Centering and the Meaning of Conditionals

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Abstract

The centering inference - p & q, therefore if p then q - is important in reasoning research because it is logically valid for some accounts of conditionals (e. g. the material and the probability conditionals), but not for others (e. g. the inferential conditional, according to which a conditional is true if and only if there is an inferential connection between p and q). We tested participants' acceptance of centering compared to valid and invalid inferences not containing conditionals, varying the presence of an inferential connection and of a common topic of discourse between p and q. Participants' acceptance of centering was more similar to valid inferences than to invalid inferences, and there was no reliable effect of a connection between p and q. Acceptance rates were higher when there was a common topic of discourse, independently of the type of inference. The findings support the probability conditional account.

Keywords: validity; uncertainty; conditionals; centering

Introduction

Conditional sentences of the form *if p then q*, like "If it is snowing, then the streets are slippery", are used on a daily basis in ordinary discourse and in science. And yet there is still not a consensus on their meaning. They are central to any account of reasoning, because every inference from *p* to *q* can be rephrased as a conditional. Our understanding of the meaning of conditionals therefore goes hand in hand with our understanding of reasoning processes as a whole (Over & Cruz, in press).

Most reasoning takes place from premises that are not certain, but are held only with higher or lower degrees of belief. This uncertainty affects the inferences people draw, and therefore has to be taken into account in theories of reasoning (Evans & Over, 2004, 2013; Oaksford & Chater, 2007, 2013; Pfeifer & Kleiter, 2009, 2011). Classical logic, with its restriction to the binary values of truth and falsity, cannot represent uncertainty, but this becomes possible with the use of probability theory (Adams, 1998; Coletti & Scozzafava, 2002; de Finetti, 1936/1995; Gilio, 2002; Ramsey, 1926/1994; Jeffrey, 1991).

One inference that has not been studied much in the psychology of reasoning is centering (or conjunctive sufficiency): inferring *if p then q* from *p & q*. Centering is important because it is logically valid for several theories of the conditional (Evans & Over, 2004; Girotto & Johnson-Laird, 2004; Lewis, 1973; Pfeifer & Kleiter, 2010; Stalnaker, 1968), and logically invalid for several others (Douven, 2015a; Cariani & Rips, in press; Kratzer, 2012) allowing a comparison between these theories. In particular, centering is valid for the *probability conditional* (Over, in press; Pfeifer & Kleiter, 2010), but invalid for the *inferential conditional* (Douven, 2015a; Skovgaard-Olsen, Singmann, & Klauer, in press). We will focus on these two theories in the following.

The probability conditional

If people interpret a natural language conditional as a probability conditional, then their degree of belief in the conditional is the conditional probability of its consequent given its antecedent: *P(if p then q) = P(q|p).* This equality is called *The Equation* as a normative philosophical proposal (Edgington, 1995). The psychological hypothesis that people's interpretation of conditionals conforms to the Equation is called the *conditional probability hypothesis* (Evans & Over, 2004). It is proposed that people compute this conditional probability by performing a *Ramsey test*: a mental simulation in which they hypothetically assume *p* to be the case, make any changes to their beliefs that may be necessary to preserve consistency, and assess the probability of *q* on this basis (Evans & Over, 2004; Ramsey, 1929/1994; Stalnaker, 1968). An inferential connection between *p* and *q* may influence people's assessment of the conditional probability, but the effect of such a relation is procedural and pragmatic and not part of the semantics of conditionals.

The inferential conditional

Inferentialism states that a high conditional probability, *P(q|p)* is high, is not sufficient for the conditional to have a high probability, *P(if p then q)* is high. For the conditional to have a high probability, there also has to be an inferential connection between *p* and *q*. Of course, *P(q|p)* can be high because *P(q)* is high and *q* is independent of *p*, but this is not sufficient to make *P(if p then q)* high for inferentialism. In the strongest version of the theory, a conditional is proposed to be true *if and only if* there is a strong enough argument from *p* (plus relevant background knowledge) to *q*, where this argument can be deductive, inductive, or abductive (Douven, 2015a; Krzyżanowska, Wenmackers, & Douven, 2014; c. f. Douven, 2015b). A deductive argument is assumed to be present when *q* is necessarily true given the truth of *p* (because for instance *p* is a subset of *q*). An abductive argument is assumed to be present when *p* is the best explanation for *q* (Douven & Verbrugge, 2010). It is

held that "*q* is an inductive consequence of *p* (given the background premises) iff *q* follows with high statistical probability from *p* (in light of the background premises)" (Krzyżanowska et al., p. 775; c. f. Douven & Verbrugge, 2010, p. 303). If taken literally, this criterion implies that a high conditional probability is sufficient for a conditional to be highly probable. We therefore take the authors to mean that an inductive argument is present not only when the conditional probability of *q* given *p* is statistically high, but when in addition it is higher than the unconditional probability of *q*, that is, when *p* raises the probability of *q* (c. f. Douven, 2008, Oaksford & Chater, 2007, and the use of the delta-p rule in research on causation, as in Cheng, 1997).

This definition of an inferential conditional in terms of the binary values of truth and falsity has not been extended to degrees of belief. But if we make the uncontroversial assumption that degrees of belief are degrees of belief that a statement is true, or true given that it has a truth value, and no further qualification is added to the inferentialist definition, then this definition seems to imply that the degree of belief in a conditional is a direct function of the strength of an inferential connection between *p* and *q*.

A less strong variant of inferentialism integrates the requirement for a connection with the conditional probability hypothesis. It proposes that people assume by default that a conditional has a connection, operationalized as a positive covariation between *p* and *q* when using naturalistic materials. If this assumption is met, then people set their degree of belief in the conditional to that of the conditional probability. If the assumption that there is a connection is not met, then people "penalize" the value of the conditional probability by adjusting it downwards (Skovgaard-Olsen et al., in press; c. f. Douven, 2008). In virtue of its contingent nature, this "penalty" is arguably a pragmatic adjustment rather than a semantic requirement, but its supporters hold that it is semantic.

Previous findings

The Equation has received strong and consistent empirical support (Evans, Handley, & Over, 2003; Fugard, Pfeifer, Mayerhofer, & Kleiter, 2011; Oberauer & Wilhelm, 2003; Politzer, Over, & Baratgin, 2010), but there has been little empirical research on inferentialism. Some studies have found an effect of a covariation between *p* and *q* on people's belief in conditionals (Oaksford & Chater, 2010; Oaksford, Chater, & Larkin, 2000; Skovgaard-Olsen et al., in press), while others have not (Oberauer, Weidenfeld, & Fischer, 2007; Over, Hadjichristidis, Evans, Handley, & Sloman, 2007; Singmann, Klauer, & Over, 2014). Oberauer et al. (2007) found that the presence of a causal connection affected people's belief in a conditional in the absence of explicit frequency information on the conditional probability. However, when frequency information was given, the effect of a causal connection was negligible. This suggests that information on a connection is relevant for estimating the conditional probability, but unnecessary when this probability is already known. Moreover, inferentialism, unlike the probability conditional hypothesis, is not in accordance with truth table tasks (Baratgin, Over, & Politzer, 2013; Evans et al., 2003; Oberauer & Wilhelm, 2003), where people hold the conditional to be true when *p* and *q* are true, and where they judge the probability of the conditional to be a function of $P(q|p)$. In these tasks, the materials, which would indicate the presence or absence of a connection, remain constant (Over & Cruz, in press).

Proponents of inferentialism have argued that such studies do not undermine their proposal because of the use in them of abstract or pseudo-naturalistic conditionals, and that the scope of their theory is restricted to naturalistic conditionals (Skovgaard-Olsen et al., in press). They have also pointed out that a distinction is made in linguistics between *content* and *inferential* conditionals, and their theory is restricted to the latter. It also does not apply to so-called *Peter-Pan conditionals*, e.g. "If fairies exist, then I am Peter Pan", or *non-interference conditionals*, which are types of conditionals that explicitly lack an inferential connection (Douven & Verbrugge, 2010; Krzyżanowska et al., 2014). One problem for inferentialism is that such restrictions reduce its falsifiability, and expose it to the danger of providing ad hoc explanations for data.

The present experiment

As described above, both variants of inferentialism assume that the role of a connection is semantic and not pragmatic. They conceive of the connection as a necessary component of what makes a linguistic form a conditional and not some other kind of statement. To test this assumption, we draw on a conception of validity from test theory. Note that this notion of (test) "validity" is different from the logical validity of an argument or inference. In test theory, a test is said to be "valid" when it is *sensitive* enough to measure the construct it is designed to measure, and when it is *specific* enough not to measure much else in addition to the construct. In analogy to this, we consider there to be evidence that the effect of a connection is semantic when it is present across conditionals of different types and contents, and when it is specific to conditionals, or at least stronger for conditionals than for other connectives.

Regarding sensitivity, we already mentioned above the restriction in scope of inferentialism, which makes it seem unwarranted to assert it as a theory of the meaning of conditionals in general, without further qualification. Here we focus on specificity: That the effect of a connection is specific or at least higher for conditionals than for other connectives. We therefore compare people's degree of belief in centering with people's degree of belief in inferences not containing conditionals, the logical validity (invalidity) of which is much less controversial.

If an effect of a connection were to be present to a similar degree for inferences with and without conditionals, then inferentialism would have no means to distinguish conditionals from other connectives, unless it reduced, in its

less strong version, to the conditional probability hypothesis.

To illustrate the problem with unconnected conditionals, proponents of inferentialism often use examples like "If Hillary Clinton runs for president in 2016, the earth weighs more than 2 kilograms." (Krzyżanowska et al., 2014). Referring to this example, the authors state "antecedent and consequent have nothing to do with each other, which at least on our hypothesis accounts for the felt falsity of this sentence." The sentence indeed sounds odd, but it not only expresses no inferential connection. As the authors say, antecedent and consequent have nothing to do with each other: they belong to different topics. This raises the question of whether the intuitive oddness of such sentences comes from the absence of an inferential connection, or alternatively from the absence of a common topic of discourse. To assess this question, we compared people's degree of belief in inferences under three conditions: (1) one in which there is a connection between *p* and *q*, (2) one in which there is no connection, but a common topic of discourse, and (3) one in which there is no connection and no common topic of discourse.

Method

Participants

A total of 670 participants from English speaking countries completed the online experiment. Following methodological recommendations for online research (Aust, Diedenhofen, Ullrich, & Musch, 2013; Reips, 2002), we excluded cases with repeated IP address; cases who failed a test question assessing whether they were reading the materials presented to them or just clicking through; cases who indicated at the end of the experiment that they did not take part seriously; cases with one or more trial reaction times of less than 3 seconds; and cases who rated their English language skills as not being high or that of a native speaker. The final sample consisted of 363 participants, reporting a mean age of 42.56 (range: 15-80) and a diverse formal educational background. They received a compensation of $ 0.16 for their participation.

Materials and design

Participants were asked to imagine that they were researchers investigating the birds of the invented island of Liaku, and also that they were following the election results in their far away home country Raimos. On each trial, participants were shown a short context story, followed by a one-premise inference. They were asked to assume that they had a specific degree of belief in the premise of the inference, and were asked to judge how confident they could reasonably be in the conclusion, given this degree of belief in the premise. Participants gave their answer by writing a percentage into a box.

Each participant was shown materials from one of three conditions. In group 1 (the connection condition) *p* and *q* referred to two features of the same bird (e. g. "The next Amri bird you see on Liaku will eat arb seeds" and "The next Amri bird you see on Liaku will build its nests on arb trees"). In group 2 (the no connection – same topic condition) *p* and *q* referred to different features of two different birds (e. g. "The next Amri bird you see on Liaku will eat arb seeds" and "The next Grauk bird you see on Liaku will live in groups"). In group 3 (the no connection – different topic condition) *p* and *q* referred to different topics (e. g. "The next Amri bird you see on Liaku will eat arb seeds" and "The Grauk province of Raimos will increase taxes"). The materials were pretested for the extent to which people perceived there to be a connection between *p* and *q* (median ratings in percent: 78, 19, and 1 for groups 1 to 3, respectively). Participants were randomly allocated to one of the three groups.

Each participant gave ratings to the six inferences displayed in Table 1.

Table 1. The inferences investigated.

	Name	Form
1	and-to-if	*p & q, ∴ if p then q*
2	if-to-and	*if p then q, ∴ p & q*
3	and-to-or	*p & q, ∴ p or q*
4	or-to-and	*p or q, ∴ p & q*
5	and-elim	*p & q, ∴ p*
6	and-intro	*p, ∴ p & q*

Note. "∴" stands for "therefore".

Inference 1 is centering, whose validity differs between theories of the conditional. Inference 2 is its converse, and is more uncontroversially invalid. The remaining inferences do not contain conditionals. Inferences 3 and 5 are more uncontroversially valid, and inferences 4 and 6 are more uncontroversially invalid. We will refer to inferences 2 to 6 simply as valid resp. invalid in what follows.

Each inference was presented three times, showing a premise probability of 1, .8 and .2, respectively. The materials in which the inferences were embedded were different on each trial. The allocation of materials to inferences, as well as the trial order, was varied randomly for each participant.

The experiment was conducted in a single online session using the platform CrowdFlower(c), and took 8.4 min on average to complete.

Results and discussion

As expected, participants' ratings of conclusion probability were lower for lower premise probabilities. However, the pattern of responses for the variables of interest to the hypotheses was very similar across premise probabilities. In particular, there was no qualitative difference in responses to inferences with certain and with uncertain premises. Because we had no specific prediction about effects of premise probability, which we varied merely to increase the generalizability of the findings, subsequent results were aggregated across this variable.

To test whether centering is generally treated as valid, and whether its treatment as valid depends on the presence of a connection and/or of a common topic of discourse between *p* and *q*, we first compared inference 1 (centering) with inference 2 (its converse). We next compared inference 1 with the average ratings for valid inferences 3 and 5. Finally, we compared inference 1 with the average ratings for invalid inferences 4 and 6. The results are displayed in Figure 1.

Centering vs. its converse A mixed ANOVA with group (1, 2, 3) as between subjects factor and inference (1, 2) as within subjects factor led to a significant effect of inference, $F(1, 360) = 18.46$, $p < .001$, $\eta_p^2 = .049$: ratings for inference 1 were higher ($M = 62.90$, $SE = .71$) than ratings for inference 2 ($M = 59.03$, $SE = .86$). There was also a significant effect of group, $F(1, 360) = 3.55$, $p = .03$, $\eta_p^2 = .019$; but no interaction between inference and group ($F < 1$). Follow-up analyses for the effect of group revealed that ratings for group 3 ($M = 58.66$, $SE = 1.14$) were lower than for group 1 ($M = 62.49$, $SE = 1.18$), $F(1, 257) = 5.46$, $p = .02$, $\eta_p^2 = .021$. Ratings for group 3 were marginally lower than for group 2 (M = 61.75, SE = 1.17), $F(1, 236) = 3.95$, $p = .048$, $\eta_p^2 = .016$; but there was no significant difference between ratings for group 1 and for group 2 ($F < 1$).

The finding of higher ratings of conclusion probability for centering than for its converse, regardless of the presence or absence of a connection, is inconsistent with inferentialism. Inferentialism would have predicted an interaction between inference and group, such that ratings are lower for centering than for the other inferences in the groups with no connection. The finding that the effect of group could be traced back to the effect of a common topic of discourse, but not to the presence of a connection, is also not in accordance with inferentialism.

Centering vs. valid inferences 3 and 5 A mixed ANOVA with group (1, 2, 3) as between subjects factor and inference (1, 3&5) as within subjects factor led to a small main effect of inference, $F(1, 360) = 4.73$, $p = .03$, $\eta_p^2 = .013$: ratings for inference 1 ($M = 62.90$, $SE = .71$) were lower than mean ratings for inferences 3 and 5 ($M = 64.57$, $SE = .55$). There was also a main effect of group, $F(1, 360) = 3.82$, $p = .023$, $\eta_p^2 = .021$. Inference and group did not interact ($F < 1$). Follow-up analyses to the effect of group showed that ratings were lower for group 3 ($M = 62.08$, $SE = .88$) than for group 1 ($M = 65.37$, $SE = .91$), $F(1, 257) = 6.79$, $p = .01$, $\eta_p^2 = .026$. There was no difference in ratings between groups 1 and 2, $F(1, 227) = 1.73$, $p = .19$, $\eta_p^2 = .008$; nor between groups 2 and 3, $F(1, 236) = 1.92$, $p = .17$, $\eta_p^2 = .008$.

The absence of an interaction between inference and group is again contrary to the predictions of inferentialism, as is the finding that the effect of group could be traced back to the effect of a common topic of discourse, but not to the effect of a connection. The small effect of inference indicates that people rated the conclusion of centering slightly lower than the conclusion of the two valid inferences. However, the effect was not reliable: it did not reach significance when analyzed individually in any of the groups (for group 1, $t < 1$; for group 2, $t = 1.39$, $p = .17$, 95%CI [-3.7, .65]; for group 3, $t = 1.86$, $p = .07$, 95%CI [-4.9, .15]). There is therefore little evidence for a treatment of centering as invalid.

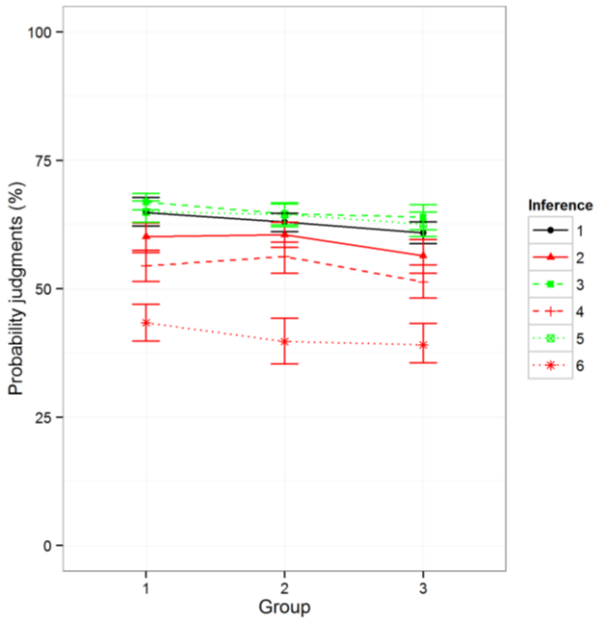

Figure 1. Judgments of conclusion probability for the six inferences investigated, separately for group 1 (connection), group 2 (no connection – same topic) and group 3 (no connection – different topic). The black line represents the target inference of centering. Green lines represent the valid and red lines the invalid comparison inferences. Error bars show 95% CI.

Centering vs. invalid inferences 4 and 6 A mixed ANOVA with group (1, 2, 3) as between subjects factor and inference (1, 4&6) as within subjects factor led to a main effect of inference, $F(1, 360) = 232.88$, $p < .001$, $\eta_p^2 = .393$: mean ratings for inferences 4 and 6 ($M = 47.38$, $SE = .88$) were lower than for inference 1 ($M = 62.90$, $SE = .71$). There was also a main effect of group, $F(1, 360) = 3.61$, $p = .028$, $\eta_p^2 = .020$; but no interaction between inference and group ($F < 1$). Follow-up analyses to the effect of group revealed that ratings for group 3 ($M = 53.04$, $SE = 1.01$) were lower than for group 1 ($M = 56.88$, $SE = 1.04$), $F(1, 257) = 6.39$, $p = .012$, $\eta_p^2 = .024$. There was no significant difference between group 1 and group 2 (for group 2: $M = 55.50$, $SE = 1.14$) ($F < 1$), nor between groups 2 and 3, $F(1, 236) = 2.61$, $p = .108$, $\eta_p^2 = .011$.

The difference between centering and the mean of the invalid inferences 4 and 6 was reliably present (for group 1, $t = 8.23$, $p < .001$, 95%CI [12.1,19.7]; for group 2, $t = 9.08$, $p < .001$, 95%CI [11.7, 18.2]; for group 3, $t = 9.69$, $p < .001$, 95%CI [12.5,18.9]). Ratings for centering were more similar to those for valid inferences (difference: $M = -1.67$,

SE = 0.8) than to those for invalid inferences (difference: *M* = 15.52, *SE* = 1.0), $F(1, 360) = 290.94$, $p < .001$, $\eta_p^2 = .447$, irrespective of group ($F < 1$).

The finding that centering was treated as a logically valid rather than as an invalid inference is at odds with theories of the conditional that reject centering. The consistent absence of an interaction between inference and group, as well as the finding that the effect of group could be traced back to that of a common topic of discourse, but not to that of a connection, is at odds with the predictions of inferentialism more specifically.

We repeated the above analyses using a linear mixed model with a random intercept for participants, finding the same pattern of significant and non-significant results. The model failed to converge when attempting to introduce a random slope for participants, or a random intercept and/or slope for item contents. We report the ANOVA here for reasons of space.

General discussion

We investigated whether people treat centering as a logically valid inference, comparing it to inferences not containing conditionals, and whether people's acceptance of centering depends on the presence of a connection or common topic of discourse between *p* and *q*. We found centering to be treated more like a logically valid inference than like an invalid one, irrespective of the presence of a connection or of a common topic of discourse. Centering was accepted less when there was no common topic of discourse, but was not accepted less when there was no connection. The effect of a common topic of discourse was not specific to centering, but occurred to a similar degree for inferences not containing conditionals.

These findings are not in line with theories implying that centering is logically invalid for the natural language conditional, and not with inferentialism more specifically. They suggest that what matters for the intuition that there is something odd in conditionals like "If Hillary Clinton runs for president in 2016, the earth weighs more than 2 kilograms", is the absence of a common topic of discourse between *p* and *q*, rather than the absence of a specific connection. Further, this intuition does not seem to be specific to conditionals, but appears to apply similarly to inferences with disjunctions and conjunctions, suggesting that the effect is pragmatic and not semantic. If it were semantic, then the stronger version of inferentialism would be unable to distinguish conditionals from other connectives, and the less strong version would reduce to the conditional probability hypothesis.

The suggestion that conditionals with no connection are odd for pragmatic reasons is in accordance with previous findings in support of the conditional probability hypothesis (Evans et al., 2003; Oberauer & Wilhelm, 2003); with findings in support of centering, albeit without varying the presence of a connection (Cruz, Baratgin, Oaksford, & Over, 2015; Politzer & Baratgin, 2015); and with evidence for the role of a connection when using conditionals in the pragmatic context of argumentation (Hahn & Oaksford, 2007).

The present findings are preliminary, however, and require replication and extension before allowing stronger conclusions. One point to consider is that the presence of a connection was varied between subjects in this experiment. This was important because it allowed us to avoid participants reacting to the variation of a connection simply because of its salience in the materials, making them think the experimenter expects them to respond differentially towards it. However, a variation within subjects would make it easier to find an effect of group, and thus also easier to find the interaction predicted by inferentialism. Further, the materials used here were pseudonaturalistic. It would be informative to test whether the findings can be generalized to naturalistic scenarios.

If subsequent research provides further evidence against inferentialism, this would undermine the generality of the inferentialist proposal. However, it would not invalidate it as such. To take the causal domain as an example, there are certainly statements of the form *p causes q*, which are true when *p* causes *q*, and false otherwise. Such statements do not necessarily change their truth conditions when they are rephrased as *if p then q*. Moreover, there is likely to be a continuum in the extent to which a conditional is meant to assert the presence of a causal or other kind of relation.

However, to the extent that a conditional is meant to assert *p causes q*, it can perhaps be considered general as opposed to singular (Cruz & Oberauer, 2014). General conditionals are useful because they allow us to build theories about the world, to help us understand it and make predictions (Chater & Oaksford, 2013). Sometimes we are looking for information that is relevant for refining our theories about the world. But other times we just want to make a prediction of *what* is the case in a particular instance, regardless of *why* it is the case. For example, we might sometimes want to know whether mosquito bites really cause a certain illness. At other times, we might be satisfied with learning simply that the conditional probability of the illness is high given mosquito bites, to take quick and easy measures against the bites. Sometimes a connection may be used as a predictor for the conditional probability, and sometimes the converse may hold. Whether a connection or the conditional probability is more basic may depend on the goals of the reasoner. In this way, a narrower scope for inferentialism in the context of singular indicative conditionals could imply a wider scope for it in the context of generals and counterfactuals.

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