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Empirical comparison of visual analog scales and three versions of the time trade-off. A study on cochlear implantation

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Abstract

Purposes To measure the increase in health-related quality of life (QoL) from unilateral to bilateral cochlear implantation (CI) in children. To analyze whether the framing of questions in the time trade-off (TTO) method affects the measurement. To measure the effect of incentives on the response rate.

Methods We invited 3,465 students to answer an online questionnaire. Each respondent was randomly assigned to one of four techniques for measuring QoL: visual analog scales (VAS), time trade-off giving up life time (TTO_{time}), time trade-off giving up quality of life (TTO_{qol}), and time trade-off based on equivalence ($\text{TTO}_{\text{equiv}}$). Each respondent was offered feedback, either from the VAS to the TTO or vice versa, and the possibility of revising their answer. Subjects who gave implausible answers were warned.

Results 583 respondents filled in the personal data screen. The incentive, which consisted of the possibility of entering a lottery, caused a small—but statistically significant—increase in the response rate. Some of the subjects assigned to TTO_{time} and TTO_{qol} declined to enter the trade-off game. Others abandoned later. For 455 of the respondents we obtained at least one QoL estimate. The average initial (i.e., before the feedback) estimate of the QoL with unilateral CI was 0.581 for the VAS, 0.787 for the TTO_{time}, 0.654 for the $\text{TTO}_{\text{equiv}}$ and 0.486 for the TTO_{qol}. Differences between these TTO estimates are statistically significant, with $p < 0.0003$ for each of the three pairwise comparisons. The average initial increase in QoL from unilateral to bilateral CI was 0.247, 0.159, 0.111, and 0.231 for the four techniques, respectively. The proportion of implausible answers was 15.9%, 82.4%, 41.0%, and 69.1%; after the feedback these percentages were 29.9%, 69.5%, 27.8%, and 63.0% respectively.

Conclusion The increase in QoL due to bilateral CI ranges from 0.106 to 0.293, depending on the elicitation technique. The status-quo trap, a well known psychological bias that makes people reluctant to give up what they already have, leads the the TTO_{time} to overestimate the QoL and the TTO_{qol} to underestimate it. When applying the TTO, we recommend the $\text{TTO}_{\text{equiv}}$ version because it seems to be more neutral, as it involves no give-up; additionally, it yields fewer implausible responses and is deemed easier by respondents. The feedback reduces to some extent the number of implausible responses for all the versions of the TTO but it is not sufficient to eliminate them. Therefore, it would be advisable to train ("calibrate") the respondents before applying this method.

Keywords: Quality of life, visual analog scale, time trade-off method, cochlear implant.

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1 Introduction

A cochlear implant (CI) is an electronic device that restores audition in the case of severe to profound neurosensorial hearing loss. Bilateral CI, i.e., one implant in each ear, offers several advantages over unilateral implantation CI, such as the ability to identify the origin of sound, improved understanding of language, especially in noisy environments, and having a backup when the other implant fails (Crathorne et al., 2012; Gaylor et al., 2013; Lammers et al., 2014). However, these advantages are small compared to those of the first implant, and for this reason the cost-effectiveness of bilateral CI has been debated for several decades (Lammers et al., 2011; NICE, 2009; Raine et al., 2010).

In this paper, effectiveness is defined as the life duration adjusted by quality of life (QoL):

$$e = \int QoL(t) \cdot dt \,.$$

QoL is measured on a scale where 0 means no QoL (the same as being dead) and 1 means perfect health. Effectiveness is measured in quality-adjusted life years (QALYs).

As QoL is subjective, it can only be estimated by surveying a significant number of subjects. There are several elicitation techniques. A common approach is to use a visual analog scale (VAS) whose extremes, marked with 0 and 100, correspond to being dead and having perfect health, respectively; the subject's response can be converted to the 0-1 scale by a simple division. The main advantage of this instrument is its simplicity, as respondents find it easy to understand the question and give an estimate. Its main drawback is that the response does not represent the subject's preferences; for example, if a respondent says that the QoL for a disease is 0.8, it does not mean that for this person living for 8 years with perfect health is as attractive as living for 10 year with the disease. Non-preference measures cannot be directly used in health economic evaluations.

One preference-based technique for measuring the QoL is the time trade-off method (TTO), in which subjects have to choose between living shorter and living healthier (Torrance, 1970; Torrance et al., 1972). The most common way of framing the trade-off is to offer the respondent the possibility —usually in a hypothetical scenario—of giving up a certain amount of the expected life-time in order to recover perfect health; we call this method TTO_{time}. A hypothesis of our study is that this framing may be affected by a psychological bias call *the status-quo trap* (Hammond et al., 1998), which makes human beings reluctant to exchange what they already have for what they might gain. In order to detect this bias, we have compared this framing with two alternative framings of the TTO. In one of them, denoted as $\text{TTO}_{\text{equiv}}$ (for "equivalence"), the subject had to compare two hypothetical scenarios (two health conditions) by directly setting time equivalence, without giving up anything. In the other, called TTO_{qol} (for "quality of life"), the subject was offered the possibility of giving up QoL in order to increase life expectancy; this version of the TTO is a novelty of our study.

Therefore, methodologically our main goal is to determine how the elicitation technique affects the QoL estimates. Additionally, we wished to estimate the QoL increase from unilateral to bilateral CI in order to conduct a cost-utility analysis of bilateral CI. An objective of minor interest is to measure how different incentives affect the response rate. In the survey the subjects chosen as representatives of the general population were students of our university. Given that they were assumed to have no knowledge about CIs, we used two vignettes describing the performance of children with unilateral and bilateral CI, adapted from those of Summerfield et al. (2010) and slightly updated in accordance with recent literature; for example, we added that children enjoy music more with two implants than with only one (Kühn-Inacker et al., 2004; Scherf et al., 2009; Gfeller et al., 2008; Veekmans et al., 2009; Vecchiato et al., 2011). The survey was conducted in Spanish, but we prepared demo version in English and Spanish that we shared with several experts so that they could give us their feedback before conducting the actual experiment. The demo is still available at www.cisiad.uned.es/cochlear-implant/demo-survey and the vignettes and questions posed can be examined in it.

2 Methods

2.1 Variants of the TTO

As mentioned above, the TTO method is based on a hypothetical trade-off between living shorter and living healthier. More precisely, the respondent is offered the possibility of living in a health state with QoL q for a time t or living in another state with q' for a time t'. A way of quantitatively comparing q and q' is to find two time durations, t and t', such that the subject is indifferent between both options. In this case,

$$q = q' \frac{t'}{t} \,. \tag{1}$$

If one of the options being compared is living for a certain time t' with perfect health ($q' = 1$, by definition), the QoL for the other condition—the condition of interest—is just $q = t'/t$. The time t lived in this condition is usually set by the experimenter and called the "time frame". In some studies it is the respondent's time life expectancy. In other cases, the time frame is arbitrarily set by the experimenter; for example, 10 or 20 years (Attema et al., 2013).

One way to find out the time t'that makes the respondent indifferent between the two options, is to propose him/her an initial amount of time t'_0 and adjust it iteratively (t'_1, $t'_2\ldots$) depending on the respondent's choice until an equilibrium between both options is achieved. This is the original version of the TTO (Torrance, 1970; Torrance et al., 1972); some authors refer to it as the ping-pong method (Gudex, 1994).

2.1.1 TTO by setting equivalence (TTO$_{\text{equiv}}$)

An alternative, which we have applied in this study under the name of TTO$_{\text{equiv}}$, consists in directly asking the subject for the value t'. In our study, we elicited the QoL of unilateral cochlear implantation (QoL$_u$) by posing this question:

> In your opinion, how many years of living with perfect audition are equivalent to living for 20 years with one cochlear implant? In this context, "equivalent" means that if you had to choose, both options would be equally attractive to you.

The answer was provided by filling in the blank in this sentence:

> —I think that living for ___ years [time t'] with perfect audition [$q' = 1$] is equivalent to living for 20 years [time t] with one cochlear implant [$q =$ QoL$_u$].

The value of QoL$_u$ can then be estimated by applying Equation 1.

The question for eliciting the QoL with bilateral implantation (QoL$_b$) was:

> In your opinion, how many years of living with two cochlear implants are equivalent to living for 20 years with one implant?
>
> —I think that living for ___ years [time t'] with two CIs [$q' =$ QoL$_b$] is equivalent to living for 20 years [time t] with one CI [$q =$ QoL$_u$].

With the same method we estimated the quotient QoL$_b$/QoL$_u$ $= q'/q = t/t'$ in order to estimate the QoL with bilateral CI (QoL$_b$) and then calculated ΔQoL = QoL$_b$ − QoL$_u$, as shown in Figure 1. The reason for directly comparing QoL$_b$ with QoL$_u$ is to measure ΔQoL as accurately as possible, while in other studies—for instance, (Summerfield et al., 2010)—QoL$_b$ and QoL$_u$ are estimated independently by comparing each of them with the QoL of perfect health (perfect audition in this context), which, in our opinion, might cause a larger measurement error.

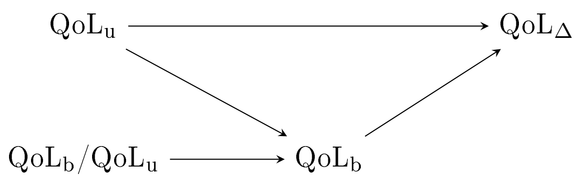

Figure 1: Measurement of the QoL for unilateral and bilateral CI.

2.1.2 TTO by giving up life time ($\mathbf{TTO_{time}}$)

Instead of asking for t' directly, a much more usual way of applying the TTO is to ask the respondent how much of t—the time expected to live in the condition under evaluation—he/she would sacrifice to recover perfect health (Arnesen and Trommald, 2005; Attema et al., 2013). If the time given up is u, then $t' = t - u$ and

$$q = q' \frac{t-u}{t} . \tag{2}$$

This expression agrees with the intuition that willingness to give up more time is due to an overestimated assessment of QoL.

In our example, the question for estimating QoL_u was:

> Imagine that there is a one y.o. child born with profound deafness in both ears, whose life expectancy is, for some reason, 20 more years [time t]. She has received one cochlear implant [$q = \mathrm{QoL}_u$]. If she were your daughter and you had to decide for her, how much of her life expectancy [time u] would you give up so that she could recover perfect audition [$q' = 1$]?
>
> —I would give up ____ years to recover perfect audition.

And the question for $\mathrm{QoL}_b/\mathrm{QoL}_u$ was:

> Imagine that there is a one y.o. little child born with profound deafness in both ears, whose life expectancy is, for some reason, 20 more years [time t]. She has received one cochlear implant [$q = \mathrm{QoL}_u$]. If she were your daughter and you had to decide for her, how much of her life expectancy [time u] would you give up so that she could get a second implant [$q' = \mathrm{QoL}_b$] ?
>
> —I would give up ____ years to get the second implant.

2.1.3 TTO by giving up quality of life ($\mathbf{TTO_{qol}}$)

Finally, another way of estimating q is to ask the subjects if they would accept a reduction in their QoL—more specifically, if they would accept to spend the rest of their life with a certain disease or disability—in order to live longer. If t' is the time frame (in this case, the time that the subject would live with perfect health) and u' the extra life-time that the subject would demand to accept the decrease in QoL, then the time lived with QoL q is $t = t' + u'$ and

$$q = q' \frac{t'}{t' + u'} . \tag{3}$$

The more time the respondent demands, the lower the QoL assigned to the condition of disease or disability.

In our example, the question for estimating QoL_u was:

Imagine a 1 y.o. little child whose life expectancy is, for some reason, 20 more years [time t']. Her audition is completely normal at this moment [$q' = 1$]. There is a treatment that will increase her life expectancy at the expense of causing her a profound bilateral deafness, which might be treated with a cochlear implant.

If she were your daughter and you had to decide for her, what is the minimum number of years [time u'] that the treatment should add to her life expectancy so that you would accept that she becomes deaf and receives a cochlear implant [$q = \mathrm{QoL}_u$]?

—I would accept the treatment, which would damage my daughter's hearing in both ears and make her a user of one cochlear implant, only if she would gain at least ___ life years.

And the question for $\mathrm{QoL}_b/\mathrm{QoL}_u$ was:

Imagine a 1 y.o. little girl who was born with profound deafness in both ears. Her life expectancy is, for some reason, 20 more years [time t']. She has now two cochlear implants [QoL q']. There is a treatment that would increase her life expectancy but would completely damage one of her ears, so that her hearing would be the same as if she only had one cochlear implant.

If you had to decide for her, what is the minimum number of years [time u'] that the treatment should add to her life expectancy so that you would accept that she loses hearing in one of her implants [$q' = \mathrm{QoL}_b$]?

—I would accept that treatment, which would make my daughter lose one of her two cochlear implants, only if she would gain at least ___ life years.

2.1.4 Expected psychological biases

The reason for trying different versions of the TTO is that there is ample psychological evidence showing that human beings in general are more willing to renounce a gain than to accept a loss of similar magnitude—see (Dawes, 1988) and references therein. This effect, sometimes called *the status-quo trap*, consists in "favoring alternatives that perpetuate the existing situation" (Hammond et al., 1998):

> Many experiments have shown the magnetic attraction of the status quo. In one, a group of people were randomly given one of two gifts of approximately the same value—half received a mug, the other half a Swiss chocolate bar. They were then told that they could easily exchange the gift they received for the other gift. While you might expect that about half would have wanted to make the exchange, only one in ten actually did. The status quo exerted its power even though it had been arbitrarily established only minutes before.

We should note that in the $\mathrm{TTO}_{\mathrm{time}}$, the respondent is placed in an imaginary scenario in which he/she has some time expectancy and is offered the possibility of exchanging it for a QoL increase. The status quo trap would then make the respondents reluctant to give up time, which would lead to a low value for u in Equation 2 and to an overestimation of the QoL of the condition of interest, q.

In the $\mathrm{TTO}_{\mathrm{qol}}$, the status quo trap would have the opposite effect, making subjects reluctant to give up QoL. Therefore, only a high gain in time (a large u' in Equation 3) would compensate them for the QoL lost, which leads to an underestimation of the QoL of the condition of interest, q.

In contrast, the $\mathrm{TTO}_{\mathrm{equiv}}$, in which the subjects do not have anything to give up, seems to be immune to the status quo trap. In the above-cited experiment the $\mathrm{TTO}_{\mathrm{equiv}}$ would be equivalent to offering the subjects a mug and a chocolate bar at the same time. Therefore, this framing of the TTO would reflect the subjects' preferences more faithfully than the other two.

2.2 Response collection

The survey consisted of three sections. The first asked about personal data, such as sex, age, disabilities, etc.; the second about QoL, and the third —which will be described and analyzed in a future paper—about willingness to pay for CI. It was implemented on LimeSurvey, an open-source tool that we customized and installed on a server of ours, thus avoiding the problem of collecting confidential data in an external server. We first created the aforementioned demo version, aimed at receiving the feedback from experts—see the acknowledgments.

In March 2015 we invited 3,465 students of the Computer Science School of our university to answer the online questionnaire. Around half of them were offered the possibility of entering a lottery in which they could win 300€; around a quarter were offered a lottery in which they could win 100€, and the other quarter were offered no incentive, as shown in Table 1.

Table 1: Invitations sent and responses received.

Incentive	invitations	responses	response rate
No incentive	866 (25.0%)	126	14.5%
Incentive: 100€ lottery	867 (25.0%)	149	17.2%
Incentive: 300€ lottery	1,732 (50.0%)	308	17.8%
Total	3,465 (100%)	583	16.8%

During the survey 583 respondents filled in the personal data screen, as shown in Figure 2. Each respondent was randomly assigned to one of the four elicitation techniques. The 144 respondents assigned to the VAS and the 121 assigned to the $\text{TTO}_{\text{equiv}}$ were immediately presented with the corresponding questions about QoL with CI. The 151 subjects assigned to the TTO_{time} were first asked whether they would ever accept to reduce their life expectancy in order to recover perfect health; we mentioned dialysis as an example of a case in which it might be worth giving up life time. The question presented to the respondents of TTO_{time} was:

> All diseases and disabilities reduce to a greater or lesser extent the quality of life of people suffering from them. Therefore many people would prefer to live for a shorter time with perfect health rather than for a longer time with a disease or disability. For example, a certain person might prefer to live for 7 years with perfect health than for 10 years with weekly dialysis sessions; i.e., that person would give up at least 3 years of time expectancy to avoid dialysis and recover health, but might refuse to give up more than 4 for the same purpose. If you had to choose, would you accept to reduce your life expectancy to some extent in order to increase your quality of life?

The two possible answers were: "Yes, I might accept depending on the amount of time reduced" and "No, never. I would always prefer to live as long as possible even with a poor quality of life". The 31 respondents (20.5%) that chose the second option were not asked about QoL; they are called *non-traders* in this paper. The purpose of this question was to distinguish them from *zero-traders*, as explained in Section 3.1.1. The 112 respondents (74.2%) that chose the first option were asked the TTO_{time} questions described above. Additionally, 8 subjects (5.3%) abandoned the survey when confronted with this question; it might be due to an accident, such as a broken internet connection, or because they did not wish to answer it.

Similarly the respondents assigned to the TTO_{qol} were asked whether they would accept a reduction in QoL in order to increase their life expectancy. 115 (68.9%) gave a positive answer, 29 (17.4%) were non-traders, and 23 (13.8%) abandoned for unknown reasons. This left us with 492 subjects: 144 assigned to the VAS, 121 to the $\text{TTO}_{\text{equiv}}$, 112 to the TTO_{time}, and 115 to the TTO_{qol}.

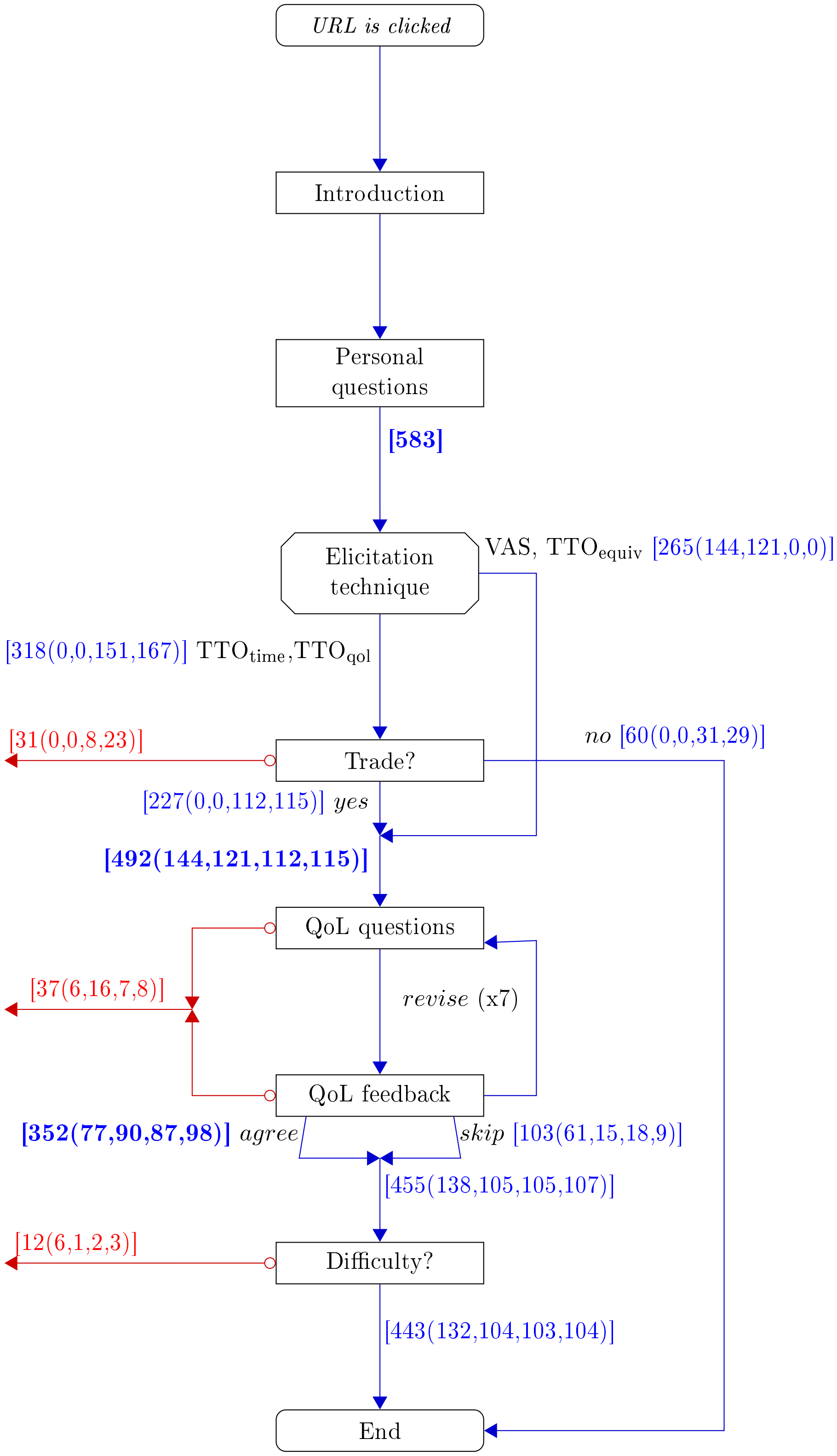

Figure 2: Response flowchart. The parentheses contain the number of subjects for each of the four elicitation techniques: (VAS, TTO_{equiv}, TTO_{time}, TTO_{qol}). The figures in bold represent the main milestones in the survey.

Those in the VAS group received feedback by means of the $\text{TTO}_{\text{equiv}}$. For example, if someone marked "80" on the VAS for unilateral CI, the feedback was: "The response you have given might be interpreted as follows: if you had to choose between living for 20 years with one cochlear implant or living for 16 years with perfect audition, you would be indifferent (i.e., both options would be equally attractive to you). Do you agree?" Similarly, those that had answered a TTO question—in any of the three versions—received feedback in the form of two VAS's, for unilateral and bilateral CI.

There were three possible answers to the feedback: "Yes, I do [agree]", "No, I wish to revise my response", and "I wish to skip this question".[1] Subjects were able to revise their answer up to 7 times, but always with the same method; for example, when the feedback had the form of two VAS's, it was not possible to drag the sliders; the respondent wishing to revise his/her answer was taken back to the screen of the TTO version originally assigned. When the answer was implausible (cf. Sec. 3.1.2 for our definition of "implausible"), the respondent was informed; for example: "You decided to give up to more years of life expectancy to get the second implant than to recover the perfect audition, which means that the quality of life of your daughter with two implants would be higher than with perfect audition. Do you agree?"

Out of the 455 subjects who explicitly answered the QoL question and completed this section of the survey, 352 (77.4%) confirmed their answer—134 of them (38.1%) after revising it—and 103 (22.6%) decided to skip the feedback question, as shown in Table 2. This section of the survey concluded by asking how difficult they had found the questions about QoL.

Table 2: Number of responses collected. "Agreed" means that the subjects confirmed their response after receiving the feedback. We give in parentheses the percentages over the number of subjects assigned to each technique. "Confirmed" is the percentage of numeric estimates confirmed after the feedback.

	VAS	$\text{TTO}_{\text{equiv}}$	TTO_{time}	TTO_{qol}	Total
Subjects assigned	144	121	151	167	583
Non-traders	—	—	31 (20.5%)	29 (17.4%)	60 (10.3%)
Abandoned	6 (4.3%)	16 (13.2%)	15 (9.9%)	31 (18.6%)	68 (11.7%)
Answered	138 (95.8%)	105 (86.8%)	105 (69.5%)	107 (64.1%)	455 (78.0%)
Revised	58 (42.0%)	40 (38.1%)	44 (41.9%)	23 (21.5%)	165 (36.3%)
Agreed	77 (53.4%)	90 (74.4%)	87 (57.6%)	98 (58.7%)	352 (60.4%)
% confirmed	55.8%	85.7%	82.9%	91.6%	77.4%

3 Results

3.1 Preliminary considerations

3.1.1 Treatment of non-traders

In the standard application of the TTO, when a respondent refuses to give up any life time, the researcher concludes, by making $u = 0$ in Equation 2, that for that person the two health conditions being compared have the same QoL. However, we conjectured the existence of *non-traders*, i.e., subjects who say that they would never accept a reduction in life expectancy to recover perfect health, even if they suffered from a severe illness. In our survey, 20.5% of the respondents assigned to the TTO_{time} were non-traders. It seems reasonable to assume that those people are not indifferent between being healthy and being seriously ill, which implies that the

[1] In a posterior survey involving CI users, we added a fourth option: "I stick to my response but do not agree with this interpretation."

Table 3: Reached point during feedback process by elicitation technique. The number at the left of each slash is the number of all responses; the number at the right represents the number of responses among the confirmed ones.

Step	VAS	$\text{TTO}_{\text{equiv}}$	TTO_{time}	TTO_{qol}	Responses
First	80/38	65/52	61/50	84/78	290/218
Second	43/28	23/21	27/21	12/11	105/81
Third	9/6	8/8	8/7	7/6	32/27
Fourth	4/3	7/7	4/4	0/0	15/14
Fifth	1/1	1/1	2/2	1/1	5/5
Sixth	1/1	1/1	2/2	3/2	7/6
Seventh	0/0	0/0	1/1	0/0	1/1
Global	138/77	105/90	105/87	107/98	455/352

Table 4: Zero-traders, where u stands for "unilateral cochlear implant", *All* for "all the respondents", *Confirmed* for "respondents that confirmed their estimate", i for "initial response" (i.e., before feedback), f for "final response" (after feedback and maybe after revision).

Technique	All-or-Confirmed	n	QoL_u^i	QoL_u^f	QoL_b^i	QoL_b^f
TTO_{time}	All	105	21 (20%)	22 (20,95%)	29 (27,62%)	26 (24,76%)
TTO_{time}	Confirmed	87	15 (17,24%)	16 (18,39%)	19 (21,84%)	17 (19,54%)
TTO_{qol}	All	107	0 (0%)	0 (0%)	1 (0,93%)	1 (0,93%)
TTO_{qol}	Confirmed	98	0 (0%)	0 (0%)	1 (1,02%)	1 (1,02%)

TTO_{time} is clearly inadequate to capture their assessment of the QoL for a serious disease—we used as an example weekly dialysis, which causes an undeniable reduction of QoL—and even more inadequate for a relatively mild health condition such as wearing CIs. For this reason, we did not ask them about QoL. In contrast, we did include zero-traders (see table 4), i.e., those who said that in some cases they would trade off life time for QoL but, if they had one CI, they would not give up any life time for a second implant or for perfect audition.

In the TTO_{qol} 17.4% of the respondents were non-traders, i.e., subjects who said that they would never accept a reduction in their QoL to increase their life expectancy; making u' arbitrarily large in Equation 3 leads to $q = 0$. This answer also seems implausible because we assume that everybody prefers having one or two CIs or receiving dialysis to being dead.

We have computed the QoL with CIs in two ways: including non-traders and leaving them out. The first case is in line with the standard application of the TTO_{time} method, which does not distinguish between non-traders and zero-traders (Arnesen and Trommald, 2005); as mentioned above, this introduces a bias by assuming that the QoL with CIs is 1 for non-traders of the $\text{TTO}_{\text{time}}$and 0 for non-traders of the TTO_{qol}, which clearly seems to be unrealistic. This bias is especially relevant in the estimation of ΔQoL, because when both QoL_u and QoL_b are pushed to 0 or to 1, $\Delta\text{QoL} = 0$. For this reason we have also computed ΔQoL leaving out non-traders, even though we acknowledge that this introduces a bias in the opposite direction, in order to compare the results.

3.1.2 Definition of "implausible answer"

We consider that wearing CIs is worse than having perfect audition and better than being dead. We also assume, in agreement with all the experts, that $\text{QoL}_b > \text{QoL}_u$ because of the significant advantages contributed by the second implant, as explained in the introduction.[2] Therefore we

[2]Some parents of profoundly deaf children refuse the second implant in order to spare that ear for future treatments, such as stem cell therapies. Those people might doubt, from the perspective of the whole life of a

Table 5: Time (in seconds) devoted to complete the questionnaire.

Incentive	Min	25% percentile	Median	Mean	75% percentile	95% percentile	Max
None	172	460	661	738	973	1411	2371
100€	162	440	644	791	922	1848	3063
300€	114	444	599	694	813	1463	3578
Global	114	447	612	728	872	1595	3578

have considered *implausible* the answers that violate the inequality $0 < \mathrm{QoL}_u < \mathrm{QoL}_b < 1$. This definition implies that all non-traders gave an implausible response, because for them either $\mathrm{QoL}_u = \mathrm{QoL}_b = 1$ or $\mathrm{QoL}_u = \mathrm{QoL}_b = 0$.

The way in which we have estimated the QoL ensured that $0 \leq \mathrm{QoL}_u \leq 1$: in the VAS these are the limits of the scale; in the TTO answers we made LimeSurvey check that $0 \leq t' \leq t$ for the $\mathrm{TTO}_{\mathrm{equiv}}$ (cf. Eq. 1), $0 \leq u \leq t$ for the $\mathrm{TTO}_{\mathrm{time}}$ (cf. Eq. 2), and $u' \geq 0$ for the $\mathrm{TTO}_{\mathrm{qol}}$ (cf. Eq. 3), thus impeding some implausible answers. The VAS also ensured that $0 \leq \mathrm{QoL}_b \leq 1$, but allows the user to respond that $\mathrm{QoL}_u > \mathrm{QoL}_b$. In contrast, the three versions of the TTO ensured that $\mathrm{QoL}_b/\mathrm{QoL}_u \geq 1$ but allowed $\mathrm{QoL}_b \geq 1$, which contravenes the definition of QoL (Torrance, 1987); when this occurred, we set $\mathrm{QoL}_b = 1$.

3.2 Effect of the incentive

We can observe in Table 1 that the response rate (including all those who filled in the personal data) was 14.5% for the students that were offered no incentive, 17.2% for those that were offered a participation at the 100€ lottery, and 17,8% for the 300€ lottery. There is a slightly significant difference between the first and third group ($p = 0.046$ for the χ^2 test with the Yates' continuity correction disabled (Hitchcock, 2009)), but the difference between the first and the second ($p = 0.13$) and between the second and the third ($p = 0.71$) are not statistically significant. The difference between the group of respondents with no incentive and those with any incentive is slightly significant ($p = 0.039$). The proportion of respondents who concluded the QoL phase of the survey was 11.4%, 13.0% and 14.0%, respectively; these differences are not statistically significant. The median time spent in completing the survey was around 10 minutes (see Table 5), with no significant difference between the three groups.

3.3 Effect of the technique on response collection

As seen in Table 2, VAS and $\mathrm{TTO}_{\mathrm{equiv}}$ are the methods that collected more qualitative estimates: 95.8 and 86.8%, respectively, which differ significantly from those of the $\mathrm{TTO}_{\mathrm{time}}$, 69.5%, and the $\mathrm{TTO}_{\mathrm{qol}}$, 64.1%. However, only 55.8% of the VAS responses were confirmed after feedback, while in the TTO methods the percentage of responses confirmed after the feedback ranged from 82.9 to 91.6%, a significant difference[3]. From the point of view of the number of subjects assigned to each technique, the $\mathrm{TTO}_{\mathrm{equiv}}$ is the method that collects more answers confirmed by the respondents: 74.4% versus around 55% for the other three methods ($p < 0.01$ for each of the three comparisons).

deaf child, that $\mathrm{QoL}_b > \mathrm{QoL}_u$. However, none of the respondents was a parent in this situation or a user of CIs, nor mentioned the irreversible damage to the cochlea as a disadvantage of the bilateral CI. Additionally, even in the likely case that some day new therapies might populate the cochlea with healthy ciliary cells, an auditory nerve that has received stimulation at an early age will take more profit of them than a nerve that has never been stimulated (Peters, 2007).

[3] As otherwise stated, the statistical significance of the differences is calculated with Student's t-test.

3.4 Effect of feedback on the number of implausible responses

When designing this experiment we expected that feedback would greatly reduce the number of implausible responses. Table 6 generally confirms our prediction; there were however two cases in which the feedback had the opposite effect. First, in the VAS several subjects revised their answers to make $\text{QoL}_u = \text{QoL}_b = 1$ and $\text{QoL}_u > \text{QoL}_b$, presumably because they did not wish their answer to be interpreted as willingness to trade off any life years, thus becoming non-traders. Second, in the TTO_{qol} feedback increased the number of responses in which $\text{QoL}_u = 0$ or $\text{QoL}_b = 0$. In all cases they were warned of the inconsistencies but, to our surprise, a considerable number of them stuck to their answers.

Considering the possibility that inconsistencies were due to haste or carelessness, we analyzed the correlation between the number of implausible answers and the time spent completing the questionnaire. We observed that the respondents who gave implausible responses spent 709 seconds, while the others spent 739, a difference that is not significant ($p = 0.47$) and rules out this explanation.

Table 6: Percentage of implausible answers for each elicitation technique. A star means that the result includes non-traders. We have assumed $\text{QoL}_u = \text{QoL}_b = 1$ for non-traders of the TTO_{time} and $\text{QoL}_u = \text{QoL}_b = 0$ for non-traders of the TTO_{qol} (cf. Sec. 3.1.1). "$\text{QoL}_{u,b} = 0$" means "$\text{QoL}_u = 0$ or $\text{QoL}_b = 0$". The number at the left of each slash is the percentage of implausible answers in the first response, i.e., before feedback; the number at the right is the percentage among the confirmed responses. A dash means that the elicitation technique or the web interface or the QoL scale made it impossible to enter an implausible answer. Some numbers in the last column are smaller than the sum of the previous columns because the responses of a subject may contain several violations of the inequalities $0 < \text{QoL}_u < \text{QoL}_b < 1$.

Technique	$\text{QoL}_{u,b} = 0$	$\text{QoL}_{u,b} \geq 1$	$\text{QoL}_u = \text{QoL}_b$	$\text{QoL}_u > \text{QoL}_b$	Total
VAS	0.0/0.0	9.4/20.8	2.2/5.2	5.8/6.5	15.9/29.9
TTO_{time}	9.5/0	66.7/56.3	30.5/20.7	—	77.1/58.6
TTO_{time}*	7.4/0	74.3/67.8	46.3/41.5	—	82.4/69.5
$\text{TTO}_{\text{equiv}}$	1.0/0.0	26.7/23.3	31.4/21.1	—	41.0/27.8
TTO_{qol}	—	57.9/49.0	0.9/1	—	58.9/50.0
TTO_{qol}*	21.3/22.8	51.5/38.6	44.9/37	—	69.1/63.0

The quantitative effect of the feedback on the estimation of the QoL is analyzed in the next section.

3.5 Estimation of the QoL

3.5.1 QoL of unilateral cochlear implantation

Table 7 summarizes the estimates of the QoL for unilateral CI. The "compressed VAS" (cVAS) value is obtained by applying the following transformation to the VAS estimate of each subject:

$$q_{cVAS} = 1 - (1 - q_{VAS}/100)^{1.6} \qquad (4)$$

This equation is taken from Summerfield et al. (2010), who applied it for the same purpose, i.e., measuring the QoL of unilateral and bilateral CI. Its purpose is to match the VAS estimates with those of the standard TTO, i.e., the TTO_{time} without feedback including non-traders.

When analyzing the effect of the feedback, we find an apparent increase in the VAS estimate from 0.581 to 0.616, also observable in Figure 3, which might be explained because the $\text{TTO}_{\text{equiv}}$ estimate is higher than that of the VAS. However, if we focus on the subjects that confirmed the VAS estimate after the $\text{TTO}_{\text{equiv}}$ feedback, we observe a slightly decrease in their estimates, but

Table 7: QoL with unilateral CI (mean value), where u stands for "unilateral cochlear implant", *all* for "all the respondents", *conf* for "respondents that confirmed their estimate", i for "initial response" (i.e., before feedback), f for "final response" (after feedback and maybe after revision), and $QoL_u^{f\text{-}i\ conf} = QoL_u^{f\ conf} - QoL_u^{i\ conf}$. A star means "including non-traders". "cVAS" stands for "compressed VAS" (cf. Eq. 4)

Technique	n all	n conf	$\text{QoL}_u^{i\ all}$	$\text{QoL}_u^{i\ conf}$	$\text{QoL}_u^{f\ conf}$	$\text{QoL}_u^{f\text{-}i\ conf}$
VAS	138	77	0.581	0.616	0.616	0
cVAS	138	77	0.729	0.764	0.761	−0.002
TTO_{time}	105	87	0.725	0.738	0.79	0.051
$\text{TTO}_{\text{time}}{}^*$	136	118	0.787	0.807	0.845	0.038
$\text{TTO}_{\text{equiv}}$	105	90	0.654	0.660	0.667	0.007
TTO_{qol}	107	98	0.618	0.619	0.621	0.001
$\text{TTO}_{\text{qol}}{}^*$	136	127	0.486	0.478	0.479	0.001

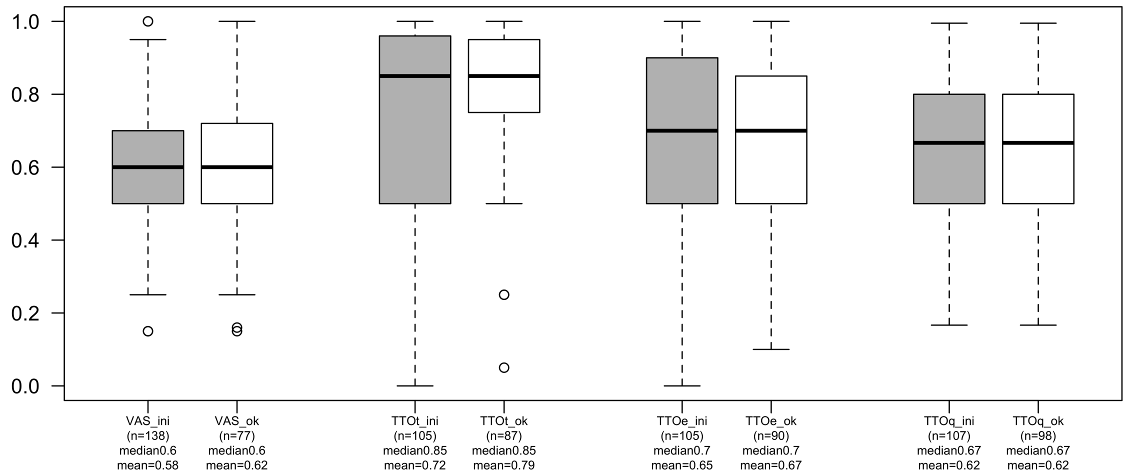

Figure 3: QoL estimates for unilateral CI.

the effect is so small that is seems to be due to random variations. In contrast, the VAS feedback consistently increased all the TTO estimates, as expected, but the increase is very small for the $\text{TTO}_{\text{equiv}}$ and the TTO_{qol}, and not significant for any of the three techniques.

If we compare the initial estimates obtained for different techniques, we observe that the QoL of unilateral CI estimated with the standard TTO, i.e., the TTO_{time} without feedback and including non-traders, is 0.787, significantly higher than for the $\text{TTO}_{\text{equiv}}$, 0.654 ($p = 3 \times 10^{-4}$), and this is in turn significantly higher than that for the TTO_{qol} including non-traders, 0.486 ($p = 1.8 \times 10^{-8}$). These results confirm the psychological biases that we had predicted (cf. Sec. 2.1.4). However, if we exclude non-traders, the estimates are 0.725 for the TTO_{time} and 0.618 for the TTO_{qol}, which differ significantly from each other ($p = 0.004$) but not from that for the $\text{TTO}_{\text{equiv}}$ ($p = 0.08$ and 0.28 respectively). If we compare the estimates confirmed after feedback—which are revised in some cases—the gaps between the three TTO techniques are a little wider and the p-values much smaller. In our opinion, these comparisons and the discussion in Section 2.1.4 mean that $\text{TTO}_{\text{equiv}}$ is clearly less biased than TTO_{time} and TTO_{qol}, especially when these methods include non-traders.

Table 8: Increase of QoL from unilateral CI to bilateral CI. The meaning of the headers is the same as in Table 7.

Technique	n all	n conf	$\text{QoL}_\Delta^{i\ all}$	$\text{QoL}_\Delta^{i\ conf}$	$\text{QoL}_\Delta^{f\ conf}$	$\text{QoL}_\Delta^{f\text{-}i\ conf}$
VAS	138	77	0.247	0.217	0.215	−0.002
cVAS	138	77	0.194	0.158	0.155	−0.002
TTO_{time}	105	87	0.206	0.204	0.144	−0.060
$\text{TTO}_{\text{time}}{}^*$	136	118	0.159	0.151	0.106	−0.045
$\text{TTO}_{\text{equiv}}$	105	90	0.111	0.103	0.126	0.023
TTO_{qol}	107	98	0.293	0.290	0.282	−0.008
$\text{TTO}_{\text{qol}}{}^*$	136	127	0.231	0.223	0.218	−0.006

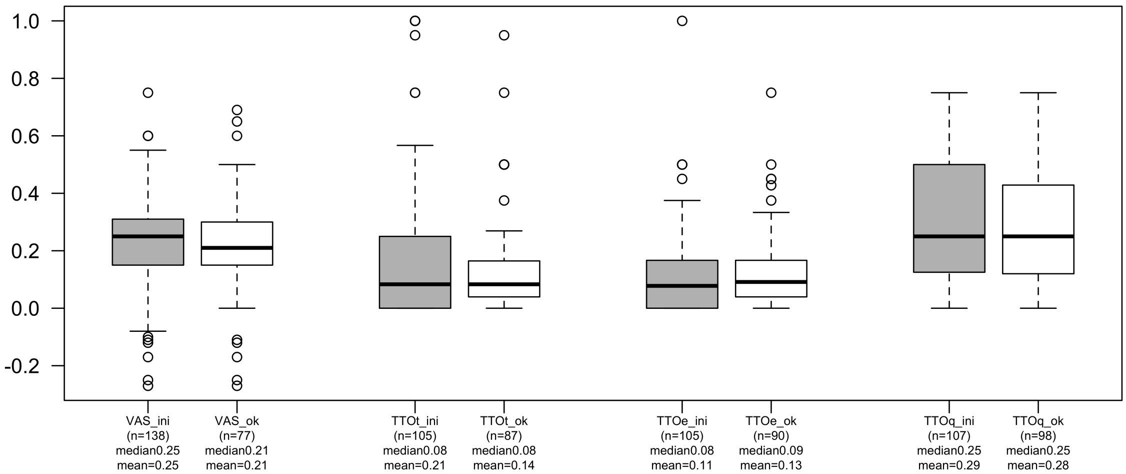

Figure 4: Estimates of QoL increase from unilateral CI to bilateral CI.

3.5.2 QoL increase from unilateral CI to bilateral CI

Table 8 contains the estimates for the increase in QoL. We observe that the TTO_{time} gives the lowest estimates and the TTO_{qol} the highest. Non-traders decreased the estimates, because because we assumed $\text{QoL}_u = \text{QoL}_b = 1$ for the former and $\text{QoL}_u = \text{QoL}_b = 0$ for the latter, which makes $\text{QoL}_\Delta = 0$ in both cases. Feedback caused a decrease for the TTO_{time} and an increase for the $\text{TTO}_{\text{equiv}}$; its impact on the VAS and the TTO_{qol} was almost null. Overall, the highest estimate, 0.106. results from the TTO_{time} after feedback, including non-traders, and the highest, 0.293, from the TTO_{qol} before feedback excluding non-traders.

3.6 Perceived difficulty of each technique

The respondents were asked about their perception on the difficulty of the technique they were elicited with. They had five possible answers: "Very easy", "Easy", "Somewhat difficult", "Difficult" and "Very difficult". As shown in Figure 5, the respondents assessed the TTO_{time} technique as the most difficult, with more than 35% of the respondents finding the questions to be very difficult.

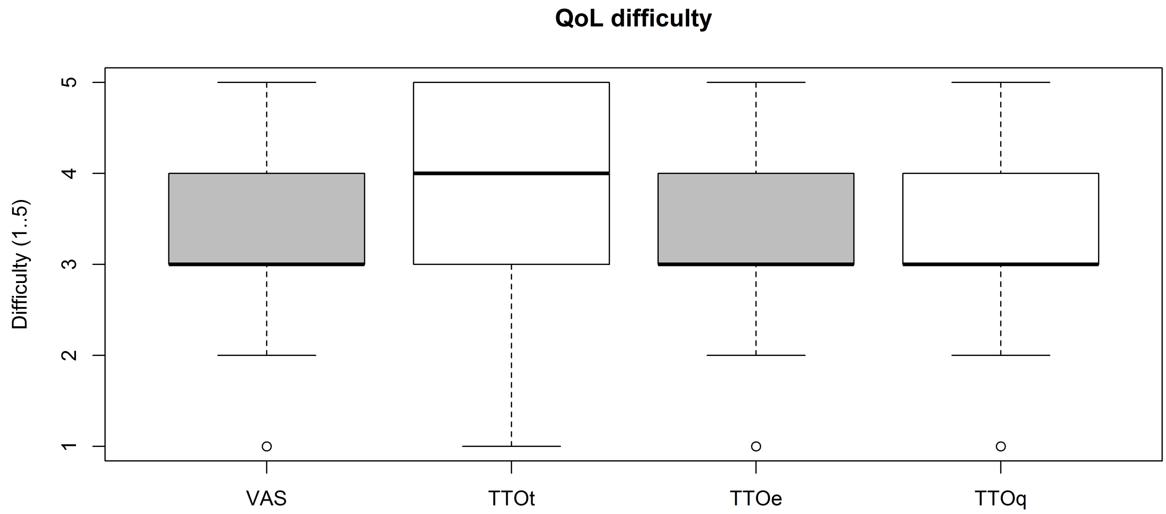

Figure 5: QoL difficulty.

Table 9: Percentages of the respondents by QoL difficulty and technique.

Technique	Very difficult	Difficult	Somewhat difficult	Easy	Very easy
VAS	13.0	21.0	42.0	15.9	8.0
TTO_{time}	35.2	21.9	28.6	11.4	2.9
TTO_{equiv}	7.6	21.0	49.5	17.1	4.8
TTO_{qol}	23.4	18.7	37.4	15.0	5.6

4 Discussion

4.1 Limitations

An apparent limitation of the study is the low overall response rate, 16.8%, as shown in Table 1. However, from the point of view of comparing different elicitation techniques, the response rate is irrelevant, because subjects were randomly assigned to each technique. A different issue is whether an individual's assessment of the QoL with CI would affect the probability of entering our survey. We find this possibility very unlikely, because none of the respondents declared to have a relative or a close friend wearing CIs. It also seems unlikely that an individual's tendency to give higher or lower QoL estimates affects the probability of responding to a QoL survey. In any case, this potential self-selection bias would affect all the QoL surveys, regardless of whether volunteers are recruited, either by posting an add at the university tabloids, by putting banners on web pages, by mailing parents of disabled children, or by any other means. In any case, the response rate of our study is higher than in other studies that recruited volunteers through internet, such as the 12.3% of (Shah et al., 2015), a study whose methodology was approved by the National Institute for Health and Care Excellence (NICE) of the UK.

A potential bias of our study is that we invited the students of a Computer Science School, which led to an over-representation of male individuals (83% of the respondents). The opposite effect would occur when a teacher at a school of psychology—a common profile among QoL researchers—recruits volunteers among their students.

On the other hand, we profited from teaching at a distance university, whose students are more representative of the general population than those of a traditional university, who are usually between 18 and 25 y.o. and have no children.

4.2 Comparison of different versions of the TTO

The above results prove that the status-quo trap (Hammond et al., 1998) affects the TTO method. In particular, we explicitly found many non-traders, i.e., individuals who declared that they would never give up life time to gain QoL situation. (We distinguish them from zero-traders, i.e., those who might be willing to give up time in some situations but not for the condition under study.) The application of the TTO_{time} assumes that for non-traders the QoL is 1 for every health condition, which is absurd because no one is indifferent between perfect health and a seriously illness. Therefore the TTO_{time} is clearly inadequate to estimate the preferences of non-traders, which in our study were 20.5% of the respondents. Even for the those who entered the trade-off game, the average estimate is significantly lower than in the $\text{TTO}_{\text{equiv}}$. The reason for including in our study the TTO_{qol}, a method that has never been used in practice or discussed in the literature, even though it is in principle as good (or as bad) as the TTO_{time}, was to prove that the status-quo trap may bias the TTO in the opposite direction. The empirical results have confirmed that the TTO_{time} estimates are higher than that of the $\text{TTO}_{\text{equiv}}$, and those the TTO_{qol} are lower.

There additional findings supporting $\text{TTO}_{\text{equiv}}$ as the version that better captures the respondents' preferences. First, it collected more qualitative estimates: 86.8% vs. 69.5% for the TTO_{time} and 64.1% for the TTO_{qol}, due to a lower dropout rate from the on-line questionnaire, and had more responses confirmed after feedback: 74.4% vs. 57.6% and 58.7% (cf. Sec. 2.2, Table 2). Second, it produces fewer implausible responses: 41% vs. 82% and 70%; feedback reduced these rates to 28% vs. 70% and 63% (vs. 59% and 50% if we exclude non-traders), as shown in Section 3.1.2, Table 6. And third, the respondents in general found the $\text{TTO}_{\text{equiv}}$ questions easier to answer than those of the TTO_{time} (cf. Sec. 3.6, Fig. 5).[4]

In the case of pediatric interventions the TTO_{time} places respondents in an emotionally hard scenario: the decision of cutting down the life their hypothetical child to improve his/her quality of life, which would presumably increase the number of non-traders. In order to avoid this difficulty, Summerfield et al. (2010) proposed the respondents to give up some of their own expected life time to gain perfect audition for their daughter. However, this solution creates new problems: first, an adult's life time may not be equivalent to the same amount of time for a child; and second, generosity (or lack of it) may bias the responses; in fact, in their experiment some subjects were willing to give up their whole life, which leads to the absurd conclusion that for them the QoL with a cochlear implant is 0, the same as being dead. In contrast, the $\text{TTO}_{\text{equiv}}$ avoids that moral dilemma.

Finally, the $\text{TTO}_{\text{equiv}}$ is similar to the ping-pong method originally proposed for the TTO Torrance (1970); Torrance et al. (1972). Some authors have argued that the ping-pong version works better than directly asking for an indifference value (Bostic et al., 1990) but, in addition to be time consuming, faces the problem that the initial question introduces a bias due to anchoring (Augestad et al., 2016)—see (Attema et al., 2013) for a discussion and additional references.

For all these reasons we recommend the $\text{TTO}_{\text{equiv}}$ as the best version of the TTO method.

4.3 Comparison with other studies for bilateral CI

In our study, the estimate for the QoL increase from unilateral CI to bilateral CI varies from 0.106 to 0.293, depending on the technique, as explained in Section 3.5.2 (cf. Table 8). These results fall within the range of values obtained previously: our VAS estimates vary from 0.155 (compressed VAS obtained after feedback) to 0.247 (uncompressed value before feedback), whereas previous studies have returned estimates of 0.33 (unpublished study by Lovett (2009), cited in (Summerfield et al., 2010)), 0.02 (Lovett, 2010), 0.22 (Lovett, 2010, retrospective assessment), 0.13 (Summerfield et al., 2010), 0.07 (Kuthubutheen et al., 2015), 0.15 for hearing and −0.2

[4] The TTO_{qol} was considered slightly easier than the $\text{TTO}_{\text{equiv}}$, but the difference was not statistically significant.

for general health (Smulders et al., 2016). The results of the TTO (all through TTO_{time} elicitation, without feedback) are 0.03 (Summerfield et al., 2002), 0.11 (Summerfield et al., 2010), 0.12 (Kuthubutheen et al., 2015), and 0.09 (Smulders et al., 2016); the last three values are very similar to the one we have obtained with the same technique, 0.106.

However, we have argued that this method tends to overestimate the QoL associated with diseases and disabilities, and consequently to reduce the incremental QoL of health interventions. We have also argued that the most accurate method for estimating the QoL is the TTO_{equiv} with feedback, which in our empirical study yielded a value of 0.126, not far away from the 0.11 of Summerfield et al. (2010) or the 0.12 of Kuthubutheen et al. (2015).

However, we have argued in Section 2.1.4 that TTO_{equiv} is the most accurate method, because the status-quo trap biases the TTO_{time} and the TTO_{qol} (in opposite directions), a conjecture confirmed by the results in Section 3.5.1. Those results also confirm that feedback reduces the number of implausible responses in all the versions of the TTO, especially in the TTO_{equiv}.

5 Conclusions

The main goal of our study was to measure the increase in health-related QoL from unilateral to bilateral cochlear implantation (CI) in children, in order to posteriorly conduct a cost-effectiveness analysis. We have used visual analog scales (VAS) and three versions of the time trade-off (TTO) method: the TTO_{time} and the TTO_{qol}, in which the subjects could give up life time for QoL, or vice versa, and the TTO_{equiv}, in which the trade-off was established by setting equivalence.

The empirical results have confirmed our conjecture that the status-quo trap, a well-known psychological bias, lead to an overestimation of QoL in the TTO_{time} and an underestimation in the TTO_{qol}. In contrast the TTO_{equiv}, in which respondents do not have to give up anything, seems to be immune to that bias. This version is similar to the ping-pong technique originally proposed for the TTO (Torrance, 1970), but does not require so much time and avoids the anchoring bias caused by the initial question (Augestad et al., 2016). Additionally, it had a lower dropout rate in our on-line questionnaire, returned fewer implausible responses, and obtained more confirmations after feedback than the TTO_{time} and the TTO_{qol}. Our subjects found it significantly easier to answer than the TTO_{time}. Additionally, in this study, focused on a pediatric intervention, respondents avoided the hard decision of cutting down the life of their (hypothetical) child to increase his/her quality of life or the dilemma of giving their life time of their own for the benefit of their child (cf. Sec. 4.2). For these reasons we recommend the TTO_{equiv} over the TTO_{time}, which is nowadays the most common version of this method.

A novelty of our study was the idea of offering feedback: subjects assigned to the VAS received feedback in the form of TTO statements, and vice versa; we also warned them about implausible answers. This feedback did not cause any significant change the numerical results, but led to an important reduction in the number of implausible responses for the TTO—from 41% to 28% for the TTO_{equiv}, as shown in Table 6.. This number is still much higher than expected, but we could not find an explanation for it—see Section 3.4.

We also observed that incentive, which consisted on the possibility of entering a lottery of 100 or 300€ after completing the survey, caused a small—but statistically significant—increase in the response rate (cf. Sec. 3.2).

The increase in QoL for bilateral CI in our study ranged from 0.106, obtained with the TTO_{time}, to 0.293, obtained with the TTO_{qol}. These results are compatible with those published previously in the literature. We have argued that the most reliable estimate is 0.126, a higher value than those typically used in cost-utility analyses of bilateral CI, but not far away from recent studies that have applied the TTO_{time} method (cf. Sec. 4.3).

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