Dissertation
zum Erwerb des Doctor of Philosophy (Ph.D.)
an der Medizinischen Fakultät
der Ludwig-Maximilians-Universität München

The Role of Behavioral Economics in Diabetes Prevention and Management

Erstellt am
Helmholtz Zentrum München, Deutsches Forschungszentrum für Gesundheit und Umwelt,
Institut für Gesundheitsökonomie und Management im Gesundheitswesen

vorgelegt von

Florian Matthias Karl

aus

Giessen, Germany

am

13. September 2019

Supervisor:	Prof. Dr. rer. biol. hum. Rolf Holle
Second expert:	Prof. Dr. med. Klaus Parhofer
Dean:	Prof. Dr. dent. med. Reinhard Hickel
Date of oral defense:	16. December 2019

Affidavit

I hereby declare that the submitted thesis, entitled *The Role of Behavioral Economics in Diabetes Prevention and Management*, is my own work. I have only used the sources indicated and have not made unauthorized use of the services of a third party. Where the work of others has been quoted or reproduced, the source is always given.

I further declare that the submitted thesis or parts thereof have not been presented as part of an examination degree to any other university.

Munich, December 16, 2019
Place, Date

Florian M. Karl
Name

Table of Contents

List of Abbreviations

BMI	Body mass index
IDF	International Diabetes Federation
KORA	Cooperative Health Research in the Region of Augsburg
SQB	Status quo bias
SMarT	Save More Tomorrow™
USA	United States of America

List of Publications included in this Thesis

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. Status quo bias and health behavior: findings from a cross-sectional study. European Journal of Public Health. 2019;29(5):992-7.

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. Time preference, outcome expectancy, and self-management in patients with type 2 diabetes. *Patient Preference and Adherence*. 2018;12:1937.

Karl FM, Holle R, Schwettmann L, Peters A, Meisinger C, Rückert-Eheberg IM, et al. The association between unrealistic comparative optimism and self-management in individuals with type 2 diabetes: results from a cross-sectional population-based study. *Working Paper*.

Introductory Summary

A Need for New Approaches to Improve Public Health

Public health is the science of “preventing disease, prolonging life, and promoting physical and mental health” [1, p. 30], while aiming at efficient and fair utilization and distribution of resources [1]. The German Public Health Association adds that consideration of the diverse needs and preferences among individuals within the population is one of the major challenges for public health [2].

The diversity of needs and preferences in a population might be one possible explanation for the mixed effects of public health interventions [3, 4]. For example, overweight and obesity are major public health problems [5]. However, despite the efforts of public health organizations and governments [3, 6], the prevalence of obesity nearly tripled between 1975 and 2016 [5]. Therefore, it can be concluded that health promotion in its current form is not sufficient to overcome the negative effects of unhealthy food environments and the high prevalence of sedentary lifestyles [7, 8]. Assuming that the promoted behaviors would actually be effective in improving population health, the problem must lie in the respective adoption rates within the population.

In February 2019, the German Minister for Health identified the same issue and said that Germany is offering many health promotion and disease prevention programs, but that the new challenge is to make Germans actually use these services [9].

Likewise, more and more researchers agree that public health policy must extend its toolkit beyond “carrots and sticks”, e.g., subsidizing preventive care and taxing harmful substances [4, 10]. One research field that might help to improve the effectiveness of public health interventions at minimum cost is behavioral economics [11].

Behavioral Economics

The intellectual basis for behavioral economics and how it is applied to public policy making today was formulated by Thaler and Sunstein in 2003 [12, 13]. In their essay, Thaler and Sunstein (2003) elaborate how an anti-paternalistic choice architecture that gives the consumer absolute freedom of choice is actually unrealistic for many situations in the private and public sector and that a *libertarian paternalism* should be preferred instead [13].

The former statement can best be explained when considering the problem facing the director of a company cafeteria who discovers that the order in which the food is arranged influences the choices people make. The director must now decide which kind of food the cafeteria is going to promote. Thus, it is unrealistic to assume that paternalistic decisions, even if they are in the best interests of the affected party, could be avoided in all situations. However, these kinds of paternalistic decisions do not involve coercion, which is why such actions were named libertarian paternalism [13].

The science of selecting the "best" of all paternalistic options in such situations is called *behavioral economics* [12]. The specific type of policy making was later popularized as "nudging" and must not be restricted to situations in which a decision by the planner (e.g., cafeteria director or government) is inevitable [11, 12]. For example, the director of the cafeteria might not only change the order of the presented food, but might choose to give an additional *nudge* by placing the dessert in another location so that the customer would need to get the dessert after finishing the rest of their meal. Thus, the price of the dessert would be indirectly increased by the additional effort needed to get it, i.e., transaction costs [13].

Nudges are discovered and developed further by ongoing research in psychology, economics, sociology, and other fields that examine the circumstances and decision biases that might explain observed but seemingly irrational human decision-making [11, 13]. For example, people have a preference for the status quo [14], a preference for immediate consumption [15], and are unrealistically optimistic about their future [16].

Status Quo Bias

Status quo bias (SQB) describes the human preference for the current state of affairs and the path of least resistance [17, 18]. This includes an increased likelihood for selecting the default option and a decreased likelihood of revoking an initial decision [14].

One of the most famous examples of how SQB can affect human decision-making comes from the USA. Save More Tomorrow™ (SMarT) is a behavioral economic intervention by Richard Thaler and Shlomo Benartzi that was designed to help employees to generate sufficient pension savings [19]. In SMarT, employees are approached about increasing their contribution rates a considerable time before their next pay increase. If they join, they also agree that their contribution rate increases parallel to their salary up to a predefined maximum. However, participants are allowed to leave SMarT at any time [19]. Thus, SMarT turns the tables and uses SQB effects to overcome self-control issues that arise from SQB and other factors. By implementing SMarT, the saving rates in many companies have quadrupled [20].

Time Preference

In (behavioral) economics, the preference for smaller but immediate over larger later rewards is called time preference [15]. An individual's time preference is defined by how much an individual discounts the future [21]. The more an individual discounts the future, the more likely an individual is to show a preference for smaller but immediate rewards over larger later rewards.

In simple terms, the basic problem is self-control when the present temptation is so salient whereas the future consequences, i.e., costs and benefits, are remote. A famous example of self-control issues that *could* be explained by time preference is the Marshmallow Test devised by Mischel, Ebbesen and Zeiss (1970, 1972) [22-24]. Within the Marshmallow Test, preschool children were faced with both an immediately available and a preferred but delayed reward. Specifically, the children were faced with a pretzel and a marshmallow. The children were then asked whether they preferred the pretzel or the marshmallow. If they preferred the marshmallow, which they often did, the experimenter told the children that the experimenter had to leave the room now. Further, the experimenter said that if the child would wait until the experimenter gets back, the child would get the preferred marshmallow. Alternatively, the child could ring a bell and have the experimenter come back immediately. However, should the child ring the bell, it would not get the preferred marshmallow but only the pretzel.

If the children were not offered any distraction while they were waiting, the average waiting time before the children chose the immediate over the preferred but delayed reward was 30 seconds [23]. This experiment is a very good example of how humans might fail to follow their best interests when their self-control cannot fight their time preference.

Unrealistic Comparative Optimism

Unrealistic comparative optimism describes the tendency for people to be unrealistically optimistic about future life events in comparison to others [16]. Specifically, people tend to make the erroneous assumption that, in comparison with their peers, they are more likely to experience positive events and less likely to experience negative events in the future [25-27].

Famous examples are marriage and start-ups. Both events have about a 50% chance of success. However, only a few couples and entrepreneurs would rate their chances of being married until death or being successful with their start-up to be 50% respectively [11].

Moreover, many individuals underestimate their comparative risk of experiencing a negative health event, e.g., heart attack, stroke, or drinking problems [16, 28]. Recently, Jansen et al (2017) showed that unrealistic comparative optimism is also relevant to clinical trials. They found that a large proportion of participants in an early phase cancer trial thought they were more likely than other participants to profit from the respective trial [29].

Type 2 Diabetes

One use case where public health could profit from behavioral economic ideas is type 2 diabetes [30, 31]. Worldwide, 425 million adults (20–79 years) live with type 2 diabetes, of whom about 58 million adults live in Europe. Specifically, Germany has the second highest number of adults living with type 2 diabetes of all European countries (7.5 million). Furthermore, Germany has the third highest diabetes-related health care expenditures (42 billion International Dollars) among all countries included in the International Diabetes Federation (IDF) [32]. Data from the German population-based KORA (Cooperative Health Research in the Region of Augsburg) study showed that direct annual costs of individuals with type 2 diabetes were about 1.8 times higher than those of individuals without type 2 diabetes. Likewise, the indirect costs, i.e., costs resulting from work loss, were about 2.1 times higher [33].

Although age is an important risk factor for type 2 diabetes and, hence, the demographic situation in Germany provides a major part of the explanation for the high prevalence of the disease, there are still multiple modifiable risk factors that could be targeted by public health interventions and could decrease the incidence of new cases in future [32]. Furthermore, individuals with type 2 diabetes can take multiple self-management measures that can reduce their risk of comorbidities, worsening of the disease, and death [34-36].

Type 2 Diabetes Prevention and Management

Despite non-modifiable risk factors such as ethnicity, genetics, or age, there are some specifically lifestyle factors that are modifiable and can be considered as preventive for type 2 diabetes [32]. The most important modifiable risk factors are diet, obesity, and physical activity

[37-41]. However, smoking cessation and moderate alcohol consumption are also relevant modifiable risk factors [32].

Obviously, the mentioned risk factors for type 2 diabetes prevention are also most important for individuals who already live with type 2 diabetes in order to stop their disease from progression and prevent comorbidities [32, 35]. However, for individuals living with type 2 diabetes, there are multiple other recommended disease-specific self-management behaviors that can help to slow down progression of the disease and prevent comorbidities [35, 36]. Recommended self-management includes, but is not limited to, the monitoring of body weight, regular foot care, regular blood pressure and blood sugar measurement, keeping a diabetes diary, and keeping to a diet [34, 42].

Behavioral Economics and Type 2 Diabetes

Many facets in the prevention and management of type 2 diabetes make the disease an ideal use case for interventions advised by behavioral economics [11, 43]. For example, the prevention and management of type 2 diabetes requires individuals to adopt new behaviors or alter old ones [44]. Thus, SQB might be a relevant factor in explaining individual differences in behavior adaptation and behavior change [11]. For example, SQB can be used to improve the success rates of goals such as regular gym visits or smoking cessation [10]. Bhattacharya et al (2015) showed that a longer duration of commitment contracts leads to more weeks of successful exercising [45]. Moreover, making the healthy option the default, i.e., the more convenient choice, increased the number of healthy choices made in a fast food restaurant [46].

Furthermore, the alteration of old habits and the adoption of new ones produces immediate costs, but remote benefits. Therefore, time preferences might play a role in explaining differences in adherence to recommended self-management behavior [21, 30, 47]. For example, time preference could also be targeted with pre-commitment devices [10, 19]. Other than that, making the later reward, e.g., positive health outcomes, more salient in the present is supposed to be effective in increasing physical activity [48, 49].

Finally, respective risks and benefits are uncertain. Hence, it requires accurate forecasts in order to enable individuals to undertake adequate and informed decision-making [13, 50, 51]. Therefore, unrealistic comparative optimism might prevent individuals from taking action when it comes to reducing future health risks [26]. Although few studies have targeted unrealistic comparative optimism to initiate behavior change or improve adherence [26], Avis et al (1989) have reported that feedback can improve the accuracy of individuals' risk perception [28].

However, knowledge about the relevance and applicability of behavioral economic theory to improve health behavior is still scarce, especially in real-world settings [52, 53].

A Need for Large-Scale Studies

As described by Galizzi and Wiesen (2018), it was just recently that health economics started to show interest in behavioral economics and respective experimental studies [52]. Consequently, Loewenstein et al (2017) rely mostly on laboratory experiments and economic modeling, and less on field studies, when they write about promising health policy interventions that are inspired by the first behavioral economic studies in the health sector [53].

At this time, experimental studies have shown mixed results of economic interventions on health behaviors such as exercising [54], smoking, or diet [53, 55, 56]. Possible reasons for this are manifold. However, one possibility is that laboratory experiments, despite all their advantages [52], do not reflect real-life decision-making because they are unhinged from other relevant factors such as culture, peer pressure, or habits [53]. Therefore, Loewenstein et al (2017) suggest that future behavioral economic research in the health sector should focus on large-scale randomized controlled trials in order to optimize behavioral economic interventions for the real world [53]. However, a necessary first step is to evaluate the measurability of behavioral economic phenomena and examine associated behaviors in large-scale observational studies. Only then can respective interventional studies be well designed and targeted.

Goal of the Dissertation

The overall goal of the thesis is to examine the relevance of behavioral economic aspects in explaining differences in health behavior in a large observational population-based cohort. In particular, health behaviors that are relevant to the prevention and management of diabetes were of interest. To reach this goal, the thesis utilized data from the German KORA study.

Specifically, this thesis consists of three essays. One looks at the association between SQB and health behavior at a population level. The other two essays examine the association between time preference, unrealistic comparative optimism, and self-management in individuals with type 2 diabetes.

Results and Conclusions of the Dissertation

Article 1 examines the association between SQB, health behavior, and body mass index (BMI) in the cross-sectional population-based KORA S4 study (1999–2001). To assess SQB, a natural experiment in the German health insurance system (i.e., freedom to switch health insurances since 1996) was combined with a question regarding hypothetical switching costs. Dependent variables were physical activity, diet, smoking and alcohol consumption, and BMI. The results showed a significant association between SQB and less physical activity and a higher BMI. In other words, a stronger preference for keeping the current health insurance plan was associated with physical inactivity and a higher BMI.

Article 2 examines the association between time preference and the self-management behavior of individuals with type 2 diabetes in the cross-sectional KORA GEFU 4 study (2016–2017). Time preference was measured by one question, which was answered on a 4-point Likert scale. Self-management was measured with six distinct self-managing behaviors and their sum score. Individuals with a high time preference showed poorer self-management. Specifically, individuals who considered their present well-being as more important than their future health status were less likely to conduct their self-management properly.

Article 3 examines the association between unrealistic comparative optimism with regard to heart attack risk and its association with self-management behavior in individuals with type 2 diabetes from the cross-sectional KORA GEFU 4 study (2016–2017). Unrealistic comparative optimism was estimated by comparing the participants' comparative risk perception with their actual comparative risk as calculated by the Framingham risk equation. Self-management was measured with six distinct self-managing behaviors and their sum score. Unrealistic comparative optimism was overly prevalent, i.e., individuals were more likely to underestimate their comparative risk than they were to overestimate their comparative risk. However, unrealistic comparative optimism was not associated with participants' self-management.

Implications

The included studies suggest small but significant associations between SQB and BMI in the general population, as well as between time preference and self-management behavior in individuals with type 2 diabetes. Unrealistic comparative optimism has been shown to be highly prevalent with regard to the perception of 5-year heart attack risk.

However, it is not advised to draw direct conclusions for respective public health interventions from these results. The main finding of this thesis is that the three behavioral economic aspects are indeed relevant when it comes to explaining health behavior at a population level. Beyond that, the three behavioral economic phenomena examined within this thesis as well as many others are often intertwined and sometimes hard to isolate from each other. Consequently, the effects described within the studies can hardly be interpreted as pure direct effects, and respective public health interventions are likely to produce externalities—within the best interest of the target group or not.

Therefore, it is important to examine respective interventional effects in controlled settings. Future research should focus on large-scale randomized controlled trials that use established tools such as taxes, education, and marketing as well as behavioral economic knowledge to create a natural decision environment [53]. Only such large-scale studies can provide results that are able to inform decision makers who aim to improve public health.

Generally, research on the mechanisms behind irrational decision-making, i.e., behavioral economics, is ongoing. Hence, the application of its findings in terms of nudges has just started. Nonetheless, first results are promising and motivating for further research.

Article 1

Status Quo Bias and Health Behavior: Findings from a Cross-Sectional Study

Published in:

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. Status quo bias and health behavior: findings from a cross-sectional study. European Journal of Public Health. 2019;29(5):992-7.

DOI: https://doi.org/10.1093/eurpub/ckz017

Article 2

Time Preference, Outcome Expectancy, and Self-Management in Patients with Type 2 Diabetes

Published in:

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. Time preference, outcome expectancy, and self-management in patients with type 2 diabetes. Patient Preference and Adherence. 2018;12:1937.

DOI: https://doi.org/10.2147/PPA.S175045

Article 3 (working paper)

The Association between Unrealistic Comparative Optimism and Self-Management in Individuals with Type 2 Diabetes: Results from a Cross-Sectional Population-Based Study

Working paper:

Karl FM, Holle R, Schwettmann L, Peters A, Meisinger C, Rückert-Eheberg IM, Laxy M. The association between unrealistic comparative optimism and self-management in individuals with type 2 diabetes: results from a cross-sectional population-based study. 2019.

RESEARCH ARTICLE WORKING PAPER

The association between unrealistic comparative optimism and self-management in individuals with type 2 diabetes: results from a cross-sectional population-based study

Florian M. Karl[1,2,*], Rolf Holle[1,2], Lars Schwettmann[1], Annette Peters[2,3], Christa Meisinger[3], Ina-Maria Rückert-Eheberg[3], Michael Laxy[1,2]

Abstract

Background: Self-management is crucial for preventing complications in people with type 2 diabetes. Unrealistic comparative optimism (UO), as the erroneous judgment of personal risks to be lower than the risks of others, could help to explain differences in self-management.

Methods: We used data from 633 individuals with type 2 diabetes participating in the German KORA (Cooperative Health Research in the Region of Augsburg) GEFU 4 (Health Follow-up 4) study (2016 – 2017). UO was estimated by comparing participants' comparative risk perception for having a heart attack within the next 5-years (i.e. "higher than that of other patients with type 2 diabetes of the same age", "about the same as that of other patients with type 2 diabetes of the same age", "lower than that of other patients with type 2 diabetes of the same age"), with the ratio between their calculated , and the mean 10-year cardiovascular disease risk (based on the Framingham equations) of people of their age. Binary logistic regression models examined which characteristics were associated with UO. We estimated binary logistic and linear regression models to test the association between UO and participants' self-management behaviors (i.e., monitoring of body weight, blood sugar, and blood pressure, regular foot care, keeping a diabetes diary, and having a diet plan), and their sum score, respectively. All models were adjusted for socio-demographic and disease-related variables.

Results: Individuals who smoke were more likely to show UO (OR = 4.94, 95% CI [2.51; 10.13]). Furthermore, participants with a higher blood pressure were more likely to be unrealistically optimistic regarding their comparative heart attack risk (OR = 1.03, 95% CI [1.01; 1.04]). However, UO was not significantly associated with patient self-management.

Conclusions: Unfavorable health behavior and risk factors are predictors for UO, however our results suggest that UO may not be a relevant factor for patient self-management.

Keywords: Adherence; Accuracy; Myocardial infarction; Heart attack; Optimistic bias; Optimism; Health behavior; Risk communication; Health belief model

[*] Correspondence: Florian.karl@helmholtz-muenchen.de

[1]Institute of Health Economics and Healthcare Management, Helmholtz Zentrum München (GmbH), German Research Center for Environmental Health, Ingolstädter Landstraße 1, 85764 Neuherberg, Germany.

Background

Type 2 diabetes is a major health concern worldwide and causes enormous societal costs [1, 2]. Previous studies have shown that good self-management can help to slow down progression of the disease, prevent the occurrence of comorbidities [3-5], reduce mortality and increase health-related quality of life [6, 7].

Unrealistic comparative optimism (UO), has been frequently suggested as a promising construct to explain health behavior and adherence in healthy and unhealthy individuals, and to ultimately tailor and improve interventions [8, 9]. UO describes the tendency for people to make the erroneous assumption that they are less likely than others to experience a negative (health) event, e.g. a heart attack [9-11]. The personal risk perception, relative and absolute, has been identified as a relevant factor for explaining preventive behavior [12]. Furthermore, other authors have reported that UO plays a role in all factors included in the Health Belief Model [8]. Therefore, UO might help to explain differences in preventive behaviors, e.g. self-management in patients with type 2 diabetes [8, 9]. As Shepperd et al. (2017) described, it is expected that individuals who show UO would show less preventive behaviors, i.e. self-management [13].

The general approach to measure UO starts with measuring comparative risk perception. The comparative risk perception is assessed by asking individuals to rate their personal risk of experiencing an event of interest relative to an appropriate peer. These ratings can be assessed with either direct or indirect methods [9, 10].

For the direct approach, participants are asked whether they consider themselves more likely, equally likely, or less likely, than the average person of their peer to experience a certain event [10]. On a group level, the assumption is that if the mean comparative risk judgement of a group is below average, then this group shows UO at a group level [9]. For example, Weinstein (1982) used the direct approach and identified a lack of experience regarding the outcome of interest as a main predictor of UO at a group level [14]. However, this approach allows no conclusion about UO at an individual level [9].

The indirect approach combines two items. First, the participants are asked to rate their personal likelihood of experiencing the event of interest, and second, to rate the likelihood of experiencing the event of interest for the average person within their peer group. The difference score between both responses is considered the amount of comparative optimism or pessimism respectively [10]. For example, Kim & Niederdeppe (2013) used an indirect approach and reported that comparative optimism had a moderating role in predicting intention to self-protect against H1N1 [15].

However, both the direct and the indirect approach do not account for the actual individual-level risk of people. Hence, they do not determine whether the individuals' comparative judgments are actually unrealistic [10]. This can only be examined with the use of an objective comparator [9, 10]. With other words, participants' estimates whether they are more likely, less likely, or equally likely to experience a specific event need to be compared with an objective comparator in order to test UO on an individual level. In health research, epidemiological risk equations are a practical option to measure people's objective risk to experience a specific event [9, 10, 16-18].

One leading cause of death in individuals with type 2 diabetes is myocardial infarction (MI) [19]. Therefore, an accurate risk perception with regard to MI is important for individuals with type 2 diabetes. Studies that analyzed UO regarding MI on an individual level are less frequent and mainly concentrate on predictors of UO [13]. For example, Avis et al. (1989) found that higher education was associated with a lower probability for UO [16]. Furthermore, Radcliffe and Klein (2002), reported that disease-specific education was associated with a lower probability for UO [18]. Moreover, Ayanian and Cleary (1999) found that smokers older than 64 years were more likely to show UO regarding their MI risk [20]. Otherwise, Strecher at al. (1995) reported that young smokers (18–29 years), individuals with lower education, and females were more likely to show UO [21].

To the best of our knowledge, there have been only a few studies on the association between UO and health behavior [13]. In a study that is unrelated to diabetes and heart attack risk, Dillard et al. (2009) reported higher rates of unpleasant alcohol-related events, e.g.

hangover or memory loss, among unrealistically optimistic individuals [22]. However, at the time of this study, we found no studies on the association between UO and self-management in individuals with type 2 diabetes.

In this study, we intended to measure individual-level UO with regard to the risk of suffering a MI with a method that is very similar to the way it has been proposed by Avis et al. (1989) [16]. We compared participants' comparative risk judgments for having a heart attack (i.e. "higher than that of other patients with type 2 diabetes of the same age", "about the same as that of other patients with type 2 diabetes of the same age", "lower than that of other patients with type 2 diabetes of the same age") with their objectively calculated individual comparative risk of having a cardiovascular disease (CVD) based on the Framingham risk equations. Subsequently, we examined the characteristics associated with UO, and tested the hypothesis that individuals who show UO have a lower adherence rate with regard to recommended self-management in a sample of 633 individuals with type 2 diabetes.

Methods

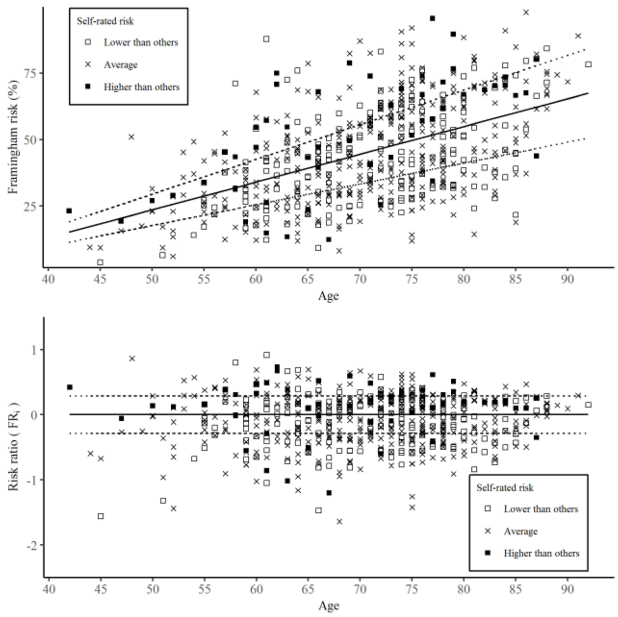
Data source

We used data from the German KORA GEFU 4 study (Cooperative Health Research in the Region of Augsburg, Health Follow-up 4). KORA is a regional research platform that was established to conduct population-based surveys and subsequent follow-up studies in the fields of epidemiology, health economics, and health care research [23, 24]. GEFU 4 was a cross-sectional postal survey conducted from 2016 to 2017. All participants from the population-based MONICA S1 (1984–1985, n = 4,022), MONICA S2 (1989–1990, n = 4,940), MONICA S3 (1994–1995, n = 4.856), and KORA S4 (1999–2001, n = 4,261) studies (n = 11,189) were invited and n = 9,035 individuals responded to the main postal questionnaire. Of those, all participants who were known to have diabetes (n = 1,025) received an additional diabetes-related questionnaire. 837 participants with diabetes responded to this diabetes-related questionnaire, 746 of them with type 2 diabetes. Of these 746 participants, 81 completed only a telephone interview that did not answer the study relevant risk perception question. Finally, n = 633 completed the key question on risk perception in the questionnaire.

Assessment of UO

Our assessment of UO was oriented to a study by Avis et al. (1989) [16].

Figure 1. Distribution of calculated Framingham risks and cut-offs for UO and UP.



UO = unrealistic comparative optimism; UP = unrealistic comparative pessimism. The upper part of Figure 1 shows the calculated Framingham risk (F_i) plotted for every individual. The solid line represents the mean risk prediction dependent on age (FP_i). The dotted lines show the non-logarithmic cut-offs for the risk ratio (FR_i) between F_i and FP_i. The lower part of Figure 1 shows the natural logarithm of the risk ratio ($ln(FR_i)$) for every individual. The solid line represents no difference (ln(1)) and the dotted lines represent the cut-offs for $ln(FR_i)$, i.e., below average (ln(0.75)) and above average (ln(1.33)).

First, we assessed the individuals' self-rated risk in comparison with other patients of their age with type 2 diabetes with the following question: "Do you believe that your personal risk of suffering a heart attack within the next 5 years is higher than that of other patients with type 2 diabetes of your age?" The response categories were (1) "yes, I believe my personal risk is higher", (2) "I believe my risk is about the same", and (3) "no, I believe my risk is lower".

Second, in order to be able to compare the individuals' self-rated comparative risk with their actual comparative risk, we calculated the "office-based" Framingham risk (%), as described by

D'Agostino et al. (2008) [25]. The score uses age, sex, body mass index (BMI), systolic blood pressure distinguished by treatment status, smoking status, and diabetes status to estimate the individual 10-year risk of suffering a CVD [26].

Third, we calculated the ratio (FR_i) of each individual's calculated Framingham risk (F_i) and the mean calculated risk of people of the respective age (FP_i). The FP_i was estimated as $FP_i = \beta_0 + age_i * \beta_{age}$ based on the distribution of calculated Framingham risks in our sample because participants were instructed to state their risk relative to other people of their *age* with diabetes. As described by Avis et al., we used $ln(FR_i)$ and the cut-offs $ln(0.75)$ and $ln(1.33)$ in order to create a symmetric distribution and equal "risk distances" [16]. See Figure 1.

Individuals with $ln(FR_i) < ln(0.75)$ were considered to have a risk below average, and individuals with $ln(FR_i) > ln(1.33)$ were considered above average. Finally, we compared the self-rated risk with the calculated risk category [16]. When individuals self-rated their comparative risk as below average, but their calculated comparative risk was average or above average, they were grouped with UO. Moreover, when individuals self-rated their comparative risk as average but their calculated comparative risk was above average they were also grouped with UO. For Unrealistic comparative pessimism (UP), the grouping was done accordingly. See Table 1 for an overview. It results from this approach that individuals with a low calculated risk ($ln(FR_i) < ln(0.75)$) could not be grouped with UO, and individuals with a high calculated risk ($ln(FR_i) > ln(1.33)$) could not be grouped with UP. To approach this conceptual limitation, we excluded individuals with a low calculated risk ($ln(FR_i) < ln(0.75)$) and individuals with a high calculated risk ($ln(FR_i) > ln(1.33)$) from all further analyses on UO (underestimation of comparative risk) and UP (overestimation of comparative risk) respectively. See Table 1 for an overview.

Table 1. Comparison between self-rated and calculated comparative risk.

	Objective relative risk		
Self-rated risk	Below average	Average	Above average
"Lower than others"	n = 65[a] (Accurate)	n = 112[b] (UO)	n = 23[c] (UO)
"Average"	n = 110[d] (UP)	n = 200[e] (Accurate)	n = 69[f] (UO)
"Higher than others"	n = 9[g] (UP)	n = 27[h] (UP)	n = 18[i] (Accurate)

Note. UO = unrealistic comparative optimism; UP = unrealistic comparative pessimism. The cells with colored background were excluded from some parts of the analysis. Specifically, individuals with an objective relative risk below average (lighter gray) were excluded from analyses regarding UO because per definition they could not be grouped with UO. Likewise, individuals with an objective relative risk above average (darker gray), were excluded from analyses regarding UP because per definition they could not be grouped with UP. [a,b,c,d,e,f,g,h,i] The superscript letters are used as reference to the respective cell in the description of Table 3.

Assessment of self-management

Our measures of self-management included the following dimensions: monitoring of body weight (at least once per week), conducting regular foot care (checking for wounds at least once per week), measuring blood sugar (at least once a day for patients treated with insulin and at least once a week for all others), measuring blood pressure (at least once per week), keeping a diabetes diary, and having a diet plan. We asked participants to consider the last 6 months for their answers ((1) "daily", (2) "at least once per week", (3) "once or twice per month", (4) "less than once per month"). Furthermore, we combined the six self-managing behaviors into a self-management score. In this score, one point was attributed per criterion in every individual, as proposed by Arnold-Wörner et al. (2008) [27]. A similar score has been shown to be highly predictive for all-cause mortality in patients with type 2 diabetes, where 44% of all deaths were due to CVD [6].

Covariates

To calculate the Framingham risk (%), we derived BMI from body height measured at the respective baseline study and self-reported body weight at the time of GEFU 4. Age, sex, systolic blood pressure, blood pressure treatment status (medication), and smoking status were also based on self-report at GEFU 4. Other than that, we assessed whether participants' treatment regimen included the injection of insulin, as we assumed treatment with insulin as an indicator for disease severity. Furthermore, we assessed education (primary education, ≤ 10 years of school; secondary/tertiary education, > 10 years of school) and whether participants had ever participated in a diabetes education program that was not part of routine care or during a hospital stay. Finally, we asked participants whether they had ever had a heart attack that was diagnosed by a physician.

Statistical analysis

In a first step, we calculated frequencies and means with regard to measured characteristics and self-management behaviors—overall and stratified for the three categories of self-rated comparative risk, i.e., "higher than others", "average", "lower than others".

Second, we regressed the self-rated comparative risk on the Framingham variables (i.e., age, sex, systolic blood pressure, blood pressure treatment status, BMI, and smoking status) and the variables education, participation in a diabetes education program, treatment with insulin, and history of MI. Likewise, UO and UP were regressed on the same set of variables in two separate binary logistic regression models.

Finally, we estimated binary logistic regression models and ordinary least square regression models to test the association between individual-level UO, UP, and the six measured self-management behaviors and their sum-score, respectively. We adjusted all models on the association with self-management for age, sex, BMI, blood pressure treatment status, systolic blood pressure, smoking status, education, participation in a diabetes education program, treatment with insulin, and history of MI. Additionally, we adjusted all models for self-rated risk. Thereby, we tried to disentangle the association between UO and self-management behavior from confounding by positive or negative self-view, i.e., self-rated risk "lower than others" or "higher than others". As described by Humberg et al. (2018), the mere positivtiy of self-view needs to be differentiated from the erroneous positive self-view, i.e. UO [28]. A p-value <0.05 was assumed to be statistically significant. Missing information in the items of the Framingham risk score was imputed using a predictive mean matching approach (see Table 2 for details) [29, 30]. Analysis was performed with R Studio [31].

Sensitivity analysis

The Framingham risk is supposed to be calculated only for individuals < 75 years of age and without a prior CVD. Therefore, we excluded individuals > 74 years or with a history of MI in our first sensitivity analysis (n = 356).

In our second sensitivity analysis, we approached the issue that individuals might have compared themselves within their gender, even though the question did not imply this. Therefore, we calculated the estimated mean risk (FP_i) based on age and sex ($FP_i = \beta_0 + age_i * \beta_{age} + sex_i * \beta_{sex}$). We then tested the association between UO and the assessed characteristics, as well as the association between UO and self-management similar to our main analysis.

In further sensitivity analyses, we examined the association between UO and self-management using different cut-offs for the calculated risk ratio ln(FR_i). We tested very sensitive cut-offs, i.e., $ln(0.86) < ln(FR_i) > ln(1.16)$, and very specific cut-offs, i.e., $ln(0.60) < ln(FR_i) > ln(1.66)$).

Results

Study sample

The analyzed sample included information from 633 individuals with a mean age of 70.7 years (sd = 9.1 years) and 55% males. The mean self-management score was about the same in all groups of self-rated risk. All details on the characteristics are given in Table 2.

Table 2. Characteristics for the complete sample and self-rated risk groups.

			Self-rated risk					
	Total (n = 633)		*Lower than others* (n = 200)		*Average* (n = 379)		*Higher than others* (n = 54)	
Framingham variables	*n or mean*	*% or sd*	*n or mean*	*% or sd*	*n or mean*	*% or sd*	*n or mean*	*% or sd*
Age	70.7	9.1	71.1	8.6	70.8	9.2	69.2	10.8
Male	349	55.1	112	56	199	52.5	38	70.4
Smoking (yes)	66	10.4	16	8.0	42	11.1	8	14.8
BMI (kg/cm^2)	29.8	5.0	30.2	4.90	30.1	4.94	29.1	5.15
Blood pressure treatment (yes)	502	79.3	141	70.5	313	82.6	48	88.9
Systolic blood pressure (mmHg)	132.4	15.9	132.1	16.0	131.8	14.9	137.8	20.5
Framingham risk (%)	45.2	18.7	43.7	17.1	45.1	19.0	51.9	21.2
Covariates								
Higher school education	260	41.1	94	47.2	150	39.6	38	70.4
Insulin therapy (yes)	127	20.1	36	18.2	76	20.1	15	27.8
D. education (yes)	336	53.7	94	47.2	206	55.2	36	66.7
MI history (yes)	66	10.4	18	9.00	32	8.4	16	29.6
Self-management								
Weigh oneself (≥ 1 per week = 1)	352	55.9	123	61.8	197	52.3	32	59.3
Wound checking (≥ 1 per week = 1)	348	55.9	116	58.9	200	53.8	32	59.3
Blood sugar (≥ 1 per week = 1 or ≥ daily when treated with insulin = 1)	235	40.8	76	41.3	140	41.1	19	37.3
Blood pressure (≥ 1 per week = 1)	305	48.8	100	50.8	180	48.1	25	46.3
Keeping a diabetes diary (yes = 1)	171	27.6	50	25.4	107	28.8	14	26.9
Having a diet plan (yes = 1)	57	9.2	20	10.2	30	8.2	7	13.2
SMB score (0–6)	2.3	1.6	2.4	1.6	2.3	1.5	2.4	1.6

Note. D. education = diabetes education program (yes), MI = myocardial infarction. The variables used for calculating the Framingham risk were essential to our study. Within the 633 individuals who self-rated their comparative MI risk, we found n = 67 missing values for systolic blood pressure, n = 3 missing values for smoking status, and n = 11 missing values for BMI. In order to avoid loss of power for our analysis, we decided to apply a predictive mean matching approach, as introduced by Little (1988) [29], within the variables that were relevant to the calculation of the Framingham risk. The imputation was performed with the R package "Mice" [30].

Associations between the individuals' characteristics and self-rated risk, UO and UP

Overall, 32% of the participants rated their MI risk lower than that of others, while only 9% rated their risk higher than that of others. Males and individuals with a history of MI were more likely to self-rate themselves with a higher than average risk of suffering a MI in the future. Individuals treated for high blood pressure were less likely to self-rate their risk lower than that of other type 2 diabetes patients of their age (Table 3, upper half).

Within the studied sample, 32% of individuals showed UO – i.e. have a higher or equal calculated Framingham risk compared to other patients with type 2 diabetes of the same age but think their risk is average or lower than average, respectively.

Otherwise, 23% showed UP – i.e. have a lower or equal calculated Framingham risk compared to other patients with type 2 diabetes of the same age but think their risk is average or higher than average, respectively. Males, smokers, individuals with a higher BMI, a higher blood pressure and no history of MI were more likely to underestimate their comparative risk, i.e. to show UO. Accordingly, males, smokers, individuals with a higher blood pressure and with no history of MI were less likely to overestimate their comparative risk, i.e. to show UP. Furthermore, older individuals were less likely to show UP (Table 3, lower half).

Table 3. Associations between the individuals' characteristics and self-rated risk, unrealistic comparative optimism and unrealistic comparative pessimism

	(1) "Lower than others" (n = 200)	(2) "Higher than others" (n = 54)
	OR [95% CI]	*OR [95% CI]*
Age/10	1.06 [0.86; 1.30]	0.80 [0.55; 1.15]
Male sex	0.92 [0.64; 1.32]	**2.00 [1.07; 3.88]**
Smoking (yes)	0.65 [0.34; 1.19]	1.49 [0.59; 3.42]
BMI	0.97 [0.94; 1.01]	1.01 [0.94; 1.07]
Blood pressure treatment	**0.49 [0.32; 0.74]**	1.74 [0.74; 4.82]
Blood pressure	1.00 [0.99; 1.01]	1.02 [1.00; 1.03]
Education	1.36 [0.95; 1.95]	0.56 [0.29; 1.04]
Insulin therapy (yes)	1.02 [0.63; 1.62]	1.21 [0.59; 2.40]
Diabetes education program (yes)	0.74 [0.52; 1.07]	1.43 [0.76; 2.74]
MI history	0.93 [0.50; 1.67]	**3.97 [1.95; 7.89]**
	(3) UO (n = 204)	(4) UP (n = 136)
	OR [95% CI]	*OR [95% CI]*
Age/10	1.14 [0.89; 1.46]	**0.64 [0.48; 0.84]**
Male sex	**5.17 [2.96; 9.34]**	**0.11 [0.06; 0.19]**
Smoking status	**4.94 [2.51; 10.13]**	**0.17 [0.05; 0.47]**
BMI	**1.06 [1.01; 1.10]**	0.97 [0.93; 1.02]
Blood pressure treatment	1.29 [0.74; 2.29]	0.75 [0.43; 1.32]
Blood pressure	**1.03 [1.01; 1.04]**	**0.94 [0.92; 0.96]**
Education	1.20 [0.79; 1.82]	0.67 [0.41; 1.09]
Insulin therapy (yes)	0.99 [0.58; 1.68]	0.83 [0.44; 1.54]
Diabetes education program (yes)	0.85 [0.56; 1.30]	1.21 [0.75; 1.95]
MI history	**0.51 [0.26; 0.96]**	**2.19 [1.03; 4.58]**

Note. UO = unrealistic comparative optimism; UP = unrealistic comparative pessimism. The association of patient characteristics with low comparative risk perception, high comparative risk perception, UO and UP was examined in four binary logistic regressions (1 – 4). (1) Participants in cells d, e, f, g, h and i were used as reference to the participants in cells a, b and c (compare Table 1). (2) Participants in cells a, b, c, d, e and f were used as reference to the participants in cells g, h and i (compare Table 1). (3) Participants in cells e, h and i were used as reference to the participants in cells b, c and f (compare Table 1). (4) Participants in cells a, b and e were used as reference to the participants in cells d, g and h (compare Table 1).

Association between UO, UP, and the participants' self-management

Overall, we found no significant association between the measured UO or UP and the six self-management behaviors (see Tables 4 and 5). However, the association of UO with self-management was predominantly negative in its direction (OR<1), while the association of a positive self-view, i.e., rating the personal risk lower than that of others, with self-management was positive (OR>1). Furthermore, a positive self-view was significantly associated with regular blood pressure measurement and having a diet plan (Table 4).

Sensitivity analysis

In the subset of individuals under 75 years of age and without a prior CVD we found very similar associations as reported for our main analysis. However, the association between BMI and UO was not significant anymore and participation in a disease specific education program was associated with a lower prevalence of UO.

When the objective comparator was based on a comparison between the calculated individual risk and the mean risk of individuals of the respective age *and* sex, smoking and a higher blood pressure were significantly associated with UO. Detailed results are provided in the Additional file 1.

The results of this and all other sensitivity analyses showed no significant associations between UO and patient self-management. However, when the objective comparator was based on a comparison between the calculated individual risk and the mean risk of individuals of the respective age *and* sex, the sum of self-management behaviors was significantly lower in individuals with UP. Moreover, using more specific cut-offs, individuals with UP were more likely to have a diet plan (Additional file 2).

Discussion

In this study, we measured individual UO with regard to the risk of suffering a MI by comparing participants' comparative risk judgments for having a MI with the ratio between their calculated CVD risk and the mean CVD risk of people of their age. Subsequently, we examined the characteristics associated with UO, and tested the hypothesis that individuals who show UO have a lower adherence rate with regard to recommended self-management in a sample of 633 individuals with type 2 diabetes. We found that 32% of the participants in our study rated their personal MI risk lower than average compared with other individuals of their age with type 2 diabetes, while only 9% rated it higher. Moreover, individuals were about 1.4 times more likely to show UO than to show UP concerning their MI risk. Specifically, individuals with no history of MI, males, smokers, and individuals with a higher blood pressure were more likely to show UO. The associations of these characteristics with UP were reversed. Finally, our main analysis showed no association between UO and self-management behavior.

The relatively high frequency of unrealistically optimistic responses compared to unrealistically pessimistic responses on a group level, as well as on an individual level, was not surprising. Similar results were reported in former studies [16, 18], and with respect to other negative events on a group level [8, 11, 32], and on an individual level [17, 33]. One reason for the predominantly optimistic responses may be the person-positivity bias [9, 34]. Person-positivity bias states that individuals dehumanize the "average person", which leads to a worse rating of the "average person" [34], hence to a better self-rating [9]. Other approaches to debiasing UO were summarized by Rose (2012) and Chambers & Windschitl (2004) [35, 36].

Most of the results regarding participant characteristics that were associated with UO are in line with findings from previous studies. Individuals with a history of MI were less likely to show UO concerning heart attack risk in our study. Likewise, the very first studies by Weinstein (1980, 1982) or Helweg & Shepperd (2001) found that personal experience was associated with less prevalent UO [10, 11, 14].

Homko et al. (2010) reported that in a sample of individuals with type 2 diabetes males had a lower comparative risk perception than females when they were asked to compare their CVD risk with others of their age and sex [36]. In our main analysis, males were also more likely than females to show UO. However, when the objective comparator was based on a comparison between the calculated individual risk and the mean risk of individuals of the respective age *and* sex in our sensitivity analysis, this association was not significant anymore. Therefore, it is likely that the association in our main analysis resulted from males and females comparing themselves to other individuals of their age and sex, even though the question did not imply this.

Smokers were more likely to show UO in our study. Strecher et al. (1995), also reported that smokers were more likely to show UO [21]. Furthermore, Ayanian et al. (1999) reported that many smokers

Table 4. Association between UO and the participants' self-management

n = 449	Weigh oneself ᵝ	Wound checking ᵝ	Blood sugar testing ᵝ	Blood pressure testing ᵝ	Keeping a diabetes diary ᵝ	Having a diet plan ᵝ	Sum-score #
	OR [95% CI]	*OR [95% CI]*	*OR [95% CI]*	*OR [95% CI]*	*OR [95% CI]*	*OR [95% CI]*	*β [95% CI]*
UO							
Unadjusted	0.99 [0.68; 1.44]	1.12 [0.77; 1.63]	1.22 [0.82; 1.82]	0.90 [0.62; 1.30]	0.98 [0.63; 1.50]	1.08 [0.55; 2.11]	–0.01 [–0.32; 0.30]
Adjusted	0.84 [0.43; 1.62]	0.93 [0.47; 1.84]	1.00 [0.45; 2.19]	0.58 [0.29; 1.13]	0.89 [0.39; 1.99]	0.41 [0.10; 1.33]	–0.21 [–0.70; 0.28]
Positive self-view	1.35 [0.69; 2.68]	1.38 [0.68; 2.81]	1.63 [0.72; 3.73]	**2.29 [1.14; 4.70]**	1.12 [0.48; 2.63]	**3.40 [1.02; 13.73]**	0.46 [–0.05; 0.98]
Age	1.03 [0.81; 1.31]	1.01 [0.79; 1.28]	1.08 [0.82; 1.43]	1.25 [0.98; 1.60]	1.22 [0.90; 1.66]	1.18 [0.77; 1.86]	0.12 [–0.05; 0.30]
Sex	1.10 [0.64; 1.89]	0.86 [0.49; 1.51]	0.94 [0.49; 1.83]	0.79 [0.46; 1.38]	0.96 [0.50; 1.87]	1.79 [0.72; 4.83]	–0.15 [–0.55; 0.26]
Smoking status	0.58 [0.30; 1.12]	0.84 [0.43; 1.67]	1.51 [0.70; 3.26]	1.02 [0.52; 1.99]	1.13 [0.48; 2.58]	1.84 [0.56; 5.42]	–0.07 [–0.56; 0.41]
BMI	0.99 [0.95; 1.04]	0.99 [0.95; 1.03]	1.00 [0.95; 1.05]	1.00 [0.96; 1.05]	0.98 [0.93; 1.04]	1.01 [0.93; 1.08]	0.00 [–0.04; 0.03]
Blood pressure treatment	0.94 [0.53; 1.65]	1.21 [0.69; 2.15]	0.98 [0.51; 1.92]	1.67 [0.94; 3.03]	1.12 [0.53; 2.49]	0.92 [0.36; 2.69]	0.08 [–0.34; 0.50]
Blood pressure	1.01 [0.99; 1.02]	1.01 [1.00; 1.03]	0.99 [0.97; 1.01]	1.00 [0.98; 1.01]	1.00 [0.99; 1.02]	1.02 [1.00; 1.04]	0.00 [–0.01; 0.01]
Education	0.98 [0.66; 1.46]	0.84 [0.56; 1.26]	**0.60 [0.37; 0.95]**	0.78 [0.52; 1.16]	0.79 [0.48; 1.31]	0.72 [0.34; 1.49]	**–0.30 [–0.60; –0.01]**
Insulin	1.03 [0.63; 1.70]	**2.57 [1.52; 4.44]**	**6.94 [3.90; 12.8]**	**1.68 [1.01; 2.83]**	**6.81 [3.98; 11.8]**	1.79 [0.77; 3.97]	1.28 [0.92; 1.64]
D. education	1.18 [0.79; 1.76]	1.39 [0.93; 2.09]	**2.32 [1.46; 3.70]**	1.22 [0.81; 1.84]	**1.83 [1.11; 3.06]**	1.47 [0.70; 3.15]	**0.44 [0.15; 0.74]**
MI history	1.38 [0.76; 2.59]	1.19 [0.64; 2.23]	1.25 [0.62; 2.50]	1.56 [0.84; 2.97]	0.94 [0.45; 1.92]	1.01 [0.32; 2.67]	0.19 [–0.25; 0.64]

Note. UO = unrealistic comparative optimism. The dotted line separates the unadjusted model from the adjusted model. ᵝ binary logistic regression analysis, # linear regression analysis, D. education = diabetes education program (yes), Positive self-view = rating one's personal risk lower than that of others. In the analysis for Table 4, we only included individuals with an average or comparatively high Framingham risk (n = 449). Values significant at a level of $p < 0.05$ are printed in bold type.

Table 5. Association between UP and the participants' self-management

n = 523	Weigh oneself ß	Wound checking ß	Blood sugar testing ß	Blood pressure testing ß	Keeping a diabetes diary ß	Having a diet plan ß	Sum-score #
	OR [95% CI]	*OR [95% CI]*	*OR [95% CI]*	*OR [95% CI]*	*OR [95% CI]*	*OR [95% CI]*	*β [95% CI]*
UP							
Unadjusted	0.84 [0.57; 1.23]	1.20 [0.81; 1.78]	0.98 [0.65; 1.47]	0.93 [0.63; 1.36]	1.32 [0.86; 2.01]	1.43 [0.74; 2.66]	0.02 [–0.31; 0.35]
Adjusted	0.66 [0.38; 1.12]	0.92 [0.53; 1.59]	1.08 [0.58; 2.00]	0.96 [0.56; 1.66]	1.50 [0.78; 2.87]	1.44 [0.57; 3.59]	–0.03 [–0.43; 0.37]
Negative self-view	1.42 [0.60; 3.44]	1.13 [0.47; 2.75]	0.57 [0.21; 1.51]	0.76 [0.31; 1.81]	0.44 [0.14; 1.32]	1.30 [0.33; 4.56]	–0.20 [–0.85; 0.45]
Age	0.90 [0.72; 1.13]	1.03 [0.82; 1.28]	1.07 [0.83; 1.38]	**1.44 [1.15; 1.80]**	1.22 [0.93; 1.62]	1.05 [0.73; 1.54]	0.13 [–0.03; 0.30]
Sex	0.81 [0.52; 1.26]	**0.62 [0.40; 0.98]**	1.34 [0.80; 2.25]	1.01 [0.65; 1.59]	0.91 [0.52; 1.59]	1.17 [0.54; 2.60]	–0.11 [–0.44; 0.22]
Smoking status	**0.30 [0.12; 0.70]**	**0.37 [0.15; 0.86]**	2.16 [0.85; 5.52]	0.79 [0.33; 1.86]	1.13 [0.36; 3.28]	1.91 [0.49; 6.23]	–0.20 [–0.84; 0.45]
BMI	0.98 [0.94; 1.02]	1.01 [0.96; 1.05]	1.03 [0.98; 1.08]	1.03 [0.99; 1.07]	1.00 [0.95; 1.05]	1.01 [0.94; 1.08]	0.01 [–0.02; 0.04]
Blood pressure treatment	0.82 [0.52; 1.27]	1.09 [0.70; 1.71]	1.15 [0.69; 1.91]	**1.83 [1.17; 2.89]**	1.02 [0.59; 1.80]	0.58 [0.29; 1.22]	0.05 [–0.28; 0.39]
Blood pressure	1.00 [0.99; 1.02]	0.99 [0.98; 1.01]	0.99 [0.98; 1.01]	0.99 [0.98; 1.01]	1.00 [0.98; 1.02]	1.00 [0.97; 1.03]	0.00 [–0.02; 0.01]
Education	0.70 [0.47; 1.02]	0.82 [0.56; 1.21]	0.76 [0.49; 1.17]	0.87 [0.59; 1.27]	0.87 [0.54; 1.40]	1.06 [0.54; 2.05]	–0.27 [–0.56; 0.02]
Insulin	1.62 [0.98; 2.74]	**3.31 [1.92; 5.91]**	**5.79 [3.33; 10.44]**	1.28 [0.78; 2.12]	**9.50 [5.53; 16.73]**	**2.37 [1.13; 4.84]**	**1.42 [1.05; 1.78]**
D. education	1.13 [0.78; 1.64]	0.99 [0.68; 1.45]	**2.60 [1.70; 4.00]**	1.19 [0.82; 1.74]	1.46 [0.91; 2.34]	1.66 [0.84; 3.37]	0.29 [0.00; 0.57]
MI history	1.54 [0.82; 2.99]	1.49 [0.79; 2.89]	1.20 [0.60; 2.41]	1.48 [0.79; 2.83]	1.02 [0.47; 2.13]	0.94 [0.29; 2.49]	0.29 [–0.18; 0.76]

Note. UP = unrealistic comparative pessimism. The dotted line separates the unadjusted model from the adjusted model. ß binary logistic regression analysis, # linear regression analysis, D. education = diabetes education program (yes), Negative self-view = rating one's personal risk higher than that of others. In the analysis for Table 5, we only included individuals with an average or comparatively low Framingham risk (n = 523). Values significant at a level of $p < 0.05$ are printed in bold type.

did not perceive themselves at increased MI risk when asked to compare themselves with non-smokers [20]. The association between increased blood pressure and UO, which was very robust towards any alterations in our sensitivity analyses, has not been reported in previous studies that examined UO. Therefore, smokers and individuals with higher blood pressure seem to underestimate the increased heart attack risk that results from their respective behavior or characteristic.

The results of our main analysis show that UO and UP were not associated with the measured self-management behaviors. This was surprising because theory suggests that UO is a relevant factor in explaining health behavior [8, 10, 13]. As Shepperd et al. (2017) described, we would have expected that individuals who showed UO would show less preventive behaviors, i.e. self-management [13]. However, our results suggest that UO is not a relevant target when aiming to improve the adherence to self-management recommendations in individuals with type 2 diabetes.

Otherwise, there are characteristics of our study design that might help to explain some of our null results. One explanation could be the domain specificity of UO. Weinstein (1982) showed that mean comparative risk judgments varied between different health threats [14]. Hence, the measure of UO and the outcome of interest need to be directly associated with each other. Five of our self-management measures, i.e., monitoring of body weight, measuring blood sugar, measuring blood pressure, keeping a diabetes diary, and having a diet plan, are highly relevant for the prevention of a MI. However, UO with regard to MI might not be representative of an unrealistic risk perception regarding the diabetic foot syndrome. Thus, at least the null association in wound checking could be explained by the health threat specificity of UO. Furthermore, it is possible that a participant is not aware of the association between a behavior and the outcome of interest. Thus, some participants might have been unaware of the link between some of the self-management behaviors and MI, e.g. association between blood sugar testing and MI. Future research should test the participants' awareness of the link between the outcome of interest and the respective behavior. Moreover, there is some critique regarding the Framingham risk equation as the objective comparator. Like other risk engines, e.g. United Kingdom Prospective Diabetes Study (UKPDS), the Framingham risk equations have been shown to be only moderately effective in discriminating between individuals at high risk and low risk [26]. Therefore, some individuals who had been grouped with UO might actually have given an accurate risk estimate and vice versa. However, the main problem reported with regard to the Framingham risk equation has been the overestimation of risk, which does not affect ranking [26], and thus does not affect the comparative risk rankings.

We tried to disentangle the association between UO and self-management behavior from confounding by a positive self-view. Therefore, we included positive self-view, i.e. self-rated risk "lower than others", as an additional covariate in our regression model. The results suggest that UO and positive self-view have opposing effects on self-management. Therefore, future studies should consider similar adjustments when examining the association between UO and health behavior.

Our study has several limitations. It is a general concern in surveys that self-report data suffer recall bias. However, it is of even greater concern in our study where we based the objective comparator, i.e., Framingham risk, on self-reported data. Nonetheless, a study by Okura et al. (2004) supports the use of self-reported information on at least MI and hypertension, as they reported a very high correlation between self-report and clinical records, i.e., 98% and 88% respectively [37]. Furthermore, our covariates "history of MI" and "participation in a disease specific education program" were not adjusted for their timely distance to our survey. Moreover, person-positivity bias might have affected the participants' responses to our subjective risk question [34]. Future studies could consider not making participants compare themselves with an "average person" but with one specifically described comparator that represents an average person. For example, Chock (2011) found that comparative optimism with regard to the healthfulness of lifestyle decreased when college students were asked to compare themselves with their best friend [38]. Another concern is that we assessed MI risk perception while comparing it with the CVD risk. However, due to the similarity of risk factors for MI and CVD and the resulting linearity between the absolute risks for MI and CVD, asking for CVD risk is justifiable [39]. Finally, our comparative risk question instructed participants to compare their risk with the risk of other patients with type 2 diabetes of their age. Hence, the instruction did not include sex specificity as most of the previous studies did [9, 16]. Accordingly, our main analyses compared the individual comparative risk perception with the ratio between the calculated individual risk and the mean risk of people of the respective age. However, as it is possible that participants compared themselves with peers of the same age and sex, we also estimated the objective comparative risk based on a comparison between the calculated individual risk and the mean risk of individuals of the respective age *and* sex. Although the overall pattern of associations was qualitatively quite similar, some of the associations of our main analysis were not significant any longer. Given this result, we can at least not exclude the possibility that some of the participants might have compared themselves with other individuals of their age *and* sex, even though the comparative risk question did not imply this. Therefore, we would recommend using an age and sex specific question in the future.

Conclusion

In light of our comprehensive main and sensitivity analyses, we conclude that there are robust associations between smoking status, increased blood pressure, and UO. Thus, participants were likely to underestimate the effects that smoking and high blood pressure have on their heart attack risk. However, we found no significant association between UO and self-management. Thus, in our sample, targeting UO with regard to heart attack risk would probably not improve the self-management of the individual.

Abbreviations

BMI: Body-mass index; CVD: Cardiovascular disease; F: Calculated Framingham risk (%); FP: Framingham risk (%) predicted, i.e. mean calculated Framingham risk (%) of people of the respective age; FR: Framingham risk (%) ratio, i.e. the ratio of each individual’s calculated Framingham risk (%) and the mean calculated risk of people of the respective age (%); GEFU 4:Health Follow-up 4; KORA: Cooperative Health Research in the Region of Augsburg; MI: Myocardial infarction; UKPDS: United Kingdom Prospective Diabetes Study; UO: Unrealistic comparative optimism; UP: Unrealistic comparative pessimism

Funding

Not applicable.

Availability of data and materials

The data that support the findings of this study are available from KORA (https://www.helmholtz-muenchen.de/en/kora/for-scientists/cooperation-with-kora/index.html) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. However, data can be requested through an individual project agreement with KORA via the online portal KORA.passt (https://epi.helmholtz-muenchen.de/).

Authors’ contributions

FMK, RH, LS, AP, CM, IMRE and ML conceptualized the paper. FMK, RH, LS and ML performed the statistical analysis and FMK, RH, LS and ML interpreted the data. FMK and ML drafted the manuscript. RH, LS, AP, CM, IMRE and ML were involved in the coordination and the data acquisition of the KORA GEFU 4 study. All authors critically reviewed the final draft of the manuscript.

Ethical approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the ethics committee of the Bavarian Medical Association and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.
Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

Not applicable.

Author details

[1]Institute of Health Economics and Healthcare Management, Helmholtz Zentrum München

(GmbH), German Research Center for Environmental Health, Ingolstädter Landstr. 1, 85764 Neuherberg, Germany. [2]German Center for Diabetes Research (DZD), Ingolstädter Landstr. 1, 85764 Neuherberg, Germany [3]Institute of Epidemiology, Helmholtz Zentrum München, GmbH, German Research Center for Environmental Health, Ingolstädter Landstr. 1, 85764 Neuherberg, Germany

Received: 17 April 2019, under review since: 13 May

References

1. World Health Organization. Global Report on Diabetes. Geneva: World Health Organization; 2016.
2. Ulrich S, Holle R, Wacker M, Stark R, Icks A, Thorand B, et al. Cost burden of type 2 diabetes in Germany: results from the population-based KORA studies. BMJ open. 2016;6(11).
3. American Diabetes Association. Prevention or Delay of Type 2 Diabetes: Standards of Medical Care in Diabetes—2018. Diabetes Care. 2018;41(Supplement 1):S51-S4.
4. 4. Houle J, Beaulieu MD, Chiasson JL, Lespérance F, Côté J, Strychar I, et al. Glycaemic control and self-management behaviours in Type 2 diabetes: results from a 1-year longitudinal cohort study. Diabet Med. 2015;32(9):1247-54.
5. Stratton IM, Adler AI, Neil HAW, Matthews DR, Manley SE, Cull CA, et al. Association of glycaemia with macrovascular and microvascular complications of type 2 diabetes (UKPDS 35): prospective observational study. BMJ. 2000;321(7258):405-12.
6. Laxy M, Mielck A, Hunger M, Schunk M, Meisinger C, Ruckert IM, et al. The association between patient-reported self-management behavior, intermediate clinical outcomes, and mortality in patients with type 2 diabetes: results from the KORA-A study. Diabetes Care. 2014;37(6):1604-12.
7. Cochran J, Conn VS. Meta-analysis of quality of life outcomes following diabetes self-management training. Diabetes Educ. 2008;34(5):815-23.
8. Clarke VA, Lovegrove H, Williams A, Machperson M. Unrealistic optimism and the health belief model. J Behav Med. 2000;23(4):367-76.
9. Shepperd JA, Waters EA, Weinstein ND, Klein WM. A primer on unrealistic optimism. Curr Dir Psychol Sci. 2015;24(3):232-7.
10. Helweg-Larsen M, Shepperd JA. Do moderators of the optimistic bias affect personal or target risk estimates? A review of the literature. Pers Soc Psychol Rev. 2001;5(1):74-95.
11. Weinstein ND. Unrealistic optimism about future life events. J Pers Soc Psychol. 1980;39(5):806.
12. Brewer NT, Chapman GB, Gibbons FX, Gerrard M, McCaul KD, Weinstein ND. Meta-analysis of the relationship between risk perception and health behavior: the example of vaccination. Health Psychol. 2007;26(2):136.
13. Shepperd JA, Pogge G, Howell JL. Assessing the consequences of unrealistic optimism: Challenges and recommendations. Consciousness and Cognition. 2017;50:69-78.
14. Weinstein ND. Unrealistic optimism about susceptibility to health problems. J Behav Med. 1982;5(4):441-60.
15. Kim HK, Niederdeppe J. Exploring optimistic bias and the integrative model of behavioral prediction in the context of a campus influenza outbreak. J Health Commun. 2013;18(2):206-22.
16. Avis NE, Smith KW, McKinlay JB. Accuracy of perceptions of heart attack risk: what influences perceptions and can they be changed? Am J Public Health. 1989;79(12):1608-12.
17. Waters EA, Klein WM, Moser RP, Yu M, Waldron WR, McNeel TS, et al. Correlates of unrealistic risk beliefs in a nationally representative sample. J Behav Med. 2011;34(3):225-35.
18. Radcliffe NM, Klein WM. Dispositional, unrealistic, and comparative optimism: Differential relations with the knowledge and processing of risk information and beliefs about personal risk. Pers Soc Psychol Bull. 2002;28(6):836-46.
19. Morrish N, Wang S-L, Stevens L, Fuller J, Keen H, Group WMS. Mortality and causes of death in the WHO Multinational Study of Vascular Disease in Diabetes. Diabetologia. 2001;44(2):S14.
20. Ayanian JZ, Cleary PD. Perceived risks of heart disease and cancer among cigarette smokers. JAMA. 1999;281(11):1019-21.
21. Strecher VJ, Kreuter MW, Kobrin SC. Do cigarette smokers have unrealistic perceptions of their heart attack, cancer, and stroke risks? J Behav Med. 1995;18(1):45-54.
22. Dillard AJ, Midboe AM, Klein WM. The dark side of optimism: Unrealistic optimism about problems with alcohol predicts subsequent negative event experiences. Pers Soc Psychol Bull. 2009;35(11):1540-50.
23. Holle R, Happich M, Löwel H, Wichmann H. KORA-a research platform for population based health research. Gesundheitswesen. 2005;67(S 01):19-25.
24. Helmholtz Zentrum München German Research Center for Environmental Health. KORA, Kooperative Gesundheitsforschung in der Region Augsburg (Cooperative Health Research in the Augsburg Region) [Available from: https://www.helmholtz-muenchen.de/en/kora/index.html.
25. D'Agostino RB, Vasan RS, Pencina MJ, Wolf PA, Cobain M, Massaro JM, et al. General cardiovascular risk profile for use in primary care. Circulation. 2008;117(6):743-53.
26. Simmons RK, Coleman RL, Price HC, Holman RR, Khaw K-T, Wareham NJ, et al. Performance of the UK

prospective diabetes study risk engine and the Framingham risk equations in estimating cardiovascular disease in the EPIC-Norfolk cohort. Diabetes Care. 2009;32(4):708-13.

27. Arnold-Wörner N, Holle R, Rathmann W, Mielck A. The importance of specialist treatment, treatment satisfaction and diabetes education for the compliance of subjects with type 2 diabetes-results from a population-based survey. Experimental and Clinical Endocrinology & Diabetes. 2008;116(02):123-8.
28. Humberg S, Dufner M, Schönbrodt FD, Geukes K, Hutteman R, van Zalk MH, et al. Enhanced versus simply positive: A new condition-based regression analysis to disentangle effects of self-enhancement from effects of positivity of self-view. J Pers Soc Psychol. 2018;114(2):303.
29. Little RJ. Missing-data adjustments in large surveys. J Bus Econ Statist. 1988;6(3):287-96.
30. Van Buuren S, Oudshoorn C. mice: Multivariate Imputation by Chained Equations. R package version 1.16. 2007.
31. RStudio Team. RStudio: integrated Development for R. Boston, MA: RStudio, Inc.; 2015.
32. Walker EA, Caban A, Schechter CB, Basch CE, Blanco E, DeWitt T, et al. Measuring comparative risk perceptions in an urban minority population. The Diabetes Educator. 2007;33(1):103-10.
33. Walker EA, Mertz C, Kalten MR, Flynn J. Risk perception for developing diabetes: comparative risk judgments of physicians. Diabetes Care. 2003;26(9):2543-8.
34. Sears DO. The person-positivity bias. J Pers Soc Psychol. 1983;44(2):233.
35. Rose JP. Debiasing comparative optimism and increasing worry for health outcomes. J Health Psychol. 2012;17(8):1121-31.
36. Chambers JR, Windschitl PD. Biases in social comparative judgments: the role of nonmotivated factors in above-average and comparative-optimism effects. Psychol Bull. 2004;130(5):813.
37. Okura Y, Urban LH, Mahoney DW, Jacobsen SJ, Rodeheffer RJ. Agreement between self-report questionnaires and medical record data was substantial for diabetes, hypertension, myocardial infarction and stroke but not for heart failure. J Clin Epidemiol. 2004;57(10):1096-103.
38. Chock TM. The influence of body mass index, sex, and race on college students’ optimistic bias for lifestyle healthfulness. J Nutr Educ Behav. 2011;43(5):331-8.
39. Anderson KM, Odell PM, Wilson PW, Kannel WB. Cardiovascular disease risk profiles. Am Heart J. 1991;121(1):293-8.

References

1. Winslow C-E. The untilled fields of public health. *science*. 1920:23-33.
2. The German Public Health Association. Public Health [Online]: The German Public Health Association; 2019 [Available from: http://www.deutsche-gesellschaft-public-health.de/information/public-health/?L=1.
3. Bailey R, Harper DR. Reviewing interventions for healthy and sustainable diets. *Chatham House, The Royal Institute of International Affairs*. 2015.
4. Reisch LA, Sunstein CR, Gwozdz W. Beyond carrots and sticks: Europeans support health nudges. *Food Policy*. 2017;69:1-10.
5. World Health Organization. Obesity and Overweight [Online]: World Health Organization; 2019 [Available from: https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight.
6. Cecchini M, Sassi F, Lauer JA, Lee YY, Guajardo-Barron V, Chisholm D. Tackling of unhealthy diets, physical inactivity, and obesity: health effects and cost-effectiveness. *The Lancet*. 2010;376(9754):1775-84.
7. Tilman D, Clark M. Global diets link environmental sustainability and human health. *Nature*. 2014;515:518.
8. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Annals of Internal Medicine*. 2015;162(2):123-32.
9. Herholz A. "Wir wollen Krebs besiegen, indem wir ihn beherrschen". Rhein-Neckar-Zeitung. 2019 February 4th.
10. Matjasko JL, Cawley JH, Baker-Goering MM, Yokum DV. Applying behavioral economics to public health policy: illustrative examples and promising directions. *American Journal of Preventive Medicine*. 2016;50(5):S13-S9.
11. Thaler R, Sunstein CR. *Nudge. Improving decisions about health wealth and happiness*. London, England: Penguin Group; 2008.
12. Bhargava S, Loewenstein G. Behavioral economics and public policy 102: Beyond nudging. *American Economic Review*. 2015;105(5):396-401.
13. Thaler RH, Sunstein CR. Libertarian paternalism. *American Economic Review*. 2003;93(2):175-9.

14. Samuelson W, Zeckhauser R. Status quo bias in decision making. *Journal of Risk and Uncertainty*. 1988;1(1):7-59.

15. O'Donoghue T, Rabin M. Present bias: Lessons learned and to be learned. *American Economic Review*. 2015;105(5):273-9.

16. Weinstein ND. Unrealistic optimism about future life events. *Journal of Personality and Social Psychology*. 1980;39(5):806.

17. Roberto CA, Kawachi I. Use of psychology and behavioral economics to promote healthy eating. *American Journal of Preventive Medicine*. 2014;47(6):832-7.

18. Loewenstein G, Brennan T, Volpp KG. Asymmetric paternalism to improve health behaviors. *Journal of the American Medical Association*. 2007;298(20):2415-7.

19. Thaler RH, Benartzi S. Save more tomorrow™: Using behavioral economics to increase employee saving. *Journal of Political Economy*. 2004;112(S1):S164-S87.

20. Rice T. The behavioral economics of health and health care. *Annual Review of Public Health*. 2013;34:431-47.

21. Story G, Vlaev I, Seymour B, Darzi A, Dolan R. Does temporal discounting explain unhealthy behavior? A systematic review and reinforcement learning perspective. *Frontiers in Behavioral Neuroscience*. 2014;8:76.

22. Mischel W, Ebbesen EB. Attention in delay of gratification. *Journal of Personality and Social Psychology*. 1970;16(2):329.

23. Mischel W, Ebbesen EB, Raskoff Zeiss A. Cognitive and attentional mechanisms in delay of gratification. *Journal of Personality and Social Psychology*. 1972;21(2):204.

24. Beck H. Was ist Behavioral Economics? *Behavioral Economics*: Springer; 2014. p. 1-24.

25. Helweg-Larsen M, Shepperd JA. Do moderators of the optimistic bias affect personal or target risk estimates? A review of the literature. *Personality and Social Psychology Review*. 2001;5(1):74-95.

26. Shepperd JA, Pogge G, Howell JL. Assessing the consequences of unrealistic optimism: Challenges and recommendations. *Consciousness and Cognition*. 2017;50:69-78.

27. Shepperd JA, Waters EA, Weinstein ND, Klein WM. A primer on unrealistic optimism. *Current Directions in Psychological Science*. 2015;24(3):232-7.

28. Avis NE, Smith KW, McKinlay JB. Accuracy of perceptions of heart attack risk: what influences perceptions and can they be changed? *American Journal of Public Health*. 1989;79(12):1608-12.

29. Jansen LA, Mahadevan D, Appelbaum PS, Klein WM, Weinstein ND, Mori M, et al. Perceptions of control and unrealistic optimism in early-phase cancer trials. *Journal of Medical Ethics*. 2017:medethics-2016-103724.

30. Shuval K, Stoklosa M, Pachucki MC, Yaroch AL, Drope J, Harding M. Economic preferences and fast food consumption in US adults: Insights from behavioral economics. *Preventive Medicine*. 2016;93:204-10.

31. Simon-Tuval T, Shmueli A, Harman-Boehm I. Adherence to Self-Care Behaviors among Patients with Type 2 Diabetes—The Role of Risk Preferences. *Value in Health*. 2016;19(6):844-51.

32. International Diabetes Federation. IDF Diabetes Atlas Eighth Edition 2017 [Online]: International Diabetes Federation; 2017 [Available from: www.diabetesatlas.org.

33. Ulrich S, Holle R, Wacker M, Stark R, Icks A, Thorand B, et al. Cost burden of type 2 diabetes in Germany: results from the population-based KORA studies. *BMJ Open*. 2016;6(11).

34. Laxy M, Mielck A, Hunger M, Schunk M, Meisinger C, Ruckert IM, et al. The association between patient-reported self-management behavior, intermediate clinical outcomes, and mortality in patients with type 2 diabetes: results from the KORA-A study. *Diabetes Care*. 2014;37(6):1604-12.

35. American Diabetes Association. Prevention or Delay of Type 2 Diabetes: Standards of Medical Care in Diabetes—2018. *Diabetes Care*. 2018;41(Supplement 1):S51-S4.

36. Powers MA, Bardsley J, Cypress M, Duker P, Funnell MM, Fischl AH, et al. Diabetes self-management education and support in type 2 diabetes: a joint position statement of the American Diabetes Association, the American Association of Diabetes Educators, and the Academy of Nutrition and Dietetics. *Diabetes Educator*. 2017;43(1):40-53.

37. Ley SH, Hamdy O, Mohan V, Hu FB. Prevention and management of type 2 diabetes: dietary components and nutritional strategies. *The Lancet*. 2014;383(9933):1999-2007.

38. Dagenais GR, Auger P, Bogaty P, Gerstein H, Lonn E, Yi Q, et al. Increased occurrence of diabetes in people with ischemic cardiovascular disease and

general and abdominal obesity. *The Canadian Journal of Cardiology*. 2003;19(12):1387-91.

39. Hu FB, Manson JE, Stampfer MJ, Colditz G, Liu S, Solomon CG, et al. Diet, lifestyle, and the risk of type 2 diabetes mellitus in women. *New England Journal of Medicine*. 2001;345(11):790-7.
40. Association AD. Physical activity/exercise and diabetes mellitus. *Diabetes Care*. 2003;26(suppl 1):s73-s7.
41. Helmrich SP, Ragland DR, Leung RW, Paffenbarger Jr RS. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *New England Journal of Medicine*. 1991;325(3):147-52.
42. Arnold-Wörner N, Holle R, Rathmann W, Mielck A. The importance of specialist treatment, treatment satisfaction and diabetes education for the compliance of subjects with type 2 diabetes-results from a population-based survey. *Experimental and Clinical Endocrinology & Diabetes*. 2008;116(02):123-8.
43. Emoto N, Okajima F, Sugihara H, Goto R. Behavioral economics survey of patients with type 1 and type 2 diabetes. *Patient Preference Adherence*. 2015;9:649-58.
44. Walther D, Curjuric I, Dratva J, Schaffner E, Quinto C, Schmidt-Trucksäss A, et al. Hypertension, diabetes and lifestyle in the long-term — Results from a Swiss population-based cohort. *Preventive Medicine*. 2017;97(Supplement C):56-61.
45. Bhattacharya J, Garber AM, Goldhaber-Fiebert JD. Nudges in exercise commitment contracts: a randomized trial. National Bureau of Economic Research; 2015.
46. Wisdom J, Downs JS, Loewenstein G. Promoting healthy choices: Information versus convenience. *American Economic Journal: Applied Economics*. 2010;2(2):164-78.
47. Van Der Pol M, Hennessy D, Manns B. The role of time and risk preferences in adherence to physician advice on health behavior change. *European Journal of Health Economics*. 2016:1-14.
48. Shuval K, Leonard T, Drope J, Katz DL, Patel AV, Maitin-Shepard M, et al. Physical activity counseling in primary care: Insights from public health and behavioral economics. *CA: A Cancer Journal for Clinicians*. 2017;67(3):233-44.

49. Estabrooks PA, Glasgow RE, Dzewaltowski DA. Physical Activity Promotion Through Primary Care. *Journal of the American Medical Association*. 2003;289(22):2913-6.

50. Becker MH. The health belief model and sick role behavior. *Health Education Quarterly*. 1974;2(4):409-19.

51. Clarke VA, Lovegrove H, Williams A, Machperson M. Unrealistic optimism and the health belief model. *Journal of Behavioral Medicine*. 2000;23(4):367-76.

52. Galizzi MM, Wiesen D. Behavioral experiments in health economics. *Oxford Research Encyclopedia of Economics and Finance* 2018.

53. Loewenstein G, Hagmann D, Schwartz J, Ericson K, Kessler JB, Bhargava S, et al. A behavioral blueprint for improving health care policy. *Behavioral Science & Policy*. 2017;3(1):52-66.

54. Milkman KL, Minson JA, Volpp KG. Holding the Hunger Games hostage at the gym: An evaluation of temptation bundling. *Management Science*. 2013;60(2):283-99.

55. Volpp KG, Troxel AB, Pauly MV, Glick HA, Puig A, Asch DA, et al. A randomized, controlled trial of financial incentives for smoking cessation. *New England Journal of Medicine*. 2009;360(7):699-709.

56. Schwartz J, Mochon D, Wyper L, Maroba J, Patel D, Ariely D. Healthier by precommitment. *Psychological Science*. 2014;25(2):538-46.

Acknowledgment

First of all, I would like to thank my supervisor, Prof. Rolf Holle. He has supported me with the utmost patience and experience. Furthermore, I would like to thank Dr. Michael Laxy. As the leader of my working group and my most frequent interlocutor, he was substantially involved almost every step of the way.

Moreover, I would like to thank PD Dr. Lars Schwettmann, Prof. Reiner Leidl, and Prof. Klaus Parhofer for their support at the institute and at the thesis committee meetings. In particular, Dr. Lars Schwettmann has been more involved than one could expect.

Also, I would like to thank all my co-workers, especially Julia, Bogi, and Matthias, but also Johanna, Christoph, Sara, Florian, Renée, and Karl. Thank you for enabling me to enjoy every single day at the Helmholtz Center Munich.

Finally, I want to thank my family and friends, especially my parents Beate and Matthias, for their constant and loving support. I am most grateful to my wife Verena. She really listened to all my thoughts and worries and was my most valuable resource and confidante. Not one of the articles in this thesis does not include some of her valuable feedback and ideas. Thank you.

List of all Scientific Publications

Karl FM, Holle R, Schwettmann L, Peters A, Meisinger C, Rückert-Eheberg I-M, et al. The association between unrealistic comparative optimism and self-management in individuals with type 2 diabetes: results from a cross-sectional population-based study. *Working Paper*

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. The association between status quo bias and body mass index in a population-based longitudinal study. *Working Paper*.

Rabel M, Mess F, **Karl FM**, Pedron S, Schwettmann L, Peters A, Heier M, Laxy M. Change in physical activity after diagnosis of diabetes or hypertension: Results from an observational population-based cohort study. *International Journal of Environmental Research and Public Health*. 2019.

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. Status quo bias and health behaviour: results from a population-based study from southern Germany. *European Journal of Public Health*. 2019.

Karl FM, Holle R, Schwettmann L, Peters A, Laxy M. Time preference, outcome expectancy, and self-management in patients with type 2 diabetes. *Patient Preference and Adherence.* 2018;12:1937.

Karl FM, Tremmel M, Luzak A, Schulz H, Peters A, Meisinger C, et al. Direct healthcare costs associated with device assessed and self-reported physical activity: results from a cross-sectional population-based study. *BMC Public Health*. 2018;18(1):966.

Karl FM, Smith J, Piedt S, Turcotte K, Pike I. Applying the health action process approach to bicycle helmet use and evaluating a social marketing campaign. *Injury Prevention*. 2018;24(4):288-95.

Karl FM, Holle R, Bals R, Greulich T, Jörres RA, Karch A, et al. Costs and health-related quality of life in Alpha-1-Antitrypsin Deficient COPD patients. *Respiratory Research*. 2017;18(1):60.

Conferences

Conference of the International Diabetes Federation 2017; Presentation: Status Quo Bias explains Success in Weight Loss Attempts – Longitudinal Results from a Population based Study

Annual Meeting German Society for Health Economics 2019; Presentation: Status Quo Bias and Health Behavior: a Longitudinal Perspective; Augsburg, Germany

European Conference on Health Economics 2018; Poster: Do Patients with Type 2 Diabetes ignore Objective Factors when estimating Personal Heart Attack Risk?; Maastricht, Netherlands

Annual Meeting German Society for Health Economics 2018; Poster & Presentation: Behavioral Economic Approach to explain Self-management in Patients with Type-2 Diabetes; Hamburg, Germany

Conference of the International Diabetes Federation 2017; Poster: Can Behavioral Economic Insights Explain a Lifestyle Relevant for Type-2 Diabetes Prevention? Abu Dhabi, United Arab Emirates

Meeting of the International Diabetes Epidemiology Group 2017; Presentation: Behavioral Economic Approaches to explain Risky Health Behavior and Self-management relevant for Type-2 diabetes; Abu Dhabi, United Arab Emirates

Safety Worlds Conference 2016; Poster: Use of Health Action Process Approach & Propensity Score to evaluate a Social Marketing Campaign; Helsinki, Finland

Confirmation on Congruency

I hereby declare that the electronic version of the submitted thesis, entitled *The Role of Behavioral Economics in Diabetes Prevention and Management*, is congruent with the printed version in both content and format.

Munich, December 16, 2019	Florian M. Karl
Place, Date	Name