC_{subject}$	0.235		0.304		0.129		0.384	
Observations	222		175		209		214	
R^2 / Ω_0^2	.430 / .367		.492 / .439		.312 / .254		.552 / .515	
AIC	159.196		595.316		2756.533		2361.951	

Note. *Est.* = estimates, *p* = p-values (presented in bold if significant), σ^2 = subject variance, *ICC* = intra-class correlation coefficient, R^2 = r-squared statistics, Ω_0^2 = adjusted Omega-squared values, *AIC* = Akaike Information Criterion

5.5 Discussion

As affective states have physiological correlates, changes in state caused by an attempt at persuasion might also have detectable physiological patterns. Finding and understanding these physiological patterns during an attempt at persuasion might increase our understanding of the underlying mechanisms. This might enable future applications by allowing physiology-contingent selection, content tailoring and unobtrusive optimization of interventions that are less subject to introspection and with higher temporal resolution than those based on questionnaires. Therefore, this study analyzed the relationship between reactivity of the peripheral nervous system to persuasive cues with self-reported susceptibility to persuasion. Physiological data were collected during exposure to persuasive messages using scarcity, consensus, authority, and commitment as persuasion principles. Measures of the peripheral nervous system included the cardiovascular, respiratory, electrodermal system and facial motor activity. The physiological data was related to self-reported susceptibility to persuasion (STPS). Building on earlier research, we expected differences in physiological activity in exposure to an attempt at persuasion in general and to various persuasion principles. We also expected this reactivity to correlate with the self-reported persuasion profiles – that is, people with higher susceptibility to a certain persuasion principle also showing more pronounced physiological reactivity during that specific condition.

Results appeared to support hypothesis 1, that is reactivity during presentation of persuasive stimuli was different from reactivity during baseline for heart rate (HR), standard deviation from normal-to-normal peaks (SDNN), skin conductance response (SCRs), facial motor activity in the corrugator supercilii and zygomaticus major (EMG-CS and EMG-ZM). There were no differences in reactivity for root mean square of successive differences (RMSSD), skin conductance level (SCL) and respiration rate (RR). However, results provided no evidence in support of hypothesis 2, which is no differences in reactivity between different persuasion principles were found. Regarding hypothesis 3, no correlations between susceptibility to persuasion attempts and physiological reactivity to the corresponding persuasion principle were found. Nevertheless, when a mixed model approach was used to explain the differences in physiological reactivity between conditions, self-report measures (i.e. STPS scores) and subject specificity, results do indicate that self-report measures (i.e. overall STPS alone or with STPS subscales and extraversion) explained SCL, SCR, EMG-ZM and EMG-CS data. This was not the case for the remaining physiological variables. Multiple explanations for these main findings are possible.

5.5.1 Physiological reactivity to persuasion attempts differs from rest state

Starting with hypothesis 1, results showed that activity during presentation of persuasive stimuli was different from physiology in rest state for HR, SDNN, SCR, EMG-CS and EMG-ZG. This indicates that information processing during persuasion attempts is characterized by different physiological activity than during baseline. However, it is unclear if the persuasiveness of the information elicited the physiological activity. It is possible that the physiological responses to the persuasive messages come from a more generic orienting reaction to the stimuli. For example, the difference in physiology might actually come from reading texts instead of persuasive content. Thus, although the results appear to be supportive, one could question if hypothesis 1 was correctly formulated. Future research should establish if the persuasive character of the information is what arouses the physiological responses, by comparing physiological reactivity during persuasive messages to an additional control block with unrelated, fact-stating texts.

Moreover, the difference in physiology during rest state and persuasive stimuli is hard to interpret. Results show higher HR values and lower SDNN values during persuasion attempts indicating higher sympathetic activity in the cardiovascular system, which represents the energization of the body (Cacioppo et al., 2007). In contrast, however, we found on average fewer SCRs during persuasion. This finding indicates more frequent sympathetic responses in the electrodermal system during baseline, while we expected this pattern during persuasion. Earlier research demonstrated that the cardiovascular and electrodermal system are, alongside nervous system control, differently subject to a range of physiological subsystems, such as hormonal influences and other neurobehavioral processes (Cacioppo et al., 2007, Chapters 7–8). It is possible that, in a part of the participants, some of these subsystems were activated during baseline, which resulted in elicitations of SCRs without influencing the overall level of electrodermal activity. This would be in line with the finding that SCL during an attempt at persuasion was predominantly similar to baseline. In a broad sense, the findings across these two physiological systems seem to contradict each other in terms of peripheral nervous system arousal. We currently do not have enough information to interpret this unexpected finding.

Concerning the somatic nervous system, results indicate more EMG-CS and less EMG-ZM activity during an attempt at persuasion compared to baseline. Roughly, this indicates that participants enjoyed the sea life movies during baseline better than the oral care information up to the extent that they disliked the latter. This could mean that, alongside just reading and thinking about the information, the attempt at persuasion indeed induced negative emotions by appealing on a person's resources or confronting them with their 'wrong' behavior. This could be explained with the theory of psychological reactance (Brehm, 1966; Eagly & Chaiken, 1993), which states that people might be motivated to reject the content of a persuasive message when they view it as threatening. This results in a resistance to influence of others and a motivation to regain their freedom. Reactance is seen as a state of arousal that can involve physiological reactions. This indicates the complexity of multiple intertwined psychological processes at play.

5.5.2 Similar physiological reactivity to persuasion principles

Although we found reactivity during persuasion, there was no difference in activity between the persuasive principles (hypothesis 2). Because the different persuasion principles target other psychological aspects, we expected different persuasion principles to elicit different degrees of valence and arousal resulting in distinct physiological patterns. One reason for this finding could be that individual differences in susceptibility to persuasion attempts were not considered in this analysis. Because we also expected that differences in susceptibility to a principle would reflect in physiology, it could be that the mixture of high and low susceptibility levels averages out the physiological responses.

An alternative explanation for the lack of differences in reactivity to different persuasive stimuli could be that - in contrast to the startle sound - the persuasive manipulation was not strong enough. A weak manipulation lessens the reactions to the different principles, making them too frail to be distinctive. The persuasive stimuli were based on earlier research that successfully used comparable messages deploying these persuasion principles (Cialdini, 2007; Kaptein, 2012). Still, our messages were not identical to those messages, mainly because the target behavior differed. An additional reason for lower manipulation strength might be that the experimental set-up with physiological measurement devices might have decreased ecological validity. Physiological measurements benefit greatly from static postures and reliable timing (Cacioppo et al., 2007, Chapter 34). Consequently, the participants had to sit perfectly still, and a preprogrammed script was used to run the experiment. This set-up might have decreased participants' belief in the stimuli, as an attempt at persuasion heavily depends on human social interaction (Cialdini, 2007). Additionally, it created a rather passive experiment set-up. This may have caused the participants to lose interest in the experiment, again lowering the manipulation strength.

Another source for leveled physiological responses could be carryover effects between conditions. It could be that the 3-minute timeslot was not sufficient to return to physiological rest state. We tried to minimize the chance of carryover effects by adding resting periods between conditions and randomizing the order of manipulation conditions and stimuli (Cacioppo et al., 2007, Chapter 34). This is in line with the finding that physiological reactivity during an attempt at persuasion did differ from rest state, but not between the different principles.

Another reason for the lack of differences in reactivity between persuasive conditions might come from the strategy that was used to persuade participants. We chose Cialdini's persuasion principles (Cialdini, 2007) as influence strategy, because of the large amount of literature on the implementation of these principles and the availability of the STPS (Kaptein, 2012). These self-reported indications of susceptibility enabled us to analyze subject-specific psychophysiological relationships. However, earlier research implemented these principles mainly in field experiments instead of lab experiments. This difference in experiment context might have decreased the ecological validity and, thereby, the effectiveness of these particular persuasion strategies. Given the short duration of our intervention, that is only one visit to the lab, it is possible that our participants did not translate the persuasive messages into their daily lives. Perhaps there are other, more appropriate, persuasive strategies to influence people in such a short timeframe. Similarly, longer termed interventions might yield different results. In similar vein, the target behavior might have not been the right one. Only people with bad oral care habits were included, it is highly plausible that not everyone is as invested with oral care. This could be a reason why these participants had unhealthy oral care habits to start with. Targeting behaviors around issues that people truly care about might yield different results. Therefore, future research should focus on powerful persuasive interventions that are able to influence someone's life profoundly.

5.5.3 Relating physiological activity to self-report measures

The third hypothesis considered the psychophysiological relationship in persuasion. The multivariate correlation analyses indicated no relationship between self-reported susceptibility and physiological reaction to persuasion. This finding appears to confirm that reactions to persuasion principles do not have a clear psychophysiological signature. However, the mixed model approach indicated that adding overall STPS scores does help in explaining the physiological reactions to the persuasive manipulations, at least for SCL, SCR and EMG-CS. Interestingly, this effect was in the opposite direction of what we expected: A higher overall STPS score indicated lower physiological reactivity and vice versa. In other words, participants low susceptible to persuasion principles overall were more physiologically reactive to messages employing persuasion principles. The results indicate that people with lower susceptibility scores were frowning more during persuasion. People tend to frown when they are, for example, thinking, paying attention, or experience negative emotions. Lower susceptibility also indicated more electrodermal arousal during persuasion. Sweat glands are driven by activity of the sympathetic nervous system. Potentially, other psychological processes are at play here, possibly psychological reactance (Brehm, 1966). This could explain why for example, less susceptible participants exhibited more frowning and more activity of the electrodermal system during persuasion. This important issue warrants future research.

The mixed model results also reveal lower SCL for people with higher STPS scores, even though on average the SCL activity during persuasion attempts did not differ from baseline. This appears to suggest that individual differences in susceptibility are important in explaining SCL activity during persuasion. Interestingly the best model fit for SCR included both average STPS scores and STPS subscales scores. Further inspection indicates that overall susceptibility and susceptibility to particular principles had opposite effects on SCR: Higher reactivity was associated with lower average and higher subscale scores. This might suggest that self-report susceptibility and physiological reactivity has a different relationship in commitment persuasion attempts compared to scarcity, authority or consensus persuasion attempts. Furthermore, the mixed model approach revealed extraversion as a predictor of zygomaticus reactivity. This finding is well understood as the zygomaticus major is involved in large facial expressions, such as laughing, and extravert people are known to exhibit more facial expressions.

5.5.4 Implications and further research

Taken together the findings of this study are not conclusive. A main reason for difficulty with interpretation of the results is that it is unclear whether the participants actually were persuaded. Consequently, although physiological activity during persuasion attempts was different from baseline, the attempt might not have been the instigator. It could also come from a difference in action, for example watching a video versus reading a text. On the other hand, the relations found between physiology and susceptibility to persuasion attempts do suggest processes relevant to persuasion were indeed triggered. Future research would benefit from adding a measurement of intention and/or attitude towards the target behavior after the persuasive manipulation. A change in intention or attitude would indicate effective persuasion and give more meaning to the physiological responses. Adding behavioral measures could reveal if the persuasion resulted in prolonged behavior change. Comparing physiological response during these persuasive versus control stimuli would provide more meaningfulness to the psychophysiological response. To ensure that physiological reactivity comes from persuasion, future research should create an experiment set-up involving powerful persuasive stimuli, targeting learning behaviors that people are interested in but experience trouble with achieving, and comparing those physiological responses to those during neutral information

Despite these ambiguities, self-reported susceptibility to attempts at persuasion did explain variations in SCL, SCR and EMG-CS reactivity partially. It does suggest a relationship between susceptibility to attempts at persuasion and physiology. If susceptibility to attempts at persuasion is measurable in physiology, this could have great applicability to behavior change interventions and persuasive design systems, even if only small changes in physiology are obtained. For example, a behavior change intervention can be created with a built-in affective loop drawing upon physiological and emotional interactions between the user and the system. With wearable technology, such as a smart watch, physiology could be measured while someone receives a persuasive text. Combined with other indicators, this physiological response could indicate how the user receives this persuasive text. Thereby, the behavior change intervention can adapt to a specific user continuously without interrupting the intervention. Physiology enables real-time measurement with higher temporal resolution and fewer introspection biases than summarizing measures. Physiology-based tailoring could be a refreshing addition to current personalization techniques. However, more research is needed before we can be sure that a system like this can work.

The findings of this study opened up new questions that need to be addressed in future research. Some of the findings were unexpected, which made us question the underlying processes of persuasion. It could be that a single persuasion principle does not activate one clear, delineated psychological process, but a mix of interacting cognitive and emotional processes. This diffusion might also be reflected in the underlying physiology, leading to ambiguous results and multi-mapping problems (Cacioppo et al., 2007; Fairclough, 2009). This justifies the potential role of the reactance phenomenon in some participants, but also implies the possible presence of other internal processes. The current study explored the peripheral path of the ELM, and hypothesized possible links in affective state to physiological reactivity. However, earlier research (Kitchen et al., 2014) questioned if peripheral processing influences affect and concluded that emotions can also serve as persuasive argument when elaboration likelihood is high. Indeed, the ELM is a descriptive model integrating both contextual and individual variables to process persuasion, but it does not effectively model the psychological process of persuasion (Kitchen et al., 2014). As a result, it is unclear how these persuasive processes may vary and result in different outcomes.

These ambiguous findings highlight the difficulty in the psychophysiological research area. In future investigations, it might be possible to test the psychophysiology of isolated persuasion-related processes. For this purpose, it might be necessary to make not only a distinction between persuasion strategies, but also between the underlying psychological aspects that are targeted. The predominant targets of the present study were health beliefs in oral care. However, persuading people to change their moral beliefs or perceived behavior control could result in different physiological patterns. Especially the latter, that is perceived behavior control, might be important for people that have trouble with adjusting their behaviors. Furthermore, people might be more aroused when persuasion targets behaviors that they are invested in more. Comparing the physiological reactions in different persuasion settings might provide better understanding of how psychological constructs underlying behavior, such as intentions, beliefs, attitude, perceived behavior control, are connected.

5.6 Conclusion

Altogether, no distinct psychophysiological patterns in exposure to different persuasion principles were found in this study, nor a clear correlation with individual susceptibility. This means that this experiment did not provide support that physiology might be appropriate for implicit profiling of susceptibility to persuasion principles. However, we did find that some of the variance in physiology was explained by self-reported susceptibility to persuasion scores. Although the findings of this study are not conclusive, they open up many new questions. In that sense, this study provides a first notion of this relationship: It is a complex relationship. Apparently, research on the psychophysiological nature of persuasion is still in its infancy, and implicit personalization with physiology remains a promising way to increase effectiveness of behavior change interventions. However, further research is needed to conclude whether different psychophysiological relationships are present and sufficient for implicit reactance-to-persuasion profiles.

Chapter 6

Persuasion-induced physiology as a predictor of persuasion effectiveness

The findings presented in Chapter 5 indicate that overall susceptibility explains more variance in physiology than susceptibility to distinct persuasion principles. In this Chapter,[23] I will study psychophysiological responses to attempts at persuasion while considering people's more general behavioral approach or avoidance orientation. Importantly, I will examine to what extent these psychophysiological responses predict consequent behavior. Next, I will quantify the extra insights that psychophysiological measures can bring over traditional predictors of persuasion like motivational state and behavioral approach or avoidance orientation.

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6.1 Introduction

Persuasion attempts are often used in technology to promote health-related behaviors, such as physical activity or healthy eating. Traditionally, PT uses self-report and behavioral measures to predict susceptibility to persuasive messages and evaluate intervention effectiveness. Recently, researchers identified new ways of assessing persuasive processes that might enable new applications, namely using psychophysiology (Barraza et al., 2015; Cacioppo et al., 2017; Correa et al., 2015; Falk & Scholz, 2018; Sittenthaler et al., 2015). It has been established that conscious and unconscious psychological processes can reflect in physiology (Koelstra et al., 2012; Picard et al., 2001). If persuasive processes indeed also show in physiology, physiological measures might function as an implicit measure of persuasion. In addition, knowledge of physiological responses to persuasive messages might help to increase our understanding of persuasive processes.

Wearable biosensors such as smartwatches enable unobtrusive, continuous and precise physiological measurement in daily life (van Lier et al., 2020). This enables high temporal resolution and sensitivity to changes in the physiological patterns, as even small changes in physiological activity level (in response to particular persuasive content presented) can be insightful. Contrary to self-report measures, physiological measurement is not subject to introspection and enables real-time feedback.

If indeed related to persuasion effectiveness, inferences from physiological patterns might also be used to personalize and optimize persuasive messaging. Technologies that employ PT can be in constant communication with biosensors. The resulting large amounts of data can be handled by machine-learning algorithms with the goal of improving interventions by physiology-dependent personalization of persuasive content. This would enable calibration to the optimal level of persuasion across individuals, context and time with great sensitivity and without disturbing the user. In this way, affective computing (Pantic & Rothkrantz, 2003) can potentially be used to improve persuasive interventions and improve behavior.

Results from earlier research indeed hint at the presence of a psychophysiological relationship in persuasion (Barraza et al., 2015; Correa et al., 2015; Sittenthaler et al., 2015; Vezich et al., 2017), but a firm link has not yet been established. This chapter seeks to extent the body of knowledge, and begins by describing (differences in) the processing of persuasive information. Next, we argue why physiology can be a measure of persuasion-related processes and discuss earlier psychophysiological persuasion research. It will then go on to describe a study examining reactions of the peripheral nervous system to gain- or loss-framed persuasive messages and relating these reactions to persuasion-induced change in motivational state and behavior.

6.1.1 Individual differences in processing of persuasive messages

Persuasion attempts aim at changing attitudes and behaviors without coercion (Perloff, 2008). These attitudes and behaviors differ per individual because of underlying motivations of behavior, for example values, beliefs, and personality characteristics. Consequently, the processing of and susceptibility to a persuasive cue differ per person. Below, we will briefly explain the importance of perceived value of compliance and relevance of persuasive information and discuss two relevant mediators on the general process; *motivational orientation* and *message framing*.

The recipient of a message has greater motivation to elaborate on information that is perceived to be relevant (Petty & Briñol, 2014; Petty & Cacioppo, 1986). Persuasive messages aim to change the recipient's perceived value of an action and, thereby, motivate the recipient to perform message-consistent behavior (Ajzen, 2002; Falk & Scholz, 2018; Festinger, 1962; O'Keefe, 2013). Thus, the perceived value of compliance and relevance of a persuasive message determine its effectiveness. Adapting messages in such a way that the recipient feels addressed by them makes elaboration, and thus persuasion, more likely to happen (Chua et al., 2011; Petty & Cacioppo, 1986; Vezich et al., 2017).

How valuable someone perceives a new piece of actionable information to be also depends on personality characteristics, and an important one is *motivational orientation* (O'Keefe, 2013; Sherman et al., 2006). Motivational orientation concerns how likely a person is to engage in risk-aversive or reward-focused behavior (Carver & White, 1994). Two self-regulatory mechanisms control attitudes and behavior (Carver & White, 1994): The *behavioral approach system* (BAS) responds to opportunities and initiates actions towards them (i.e. approach), whereas the *behavioral inhibition system* (BIS) seeks to avoid punishment or losses (i.e. avoidance) (Carver & White, 1994; O'Keefe & Jensen, 2009). Motivational orientation explains how the same message can be valued differently depending on more active BIS or

BAS; people with active BIS will focus on the detrimental effects of inaction, whereas people with more active BAS will focus on the gains of action (Sherman et al., 2006).

As a consequence, attempts at persuasion can be personalized (Markopoulos et al., 2015) by adapting the *message framing* to the recipient's motivational orientation. The same factual information can be presented as a potential gain or as a potential loss (Kahneman & Tversky, 1979; O'Keefe & Jensen, 2009; Sherman et al., 2006). In behavior change, *gain-framed* messages emphasize potential benefits of the behavior adjustment (compliance), whereas *loss-framed* messages focus on the costs of inaction (non-compliance). People tend to be more focused on persuasive messages in line with their own motivational orientation; aligned messages are likely to be closer to current goals, attitudes, and intentions, which promotes compliance and facilitates persuasion (Sherman et al., 2006). As such, loss framing is expected to be more effective for individuals with more active BIS, whereas gain framing for individuals with more active BAS, and matching persuasive messages to subjective valuation of potential consequences is key to successful influence.

In the next section we will argue that our understanding of these persuasive processes can be improved by considering physiological responses (Cacioppo et al., 2007), and that physiology might therefore also be used to strengthen the described traditional personalization methods based on self-report and behavior measures (Markopoulos et al., 2015).

6.1.2 Physiology as measure of persuasion

Research showed that emotions and cognitions have a neurophysiological basis (Posner et al., 2005; Thayer & Lane, 2009) and can influence nervous system activity (Fairclough, Venables, & Tattersall, 2005; Jänig, 2003; Koelstra et al., 2012). The *autonomic nervous system* (ANS) helps the body to facilitate an optimal internal environment for cells, tissue and organs to execute their functions and cope with internal and external demands (Jänig, 2003). Processing a persuasive message could be such a demand. The ANS is divided in a *sympathetic* and *parasympathetic branch* that control organ activity by either increasing (sympathetic) or decreasing (parasympathetic) activity (Jänig, 2003; Shaffer & Ginsberg, 2017). ANS activity can easily be measured in features of four subsystems; heart rate and heart rate variability in the cardiovascular system, skin conductance levels and the number of peaks in the electrodermal system, breathing rate in the respiratory system and facial activity in the facial muscle system (Boxtel, 2010; Cacioppo et al., 2007; Shaffer & Ginsberg, 2017).

Fluctuations in nervous system activity can reveal a psychological state or emotion (see Kreibig, 2010 for a full review). Therefore, studying bodily activation during exposure to persuasive messages might help us understand their impact on human psychology. Physiology might also reflect parts of the persuasion-related processes that are missed or misinterpreted in self-report or behavioral data. Combining physiological with self-report and behavioral measures renders an all-round picture of the active mechanisms during persuasion. It might be easier to pinpoint successful parts of a persuasive strategy in relation to individual differences based on physiological patterns.

Earlier research indeed suggests that this link between persuasion-related processes and physiology is present to some extent: Physiological patterns in the brain and peripheral nervous system during an attempt at persuasion differ from rest states (Vezich et al., 2017). Electrodermal and cardiovascular patterns can reveal effectiveness of narrative persuasion (Barraza et al., 2015; Correa et al., 2015), as well as resistance and reactance to persuasive messages (Sittenthaler et al., 2015). Brain activation during an attempt at persuasion can predict behavioral compliance to the message (Cacioppo et al., 2017; Cascio et al., 2015; Pegors et al., 2017) in studies about sunscreen use (Falk et al., 2010), smoking reduction (Chua et al., 2011; Pegors et al., 2017), and reduction of sedentary behavior (Falk et al., 2015).

In a non-persuasion context, research revealed that the cardiovascular system responds to gain- and loss-framing in task challenges; gain-framing led to lower peripheral resistance and higher cardiac output than loss framing (Seery, Weisbuch, & Blascovich, 2009). Persuasion studies found more brain activity in gain- versus loss-framed messages and this activity predicted actual behavior (Vezich et al., 2017). Furthermore, as motivational orientation relies on two distinct neuro-chemical systems, it was found to reflect in electrodermal responding and vertical pupil dilation for BIS and in cardiovascular pre-ejection period, respiratory sinus arrhythmia and eye blink rate for BAS (Berkovsky et al., 2019; Brenner, Beauchaine, & Sylvers, 2005). Interaction effects between message framing and motivational orientation, that is personality-message congruency, on peripheral physiology have also been found: BAS sensitivity leads to higher electrodermal response and lower cardiovascular arousal in response to positive stimuli, whereas BIS activity leads to higher electrodermal response and lower heart rate during negative stimuli (Balconi et al., 2009).

In sum, new measures of persuasion-related processes enable advanced applications. Physiology can expose psychological processes; among others (the interaction between) message framing and a person's motivational orientation. These latter characteristics are also known to influence persuasion effectiveness. Hence, physiology has the potential to be such a new persuasion measure.

6.1.3 Research goal

Early findings seem to suggest that to some extent peripheral physiology can reflect persuasion-related processes. However, the precise effect of an attempt at persuasion on peripheral physiology has not been established, especially when also considering effects of motivational orientation and message framing on physiology and persuasion effectiveness. In addition, most studies do not analyze the long-term persuasion effects on behavior in relation to physiology. Moreover, to date the added value of psychophysiological measurement compared to traditional predictors of persuasion is unclear. Therefore, the first question this study tries to answer is: 1) Does peripheral physiology reflect effectiveness of persuasive messages? Whilst answering this question, we will consider potential effects of motivational orientation and message framing on persuasion and physiology. In addition, we have a more generic question: 2) Does the assessment of this psychophysiological relation yield information that is not represented in other predictors of persuasion?

To answer these questions, this study intents to link persuasion-related processes and peripheral physiological activity. We build on earlier work on neural indices of persuasion-related processes by using a similar experimental set-up with persuasive content framed as either gains or losses (Vezich et al., 2017), but now measuring peripheral physiology, tracking changes in behavior, and controlling for motivational orientation. The persuasive intervention will try to improve oral healthcare routines. As such, long-term persuasion effectiveness will be measured in terms of change in behavioral compliance to the goal, that is tooth brushing behavior, over several weeks. Short-term persuasion effectiveness of the intervention is defined as a change from directly before to directly after the invention. Since it is not feasible to measure that change in terms of behavioral compliance, it will be assessed using changes in motivational state, that is attitudes and intention. Based on earlier research, we expect that physiology reflects persuasion effectiveness, for example changes in motivational state or behavioral compliance will relate to increased physiological activity. We also expect that these psychophysiological data hold extra information over other predictors of persuasion.

6.2 Methodology

6.2.1 Design

This study has a between-subjects repeated measures design in which participants received either loss- or gain-framed persuasive information promoting an optimal oral health routine. The advocated goal focused on frequency, that is twice per day, and duration, that is two minutes per session, of brushing behavior. The study was reviewed and approved by the Internal Committee on Biomedical Experiments (ICBE) at Philips Research. As the effects of message framing on physiology or persuasion effectiveness were not the main objective of the study, this study did not include a neutral-framed slideshow as control. Providing neutral-framed educational information can be persuasive in itself (Armstrong, 2010, Chapter 1). A truly 'neutral activity' would therefore be a presentation on a topic entirely different from oral healthcare. In our study, this is a nature video preceding the intervention.

6.2.2 Participants

Seventy-eight healthy people who indicated to manually brush their teeth infrequently and/or less than two minutes per session were included in this study (41 women, 37 men; M_{age} 40 years, SD_{age} = 11). At inclusion, 58 participants did not meet the brushing length target, 4 participants did not meet the brushing frequency target and another 16 participants did not meet both targets. Participants were recruited by a professional external recruitment agency with access to a database of active panelists. Panelists living nearby the study site received an email asking for their participation. The agency checked the extent to which willing participants qualified for the study via phone before inclusion. Exclusion criteria were (a history of) cardiovascular diseases, orthodontia, dentures or frequently using an electric toothbrush. Furthermore, participants had to have sufficient Dutch language skills, and be willing to provide informed consent and use a dedicated toothbrush with tracker for at least three weeks.

6.2.3 Materials

The oral care intervention had several persuasive elements. First, it took place in a professional oral healthcare laboratory at Philips Research to increase ecological validity (Figure 6-1). The room was equipped with dental-related ornaments such as a dentist chair, informational posters and hygiene accessories.

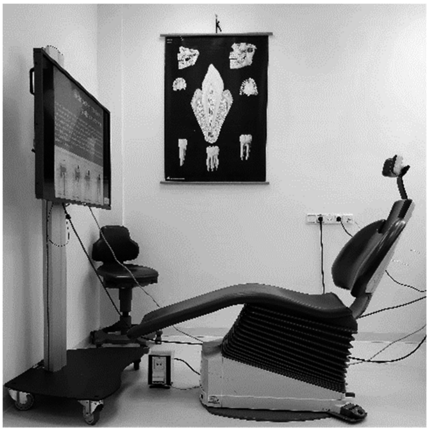
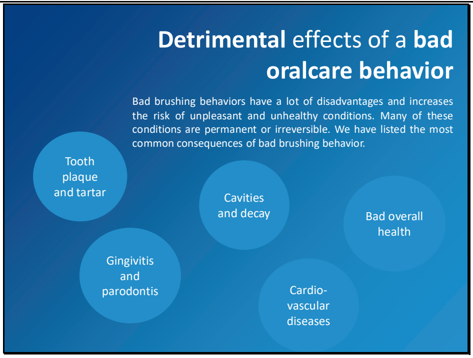


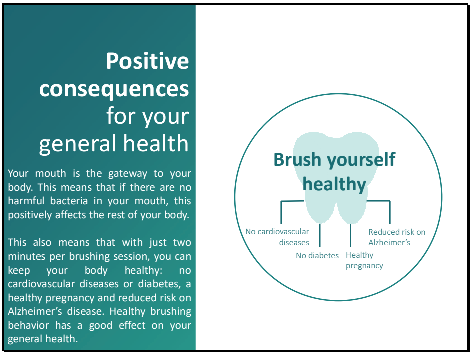
Figure 6-1 Oral healthcare laboratory at Philips Research equipped with dental-related ornaments.

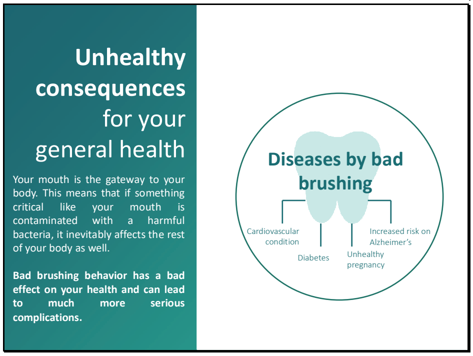
Secondly, the participants were asked to perform a plaque-disclosing test and to verbally reflect on the results of the test. The disclosing solution reveals dental areas with persistent dental plaque with a blue color, whereas newer plaque colors are pink (Volgenant et al., 2016). In front of a mirror, participants were asked if their teeth discolored as expected and how they judged these results. Confronting participants with their oral hygiene increased the relevance and value of the study. Thirdly, participants viewed an informational slideshow with motivational messages discussing why good oral care is beneficial (gain-framed) or why bad oral care is harmful (loss-framed). Both slide decks advocated to optimize oral care by brushing at least twice per day for two minutes per session. The two slideshows had exactly the same factual content, but differed in framing (Table 6-1). For example, the gain-framed manipulation started with "the positive consequences of healthy oral health behavior", whereas the loss-framed manipulation started with "the harmful consequences of unhealthy oral health behavior". As a result, both slide decks had 14 slides with a similar number of words and lasted for six minutes, or longer depending on the participants' reading speed.

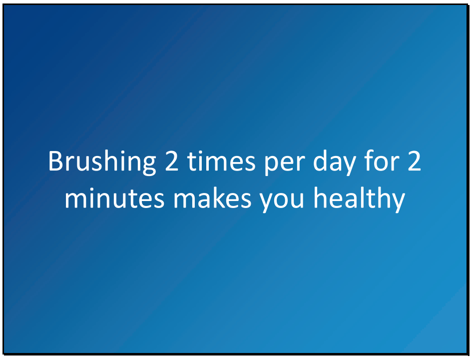
Table 6-1 Subset of the slideshow including motivational messages discussing why good oral health is beneficial (gain-framed) or why bad oral health is harmful (loss-framed). Pictures under copyright have been masked.

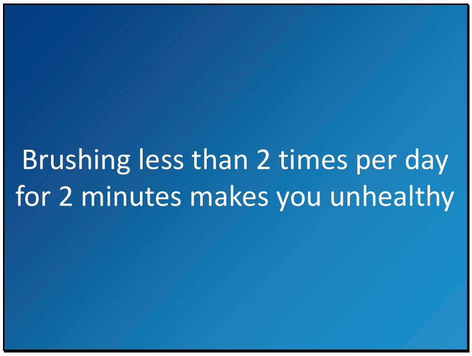
Gain-framed slides	Loss-framed slides











6.2.4 Measurements

6.2.4.1 Self-report measures

Demographic questions included age, gender, and education. Questions to assess participants' behavioral motivations were adapted from the theory of planned behavior (Ajzen, 2002): The advocated goal considered clear target, action, context and time elements, and was defined as 'optimizing oral care by brushing at least twice per day for two minutes per session in the forthcoming week'. Participants' view on this optimal oral health routine was assessed using questions about (Ajzen, 2002):

- *Instrumental attitude* towards this behavior using five items focusing on satisfaction in instrumental nature, for example useless – useful.
- *Experiential or affective attitude* towards this behavior using two items focusing on the experiential quality of the behavior, for example unpleasant-pleasant.
- *Intention* to perform this behavior using six items questioning whether the participant intended to perform the optimal health care routine, even in not optimal circumstances.

These items were presented as 7-point Likert scales ranging from 'strong disagreement' to 'strong agreement' with counterbalanced positive and negative endpoints.

In addition, participants' *motivational orientation*, that is tendencies to avoid punishment or approach reward, was measured using a validated Dutch version of the BIS/BAS scales (Franken, Muris, & Rassin, 2005). The instrument consists of one inhibitory factor (BIS scale; 7 items) and three activation factors (BAS scales; 13 items). The BAS scales can be subdivided into drive (BAS_{drive}; 4 items), reward responsiveness (BAS_{reward}; 5 items) and fun seeking (BAS_{fun}; 4 items). The items were presented as 4-point Likert scales ranging from 'strong disagreement' to 'strong agreement' (Carver & White, 1994). All questionnaires[24] in this study were presented in Dutch.

6.2.4.2 Behavior measures

An Axivity AX3 data logger attached to the lower-end of a manual toothbrush logged oral health behavior (Zhang, 2019). The Axivity AX3 contained a 3-axis accelerometer, could record for >21 days with a 50 Hz frequency and was waterproof (Axivity, 2015; Doherty et al., 2017). Sensitivity range for accelerations was set at 8g.

[24] Other measures administered were trait self-control, behavioral automaticity, and self-reported past behaviors, but these are reported elsewhere (Zhang, 2019).

6.2.4.3 Physiological measures

A 10-channel NeXus with a sampling frequency of 1029.5 Hz measured physiology during the presentation of the persuasive messages and completion of the survey. Three sticky Kendal H124SG electrodes in Lead II placement were attached with wires to the NeXus for cardiovascular measurement (ECG), two dry electrodes on the thenar eminences of the non-dominant hand for electrodermal measurement (EDA) (Andreassi, 2007, p. 265), a piezoelectric belt transducer around the higher abdomen for measuring respiration, and four reusable Ag/Cl surface electrodes with disposable adhesives attached to the skin on the corrugator supercillii (EMG-CS) and the zygomaticus major (EMG-ZM) for facial electromyography (Boxtel, 2010).

6.2.5 Procedure

The experimental procedure included two visits to the experiment site, that is the intake and the laboratory session, and lasted three weeks, that is a control week and two monitor weeks (Figure 6-2). During the *intake*, participants received general information about the experiment[25] and had the opportunity to ask questions before signing the consent forms. Participants were instructed to use a manual toothbrush with an AX3-tracker attached for at least three weeks. A survey captured demographic information, motivational state, and motivational orientation. Throughout the *control week*, participants were to perform their brushing behavior as usual to obtain a baseline measurement of brushing behavior.

Participants visited the oral health care laboratory for the *laboratory session*. Participants were instructed to refrain from caffeinated drinks in the two hours preceding the visit. The session had five segments; a pre survey, a tooth plaque-disclosing test, a baseline measurement of physiological state in rest, exposure to the slide deck with loss- or gain-framed persuasive information, and a post survey (Figure 6-2). Both *pre* and *post surveys* assessed attitude and intentions towards tooth brushing. The *plaque-disclosing test* intended to increase participants' engagement to the intervention. The participants dripped 3-4 drops of solution in their mouth and swished it around for 30 seconds before spitting it out. The participants were given a mirror to review the discoloring of their teeth. After brushing their teeth, participants were attached to physiological recording sensors and seated in a dentist chair facing a TV-screen. Physiology was measured during the baseline video,

[25] Participants were informed that the experiment was about oral health care, but not about the main goal of the intervention, that is persuasion towards an optimal oral health routine measured in physiology.

motivational messages and post survey. Physiology in rest was measured during a 6-minute relaxing bird-wildlife video with classical music (*baseline video*). Next, the presentation with the *gain- or loss-framed motivational messages* appeared on screen. A python script assigned the participant to the gain- or loss framed condition at random.

In the two consecutive *monitor weeks*, participants' brushing behaviors were again tracked continuously, while self-reported attitude and intention towards brushing was assessed weekly (*follow-up survey 1 and 2*). At the end of the three weeks, participants received a debriefing e-mail. They were thanked for their participation and reminded to send back the AX3-trackers using a prepaid envelope. Reimbursement was paid via the recruitment agency.

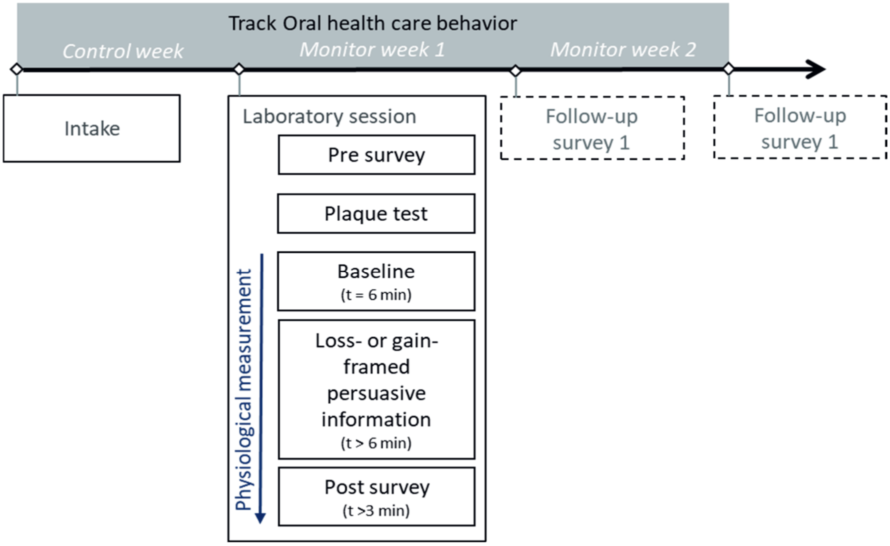


Figure 6-2 Experimental procedure lasting three weeks with tracking of tooth brushing behavior, weekly surveys assessing motivational state and a persuasive intervention after one week.

6.2.6 Analysis

6.2.6.1 Preprocessing of the self-report and behavioral data

All questionnaires in this study were validated in previous research and analyzed as instructed (Ajzen, 2002; Franken et al., 2005). Outliers in the distribution of the parameters were detected using Mahalanobis distances (Revelle, 2017) and removed if necessary. Cronbach's α for all self-report measures was checked. Short-term persuasion, that is the change in intention and attitude caused by the persuasive messages, was calculated by subtracting the scores before the persuasive messages from the scores after.

Pre-processing methods of the raw 3-axis accelerometer data to behavior data are described elsewhere (Zhang, 2019). Brushing compliance rate was calculated at week and day-level by dividing total duration of brushing per day by the advocated duration per day, that is day duration in seconds / 240 seconds. Long-term persuasion was calculated by subtracting the average compliance rate in week one from the average compliance rate in week three.

6.2.6.2 Preprocessing of the physiological data

First, the signal quality was enhanced by eliminating artifacts or outliers; a 50 Hz notch filter was applied to all signals. After a manual check of the R-peaks in the ECG signal using EDFBrowser (van Beelen, 2017), the inter-beat intervals (IBIs) were derived. IBIs outside 0.2-2s were checked and interpolated if the values seemed an artifact (Cacioppo et al., 2007). Both EMG signals were band pass filtered within a 20-500 Hz frequency range, followed by a third order 20 Hz high-pass Butterworth filter and signal rectification (Boxtel, 2010). The EDA signal was converted from a resistance to a conductance signal and down sampled to 5 Hz. A 0.5 low-pass Butterworth filter was applied to the log-transformed conductance as well as to the respiratory signal (Boucsein, 2012; Cacioppo et al., 2007).

Parameter extraction was performed for three experiment segments – baseline, persuasive messages, and post survey – that differed in length depending on the participant. The physiological parameters of interest were calculated using the first 6 minutes of the baseline and persuasive messages, and the first 3 minutes of the post-survey. The extracted physiological parameters were mean heart rate (HR), standard-deviation from normal-to-normal peaks (SDNN) and root mean square of successive differences (RMSSD) from filtered IBI data (Camm et al., 1996), mean EMG-CS, mean EMG-ZM (Boxtel, 2010), mean skin conductance level (SCL), mean number of skin conductance responses (SCRs) (Boucsein, 2012), and mean respiration rate (RR). For SCRs and RR extraction, peaks were determined by a change of the first derivative of the physiological signal from a positive to negative sign. Outliers in the distribution of the parameters were detected using the Mahalanobis distances (Revelle, 2017). The difference in physiology between rest-state (baseline) and exposure to the persuasive information served as measure of reactivity.

6.2.6.3 Statistical analyses

The effect of the intervention on attitude, intention and behavior compliance was checked using multiple paired-sample left-tailed t-tests ($H_{pre} < H_{post}$). Short-term persuasion was investigated by comparing instrumental and affective attitudes as well as intention measured before and after the persuasive messages in the laboratory test. Long-term change was assessed by comparing the average behavior compliance in the first week with the compliance in the last week (week 1 vs. week 3). For each physiological reactivity parameter, a t-test ($H_{\text{reactivity to messages}} > 0$) showed if participants had more activity during either condition compared to baseline.

As main analysis, the best predictors of short- and long-term persuasion were established by evaluating several candidate models. We considered the change in behavioral compliance as the best measure of long-term persuasion. We investigated short-term persuasion by assessing the change in attitudes and intention from directly before to directly after the intervention.

We defined three clusters of variables (see Table 6-2) that could possibly predict persuasion: 1) Physiological reactivity during presentation of the persuasive messages (HR, SDNN, SCL, SCRs, EMG-CS, EMG-ZM, and RR), 2) Personal characteristics including demographic information (age, gender, and education), motivational orientation (the BIS/BAS scores), and (interactions with) condition (gain- or loss-framing), and 3) motivational states (initial intention, initial affective and instrumental attitude). To rule out multi-collinearity, we required that the predictors used had appropriate variance inflation factors (VIFs < 2.5, Table 6-2), which led to the exclusion of RMSSD. For each cluster, the predictor model with the best fit was found by starting with a simple model and comparing it to increasingly more complex fits using AIC weights (Wagenmakers & Farrell, 2004). For each possible combination of clusters, for example physiological reactivity and states, this iterative model building process was also carried out. In combination models, all variables were considered, also the ones that did not appear to be significant in a single cluster model. Only significant models will be presented and only including those variables that improved predictive power of the model by explaining extra variance in the outcome measure based on AIC weights (Wagenmakers & Farrell, 2004).

For each variable modelled, the best fit models were compared between clusters and cluster combinations looking for the largest AIC weights and lowest AIC (Wagenmakers & Farrell, 2004). This evaluation reveals not only the best fit, but also which cluster of variables predicts persuasion best and what the added value of each cluster in the prediction of persuasion is. Analyses were carried out in R Studio using *Psych* (Revelle, 2017), *Tidyverse* (Wickham, 2017), and *lme4* (Bates et al., 2015).

Table 6-2 Variance inflation factors of predictors used for model evaluation.

Cluster	Predictor	VIFs
	Manipulation	1.152860
Physiological Reactivity	HR reactivity	1.178875
	RMSSD reactivity	-
	SDNN reactivity	1.159390
	SCL reactivity	1.183549
	SCRs reactivity	1.087384
	EMG-CS reactivity	1.235895
	EMG-ZM reactivity	1.220094
	RR reactivity	1.344768
Characteristics	Age	1.555652
	Gender	1.787639
	Education	1.497082
	BIS	1.932864
	BAS_{drive}	1.998201
	$BAS_{reward\ responsiveness}$	2.049879
	$BAS_{fun\ seeking}$	1.346770
States	Initial affective attitude	2.352852
	Initial instrumental attitude	1.522093
	Initial intention	1.522093

Note. Values presented were calculated after excluding RMSSD. RMSSD was removed from analysis as it had a VIF of 4.046758.

6.3 Results

6.3.1 Descriptive results

The final dataset included self-report, behavioral and physiological data for 36 participants in the gain-framed condition and 39 participants in the loss-framed condition. The data of three participants had to be excluded due to incompleteness. There were no significant differences between the two groups with respect to demographics (i.e. age, gender, and education), motivational orientation (i.e. BIS, BAS) or starting attitudes and intentions (Table 6-3). Both groups started the procedure with relatively positive attitudes towards and strong intentions to perform an optimal oral health care routine. The participants scored relatively high on all subscales of the motivational orientation measures. Attitudes, intention, BIS and the BAS subscales could not achieve normal distribution using simple data transformations, for example Log, Tukey's ladder of Power, Square or Cube root. BAS_{fun} was excluded from the analyses due to insufficient reliability (α = 0.42). Other self-report scales had sufficient reliability (α > 0.7).

Table 6-3 Descriptive statistics of the subjective measures at intake

Persuasive messages	Gain condition	Loss condition		
N	36	39		
Gender (males)	17 (47.2%)	18 (46.2%)		
	Mean (SD)	*Mean (SD)*	*p-value*	*α*
Age	39.78 (11.01)	39.50 (11.04)	0.904	-
Instrumental attitude	5.80 (0.87)	5.93 (0.81)	0.526	0.93
Affective attitude	4.59 (1.10)	4.41 (1.20)	0.493	0.72
Intention	4.75 (1.14)	4.38 (1.17)	0.158	0.86
BIS	2.84 (0.59)	2.88 (0.54)	0.609	0.79
BAS_{drive}	2.73 (0.65)	2.89 (0.59)	0.348	0.80
BAS_{fun}	2.69 (0.48)	2.78 (0.50)	0.452	0.42
BAS_{reward}	3.47 (0.38)	3.49 (0.35)	0.634	0.71

6.3.2 Overview of the dependent variables

Multiple Wilcoxon signed-rank one-sample t-tests revealed that physiological reactivity during the persuasive messages was significantly different from zero (baseline) for HR (Z = 1932, p = 0.004), EMG-CS (Z = 2805, p < 0.001), SCRs (Z = 2234, p < 0.001), and RR (Z = 2458, p < 0.001). There was no difference between conditions (Figure 6-4).

For short-term persuasion, multiple paired sample left-tailed Wilcoxon signed-rank tests showed a significant increase in intention (Z = 124, p < 0.001), instrumental (Z = 97, p < 0.001), and affective attitude (Z = 184, p < 0.001) from before to after the persuasive intervention (Figure 6-3). This increase persisted over time for instrumental attitude (Z = 371.5, p < 0.001), and intention (Z = 1001, p = 0.040). For long-term persuasion, behavior compliance rate did not significantly change during the course of this experiment (Figure 6-3).

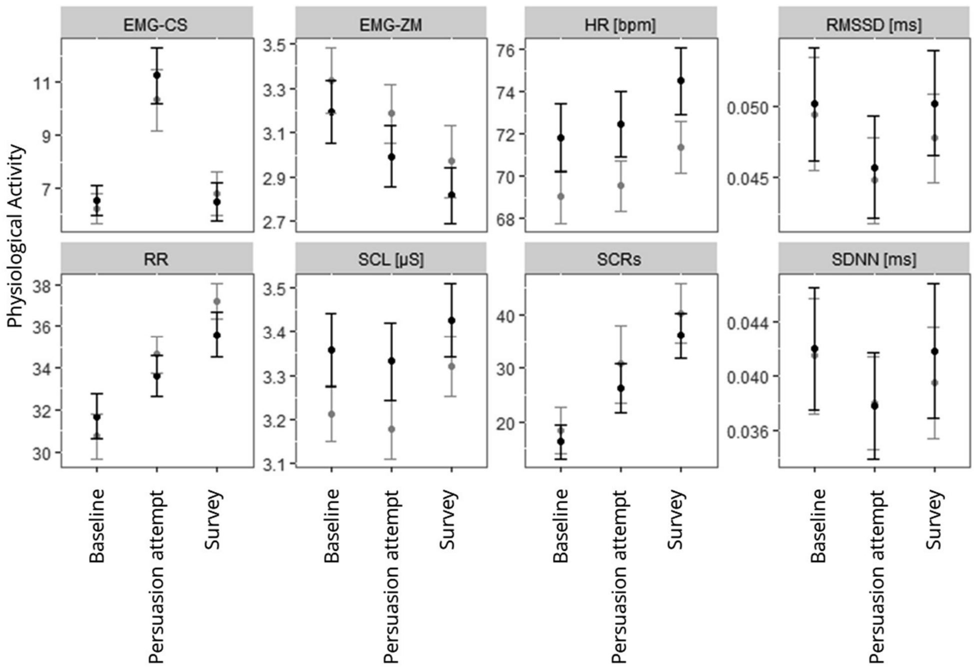


Figure 6-4 Average physiological arousal during experiment segments in the gain-framed (grey) and loss-framed (black) condition with error bars representing standard errors of the mean. Baseline and persuasive messages lasted six minutes, whereas the survey lasted three minutes. Activity to persuasive messages was significantly different from baseline for HR, EMG-CS, SCRs and RR.

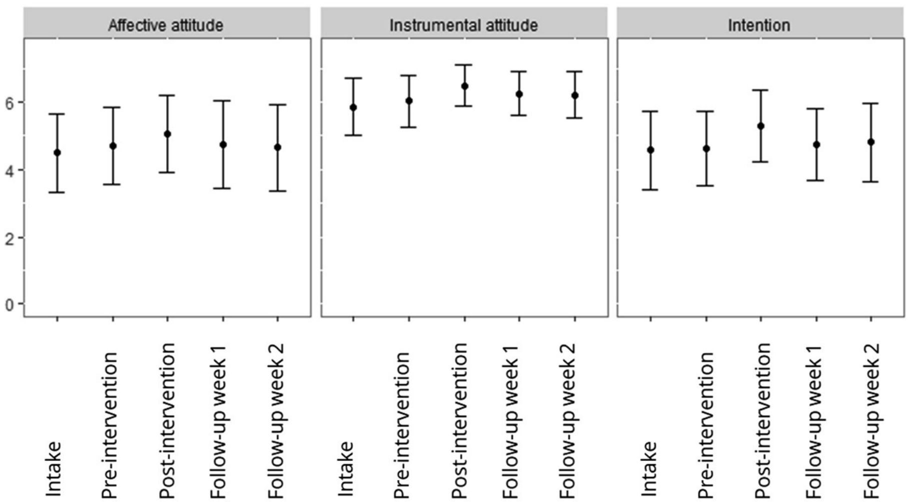


Figure 6-3 Average self-reported motivational state and measured behavioral compliance over the course of the study with error bars representing standard errors of the mean.

6.3.3 Model evaluation

First discussed are the short-term effects on motivational state (sections 6.3.3.1 - 6.3.3.3), then the long-term impact on behavior (section 6.3.3.4).

6.3.3.1 Instrumental attitude

Personal characteristics did not predict persuasion effects on instrumental attitude, and neither did the condition (manipulation). There were four potential models to predict the short-term change in instrumental attitude; a null model, a physiological reactivity model, a motivational state model and a full model, which was essentially a combination of the reactivity and state model (Table 6-4). All models had a significant positive intercept, indicating an increase in instrumental attitude. The predictors in the full model provided the best fit, followed by the state and reactivity models, respectively. The reactivity model revealed that an increase in instrumental attitude relates to increased EMG-CS reactivity and lowered HR-reactivity during persuasive messages. The state model revealed that stronger initial intention leads to less change in instrumental attitude. The full model had an adjusted R^2 of 0.154 and contained EMG-CS reactivity and initial intention as predictors. More EMG-CS reactivity during the persuasive messages predicted an increase in instrumental attitude change. Participants with a stronger initial intention demonstrated a smaller change in instrumental attitude.

Table 6-4 Results of four linear models predicting short-term change in instrumental attitude due to persuasive messages.

	Null model		Reactivity model		State model		Full model *	
Predictors	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
(Intercept)	0.46	**<0.001**	0.35	**<0.001**	1.34	**<0.001**	1.17	**<0.001**
HR reactivity			-0.07	0.051				
EMG-CS reactivity			0.04	**0.017**			0.03	**0.025**
Initial intention					-0.19	**0.003**	-0.18	**0.003**
Obs.	75		75		75		75	
R^2 / adj. R^2	0.000 / 0.000		0.115 / 0.091		0.118 / 0.106		0.177 / 0.154	
AIC	140.585		135.385		133.195		129.949	
AIC weights	0.005		0.051		0.171		0.773	

Note. *Est.* = Estimated change in outcome variable, *p* = p-value (presented in bold if significant), R^2 = r-squared statistics, *AIC* = Akaike Information Criterion, * = indicating best fit

6.3.3.2 Affective attitude

None of the predictor clusters significantly explained the short-term change in affective attitude caused by the experiment (Table 6-5). The null model reveals an increase in affective attitude due to the persuasive messages. The full model with an adjusted R^2 of 0.055 had the best fit and reveals an effect of manipulation; loss-framed messages lead to a 0.38 smaller change in affective attitude than gain-framed messages.

Table 6-5 Results of two linear models predicting short-term change in affective attitude due to persuasive messages.

	Null model		Full model*	
Predictors	*Est.*	*p*	*Est.*	*p*
(Intercept)	0.39	**<0.001**	0.58	**<0.001**
Loss condition			-0.38	**0.025**
Observations	75		75	
R^2 / adjusted R^2	0.000 / 0.000		0.067 / 0.055	
AIC	169.294		166.069	
AIC weights	0.180		0.820	

Note. *Est*. = Estimated change in outcome variable, *p* = p-value (presented in bold if significant), R^2 = r-squared statistics, *AIC* = Akaike Information Criterion, * = indicating best fit

6.3.3.3 Intention

There were no state variables that proved to explain (extra) variance in short-term intention change. Four models were qualified to predict the short-term change in intention; a null model, a physiological reactivity model, a personal characteristics model and a full model (Table 6-6). In all models, the intercept revealed an increase in intention caused by the persuasive messages. Adding HR-reactivity improved model fit; participants had a 0.10 smaller change in intention for each bpm rise in HR. The characteristics model revealed a main effect of manipulation, for example loss-framed persuasive messages lead to 0.40 more change in intention, and an interaction between the manipulation and BAS_{drive}. The full model with an adjusted R^2 of 0.152 had the best fit and combines the physiological reactivity and the characteristics model.

Table 6-6 Results of four linear models predicting short-term change in intention due to persuasive messages.

	Null model		Reactivity model		Characteristics model		Full model *	
Predictors	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
(Intercept)	0.69	**<0.001**	0.75	**<0.001**	0.51	**<0.001**	0.56	**<0.001**
HR reactivity			-0.10	**0.030**			-0.10	**0.024**
Loss condition					0.40	**0.021**	0.41	**0.015**
BAS_{drive} (centered)					0.28	0.142	0.27	0.149
Interaction loss condition and BAS_{drive}					-0.65	**0.019**	-0.62	**0.021**
Observations	75		75		75		75	
R^2 / adjusted R^2	0.000 / 0.000		0.063 / 0.050		0.137 / 0.101		0.198 / 0.152	
AIC	173.951		171.108		168.871		165.391	
AIC weights	0.018		0.068		0.159		0.755	

Note. *Est*. = Estimated change in outcome variable, *p* = p-value (presented in bold if significant), R^2 = r-squared statistics, *AIC* = Akaike Information Criterion, * = indicating best fit

6.3.3.4 Behavioral compliance

Five models qualified to predict long-term change in behavioral compliance, that is week 3 minus week 1. From least until best fit, these models were; a null model, a personal characteristics model, a physiological reactivity model, a physiological reactivity plus personal characteristics model, and a full model (Table 6-7). The significantly negative intercepts revealed that on average behavioral compliance decreased over time. Reactivity parameters revealed an increase in compliance of 0.52 for each unit rise in SCL, while each unit rise in EMG-ZM reactivity decreased compliance by 0.10. According to the characteristics model, more active BAS_{reward} increased compliance (*Est.* = 0.12, *p* = 0.083). The full model had the best fit with an adjusted R^2 of 0.231 and combines physiological reactivity and demographic variables; there was a positive relation of compliance with SCL or education and a negative link with EMG-ZM and HR. The full model is the best of these models based on AIC weights (0.474).

Table 6-7 Results of five linear models predicting change in behavioral compliance due to persuasive messages.

	Null model		Reactivity model		Characteristic model		Reactivity & Characteristic model		Full model *	
Predictors	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
(Intercept)	-0.07	**0.005**	-0.06	**0.017**	-0.22	**0.024**	-0.06	**0.014**	-0.24	**0.006**
SCL reactivity			0.52	**0.006**			0.56	**0.003**	0.61	**0.001**
EMG-ZM reactivity			-0.10	**0.003**			-0.10	**0.003**	-0.10	**0.003**
HR reactivity			-0.02	0.100			-0.02	0.082	-0.02	0.069
BAS_{reward} (centered)					0.15	**0.036**	0.13	**0.038**		
Age					0.00	0.119				
Education									0.05	**0.031**
Obs.	68		68		68		68		68	
R^2 / adj. R^2	0.000 / 0.000		0.221 / 0.184		0.080 / 0.052		0.273 / 0.227		0.277 / 0.231	
AIC	-22.013		-32.988		-23.686		-35.678		-36.040	
AIC weights	<0.001		0.127		0.001		0.396		0.474	

Note. Est. = Estimated change in outcome variable, *p* = p-value (presented in bold if significant), *Obs.* = observations, R^2 = r-squared statistics, *AIC* = Akaike Information Criterion, * = indicating best fit, BAS_{reward} = BAS reward responsiveness

6.4 Discussion

Assessing persuasion-related processes with physiology might entail important insights of the psychology behind persuasion and, thereby, help to optimize persuasive interventions. Physiology might enable new methods to personalize PT as current wearables can measure physiology all day, every day, with little effort. As such, people who intend to behave more healthily or sustainably can be helped to act on their intention. We investigated whether physiology reflects persuasion effectiveness, while considering potential (interaction) effects of motivational orientation and message framing. We also analyzed the added value of this assessment over traditional predictors of persuasion.

Physiology was measured while people read gain- or loss-framed persuasive messages advocating healthy oral care behaviors. Over the course of three weeks changes in attitudes and intentions towards tooth brushing, as well as actual brushing behavior were monitored. We indeed found more physiological activity when processing persuasive messages compared to rest state. On average, the persuasive messages did change people's motivational state, but not their behavior. Part of the variability in the change in motivational state and behavior caused by the persuasive messages could be explained by physiological reactivity to them. Particularly for behavior change, physiological reactivity was more insightful than self-report data. Thus, in this study physiological measures complemented traditional persuasion predictors like personality characteristics, demographics and subjective states.

6.4.1 Variance in persuasion is partially explained by physiological reactivity

Our first research question concerned whether peripheral physiology reflects effectiveness of persuasive messages. Our findings indeed indicate a different physiological pattern during processing the persuasive messages compared to rest state; as indicated by an average increased heart rate (HR), respiration rate (RR), frowning muscle activity (EMG-CS) and more skin conductance peaks per minute (SCRs) (Figure 6-4). This change in physiology likely results from exposure to the persuasive messages; frowning can indicate the presence of negative cognitions or emotions, for example frustration or guilt, or relate to increased concentration. Elicitation of SCRs is associated with orienting responses and brain areas evaluating the significance of stimuli or affective associations (Cacioppo et al., 2007, p. 161). This could mean that the participants elaborated more on the persuasive information than during the baseline video, which fosters persuasion.

Results indeed indicate that our manipulation was successful; the messages helped to persuade people to change their thoughts about brushing their teeth two times per day for two minutes on the short-term. Even though participants had strong attitudes and intentions to perform healthy oral care behaviors already at the beginning of the experiment, these feelings increased by both gain- and loss-framed persuasive messages. The increase in instrumental attitudes and intentions lasted as long as three weeks. However, overall oral health care behaviors did not increase over time. Presumably, the intervention was not persuasive enough to have long-lasting effects on behavior. Surprisingly, the messages were not more persuasive in personalized settings, for example loss-framing for people with higher BIS activation, possibly because the motivational states were already high to start with, which reduces the range for improvements and with it the possibility to find differences according to message congruency.

We investigated how much of the persuasive messages' effectiveness can be predicted by physiological reactivity to them. The results in section 6.3.3 indicate that various physiological reactivity parameters explained variance (from 5 to 18.4%) in instrumental attitude, intention and behavioral compliance, but not in affective attitude. The following part describes the results in more detail per outcome measure. Since message framing (Seery et al., 2009), motivational orientation (Brenner et al., 2005), or an interaction between the two (Balconi et al., 2009) can affect persuasion as well as physiology, results from these parameters are also discussed.

For instrumental attitude, frowning and heart rate (HR) reactivity explained 9.1% variance. Participants were more persuaded if they frowned. As frowning can indicate increased concentration and active processing, the participant might be assessing the relevance and value of the message. More HR reactivity in exposure to persuasive messages related to less persuasion, both for intention and instrumental attitude change. As HR accelerations are associated with emotions that are high in arousal and negativity, such as fear, anger or sadness (Cacioppo et al., 2000; Kreibig, 2010), this finding might indicate the presence of psychological reactance (Brehm, 1966; Sittenthaler et al., 2015).

Since autonomic nervous system activity is closely related to affect (Kreibig, 2010), we anticipated to find this link in our study. While affective attitude did change over time, its change was not related to physiological reactivity according to our results. A reason for this unexpected finding could be that our measurement of affective attitude was lacking construct validity; only two items addressed this variable instead of five for instrumental attitude. Yet, the measurement had sufficient reliability ($\alpha > 0.7$). The loss-framed messages appeared to be more effective in influencing affective attitude.

For intention, HR reactivity explained 5.0% variance in the physiological reactivity model; acceleration of HR related to less persuasion, and, as discussed above, to the potential presence of psychological reactance. The loss-framed messages were more effective in general, except for BAS_{drive} sensitive people. Contra-tailoring can indeed decrease the persuasiveness of a message (Kaptein et al., 2012). Compared with information from physiological reactivity, message framing and motivational orientation contributed more to the prediction of persuasion effectiveness.

The psychophysiological relationship with persuasion was most convincing when considering long-term effects on behavioral compliance; although on average compliance rate decreased over time, reactivity in SCL, HR and EMG-ZM explained 18.4% of its variance. This is in line with earlier results (Falk et al., 2010; Vezich et al., 2017), where neural activity predicted behavior change even when controlling for not correlated attitudes and intentions. Assumingly this neural activation was related to elaborating on the information and integrating it in one's self-image (Falk et al., 2010).

This psychophysiological relation could also hint at the involvement of affect in persuasion. SCL was the strongest predictor of behavioral compliance; each unit rise in SCL while reading the persuasive information resulted in an increase in compliance rate by 0.52 on a 0-1 scale. Skin conductance level is known to reflect affective responses (Betella et al., 2014; Cacioppo et al., 2000; Kreibig, 2010) over attentional efforts (Lang et al., 1990). Additionally, people became less compliant when they exhibited increased HR and EMG-ZM activity during the messages. The zygomaticus major is the main smiling muscle (Boxtel, 2010). The messages might have made these participants feel skeptical or cynical - which reflects in laughing or grinning – and consequently did not change their behavior. Again, a possible explanation for lower compliance with higher HR could be feelings of reactance (Sittenthaler et al., 2015). Potentially, participants that did change their behaviors were emotionally affected by the persuasive stimuli. While reading the messages, participants might have experienced emotions that influenced physiological activity, for example guilt, frustration (Kreibig, 2010), or more complex ones such as cognitive dissonance (Colosio, Shestakova, Nikulin, Blagovechtchenski, & Klucharev, 2017; Van Veen, Krug, Schooler, & Carter, 2009).

6.4.2 Persuasion is best predicted by a combination of measures

In our second research question, we examined the added value of physiological reactivity over traditional self-report predictors of persuasion. In this study, we used demographic information, initial motivational state based on the Theory of Planned Behavior (Ajzen, 1991), and motivational orientation (Carver & White, 1994) to explain the persuasiveness of our messages. Currently, self-report measures are the golden standard for prediction persuasion effectiveness. Indeed these measures predicted intention and attitude change better than only physiological measures (as indicated by the adjusted R squared in Table 6-4 and Table 6-6). However, results in section 6.3.3 reveal that physiological measures complement traditional predictors of persuasion for all outcome measures except affective attitude. Especially for behavior change, physiological reactivity was more insightful than self-report data. This means that considering physiology yields information that would otherwise be missed.

The added value of physiological assessment was most obvious considering behavioral compliance. For change in behavioral compliance, the addition of physiological reactivity, that is SCL, HR and EMG-ZM, explained 17.9% extra variance over self-report measures, that is 23.1% versus 5.2%. In addition to physiological reactivity, personal characteristics, that is motivational orientation and demographics, explained variance in brushing behavior; more active BAS_{reward}, higher age or education related to more behavior change. The results indicate that behavioral compliance is best understood using multiple predictors; physiological reactivity, motivational orientation, and characteristics.

Importantly, while physiology correlates with changed behavioral compliance, attitudes and intentions did not (Table 6-7). This is not in line with behavior models viewing attitudes and intentions as determinants of behavior (Ajzen, 1991; Armitage & Conner, 2001). A reason could be that, independent of the (change in) valence of the attitudes, their strengths were not enough to (persistently) affect behavior, as attitude strength refers to the extent that attitudes are durable and depend on, amongst others, importance, accessibility and certainty (Briñol et al., 2019).

Although our participants felt more positive about healthy oral care, they might not have valued this attitude as important.

6.4.3 Limitations

This study is not without limitations. Firstly, we would like to emphasize that this study was not designed to investigate the effects of message framing per se. Because of the lack of a neutral-framed control condition, we therefore cannot be sure that the persuasive effects of our gain-framed and loss-framed slide shows were due to the framing, rather than to the educational material itself, especially since it is known that also neutral-framed educational material can be persuasive (Armstrong, 2010, Chapter 1). And indeed, we found little evidence for differences between gain- and loss-framing, or that gain-framed messages were more persuasive for more BAS activated participants. The results of a neutral-framed control condition might have given more context to the absence of significant differences in this respect. Nevertheless, the current design does permit to draw conclusions at a higher level that is regarding the link between physiology and persuasion-induced change in motivational state and behavior.

Secondly, we could not control the results for the effects of the tooth plaque test (section 6.2.3). Upfront, we did not expect the plaque test to be a considerable persuasive element. Therefore, we did not record nor rate the participant's reactions to the test. In retrospect, pointing out oral hygiene to people could have had an impact on their subsequent responses in this study. Even though these tests are a regular part of dentist procedures, the amount of plaque, and its exposure to the experimenter, indeed appeared to be uncomfortable for some participants. It is quite possible that for these high responders the slideshow was more persuasive. Whether reactions during such reflective moments are indicative for (individual differences in) the persuasiveness of an intervention, is an interesting topic for future research.

Thirdly, relating short-term persuasion interventions to longer-term behavior change will require further work. It is more than likely that any lasting behavior change will require repeated interventions over a longer period of time in order to affect habitual behaviors alongside reported attitude changes (Zhang, 2019). However, the long-term results still hold merit, as the participants who did change their behavior had particular physiological responses (section 6.3.3.4). The psychophysiology of behavior change could be an interesting avenue for future research.

Lastly, our sample consisted of volunteer participants, which may limit generalizability in that they may have been interested in the topic or sensitized to behavior change in relation to their oral hygiene prior to the experiment. This may be difficult to avoid, but points to the necessity of sampling strategies that help draw a representative sample from a larger, perhaps more diverse population through, for example, oversampling underrepresented groups.

6.4.4 Implications of the findings and further research

In this study, physiological responses to persuasive messages yielded additional insights in the underlying processes of persuasion. The most powerful predictor of behavior appeared to be skin conductance level, which mainly reflects affective responses. This seems to indicate that in this study the processing of persuasive information was not purely a cognitive process. It is also important to note that physiology appeared to be effective especially when attitudes and intentions failed to predict behavior. This shows that studying physiology adds value to persuasion research.

The considerable amount of extra variance that was explained by physiological reactivity over self-report measures encourages further research on this topic. Although we only considered averaged physiological reactivity in a one-time intervention, we still found that physiological reactivity explained between 5.1-17.9% extra variance in persuasion in addition to that explained by self-report measures. To put this in perspective; a meta-analyses of 185 independent studies on the Theory of Planned Behavior (TPB) revealed that multiple self-report measures of motivational state explain respectively 39% and 31% of the variance in intention and observed behavior (Armitage & Conner, 2001), and these explained variances in the TPB-model result from years of research. The prediction rate of physiology might be even more promising in longitudinal field studies where, in addition to summative self-report measures, physiological activity is measured continuously and analyzed in relation to the target behavior.

The consistency between findings of various psychophysiological persuasion studies highlights the potential of this research domain. Our study design was based on earlier research from Vezich et al. (2017). Both studies analyzed framing-effects of persuasive messages concerning preventive health behavior on physiology, but we studied a different target behavior, that is oral health care instead of sunscreen use, measured other physiological features, considered other covariates and used different methods of analysis. Despite these differences, we did find similar results, that is physiological reactivity predicts behavioral compliance.

Psychophysiological insights can have implications for future design of Persuasive Technology. If persuasion has clear and identifiable psychophysiological underpinnings, this information can be used to optimize behavior change interventions by personalization of the PT. The added benefit of physiology for persuasive design is the high temporal resolution and sensitivity to change as well the ability to process reactions in real-time. Physiological measurements yield large amounts of data that might bring new insights through for example data mining or machine learning. Potentially, PT could learn to interpret the user's physiological responses overtime and tailor their persuasive content as part of a biocybernetic loop (Fairclough, 2009). However, more research is needed before it is clear if such a system can be realized.

6.5 Conclusion

This study investigated if peripheral physiology can reflect persuasion effectiveness, and what the advantage of this psychophysiological assessment is over traditional predictors of persuasion. Results suggested that peripheral physiology indeed reflects 5 to 18.4% of persuasion effectiveness. Additionally, the analysis of physiological responses generated insights that would have been missed in traditional self-report measures, especially in the prediction of long-term behavioral compliance.

The current research is a step towards understanding the psychophysiological relationship in persuasion. This psychophysiological approach improved our understanding of the underlying psychological processes of persuasion. The important role of physiological features as skin conductance and facial muscle activity hint at the involvement of affect in persuasion. However, further research is needed. Potentially, insight from physiology can be used to advance PT by physiology-contingent personalization.

Chapter 7

General discussion

This thesis studied how physiology reflects persuasion-related processes and whether this knowledge can be used for physiology-contingent personalization of Persuasive Technology. Based on literature on PT, (personalized) persuasion and psychophysiology, Chapter 3 presented a model describing how PT could adjust to the user's physiology. Four empirical chapters gained psychophysiological persuasion knowledge by 1) analyzing physiological reactions to attempts at persuasion, 2) relating those patterns to persuasion-related processes as well as persuasion effectiveness, and by controlling the psychophysiological responses for differences 3) in a person's motivational state or trait, and 4) in the persuasive strategy employed. This final chapter[26] will discuss our findings, also in relation to the possibility that PT systems adapt to physiological reactivity, as presented in Chapter 2, as well as potential implications for persuasion research, persuasive systems design and ethics.

[26] Part of this chapter has been submitted for publication to the journal User Modeling and User-Adapted Interaction as Spelt, H.A.A., Westerink, J.H.D.M., Frank, L.E., Ham, J., & IJsselsteijn, W.A., Physiology-based personalization of Persuasive Technology: A user modeling perspective. *User Modeling and User-Adapted Interaction.*

7.1 Overview of the findings

In this section, we present how we investigated the research questions in four empirical studies (Table 7-1) and their findings. First, all studies analyzed physiological reactions to attempts at persuasion. Second, in Chapters 3 and 6 these physiological patterns were related to persuasion effectiveness: Does physiological reactivity relate to changes in motivations or behaviors? In Chapter 4, we checked just the opposite: Does physiological reactivity relate to psychological reactance to the attempt? Third, in all chapters we controlled our findings for individual differences: for initial motivational state (Ajzen, 1991; Zur & Klöckner, 2014) in Chapters 3-6, for susceptibility to persuasion (Kaptein et al., 2012) and Big Five personality traits (Gosling et al., 2003) in Chapter 5 and for behavioral inhibition or approach orientation (Carver & White, 1994) in Chapter 6. Fourth and last, each chapter assessed psychophysiology during persuasion attempts deploying different persuasive strategies. In Chapter 3 several persuasive strategies were used in one video (see Table 3-2). Chapter 4 compared the effects of high-controlling persuasive messages to the effects of low-controlling persuasive messages. In Chapter 5 participants viewed messages deploying specific persuasion principles, that is authority, scarcity, consensus and commitment. And in Chapter 6, participants were presented with either gain- or loss-framed persuasive messages. Before we combine all findings into overall results, we will first summarize the outcomes per chapter.

Table 7-1 Overview of the study characteristics in the empirical chapters.

Chapter	3	4	5	6
Study objective	Persuasion	Psychological reactance	Persuasion	Persuasion
Persuasion objective	Decrease meat consumption	Decrease meat consumption	Increase teeth brushing	Increase teeth brushing
State characteristics	Motivational state (Zur & Klöckner, 2014)	Motivational state (Ajzen, 1991) Psychological reactance (Dillard & Shen, 2005)	Motivational state (Ajzen, 1991)	Motivational state (Ajzen, 1991)
Trait characteristics			Susceptibility to persuasion (Kaptein et al., 2012) Big five personality (Gosling et al., 2003)	Behavioral approach or avoidance orientation (Carver & White, 1994)
Persuasive strategies	Several strategies (see Table 3-2)	High or low controlling language (Miller et al., 2007)	Authority, scarcity, consensus and commitment (Cialdini, 2007)	Gain- or loss-framing (O'Keefe, 2013)

In Chapter 3, we investigated if physiology indeed reflects persuasion-related processes. The results indicated that a persuasive video effectively changed people's motivations to perform the advocated behavior, that is increased moral beliefs, perceived behavioral control and reduction intention, and affected physiology, that is SDNN and SCRs reactivity. All physiology levels changed during completion of the survey, and we discussed how the increases in HR and SCL reactivity could possibly reflect people integrating the new information into their self-image, that is self-related processing. Results provided no evidence for a positive relationship between persuasion-induced motivation change and physiological reactivity. However, people with initial motivations less aligned with the advocated messages had higher physiological activity during the attempt at persuasion than people with more aligned motivations.

Chapter 4 tested whether psychological reactance of people with motivations less aligned to the persuasion objective related to increased physiological activity. The persuasive messages again affected physiology, that is increased HR, decreased SDNN and RMSSD. Participants did indeed experience reactance, and results provided no evidence that the persuasive messages changed people's motivations. Psychological reactance was best explained by considering both intentions and cardiovascular activity (Table 4-5): People with higher initial intentions to perform the advocated behavior reported lower psychological reactance to the persuasive messages.

The effects of personality traits on psychophysiological reactions to an attempt at persuasion with specific persuasion principles were first considered in Chapter 5. Physiology was affected by persuasive messages, but not differently by the specific persuasion principles they deployed. People with higher overall susceptibility to persuasion had lower SCL and SCRs values in exposure to persuasive messages. Additionally, extravert people smiled more when reading the messages. Thus, there was no conclusive support for distinct psychophysiological patterns associated with different persuasion principles, although overall susceptibility seemed to be reflected in physiology to some extent.

Chapter 6 investigated whether physiological reactivity to persuasive messages predicted their effectiveness, while considering people's behavioral inhibition or approach orientation. The study also investigated if physiological assessment reveals information that is not represented by traditional self-report predictors of persuasion. On average, the persuasive messages indeed increased people's motivational state, that is attitudes and intention, but not their behavior. Individual persuasion effectiveness was best predicted by a combination of self-report and physiological reactivity parameters. Thus, the findings suggested a positive relationship between physiological reactivity to persuasive messages and subsequent changes in attitude, intention and behavior, and physiological reactivity parameters yielded additional insights that were not presented by self-report measures.

These results boil down to four main findings on physiology during persuasion: 1) physiology changes in exposure to an attempt at persuasion, 2) persuasion strategies per se do not appear to impact physiology differently, 3) initial states and traits do seem to impact physiology, and 4) physiology can help in predicting persuasion outcomes. These conclusions will be elaborated and discussed in relation to both research questions in sections 7.2 and 7.4, as well as in relation to their impact on persuasion research (section 7.3) and the ethical consequences of such systems (section 7.5).

7.2 Physiological reactions to attempts at persuasion

This section will formulate an answer to the first part of the research question: How does physiology reflect persuasion? In essence, our first main finding that physiology does change in reaction to persuasion attempts provides a basic answer to this question, and it will be discussed in section 7.2.1. However, the main findings hold more information about physiology during attempts at persuasion. Sections 7.2.2 - 7.2.4 consider the influence of persuasive strategy, motivational state or personality trait on physiological reactivity to persuasion attempts, as well as the meaning of physiological reactivity to persuasion attempts in terms of persuasion effectiveness.

7.2.1 Physiology changes in exposure to persuasive stimuli

First, the results showed that people's physiology changes when exposed to persuasive stimuli: HR rises (Chapters 4, 5 and 6), SDNN lowers (Chapters 3, 4 and 5), RMSSD lowers (Chapter 4), SCRs activity changes (more SCRs in Chapters 3 and 6, but less in Chapter 5), more RR (Chapter 6), as well as more EMG-CS (Chapters 5 and 6), and less EMG-ZM activity (Chapter 5). The findings indicate that physiology indeed reacts to attempts at persuasion. This is particularly clear from Chapters 3 and 4: In Chapter 3 variations in physiological activity during the persuasive video corresponded to active persuasion principles and especially to a call for action. In Chapter 4 physiological activity during the persuasive messages was higher than during a neutral video on the same subject. The changes in physiology found in Chapters 5 and 6 do not directly prove that persuasion attempts elicit physiological responses due to the lack of a control condition.

The physiological patterns found translate into an activation of people's heart muscle by the sympathetic nerves (Jänig, 2003, Chapter 9), while they frown more and smile less when they see persuasive information. Although it is difficult to pinpoint a specific mental state to this physiological reaction, the activation of a person's physiology indicates that he/she is not ignorant of the persuasive messages. Perhaps the increase in physiological activity suggests that someone is processing the information and/or preparing to act on it (Gendolla, Tops, & Koole, 2015). The magnitude of the reactivity might tell to what extent a person is processing the presented messages. The psychological interpretation of the physiological reactivity to persuasion attempts is an important topic for future research.

It is remarkable that, except for SCRs activity, the findings of all the chapters align; higher HR and EMG-CS, lower SDNN. Our findings also align with previous research indicating lowered heart rate variability in persuaded participants (Barraza et al., 2015; Correa et al., 2015). However, in contrast to earlier research (Barraza et al., 2015), SCRs and SCL activity did not increase consistently to attempts at persuasion. SCRs activity increased during persuasion attempts in Chapters 3 and 6, which aligns with findings from Barraza et al. (2015), but results in Chapter 5 indicate the opposite effect. SCL activity seemed to correspond with persuasion principles in Chapter 3, but we did not find this again in any of the other studies. This repeated absence of SCL reactivity is especially unexpected as the increased HR reactivity could be interpreted as indicating sympathetic arousal.

7.2.2 Persuasion strategies do not impact physiology

Our second main finding states that different persuasion strategies do not appear to differently impact physiological activity during an attempt at persuasion. That is, on average there were no differences in physiological responses to high- or low-controlling messages (Chapter 4), nor to the different persuasion principles authority, consensus, commitment and scarcity (Chapter 5), nor to gain- or loss-framed messages (Chapter 6). Notably, in Chapter 5 this conclusion is based on within-subject results, while in Chapters 4 and 6 on between-subject results. The results in Chapter 3 did seem to suggest that on average physiological activity coincided with the persuasion principles use of reason, a call for action, evidence, rational arguments, informative illustrations, and the use of a spokesperson. However, these suggestions could not be backed up by statistical evidence.

The absence of physiological differences due to strategy is somewhat surprising, but it could be in line with our expectation that people have different susceptibilities to different persuasion attempts, which would reflect in physiological activity. These individual differences in susceptibility might have averaged out the impact of persuasive strategy on physiology in general. Our results are not in line previous research indicating more brain activity during gain-framed than loss-framed messages (Vezich et al., 2017). Further research, also involving other persuasion strategies than gain- and loss-framing is needed before clear conclusions on the average impact of persuasive strategies on physiology can be drawn.

7.2.3 Initial states and traits do impact physiology

Our third main finding indicates that initial motivational states and personality traits do impact physiological activity during an attempt at persuasion: Variance in physiological reactivity to persuasive stimuli was best explained by considering initial motivational state (Chapter 3), that is moral beliefs, reduction intention, injunctive norm and attitude, and/or personality traits (Chapter 5), that is extraversion and susceptibility to persuasion. This finding underlines that variations in physiology do not occur in isolation, but are intertwined with the psychological characteristics of a person. Previous research already indicated that a person's physiology can reveal behavioral approach or avoidance orientation (Balconi et al., 2009) or the Big Five personality traits (Berkovsky et al., 2019; Norris et al., 2007; Subramanian et al., 2018). It also underlines that susceptibility to attempts at persuasion is influenced by personality characteristics as Big Five personality traits (Alkiş & Taşkaya Temizel, 2015; Kientz, Halko, & Kientz, 2016) and behavioral approach and avoidance orientation (Vezich et al., 2017).

7.2.4 Physiology helps predict persuasion outcomes

Our fourth main finding indicates that physiology can help in predicting persuasion outcomes, namely reactance (in Chapter 4 the best model contained HR and SDNN), changes in instrumental attitude (EMG-CS in Chapter 6), intention (HR in Chapter 6), and behavior (SCL, HR, and EMG-ZM in Chapter 6). This suggest that persuasion effectiveness is understood best when considering both self-report measures and physiological reactivity measures in a subject-specific approach. On the other hand, this is not always the case: In Chapter 3 we did not find a positive correlation between persuasion and physiological activity, and it seems to contradict the findings from Chapters 4 and 6. The main difference here is the way of analysis: The mixed models made for each individual subject in Chapters 4 and 6 allow a finer estimation of these relationships than the overall correlation deployed in Chapter 3. Our finding is in line with previous research: Neuroscientific research indicated that brain activity to persuasive messages (Falk et al., 2010; Vezich et al., 2017) and heart rate variability (Correa et al., 2015) can be associated with subsequent behavior. Also, brain activity (Falk et al., 2010; Falk, Berkman, Whalen, & Lieberman, 2011) and heart rate variability (Correa et al., 2015) have proven to complement existing self-report measures predicting persuasion-induced behavior change.

Using the mixed model approach, variance in reactance to persuasive messages was best explained with cardiovascular measures in addition to self-report measures, as indicated with an improvement of adjusted R^2 from 9.5 to 15.5% (Chapter 4). Various physiological reactivity parameters explained 5 to 18.4% extra variance of persuasion-induced attitude, intention and behavior change in addition to self-report measures (Chapter 6). Especially HR seemed to have a great contribution in these models. Again these findings align with previous findings relating cardiovascular activity to persuasion (Barraza et al., 2015). In other words, only self-report or only physiology assessment seem to illustrate just part of the persuasion process. Thereby these results suggested that different types of data and a computational approach might be the way forward for personalization of persuasive interventions.

7.3 Implications for persuasion research

Although it was not one of the research goals, the psychophysiological approach in this thesis also gave some insights into the psychological processes related to persuasion. To start, the results seem to suggest that the process of persuasion contains several sub-processes generating different psychophysiological patterns: Physiological activity increased when people completed a survey after the persuasive stimuli (Chapter 4 and 7). This reasoning aligns with earlier research: Recent neurophysiology studies hypothesized the involvement of psychological mechanisms as valuation, conflict detection and self-related processing in persuasion based on existent neuroscientific knowledge (Cascio et al., 2015; Chua et al., 2011; Falk & Scholz, 2018). Although the studies in this thesis have mainly focused on physiology during persuasion attempts, the results do indicate the complexity of persuasion-related processes. Further psychophysiological studies that make a distinction in several sub-processes of persuasion might yield valuable addition to our current knowledge.

The findings also show that initial motivational state resonates in physiological reactivity to persuasion attempts (Chapter 3), and that physiological reactivity, sometimes combined with initial motivational state, explains persuasion effectiveness (Chapter 6). This suggests that not so much the way of information processing, as proposed in among others the ELM, but the alignment between motivational state and the persuasion objective can be indicative for the success of the attempt. Expectedly, persuasion is most likely when the attempt's objective is slightly misaligned with a person's motivation: Aligned objectives will not encourage change, and greatly misaligned objectives might cause reactance, not resulting in any change. Our results indicate that people with motivations less aligned to the persuasion objective had more physiological reactivity (Chapter 3). Following this reasoning, we would expect even more arousal during psychological reactance, as found in previous research (Sittenthaler et al., 2015) but not in the results of Chapter 4. Taken together these findings might suggest that a coherence between persuasiveness, motivations-attempt alignment and physiological reactivity as presented in Figure 7-1 might be present. Future persuasion research would benefit from putting more emphasis on people's motivational state and should verify if this coherence between persuasion effectiveness, misalignment and physiological reactivity is indeed present.

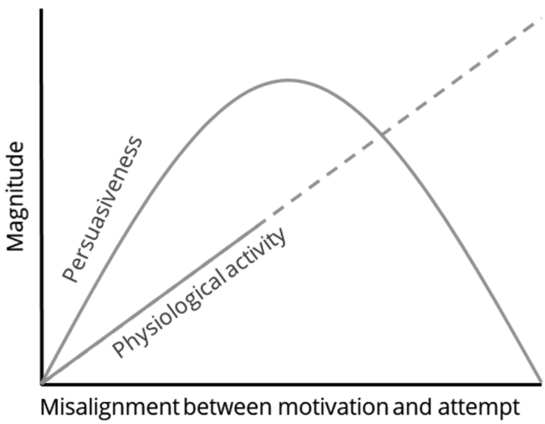


Figure 7-1 Potential coherences between persuasiveness, physiological activity and alignment between the recipients motivation and the objective of the persuasion attempt. The dashed part is based on the results of Sittenthaler et al. (2015), but was not observed in this thesis.

The findings of this thesis also suggest that psychophysiology is a suitable approach to study persuasion. Psychophysiological persuasion insights might inspire renewal of contemporary psychological persuasion models. For example, critics have argued that current persuasion models are descriptive in nature and fail to pinpoint underlying mechanisms (Kitchen et al., 2014), potentially because they lack temporal and spatial resolution (Zhang, 2019). An important advantage of physiological measures is that they enable computing approaches,[27] such as pattern recognition by sophisticated algorithms, that could yield additional insights in persuasion in general and for that specific user. The data-driven approaches associated with physiological measures might bypass deficiencies in existing knowledge, and thereby advance the field of persuasion.

7.4 Physiology as personalization input in Persuasive Technology

The following section addresses the second part of the research question of this thesis: Can insights from physiology be used to personalize Persuasive Technology? For this, a model to personalize PT on the basis of physiology was proposed at the beginning of this thesis (see Figure 2-4 on page 26). This section will relate the empirical findings from Chapters 3-6 to the steps in the reactivity-based adaptation loop of this model (the green paths in Figure 2-4).

The first step of physiological reactivity adaptation is measuring the *physiological reactivity* to an exposure to a persuasion attempt. The first main finding verifies this step: Physiology can indeed change during an attempt at persuasion (Chapters 3 and 4). Next, the system *interprets this physiological reactivity* to provide a prediction of the user's susceptibility to that message based on existent or application-specific knowledge. Our fourth finding indicates that assessing physiology during an attempt at persuasion even has merit when the characteristics of that specific individual are also considered: The predictive models in Chapter 6 with the best fit involved both physiology and self-report measures, although there was no interaction between the two. Thus, if this relationship also holds within an individual, the physiological reactivity to a particular message is informative about

[27] Physiological measures yield large amounts of data and have a high temporal resolution, especially when compared to periodic self-report measures. This makes them sensitive to small changes in the process as well, thus picking up information that would have been missed by traditional measures. Physiological data can be used in "black box" approaches such as neural networks to establish psychophysiological validity (see Fairclough, 2009). The use of big data to gain insight in psychological processes is also known as psychological computing (see Zhang, 2019).

its likely success, and suggests that this message could be used more often in order to persuade the user.

Additionally, physiological activity during a persuasion attempt seems to be able to inform the system about the personality and motivational state of the user. First, if the user (repeatedly) has more electrodermal activity than the average user, this user is likely to score lower on the susceptibility to persuasion scale (Chapter 5). Since susceptibility to persuasion principles is a trait, we would expect that users with lower skin conductance activity are more susceptible to persuasive messages, irrespective of the goals they advocate. Similarly, if the user smiles more he/she is probably more extravert (Chapter 5), and a consistent rise in heart rate during persuasive messages might be an indication that a user has high moral beliefs concerning the objective of the message (Chapter 3). Second, the finding that motivational state resonates in physiology suggests that physiology might tell how much effort is needed to make that person reach the persuasion objective. Physiology in combination with persuasion effectiveness seems to reveal how well an attempt fits the person (Figure 7-1): if a user (repeatedly) shows more physiological activity during unsuccessful persuasion attempts advocating a certain goal than to other goals, this particular objective might be too misaligned with the user's motivations regarding that objective (Chapter 3). In such a case, it may be advisable to adjust the persuasion objective towards the person's motivations. These types of information about the user might serve as input for the next reactivity adaptation step; *finding an appropriate persuasive message*.

This suggest that physiological measures might not only inform the system about the effectiveness of specific persuasive messages, but it will allow the system to understand its user better. The insights gained from coaching one behavior might be transferred to coaching a second behavior. This is especially useful when behavioral or self-report data for the second behavior are not available or hard to measure, for example food intake. With a persuasion profile per user, we might no longer have to measure behavior, but only physiology.

All in all, the findings in this thesis cover only a small portion of the model for physiology-aware PT. Nevertheless, these initial results are compelling and encourage further research. Future studies might investigate if physiology can be used for the remaining steps of physiological reactivity adaptation. It would be interesting if more studies could underline that *physiological reactivity links to the effectivity of the message* and that this assessment generates useful *user-specific knowledge* that can optimize future interactions (see Figure 2-4). Also, the possibilities of physiological state adaptation and the interaction between the various types of adaptation might interesting to explore. Furthermore, future field studies should validate if the psychophysiological relationships associated with persuasion are strong enough to use in real-life situations and withstand external interferences that influence physiology.

7.5 Ethics of physiology-aware Persuasive Technology

Health-related physiology-aware PT promises to provide morally valuable benefits, such as reduction in the burdens of disease. Along with these benefits, several potential ethical risks should also be highlighted and considered in the design of such PT systems. The following is by no means an exhaustive account of the relevant ethical issues surrounding these technologies; rather we have chosen to draw attention to two sets of concerns that are intensified with the use of physiology-aware PT, namely user autonomy and trustworthiness. Although ethics is discussed in the final section of this book, these considerations were an integral part of the research from the beginning. The scope and focal point of these considerations kept changing as our understanding of the findings and their impact on PT design became clearer. As the findings of this thesis may encourage (further) design of physiology-aware PT, I will present the most important considerations here. It is important that ethical considerations take place at the beginning of an actual design process in order to construct PT that takes into account relevant values.[28] Notably, raising questions about the potential ethical risks of using physiology-aware PT does not mean that the status quo – less efficient PT – is not ethically problematic in and of itself.

A growing literature discusses ethical issues surrounding PT in general (Berdichevsky & Neunschwander, 1999; Davis, 2009; Frank & Nickel, 2017; Jacobs, 2019; Smids, 2012; Spahn, 2012; Yetim, 2011). Assuming that physiology enables more effective and personalized attempts at persuasion in PT, the ethical concerns regarding existing and less effective methods of PT will be exacerbated. In the future, other ethical considerations should be evaluated in relation to physiological measurement, such as the effects of the system's costs on distributive justice (Smids, 2018), the threat of deskilling (Nickel, 2012), the contribution to the moralization of

[28] The methodology of value sensitive design is relevant, as it comprises an iterative design process that explicitly takes values and stakeholder concerns into the design process from the beginning (Friedman, Kahn, & Borning, 2002).

health behaviors (Swierstra, 2015; Swierstra & Waelbers, 2012; Verbeek, 2006), and the relation with user vulnerability (Jacobs, 2019).

7.5.1 Autonomy

For any PT, the central ethical question has to do with autonomy (Smids, 2018; Spahn, 2012) and whether or not the behavior change they induce is voluntary (Smids, 2012). Indeed, the most widely accepted definition of PT excludes the use of coercion or misinformation (Fogg, 2003). Use of physiological data to persuade users at the right time and in the right way, in an increasingly personalized manner can be understood as heightening the concerns about autonomy and voluntariness for at least two reasons: 1) Physiological data are more out of individual control than self-reports or behavior data. The user will not always, presumably rarely, be consciously aware of the physiological measurements being taken. Nor can the user reflect on and make decisions about the specific information that they want to feed into the physiology-aware PT after the initial adoption of the device. 2) In theory, physiological data can reveal affective states of the user before or without the user themselves being aware of it. Thus, potentially bypassing the user's own conscious awareness of the states to which the PT is responding.

Informed consent is the standard way to ensure voluntary use of technology that collects a person's data and attempts to influence their behavior (White, 2013). However, physiology-contingent adaptations challenge some of the traditional methods of obtaining and conceptualizing informed consent. To obtain a morally justified consent, it must be specified exactly to which element of the PT a user is consenting. Jacobs (2019, p. 6) points out four distinct elements of PT to which consent could apply: "First, the goals and intended behavioral outcomes. Second, persuasive tools that a PT utilizes. Third, the types of individual interactions of the PT with the user. Fourth, the use and storage of data".[29] However, personalization, as a persuasive tool, is more prominent in physiology-aware PT compared to normal PT. As explained in Chapter 2, the rules for personalization might change as time progresses making one-time consents insufficient. Besides, the interactions of a PT with the user are partially based on interpretations of automatic responses by the user. When signing the consent, the details of the interpretations are not yet clear. Future research should indicate which alternative models of consent are most

[29] Physiological measurements produce, store, and analyze a large amount of personal data, some of it potentially sensitive, but this is not a unique privacy concern raised by physiology-aware PT.

appropriate for physiology-aware PT, for example dynamic consent (Kaye et al., 2015) or temporally distributed consent (Loosman, 2020).

7.5.2 Reliability and trustworthiness

The reliability and trustworthiness of physiology-aware PT is of ethical concern because physiological data can be seen as a kind of biomedical data. Physiological data is likely to be perceived as more objective, scientific, and closer to medicine (Crawford, Miltner, & Gray, 2014; Mittelstadt & Floridi, 2016), than, for example, self-reports. This idea stems from the perception that data, as well as the algorithms used for analysis, are much more complex than what we humans can understand (Callebaut, 2012, p. 70). The assumption is that these data represent an objective truth, without the need for human interpretation (Mittelstadt & Floridi, 2016). In reality, all data undergoes various human-imposed transformations before interpretation,[30] such as noise elimination, filtering, sub setting, et cetera. Which data is important differs depending on the question that needs to be answered (Mittelstadt & Floridi, 2016). Therefore, the data and interpretations are not necessarily objective in the sense that people take them to be and rely on "*what data is recognized, how that data is collected, and by whom*" (Crawford et al., 2014, pp. 1669–1670). In the context of PT informed by physiology, the danger is that users may overestimate the reliability and objectivity of the technology by thinking that physiological assessment is error free and free from interpretation.

When a user chooses to use a PT, this is usually because they think it will help them to change a behavior they struggle to change independently. The user intends to comply with the system, as its functionalities are expected to contribute to their well-being. The user puts trust in the system (Nickel, 2012). However, a physiology-based system quickly becomes a complex system. This complexity may complicate user's perceptions of the trustworthiness of the system. Questions of trustworthiness may arise for users for at least two kinds of reasons. First, users may not understand the functioning of the system, its limitations, or capabilities. For example, which information can be derived from physiological data and how does this changes the system's behavior? Users might lose confidence if they do not understand why something is measured or feel like the system is measuring more things than needed. Trust is related to explainability – if the system can be more explicit about why it gives certain recommendations, people may be able to better

[30] This rather complex processing of data limits the transparency of the operation of such technologies for a user.

assess its recommendations in a given context, and may be able to better adjust the system settings or goals to fit their own needs and capabilities (Cutillo et al., 2020).

Second, an issue of trust arises if users do understand the complexities and limitations of the system. Some complexities are difficult to circumvent, but can have major consequences. To illustrate, any type of inference making between physiology and psychology can be subject to the *multi-mapping problem*, that is one psychological process might arouse various physiological features (many-to-one) or one physiological measure could indicate the presence of several psychological states (one-to-many) (Cacioppo et al., 2007). This complexity can make the user wonder whether the physiological values obtained by the system are valid, and consequently, whether or not the system is adapted properly. Given that the precise psychophysiological relationship in persuasion is not yet established, we must consider whether or not and to what extent it is morally acceptable to draw inferences from these less-then-perfect representations of mental states (Fairclough, 2009) and give feedback or attempt to persuade based on such representations. Therefore, when possible, the system might try to decipher the physiological response directly in terms of (changes in) behavior, independent of psychological interpretations. Although time and perhaps extra messages could pass between the original message and the final behavior change, we can use the reactivity values to see whether the message has had an impact or not. Currently, it is unknown whether a problem like the multi-mapping problem might occur when relating physiology directly to behavior.

In either of the above scenarios, users may end up over- or under-trusting the system (Weitz et al., 2019). Both situations have costs: With over trust, the user perceives the system as more accurate and persuasive than it is. This might result in being too confident in the functionalities of the system and not using his or her own resources, such as self-regulation or intrinsic motivation, to achieve the wanted change in behavior. This is undesirable, as a PT can never fully understand the user and their context, that is the system will always have flaws. Therefore, it is important for the user to keep ownership of their progression towards a certain goal. When users under trust the system users may not take the system seriously. Perceived persuasiveness is lower than actual persuasiveness, which will make the user abandon the system. The risk here is that the user does not accomplish the self-set behavior goal.

The presence of these medical data issues and physiology-inference challenges does not mean that such a system should not be developed – future research might resolve some of these issues – but it does mean that physiology-aware PT is not error free or without risks. Thus, without precautions and sufficient an attitude of blind trust towards physiology-aware PT is not justified. To ensure trustworthiness, PT should communicate its capabilities and limitations to the users. For this, we propose several options: 1) Explain the problem of unreliability of measurements and ambiguity of inferences before usage in the informed consent. 2) Provide a real-time measure of unreliability to the user while using the system. 3) Enable the user to provide continuous feedback on the experienced relevance and correctness of the physiological inferences. And 4) show how physiological assessment increases the confidence of the system to guide you. Additionally, the system should convey which physiological features it measures, how these are interpreted, and in which system adaptations these interpretations result (Picard, 1995). The user has to be aware of changing functionalities due to learning phases,[31] and should be able to indicate their resilience against misclassifications. That way the user can know when the system is more or less reliable and decide whether that is desirable.

7.6 Limitations

This thesis has demonstrated the potential of physiological measurement to study persuasion and to personalize Persuasive Technology systems. However, the claims made in this thesis are subject to several limitations. Spread throughout this book, I have mentioned shortcomings of the empirical studies in their related discussion sections. Furthermore, several research field-wide limitations were acknowledged, such as the multi-mapping problem in psychophysiology and the limitations of current biosensor technology (section 7.5.2), as well as criticism on contemporary persuasion models (section 7.3). In this section, I want to discuss the main limitations of this thesis.

Section 2.2 starts with an introduction of persuasion as a communicative process in which one person influences another. However, in the experiments that try to simulate this process, little of this intention remains: Participants viewed persuasive messages in front of a computer screen, in a lab room while they were connected to a bunch of sensors. They could not communicate with the computer and the computer could not adapt to them. This rigid set-up might have decreased the likelihood of persuading the participants. However, this set-up did have many important advantages: It ensured that each participant received the exact same

[31] Many personalized technologies suffer from a cold start (Schein et al., 2002). Before a system can offer personalization based on user specific (physiological) inferences, it needs a learning phase and a large amount of data. As a result, the system will have less functionalities when the user first adopts it.

persuasive manipulation. It made that I knew precisely when a participant saw which message, and that enabled a reliable linking of physiological reactivity to a specific attempt. It also allowed the investigation of many physiological features at once, which was important to answer the first part of the research question. Hence, I considered the downsides of these choices acceptable, especially when bearing in mind that the ultimate venue of it is Persuasive Technology (i.e. second part of the research question), which might share some similarities in set-up. Future research into the psychophysiology of persuasion-related processes might benefit from creating a communicative experiment setting, perhaps with less physiological sensors and a human persuader.

Other shortcomings relate to our cross-subjects correlational analyses. With the exception of Chapter 5, there was only one observation per participant. Since human processes are most likely non-ergodic [32] due to limitations in their individual variability, this impedes the generalizability of group results to individual cases ("ecological fallacy", Fisher, Medaglia, & Jeronimus, 2018). To circumvent this issue, most analyses in the current work employed multi-level models accounting for individual differences. This approach has, however, two shortcomings. First, the individual differences in the models were based on aggregated results (intercepts and slopes), instead of real individual variation (Molenaar, 2005). Second, the results were obtained using group-models that accounted for individual differences, instead of individual models (Fisher et al., 2018). For the latter, some variables, such as the random effect subject, might be no longer relevant whereas other variables, such as time of the day, might be. Results would become more meaningful when comparing multiple observations of one participant in a longitudinal study, [33] perhaps using different persuasion strategies. Future research could compare the central tendency and variation of the intra- and inter-individual data sets as well as consider true individual variation, perhaps using a Durbin-Watson test (Fisher et al., 2018). This would assure that the cross-sectional relationships of physiology with persuasion effectiveness or initial motivational state also hold within an individual, which is important for their use in physiology-aware PT.

Additionally, the relational tests used in the empirical chapters assumed a linear or monotonic relationship between persuasion effectiveness and physiological arousal.

[32] Ergodicity refers to the notion that the behavior in a subset of a dynamic system is approximately identical to the average behavior over all states that the system can be in (see Molenaar, 2004 for a full explanation).

[33] In this case the analyses should consider the temporal dependence in longitudinal physiological data, which cause intra-individual correlations that do not relate to the relation under investigation (Fisher et al., 2018).

It could be that the full psychophysiological relationship has an alternative shape such as an (inversed) parabola (Aggarwal & Ranganathan, 2016). Similar to, for example, the hypnotized U-shaped relationship between self-value and neural activity (Bartra et al., 2013). Furthermore, no control groups were used to compare the physiological reactivity to persuasion. This was because our first research question focused on whether physiology even reacts to persuasion attempts. Therefore, comparisons between physiological reactivity during persuasion attempts and baseline physiology (Chapters 3-6), neutral information (Chapter 4), the effect of manipulation between participants (Chapter 4 and 6) or within one participant (Chapter 5) were made. Future work should focus on longitudinal studies, test also non-linear relationships and use control groups.

Another limitation might be the generalizability of our results. People chose to participate in the studies voluntarily. Therefore, it could be that people participated because they were already interested in the topic. This might affect the applicability of the results to people with other interests or motivations. Additionally, the results might not be generalizable to other behaviors, as the studies considered meat consumption and oral health care. We chose oral care as this is a measurable health behavior that is almost-equally relevant to everyone. In addition, it seemed interesting to consider a behavior that people are more invested in, that is meat consumption. These two behaviors are possibly differently ingrained in our psychology and our physiology therewith: As also remarked in the discussion of Chapter 4, eating animal is a moral dilemma and wired differently as health beliefs. Therefore, future research might benefit from persuading a diverse set of people over a range of behaviors or attitudes.

7.7 Main contributions

This thesis may have several contributions. First of all, it indicated that peoples' physiology reacts to attempts at persuasion and can hold specific information about that person. These results contribute to the field of psychophysiology. Second, the findings of this thesis showed that physiology can be used to study persuasion-related processes, although further research is needed to identify underlying mechanisms of persuasion. This result contributes to persuasion research. Third, we reviewed physiology as personalization method and created a model that allows a system to adapt its features to a person's physiological state and reactivity. These results contribute to the fields of human-computer interaction and persuasive systems design. A fourth contribution is to persuasive systems design and ethics, as we formulated first guidelines for the implementation of physiology-aware PT systems, and discussed the ethics of those physiology-aware persuasive systems.

7.8 Conclusion

The general conclusion is that physiology can hold information about persuasion-related processes. Persuasion consists of a diversity of mental processes that, despite the efforts of many scholars including myself, are not fully understood. I have shown and do firmly believe that physiological assessment exposes a side of this phenomenon that was underexposed until recently. Physiology gives a real-time indication of whether persuasive information affects a person (and potentially to what extent). Additionally, considering physiology can significantly improve a prediction of persuasion effectiveness that is only based on self-report. Thereby, it can be a means to *personalization* of *Persuasive Technology*. As such, physiology-aware PT systems have the potential to support people better in their desired health-related behavior change. As an important asset, physiology can be assessed real-time with high-temporal resolution, while the person has no control over it or is unaware of it. This has some advantages and disadvantages with regard to traditional self-report measures. Physiology provides an unbiased measurement, but also entails ethical objections, especially when used outside research in for example consumer products that use PT.

Adapting to physiology can bring enormous possibilities for PT, if we take into account the rapid developments in data science and sensing technology. In addition, people are becoming increasingly dependent on personal information systems, which might employ PT. In that sense, it is only a matter of time before physiology is integrated into PT, but it is important to do this in a responsible, thoughtful way. False inferences and ethical missteps can potentially have major consequences. People's desire for personal information systems, the inescapable growth of technology, and the drive of designers to create user-centered systems encourage timely research on this topic. This research is needed to oversee these emerging trends, but most of all, because PT systems that personalize on the basis of physiology have the possibility to offer considerable benefits in terms of relieving human suffering caused by behavior that is detrimental for health, sustainability or leads to other negative effects.

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Summary

Persuasive Technology (PT) can assist in behavior change. This technology employs *persuasion* in order to change attitudes, intentions and potentially behavior. By increasing our understanding of the cognitive and affective mental processes related to persuasion, we can improve the effectiveness of PT. In this thesis, *physiology* is investigated as a measurement of the psychophysiological derivatives of the mental processes related to persuasion and as input for the personalization of persuasive interventions. The emotions and cognitions activated during persuasion-related processes can be reflected in the user's physiological activity. State-of-the-art sensor-technologies enable continuous measurement of such nervous system features to give information about the mental state without disturbing the user. Therefore, physiological measurements might be used to further personalize and improve PT systems using, for example, biocybernetic loops and data-driven approaches. This can advance the personalization of persuasive interventions as physiological assessment differs from self-report or behavioral measurements with respect to what they represent, how much control a person has over the responses they capture, and how they can be used for personalization. Personalization is expected to increase effectiveness and entails adapting goals, content and persuasive strategies to a person based on self-report and behavior measures, among others.

This thesis has set out to investigate whether physiology indeed reacts to attempts at persuasion and whether these insights can be used to personalize Persuasive Technology. Several aspects of these questions have been addressed in this book. To start, it is important to consider how psychophysiological knowledge can be applied to PT systems. *Chapter 2* presents an overview of current personalization methods in PT and describes how physiology can complement these existing methods. I proposed a model for physiology-aware PT systems, in which a system can adapt to the current physiological state of the user, and their physiological reactivity to a persuasion attempt. To provide support for the physiological reactivity part of this model, I conducted four empirical studies. In these studies, I repeatedly examined physiological reactivity to persuasion attempts, and related it to persuasive effectiveness. Additionally, the studies identified whether certain persuasive strategies or individual characteristics correspond to specific psychophysiological reactions to attempts at persuasion.

Chapter 3 describes the first empirical study. This study explored whether psychophysiological responses to persuasive information reflect persuasion-related processes, and specifically whether individual differences in motivations and behaviors affect psychophysiological reactions to persuasive information. This study found an increase in physiology during an attempt at persuasion and that people with motivations less aligned to the persuasion objective have more physiological reactivity to the attempt. *Chapter 4* describes a study investigating physiology during *psychological reactance* - that is when a person rejects the persuasive information. The findings indicate that self-reported psychological reactance to persuasive messages in controlling language relates to cardiovascular reactivity during those messages.

However, susceptibility to an attempt at persuasion and reactance does not only depend on someone's initial motivation state, but also on personality characteristics since various persuasion strategies might affect a person differently as well. *Chapter 5* reports a study examining physiological reactions to messages deploying the persuasion principles scarcity, consensus, commitment, or authority. A subject-specific analysis revealed that people with a lower level of general susceptibility to an attempt at persuasion have higher physiology in exposure to persuasion, that is smiling, skin conductance level and skin conductance responses. In *Chapter 6*, a study investigates if physiology predicts effectiveness of gain or loss framed persuasive information, while considering the person's behavioral tendency to approach gains or avoid losses. The results indicate that physiological reactivity yielded additional information – next to self-report measures – to predict persuasion effectiveness on attitude, intention and, perhaps more importantly, on behavioral compliance.

Overall, the findings indicate that 1) people indeed show physiological reactivity to persuasive stimuli, although 2) persuasion strategies per se do not appear to impact physiology differently. Moreover, 3) psychophysiological reactions to persuasion are understood best when considering the person's initial motivations (attitude, intentions, perceived behavioral control) and personality characteristics (susceptibility to persuasion, extraversion). I also showed that 4) considering physiological reactivity – in addition to traditional self-report measures – improves the prediction of persuasion effectiveness. In *Chapter 8* it is discussed how these insights shed light on the way in which persuasion is reflected in physiology, how they verified the possibility of physiological reactivity adaptation, but also how the design of physiology-contingent PT needs to balance the gain of increased

effectiveness with important ethical considerations, such as reliability and trustworthiness.

We conclude that technological advancements in combination with further psychophysiological research will permit powerful and ethical persuasive systems that can assist individuals in their journey towards a better quality of life.

Samenvatting

Beïnvloedingstechnologie, ook wel *Persuasieve Technologie* (PT), kan helpen bij het veranderen van gedrag. Deze technologie maakt gebruik van *beïnvloeding* of *overtuiging* om attitudes, intenties en potentieel gedrag te veranderen. PT-systemen kunnen effectiever worden met meer begrip van de cognitieve en emotionele processen die komen kijken bij beïnvloeding. In dit proefschrift wordt *fysiologie* onderzocht als manier om meer te weten te komen over de mentale processen tijdens beïnvloeding en als input voor de personalisatie van PT-systemen. Moderne sensortechnologie kan de fysiologie van gebruikers continu meten zonder ze te storen in zijn/haar dagelijkse bezigheden, om inzicht te geven in hun mentale toestand. Zodoende kunnen fysiologische metingen worden gebruikt om PT-system verder te personaliseren en verbeteren, bijvoorbeeld met behulp van *biocybernetic loops* en data-gedreven benaderingen. Gepersonaliseerde PT-systemen zijn effectiever doordat zij het doel, de communicatie en de beïnvloedingsstrategie aanpassen op de gebruiker. Dit gebeurt nu met vragenlijsten en gedragsmetingen, maar fysiologie kan hieraan bijdragen, omdat fysiologische metingen verschillen van vragenlijsten of gedragsmetingen voor wat betreft de soort informatie die ze kunnen registreren en de manier waarop deze informatie wordt gebruikt voor de personalisatie van een systeem.

In dit proefschrift is onderzocht of de fysiologie inderdaad reageert op beïnvloedingspogingen en of deze inzichten gebruikt kunnen worden om Persuasive Technology te personaliseren. In dit boek komen verschillende aspecten van het onderzoek aan bod. *Hoofdstuk 2* presenteert een overzicht van huidige personalisatiemethodes in persuasieve technologie en beschrijft hoe fysiologie de bestaande methodes kan aanvullen. Ik heb een model voorgesteld voor fysiologie-bewuste PT-systemen, waarbij een systeem zich kan aanpassen aan de huidige fysiologische toestand van de gebruikers, en/of aan hun fysiologische reactiviteit op een beïnvloedingspoging. Ter ondersteuning van het fysiologische reactiviteitsdeel van dit model heb ik vier empirische studies uitgevoerd. In deze studies heb ik herhaaldelijk de fysiologische reactiviteit op beïnvloedingspogingen onderzocht en deze in verband gebracht met de overtuigingskracht van de poging. Daarnaast is in de studies vastgesteld of er een verband is tussen bepaalde beïnvloedingsstrategieën of individuele kenmerken en de specifieke psychofysiologische reacties op beïnvloedingspogingen.

Hoofdstuk 3 beschrijft de eerste empirische studie. Deze studie onderzocht of psychofysiologische reacties op beïnvloedingspogingen een weerspiegeling zijn van beïnvloedingsprocessen, en of deze psychofysiologische reacties verschillend zijn voor mensen met hogere of lagere initiële motivaties. Ik vond inderdaad een verhoging in fysiologische activiteit tijdens beïnvloedingspogingen. Ook bleek dat mensen met lagere motivaties gemiddeld meer fysiologische reactiviteit tijdens de beïnvloedingspogingen hadden. Daarom beschrijft *hoofdstuk 4* een onderzoek naar fysiologie tijdens *psychologische reactantie* - dat is wanneer iemand zich verzet tegen de beïnvloedingspoging. De resultaten van deze studie laten zien dat zelfverklaarde psychologische reactantie tegen dwingende beïnvloedingspogingen samenhangt met cardiovasculaire reactiviteit tijdens die pogingen.

De ontvankelijkheid voor een beïnvloedingspogingen hangt echter niet alleen af van initiële motivatie, maar ook van persoonlijkheidskenmerken. *Hoofdstuk 5* presenteert een onderzoek naar fysiologische reacties op berichten waarbij de beïnvloedingsprincipes schaarste, consensus, betrokkenheid en autoriteit worden ingezet. Een individu-specifieke analyse toont aan dat mensen met een lagere algemene gevoeligheid voor beïnvloedingspogingen een grotere fysiologische reactie hebben tijdens beïnvloedingspogingen, namelijk meer glimlachen en zweten. In *hoofdstuk 6* wordt onderzocht of fysiologische reactiviteit het succes van positief en negatief geformuleerde beïnvloedingsberichten voorspelt, terwijl hiervoor ook gedragsmatige neigingen van de persoon om winsten te benaderen en verliezen te vermijden worden meegenomen. De resultaten laten zien dat fysiologische metingen extra inzichten genereren, bovenop de inzichten verkregen uit vragenlijsten: Het effect van de beïnvloedingspoging op attitude, intenties en gedrag wordt het best voorspeld door beide informatiebronnen, vragenlijsten en fysiologie, mee te nemen.

Concluderend laten de bevindingen zien dat 1) mensen inderdaad fysiologisch reageren op beïnvloedingspogingen, hoewel 2) verschillende soorten beïnvloedingsstrategieën geen andere invloed lijken te hebben op fysiologie. Bovendien 3) worden psychofysiologische reacties op een beïnvloedingspoging het best begrepen wanneer de initiële motivaties (attitudes en intenties) en de persoonlijkheidskenmerken van de persoon (gevoeligheid voor beïnvloeding en extraversie) worden overwogen. Ik heb ook laten zien dat 4) het overwegen van fysiologische reactiviteit – bovenop vragenlijst data – de voorspelling van overtuigingssucces verbetert. *Hoofdstuk 7* bespreekt de betekenis van deze vier bevindingen zowel voor onderzoek naar beïnvloedingsprocessen als voor het ontwerpen van persuasieve technologie. Bovendien worden in dit hoofdstuk een tweetal ethische overwegingen van fysiologie-bewuste PT gepresenteerd, in balans met het voordeel van hun verhoogde effectiviteit.

We concluderen dat technologische vooruitgang in combinatie met verder psychofysiologisch onderzoek krachtige en ethische PT-systemen mogelijk zal maken die mensen kunnen ondersteunen bij het aannemen van een gezondere levensstijl.

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Hanne Spelt

January 2021, Eindhoven

Curriculum Vitae

Hanne Adriana Alijda Spelt was born on March 12, 1992 in IJsselstein, the Netherlands. She received her VWO education at the Oosterlicht College in Nieuwegein, and then moved on to her bachelor studies Bèta-gamma at the University of Amsterdam, with the major Business Studies and minor Brain & Cognitive Psychology. After this, she fulfilled an active role in the Amsterdam student union (ASVA) as vice-president. In 2016, she obtained her M.Sc. in Applied Cognitive Psychology from the University of Utrecht. In September 2016, she started a Ph.D. trajectory in Psychophysiology and Persuasion at the Digital Engagement, Cognition and Behavior group at Philips Research (NL) and the Human-Technology Interaction group at Eindhoven University of Technology (TU/e). In this role, she was part of INHERIT, a European Union Horizon 2020 research and innovation project on the adoption of healthy and sustainable lifestyles. Her research in this field resulted in several peer-reviewed papers in international journals and conference proceedings. Since September 2020, Hanne has worked as a Research Scientist at the Digital Engagement, Cognition and Behavior group at Philips Research (NL).

Publications

Peer-reviewed journal publications

Spelt, H.A.A., Zhang, C., Westerink, J.H.D.M., Ham, J., & IJsselsteijn, W.A., (pre-print 2020). Persuasion-Induced Physiology as a predictor of Persuasion Effectiveness. *IEEE Transactions on Affective Computing*

Bell, R., Khan, M., Romeo-Velilla, M., Stegeman, I., Godfrey, A., Taylor, T., … Costongs, C. (2019). Ten Lessons for Good Practice for the INHERIT Triple Win : Health, Equity, and Environmental Sustainability. *International Journal of Environmental Research and Public Health*, *16*(4546).

Spelt, H. A. A., Tsiampalis, T., Karnaki, P., Kouvari, M., & Zota, D. (2019). Lifestyle E-Coaching for Physical Activity Level Improvement : Short-Term and Long-Term Effectivity in Low Socioeconomic Status Groups. *International Journal of Environmental Research and Public Health*, *16*(4427), 8–11. https://doi.org/10.3390/ijerph16224427

Spelt, H., Kersten-van Dijk, E., Ham, J., Westerink, J., & IJsselsteijn, W. A. (2019). Psychophysiological Measures of Reactance to Persuasive Messages Advocating Limited Meat Consumption. *Information*, *10*(10), 320–332. https://doi.org/10.3390/info10100320

Spelt, H. A. A., Westerink, J. H. D. M., Ham, J., & IJsselsteijn, W. A. (pre-print 2019). Psychophysiological Reactions to Persuasive Messages Deploying Persuasion Principles. *IEEE Transactions on Affective Computing*, 1–13. https://doi.org/10.1109/TAFFC.2019.2931689

Peer-reviewed conference contributions

Spelt, H., Karnaki, P., Tsiampalis, T., Kouvari, M., Petralias, A., Zota, D., … Linos, A. (2019). Short-term and long-term effectiveness of an e-coaching application: the INHERIT project. In *12th European Public Health Conference* (p. 161). Oxford University Press.

Spelt, H. A. A., Westerink, J., Ham, J., & IJsselsteijn, W. A. (2018). Cardiovascular Reactions During Exposure to Persuasion Principles. In *Persuasive Technology* (Vol. 10809, pp. 267–278). Waterloo: Springer International Publishing. https://doi.org/10.1007/978-3-319-78978-1

Submitted work

Altmeyer, M., Zenuni, B., Spelt, H., Jegen, T., Lessel, P., Krüger, A., (submitted). Do Hexad User Types Matter? Effects of (Non-) Personalized Gamification on Task Performance, User Experience and Psychophysiological Reactions. To *CHI Play 2021*

Spelt, H.A.A., Westerink, J.H.D.M., Frank, L.E., Ham, J., & IJsselsteijn, W.A., (submitted). Physiology-based personalization of Persuasive Technology: A user modeling perspective. To *User Modeling and User-Adapted Interaction*.

Spelt, H., Asta, L., Kersten-van Dijk, E., Ham, J., IJsselsteijn, W., & Westerink, J., (submitted). Exploring psychophysiological reactions to persuasive information. To *Behavior & Information Technology*.

Zhang, C., Spelt, H., van Wissen, A., Lakens, D., & IJsselsteijn, W.A., (submitted). Habit-Goal Interactions in Tooth brushing: Two Longitudinal Studies Examining Inter- and Intra-individual Effects. To *Health Psychology*

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