Keeping a cool head at all times. What determines choice consistency?

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Abstract

Many rational choice theories posit that rational decision makers assign subjective values to all available choice options and choose the option with highest subjective value. Choice options are usually composed of multiple attributes, e.g. healthiness and taste in dietary choice or risk and expected returns in financial choice. These attributes have to be integrated into a single subjective value. Subjective value maximizing choice requires choice consistency, i.e. consistent weighing of the choice attributes across choices. However, empirical work suggests that perfect choice consistency is often violated, for example when decision makers weigh choice attributes differently across multiple decisions. Some researchers propose to extend certain bounds of rationality or to abandon the concept of rationality as adherence to consistency principles altogether. A more conservative stance assumes that perfect consistency can be violated by decision makers in practice, but that consistency principles still can explain large parts of behavior. In a review of the recent literature, we identify factors for compromised consistency relative to baseline conditions. Broadly, we distinguish between undynamic trait factors and fluid state factors. We find evidence for an influence of age, education, intelligence, and neurological status. In contrast, choice consistency appears to be relatively robust to the influence of sex, personality traits, cognitive load, sleepiness and blood alcohol levels. We conclude, that, according to the current state of the literature, only fundamental differences in decision makers, that is, trait differences, have a significant impact on choice consistency.

Keywords: Choice consistency, rationality, trait factors, state factors

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Should you order one glass of champagne, a large *Stein* of Bavarian beer, or rather a non-alcoholic carafe of water? Choice theory posits that decision makers assign subjective values to all choice alternatives, rank order them according to their value, and choose the alternative with the highest value. The above example illustrates that choice alternatives are often composed of multiple attributes, e.g. magnitude (one glass, one carafe, one *Stein*), healthiness (alcoholic vs. non-alcoholic, sugar content etc.), subjective taste (the sourness of champagne vs. the bitterness of beer), cultural value or other components. Decision theory assumes that all of these attributes are integrated into a single subjective value. Importantly, the importance of taste as well as all other attributes is subjective and differs between individuals. Hence, in many decisions, there is no single best alternative. Instead, we have to deal with trade-offs of different choice attributes: In our diet we have to weigh taste, healthiness, magnitude or other factors. In financial decisions we have to weigh risk and expected returns, as well as the time until we can realize those returns. In such situations, our decisions depend on our individual preferences – so how can we measure decision making quality or rationality?

Because preferences are subjective, they are undisputable, an insight already noted by Immanuel Kant (1790). Positivist economic theories of rationality are agnostic about the specific direction of preferences. Instead they define rationality by placing bounds on preference structure, often in the form of consistency principles (Sugden, 1991). One example for a consistency principle is transitivity: If a decision maker chooses a glass of champagne over a glass of beer, and a glass of beer over a glass of water, she should also choose a glass of champagne over a glass of water. Decision makers who adhere to those consistency principles are assumed to choose their most preferred choice alternative, and, hence, make optimal choices. Table 1 provides an overview of different formalizations of choice consistency and their interdependence.

Hence, choice consistency is considered a hallmark of rational choice. That is, in order for a decision maker to always choose the best option according to their subjective preferences, she

needs to choose consistently. On the flipside, an inconsistent decision maker systematically foregoes better options in choice situations. For example, if a decision maker chose champagne over beer, and beer over water, but *not* champagne over water, she would make an inconsistent choice. Rational choice theory then implies, that at least one chosen option along that choice chain would not be in accordance with the decision maker's true preferences. What is possibly worse, in a market situation, such a decision maker would continuously pay to swap water with beer, beer with champagne, and champagne with water again, thus, she would inevitably lose wealth and would, ultimately, be driven out of the market (this is the so-called *money pump* phenomenon).

Inferring the underlying preference structure of decision makers is non-trivial: Simply asking people about their preferences often gives conflicting results to actual choice behavior (MacDonald et al., 2009): People do not do what they say. Revealed preference theory (Houthakker, 1950; Samuelson, 1938; Varian, 1982) infers the underlying preference structure from behavior and allows for a theoretically sound test of choice consistency: that is, whether a decision maker has a definite structure of wants, acts cost efficient and acyclic (Afriat, 1973). Figure 1 provides schematic representation of a choice attribute weighing process compliant with revealed preference theory.

However, empirical work suggests that perfect consistency is often violated. Violations can occur when decision makers weigh choice attributes differently across multiple decisions. An inconsistent decision maker would assign variable weights to healthiness and taste in dietary choices, or to risk, expected returns and time of returns in financial choices, respectively: Choice inconsistency across multiple choices would imply that the different choice attributes (healthiness and taste; risk, expected returns, and time of returns) are differentially important to the decision maker across choices and may be considered to a further or lesser extent. For example, an inconsistent decision maker may mostly consider healthiness in one choice and mostly taste in another, leading her to choose the sugary option at one time, and the healthy option at another time. Under certain conditions, such inconsequential weighting of choice attributes can lead to violations of consistency principles, such as transitivity, or others (cf. table 1).

Some researchers propose to extend certain bounds of choice consistency (Rieskamp et al., 2006) or to abandon the concept of rationality as adherence to consistency principles altogether (Gigerenzer & Selten, 2002). This would have important theoretical implications — the rationality assumption is at the core of most economics, game theory and decision theory — and practical implications for the justification of policy decisions.

We are going to adopt a conservative stance of assuming that perfect consistency can be violated by decision makers in practice, but that consistency principles still can explain large parts of behavior. There are several sophisticated goodness of fit measures that quantify the degree to which choice behavior is consistent (Dean & Martin, 2016; Echenique et al., 2011; Heufer & Hjertstrand, 2015; Varian, 1993). The most prominent of these measures is Afriat's critical cost efficiency index (Afriat, 1972, 1973; Varian, 1993), which has been used in many studies on choice consistency as defined by revealed preference theory (Andreoni & Miller, 2002; Banks et al., 2018; Bruyneel et al., 2012; Burghart et al., 2013; Cappelen et al., 2014; Castillo et al., 2017; Choi et al., 2007, 2014; Drichoutis & Nayga, 2017; Harbaugh et al., 2001; Kim et al., 2018; Lazzaro et al., 2016). The critical cost efficiency index is inspired by the fact that inconsistent choice behavior is not cost efficient. With given prices of choice options, the budget determines all affordable choice options. A revealed preference violation occurs, when the decision maker does not choose the most preferred alternative that was affordable given the budget, but selects another less preferred option. This can be interpreted as a waste of money, as the decision maker did not obtain the maximum subjective value for her money. The critical cost efficiency index denotes the minimal hypothetical reduction of the budget of the decision maker necessary, so that all more preferred but not chosen options become unaffordable when the revealed preference violation occurred. A critical cost efficiency index of 1 denotes perfect consistency: The budget does not need to be reduced. The index approaches zero as the behavior becomes more inconsistent and the budget needs to be reduced starkly to eliminate inconsistency. It is possible to impose (arbitrary) consistency bounds on choice behavior (Varian, 1993) or to benchmark choice behavior against simulated random choices

(Bronars, 1987). Simulated choices can also be used to determine the statistical power of a revealed preference test. An in our eyes sensible approach is comparing different experimental conditions regarding choice consistency or relating choice consistency to other variables in a correlational data set. This allows for identifying determinants of choice consistency without requiring perfect consistency under neutral conditions. Identifying such determinants is crucial from at least three stances:

1. From a theoretical point of view, the robustness of relative choice consistency is informative about the generalizability of axiomatic choice theory beyond idealized conditions only found in thought experiments and the laboratory.
2. From a practitioner point of view, identifying detrimental factors for decision quality helps to optimize decision processes for human decision makers and the selection of decision makers with highest expected performance.
3. From a societal point of view, the identification of influences on the quality of individual financial decisions might provide powerful levers to fight socioeconomic inequality.

Scope of this literature review

Empirical work on rationality has been reviewed extensively by Rieskamp (2006). Specifically, Rieskamp focuses on whether or to which degree choice behavior can be reunited with axiomatic choice theory. In contrast, we will identify factors for compromised consistency relative to baseline conditions from recent literature instead of searching for a definite test of axiomatic choice theory as a concept.

We believe, that the term *rationality* bears different meanings in different fields and, therefore, is an umbrella term for theoretically different concepts. In order to avoid normative debates on the meaning of rationality, in the remainder of this review article, we will use the term *choice consistency* instead. While, as mentioned, choice consistency is considered a hallmark of rationality in many axiomatic choice theories and, therefore, bears important theoretical relevance, choice consistency is no necessary condition for rationality as defined by all fields of research. For

example, Pham (2007) provided a multi-disciplinary review on the influence of emotion on rationality, specifically. While the scope of this review appears to be related to ours, Pham (2007) defines rationality without reference to revealed preference theory and, therefore, ultimately addresses a different question. We will interpret studies in terms of choice consistency even when the original publication uses the term rationality, as long as rationality is operationalized through revealed preference theory. For the purpose of this review, we are only considering choice data that are interpreted within the revealed preference framework, which we consider one of the most rigorous approaches to conceptualize and quantify choice consistency. We are by no means implying that other frameworks, or model-free analyses, yield less meaningful conclusions, but they do differ in their conceptual underpinning, and are, hence, difficult to compare (see below for a brief discussion of other consistency indices). We are going to differentiate between trait and state factors, as we find this to be the most intuitive structure of the current research on influence factors of choice consistency. Table 2 provides a concise summary of our findings.

Trait factors of choice consistency

In the next section we are going to review studies that investigated the effect of trait factors on choice consistency. As trait factors we consider temporally undynamic factors which are often subject to interindividual but less to intraindividual variability.

Age

Harbaugh et al. (2001) investigated food choice consistency in 7- and 11-year-old children and undergraduates. In their experimental task, participants had to choose one out of set of snack bundles for a total of 11 trials. Each snack bundle consisted of specific amounts of bags of chips and boxes of juice. Participants were ensured that at the end of the study one randomly selected trial would be paid out to them. In total, 31 second graders (7 years old) and 42 sixth graders (11 years old) and 55 undergraduates (21 years old) were included for the study. The study found a significant decrease in the number of inconsistent choices from second to sixth grade. However, this result did not hold for the critical cost efficiency index.

A similar design was deployed by Bruyneel et al. (2012) who investigated food choice consistency in kindergarteners, third graders and sixth graders with ages ranging from 5 to 12 years (on average 8 years). Similar to Harbaugh et al. (2001), participants had to choose one out of a set of snack bundles for a total of 9 trials. Each snack bundle consisted of specific amounts of grapes, tangerines and letter biscuits. Participants were ensured that at the end of the study one randomly selected trial would be paid out to them. In total, 39 kindergarteners, 31 third graders and 30 sixth graders were included for the study. The study found that belonging to the kindergartener group was a significant predictor of committing inconsistent choices. However, again, this result did not hold for the critical cost efficiency index at a significance level of 5%.

Echenique et al. (2011) investigated choice consistency in household-level food grocery purchases in a panel study of 494 households in an urban area of large mid-western US city between 1991 and 1993. The study found older households, with the average age of the spouses exceeding 65 years, were less consistent in their grocery purchases as measured by the money pump index, which is conceptually similar to critical cost efficiency index.

Choi et al. (2014) conducted an online study with 1,182 participants randomly selected from a survey designed to be representative of the Dutch population. In their experimental task, participants had to allocate a monetary endowment between two accounts. Both accounts were equally likely to be selected for payout: in half of the cases, the money in the first account would be selected for payout and in the other half, the second account would be selected. Importantly, the two accounts offered different relative returns. For example, the first account might offer double the returns of the second account or vice versa. The task challenged participants to balance expected value and variance of payout (risk). To maximize expected value, participants would need to allocate the complete monetary endowment to the account with higher relative returns. To minimize variance, participants would have to perfectly balance returns of the two accounts, so that both accounts would offer the same payout if they were selected. Except for rare cases, when both accounts offered equal relative returns, maximizing expected value and minimizing variance were

mutually exclusive strategies. Participants solved a total of 25 trials. At the end of the study one trial was randomly chosen and one of the two accounts corresponding to the trial was selected for payout. The study found that an age above 50 was a significant predictor of scoring a lower critical cost efficiency index.

Brocas et al. (2019) investigated choice consistency of younger (age 18 – 34) and older (age 59 – 89) adults in a simple and a complex choice task. The simple choice task was an adaptation of Harbaugh (2001), with choice bundles consisting of two different types of snacks. The complex choice task was an adaptation of Bruyneel et al. (2012), with choice bundles consisting of three different types of snacks. Each trial consisted of a choice between only two bundles. Note, that this was accounted for in the consistency analysis, effectively compromising the power of the consistency test. The study found that, in the complex choice task, the older adults violated choice consistency significantly more often and more severely than younger adults (using their own original measures of choice consistency). The study did not find a difference between younger and older adults for the simple choice task.

Dean & Martin (2016) investigated choice consistency in household-level food grocery purchases in a panel study of 977 representative households in the Denver metropolitan area from 1993 to 1995. The study did not find a significant influence of age on choice consistency at a 5% significance level.

Chung, Tymula & Glimcher (2017) included 39 healthy adults over the age of 65 with functionally normal Mini-Mental State Examination scores for a study using whole-brain voxel-based morphometry. They used an experimental task conceptually similar to Harbaugh et al. (2001), where participants had to choose one out of a set of bundles of small presents. Each bundle consisted of specific amounts of two types of presents (e.g. sudoku books, cross word puzzles), which were previously rated to be desired by the participants. In their age restricted sample, they did not find that age was correlated with choice inconsistency. However, the authors largely attribute this to a statistical power problem.

Overall, there is evidence that both young and old age compromise choice consistency to some extent. However, the reported effects of young age predominantly show for the number of inconsistent choices. This measure of inconsistency does not distinguish between minor and major violations of consistency, which could lead to an overestimation of the effect size. More research is necessary especially for the effect of young age, to provide more robust effect size estimations and to investigate the causal mechanisms for potential age effects on choice consistency. Moreover, in most samples, the age of children is confounded with the amount of formal education they received. We, therefore, evaluate the role of education in making consistent choices in the following.

Education

Echenique et al. (2011) found that less educated households were significantly less consistent in their grocery purchases as measured by the money pump index (a consistency measure conceptually similar to the critical cost efficiency index).

Cappelen et al. (2014) addressed the question whether there is a development gap in choice consistency between the United States and Tanzania. They included students from one of the most reputable universities in each country, namely UC Berkeley and the University of Dar es Salaam. Nevertheless, the Tanzanian and the US subjects differed substantially in sociodemographic and economic backgrounds. The study used the experimental task of Choi et al. (2014), in which participants had to allocate monetary endowments between two risk accounts, for a total of 50 trials. 126 students from the US and 216 students from Tanzania were included. They found that students from Tanzania were significantly less consistent than students from the US as measured by the critical cost efficiency index. However, both samples displayed a high degree of choice consistency and the authors consider the reported differences in choice consistency as economically irrelevant.

Choi et al. (2014) also assessed the education level. They found that a high level of education was a significant predictor for scoring a higher critical cost efficiency index.

Kim et al. (2018) investigated the effect of education in a randomized-controlled design, by randomly granting a 1-year financial support program for education among 2812 female Malawi students. The program reduced absence and drop-out rates and increased scores in a qualification exam. The study measured choice consistency by lab-in-the-field experiments. Their task consisted of 20 choice trials in the risk domain, and additional 30 trials in the time domain. The risk domain task was similar to the task of Choi et al. (2014). In the time domain task, participants had to allocate money between two accounts with different payment dates. The study found, that receiving the education intervention was a significant predictor for a higher critical cost efficiency index in ninth graders for both choice domains, but not for tenth graders.

Dean & Martin (2016) found no significant influence of education on choice consistency in their dataset.

Banks, Carvalho & Perez-Arce (2018) assessed whether an educational reform in England affected choice consistency. They used the task of Choi et al. (2014) for a total of 25 trials. The *1972 Raising of the School Leaving Age Order* increased minimum allowed age to leave school from 15 to 16. The authors carried out an online panel study with 2,700 participants born between September 1, 1954 and August 31, 1960 who left school at age 16 or younger. They did not find an effect of the educational reform on choice consistency.

Overall, there is evidence for a positive relationship of education on choice consistency. However, a causal effect of education seems to be especially pronounced in younger children, as the educational intervention in Kim et al. (2018) did affect choice consistency of ninth graders but not tenth graders and Banks, Carvalho & Perez-Arce (2018) did not find an effect of an educational reform increasing the minimum allowed age to leave school from 15 to 16. Since both studies used a large sample, their null (sub-)findings are unlikely due to a lack of statistical power.

Income

Household income is, generally, correlated with choice consistency as measured by the critical cost efficiency index or similar measures (Banks et al., 2018; Choi et al., 2014; Echenique et

al., 2011). However, the direction of this relationship is unclear. By definition, inconsistent choice leads to loss of wealth (money pump phenomenon; see above). On the other hand, a surge of income can increase access to education and, thus, indirectly increase choice consistency (Kim et al., 2018). Hence, while choice consistency and income seem to be closely intertwined, causal inference of a direct influence of income on choice consistency is beyond what is allowed for by the data at this point.

Intelligence

Bruyneel et al. (2012) also assessed mathematical, language and creative abilities of children through teacher ratings. They found that lower mathematical abilities predicted inconsistent choices and a lower critical cost efficiency index. Interestingly, the opposite pattern was found for language abilities: Higher language abilities predicted inconsistent choices and a lower critical cost efficiency index.

Choi et al. (2014) also assessed intelligence using the Cognitive Reflection Test (Frederick, 2005), which consists of three arithmetic riddles. Importantly, every riddle has an intuitive, but false answer. The cognitive reflection test is strongly correlated with measures of intelligence, but is not an intelligence test per se (Frederick, 2005). It has been shown to be related to decision making biases. Choi et al. found that the score of the Cognitive Reflection Test was significantly correlated with the critical cost efficiency index.

Brocas et al. (2019) also assessed intelligence using Raven's Matrices Test (Raven, 1983), a visual pattern-detection task. They found that lower intelligence was significantly correlated with number and severity of choice inconsistencies in the complex choice task. However, as the authors note themselves, a causal interpretation is not possible due to their sampling plan: They found that younger adults scored significantly higher in the Raven's Matrices Test than older adults, which confounds the result on intelligence with an age effect.

Harbaugh et al. (2001) investigated, in a subsample of 37 sixth graders (11 years old), whether choice consistency was related to performance in the Oregon Mathematics Problem Solving

Assessment, an hour-long test of mathematical achievement for students. They did not find a significant correlation between both measures. However, due to the small size of the subsample the absence of evidence should not be interpreted as evidence of absence.

Overall, there is preliminary evidence for the relationship of intelligence and choice consistency. However, as Bruyneel et al. (2012) note, there are meaningful differences between different measures of intelligence which can explain divergent results. Future studies on the relationship of intelligence and choice consistency should deploy standardized and validated measures of intelligence.

Neurological status

Camille, Griffiths, Vo, Fellows, & Kable (2011) investigated the impact of ventromedial frontal lobe damage on choice consistency. The ventromedial frontal cortex is a brain region relevant for the representation of choice value (Levy & Glimcher, 2012). Therefore, it is a natural region of interest for investigating questions of choice consistency in the sense of subjective value maximization. Camille et al. (2011) used the experimental task of Harbaugh et al. (2001), substituting bags of chips for chocolate bars as a second type of snacks besides boxes of juice. The study included 9 participants with ventromedial frontal lobe damage and 22 age-, and education-matched controls. The study found that patients violated choice consistency significantly more often and scored a lower critical cost efficiency index than healthy controls.

Chung, Tymula & Glimcher (2017) also investigated the relationship of age-related grey matter brain atrophy and choice consistency. They found that a reduction of grey matter density in the ventro-lateral prefrontal cortex correlated significantly with higher frequency of inconsistent choices and a lower critical cost efficiency index. Furthermore, they found, in a meta-analysis, that the ventrolateral prefrontal cortex is often co-activated with regions relevant for choice value such as the ventro-medial prefrontal cortex, which substantiates the results of Camille et al. (2011).

Overall, there is preliminary evidence for the impact of impairments of value-related regions on choice consistency. Note, that the reviewed studies used only a relatively small sample size, so that conclusions should be drawn cautiously.

However, the importance of value-related regions for choice consistency finds additional support in the functional brain imaging study of Kurtz-David et al. (2019). Kurtz-David et al. (2019) used the experimental task of Choi et al. (2014) for a total of 108 trials. The study found that trial-specific choice inconsistency is correlated to functional activity in the ventro-medial prefrontal cortex, the anterior and the posterior cingulate cortex. Trial-specific inconsistency was measured by the money metric index (Halevy et al., 2018), which is conceptually similar to the critical cost efficiency index, applying a leave-one-out procedure.

Sex and menstrual cycle

Choi et al. (2014) found that female sex was a significant predictor for a lower critical cost efficiency index, but their correlational design does not allow for a causal interpretation.

Lazarro et al. (2016) compared choice consistency of females over all phases of the menstrual cycle to male controls. They used the experimental task of Harbaugh et al. (2001), substituting bags of chips for chocolate cookies and boxes of juice for ounces of milk. The study included 39 females tested during all 4 phases of the menstrual cycle and 36 male controls. They found high levels of consistency (mean critical cost efficiency index larger than 0.95) across all menstrual cycle phase and no difference to their male counterparts.

Overall, based on the reviewed studies there is no sufficient evidence for sex differences in choice consistency.

Personality traits

Cappelen et al. (2014) also assessed personality traits via the Big Five Inventory (John et al., 1991). None of the Big Five factors, namely Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism, significantly predicted choice consistency as measured by the

critical cost efficiency index. Concludingly, there is no evidence that personality traits affect choice consistency. However, this conclusion is only based on a single study.

State factors of choice consistency

In the next sections we are going to review studies that investigated the effect of state factors on choice consistency. As state factors we consider temporally dynamic factors which are subject to inter- and intraindividual variability

Choice domain

Choice consistency has been tested in various domains, such as food choice (Bruyneel et al., 2012; Burghart et al., 2013; Camille et al., 2011; Harbaugh et al., 2001; Lazzaro et al., 2016), decisions under risk (Castillo et al., 2017; Choi et al., 2007, 2014; Drichoutis & Nayga, 2017; Kim et al., 2018), intertemporal choice (Andreoni & Sprenger, 2012; Chakraborty et al., 2017; Kim et al., 2018), altruistic decisions (Andreoni & Miller, 2002) and moral intuitions (Barbato et al., 2017). However, direct cross-domain comparisons have not been attempted to date. So far, Kim et al. (2018) is the only study that assessed choice consistency in two domains within the same sample. They do not report stark qualitative or quantitative differences in choice consistency with regard to the two different domains. Harbaugh et al. (2001) note, that they find more violations of consistent choice in food choice than Andreoni & Miller (2002) in social choice. However, the studies vary in their statistical power to detect inconsistent choices and sample composition, so that any differences cannot be clearly attributed to an effect of the choice domain.

Overall, it is unclear whether there are choice domain effects on choice consistency. Future studies should deploy choice tasks in multiple domains to ensure generalizability of results. Furthermore, a direct test of choice domain effects is required.

Cognitive Load

Drichoutis & Nayga (2017) investigated the effect of cognitive load on choice consistency. They used the experimental task of Choi et al. (2014) for a total of 60 trials. Furthermore, participants underwent 5 trials of a mental addition task, a mental multiplication task and a click-a-

button task each. To manipulate cognitive load, participants had to solve an incentivized number-memorization task in parallel to the main task of each trial. Subjects in the high cognitive load treatment had to memorize 8-digit numbers, participants in the low cognitive load treatment had to memorize 1-digit numbers. The experiment included a total of 178 undergraduate participants from the Agricultural University of Athens, Greece. While the cognitive manipulation affected performance in the two mental arithmetic tasks it did not affect choice consistency in any considered measure, including the critical cost efficiency index. A post hoc power analysis showed that the study design was able to detect even small differences in choice consistency. Concludingly, there is no evidence that cognitive load affects choice consistency. However, this conclusion is only based on a single study.

Sleepiness

Castillo et al. (2017) investigated the effect of sleepiness on choice consistency. They used the experimental task of Choi et al. (2014) for a total of 50 trials. To manipulate sleepiness, participants were randomly assigned to an experimental session at a preferred time of the day relative to their diurnal preference or at a non-preferred time. The experiment included a total of 202 participants, with 115 participants doing the experiment at a preferred time. While the manipulation successfully affected sleepiness, there was no significant difference in choice consistency between both groups as measured by the critical cost efficiency index. Concludingly, there is no evidence that sleepiness affects choice consistency. However, this conclusion is only based on a single study.

Alcohol

Burghart et al. (2013) investigated the effect of blood alcohol concentration on choice consistency. They recruited participants from a bar in Manhattan, New York to conduct a field choice study. Blood alcohol concentration was measured by breath alcohol concentration. They used the experimental task of Harbaugh et al. (2001), substituting bags of chips for mini burgers and boxes of juice for dumplings. The study included a total of 101 participants with blood alcohol concentrations

mostly uniformly distributed between 0.020% and 0.125%. Expected effects for these values range from minimal effects to major impairments of mental and physical control. The study found that blood alcohol concentration did not significantly predict choice consistency as measured by the critical cost efficiency index. Concludingly, there is no evidence that blood alcohol concentration affects choice consistency. However, this conclusion is only based on a single study.

Methodological caveats

Replications

A problem with drawing conclusions from the current literature on choice consistency is the lack of replications. While a few factors of choice consistency, such as age and education, have been the target of multiple studies, many of the reported effects have neither been replicated directly nor conceptually. Direct replications accumulate data to improve the precision of effect size estimates via meta-analysis. This can contribute to weeding out false-positive results (Nosek & Lakens, 2014). While conceptual replications are not best suited for validating a particular effect, they allow to abstract a phenomenon from its original operationalization (Nosek & Lakens, 2014). This is especially important for lab-based experimental studies, which often struggle to establish external validity.

Interpretation of effects and causality

Most studies reported here use frequentist statistics, that is p-value-based null hypothesis testing. However, p-values are inversely correlated with sample size (Lantz, 2013; Sullivan & Feinn, 2012). Since there are huge differences in the sample sizes of large-scale panel studies and lab-based experimental studies, comparative interpretation is difficult and not straight-forward. A stronger focus on effect sizes could, for example, contribute to understanding conflicting results on the effect of sex on choice consistency.

Another caveat lies in the interpretation of heterogeneous research designs. Some studies use a correlational approach for large representative datasets (Choi et al., 2014), sometimes using natural experiments to establish causality (Banks et al., 2018). These studies typically have a greater external validity, but do not contribute to understanding mechanisms and processes behind

observed relationships. Other studies use pseudo-experimental approaches, often when the variable of interest cannot be manipulated (Bruyneel et al., 2012; Burghart et al., 2013; Cappelen et al., 2014; Chung et al., 2017; Harbaugh et al., 2001; Lazzaro et al., 2016). These studies essentially require the same caution in interpretation as correlational studies, as various confounds remain uncontrolled for. Furthermore, these studies often lack the large, representative samples of panel studies. Finally, there are studies deploying randomized controlled experimental designs (Castillo et al., 2017; Drichoutis & Nayga, 2017) which arguably are the gold-standard for establishing causality. However, these studies do not necessarily have strong generalizability beyond their original operationalization. Kim et al. (2018) deserve a special mention here, as their randomized controlled lab-in-the-field experiment promises both, high internal and external validity.

Process models

Few studies have tackled the question of how certain factors might influence choice consistency, which is especially relevant from a cognitive psychologist and neuroscientific point of view. A positive mention deserve the few studies investigating the neural underpinnings of choice inconsistency (Camille et al., 2011; Chung et al., 2017; Kalenscher et al., 2010; Kurtz-David et al., 2019), which suggest that value-encoding regions play a key role. Future studies should use a more theory-driven approach to identify moderators of choice consistency. Currently, it is unclear whether choice consistencies arise at the level of preference representations, choice value integration or behavior (trembling hand).

Choice of paradigm

The studies on choice consistency we reviewed in this article are all heavily influenced in their paradigms by the two seminal papers of Harbaugh et al. (2001) and Choi et al. (2007), which are rooted in the framework of revealed preference theory. While these paradigms allow for a statistically powerful test of choice consistency, there might be specific effects on choice inherent to the construction of the paradigms. That is, precise critical cost efficiency estimation requires a specific way the decision problem is presented, e.g. in forms of graded choice bundles. It is possible

that the very structure of the problem presentation is insensitive to relative changes in choice consistency, while the same decision problem framed differently might reveal stronger changes in relative inconsistency. For example, other paradigms similar to the one deployed by Tversky (1969) have borne different results. To enable meaningful interpretation, effects or their absence should, ideally, be robust across different paradigms.

Measure of consistency

Another concern is that critical cost efficiency, which is the basic measure of consistency in most of the findings reviewed here, is a compelling specification of choice consistency but not without alternatives. By design, its magnitude is solely determined by the strongest incidence of choice inconsistency in a given dataset. Therefore, it might not be sensitive to detect more subtle changes in choice consistency, which was for example the case in Harbaugh et al. (2001) and Bruyneel et al. (2012). Besides the other already mentioned goodness-of-fit measures for revealed preference theory, such as the money pump index (Echenique et al., 2011) or the money metric index (Halevy et al., 2018), there are several conceptually distinct operationalizations of choice consistency.

One approach is to parametrically estimate decision noise of a given choice model using a probabilistic choice rule (cf. Stott (2006) for an overview of probabilistic choice rules for binary choice). This parametric estimation of decision noise is favorable when there is a designated candidate model for the decision problem at hand and a general test of choice consistency is not necessary (Chumbley et al., 2014; Margittai et al., 2018; Sokol-Hessner et al., 2009).

Regenwetter et al. (2010) have proposed to conceptualize violations of choice consistency as the results of a mixture process of multiple for themselves consistent preference relations. Importantly, for each decision a consistent preference relation is probabilistically sampled from the collection of all consistent preference relations. Hence, their model treats choice inconsistency not as behavioral noise but as instable preferences.

Finally, the critical cost efficiency index is based on revealed preference theory and, thus, its validity is tied to the validity of revealed preference theory itself. Revealed preference theory has been conceptually and empirically criticized on several grounds (Arkes et al., 2016; Berg & Gigerenzer, 2010; Cason & Plott, 2014; Kőszegi & Rabin, 2007). Again, conceptual replications of the studies reviewed here using alternative measures of choice consistency are necessary to strengthen our confidence in the results.

Concluding Remarks

Here, we have reviewed recent literature to identify state and trait factors that determine the degree of choice consistency of decision makers as defined by revealed preference theory. While choice behavior of real-world decision makers systematically deviates from perfect consistency, it appears that the baseline degree of consistency seems to be relatively robust to trait and state factors. There is no or only limited evidence for an influence of sex and menstrual cycle (Lazzaro et al., 2016), personality traits (Cappelen et al., 2014), cognitive load (Drichoutis & Nayga, 2017), sleepiness (Castillo et al., 2017) or alcohol (Burghart et al., 2013) on choice consistency. There is evidence for an influence of age (Bruyneel et al., 2012; Choi et al., 2014; Harbaugh et al., 2001), education (Cappelen et al., 2014; Choi et al., 2014; Kim et al., 2018), intelligence (Bruyneel et al., 2012; Choi et al., 2014) and neurological status (Camille et al., 2011; Chung et al., 2017), but interpretation is often not possible without caution. Furthermore, there are also studies failing to find an effect of age, education or intelligence (Banks et al., 2018; Chung et al., 2017; Harbaugh et al., 2001). Overall, this suggests that choice consistency, apart from natural behavioral variability, seems to be a relatively robust trait of decision makers. Only fundamental differences in decision making ability, which might, for example, be age, education, and intelligence related, have an impact on choice consistency.

Future research on influence factors of choice consistency should replicate results directly and conceptually (in multiple paradigms), consistently report (standardized) effect sizes and develop

a theoretical framework for the generative processes of choice inconsistency instead of endorsing a purely effect driven research agenda.

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Table 1*Different consistency principles and their implications*

Consistency principle	Verbal description	Implies
First-Order Stochastic Dominance (FOSD)	If A is at least as good as B in all attributes and better in at least one attribute, then a decision maker should choose A over B.	GARP, IIA, SST, WST, Regularity
Generalized Axiom of Revealed Preference (GARP)	If a decision maker chooses A over B, and B over C then she should neither choose B or C over A, when A is strictly cheaper.	IIA, SST, WST, Regularity
Strong Stochastic Transitivity (SST)	If a decision maker chooses A over B with at least 50% probability and B over C with at least 50% probability, then she should choose A over C with a probability at least the larger of the probabilities of choosing A over B or C over B.	IIA, WST
Independence of Irrelevant Alternatives (IIA)	If a decision maker chooses A over C with a probability at least as great as that with which she chooses B over C, then she should choose A over D with a probability at least as great as that with which she chooses B over D.	SST, WST
Weak Stochastic Transitivity (WST)	If a decision maker chooses A over B with at least 50% probability and B over C with at least 50% probability, then she should choose A over C with at least 50% probability.	
Regularity	If a decision maker chooses options A and B each with a certain probability, then the addition of a third option C to the choice set may not increase these probabilities.	

Note. GARP: Generalized Axiom of Revealed Preferences, IIA: Independence of Irrelevant

Alternatives, SST: Strong Stochastic Transitivity, WST: Weak Stochastic Transitivity.

Table 2*Influence factors on choice consistency*

Influence Factor	Trait or state?	Number of studies	Experimental designs	Studies reporting a significant effect
Age	Trait	6	Correlational, pseudo-experimental	4/6
Education	Trait	6	Correlational, pseudo-experimental, randomized controlled	4/6
Intelligence	Trait	4	Correlational, pseudo-experimental	3/4
Neurological status	Trait	2	Correlational, pseudo-experimental	2/2
Sex & menstrual cycle	Trait	2	Correlational, pseudo-experimental	1/2
Personality traits	Trait	1	Correlational	0/1
Cognitive load	State	1	Randomized controlled	0/1
Sleepiness	State	1	Randomized controlled	0/1
Alcohol	State	1	Pseudo-experimental	0/1

Figure 1*Schematic representation of consistent multi-attribute choice*

Note. Imagine decision maker wants to decide on which snack to buy. She can choose between 5 different snacks (broccoli, grapefruit, peanuts, fries, chocolate), which all differ with regard to healthiness and taste. One option is very healthy but not tasty at all (broccoli). Another option is very tasty but not healthy at all (chocolate). Also, there are some compromise options (grapefruit, peanuts, fries) which are healthy and tasty to varying degrees. We call these 5 different snacks the choice set. Let us assume that the decision maker considers healthiness and taste equally important and prefers a compromise of health and taste over extreme options. When the preferences are well-defined like in our example, we can create collections of choice options which have the same overall subjective value to the decision maker (so-called *indifference curves*; dashed lines in the graph). Generally, collections of higher subjective value include options with higher healthiness and taste values. According to axiomatic choice theory, a decision maker should always choose the option from the choice set which is part of the collection of highest subjective value. In our example, the most preferred option is a perfect compromise of healthiness and taste (peanuts).