Study on the introduction of 100cm target face and a 60 arrow ranking round for World Archery competitions

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Abstract

This study shows the expected (scoring and ranking) consequences of changing the target face size from 122cm to 100cm without and in combination with changing the number of arrows for the ranking round from 72 to 60.

Tests have been performed under supervised conditions with 16 top-level archers (male and female) with several of them in the top 20 of the world ranking. Part of the test was to fill out a questionaire. Based on these tests, simulations of competitions have been performed and compared with actual results (World Championships 2019).

Results show that the 100cm target face will reduce scores (as expected) on both the high end and the lower end of the ranking round. Recurve men top score 696 becomes 683 and a score of 645 becomes 621. For recurve women the top score 692 becomes 678 and a score of 613 becomes 581. The score difference between the 1st and 104th score will increase going to 100cm. An increase in score difference means less tied score in a ranking round.

Visually, the 100cm target face will reflect almost a 122cm target face at 90m (actually 85m) and thus changes the sight picture and might require a different aiming dot or circle and archers will need some time to adjust.

For the elimination rounds the effect of changing to 100cm results in more matches that will be decided in 3 sets and less in 5 sets and slightly less matches will be decided by shoot-off.

A correctness (or fitness) metric is defined which indicates how well the end-result represents the skill-levels. This fittness metric will decrease (smaller = better fit) slightly. With 100cm the format becomes 'better' in selecting the best performing archer.

Introducing a ranking round of 60 arrows without changing the target face size, will close the gap, or score differenec, between the 1st and 104th score. The number of tied scores in the ranking round will rise significantly. However, when introduced in combination with the smaller 100cm target face this will result in the same number of ties as we have currently.

1. Introduction

The World Archery Target Archery Committee (TAC) wants to propose a 100 cm target face to replace the 122cm target face in all World Archery competition formats, except the WA 1440 round. The World Archery Coach Committee (CC) supports this motion. The goal of this change is to get a higher differentiation of scores in both qualification and elimination rounds which a.o. will reduce the number of tied scores and the 'feeling' that even though one archer shot smaller/better groups, it still didn't pay-out with a win. The 100cm is better in 'deciding the better archer' than the 122cm.

The proposal will be made at the 2021 Congress to change starting 2022.

In a joint collaboration between TAC and CC a test protocol was setup and tests have been executed by international archers using these new target faces.

The first part of the test protocol was actual shooting under controlled conditions and on the same day on both target face sizes and accurately record arrow positions and score.

Because the shooting distance does not change, in theory, the grouping/group-patterns will stay the same absolute size. However, there may be a reason for the archers' performance to change a bit due to having more (or less) difficulty in aiming. The sight picture will change; a 100cm at 70m will look like a 122cm at 85 meters. Most archers

are familiar with their sight-picture (the sight's aiming dot and/or ring relative to the target face size) and that may have an impact. To find out more, the second part of the test protocol was to interview each participating archer about the possible influence of the sight-picture.

A second proposal will be made at the 2021 Congress, and that is to redcue the number of arrows shot in the ranking round to 60 arrows. The effect of this (and the 100cm target face) will be discussed as well.

2. Test protocol 100cm vs 122cm

The test protocol was;

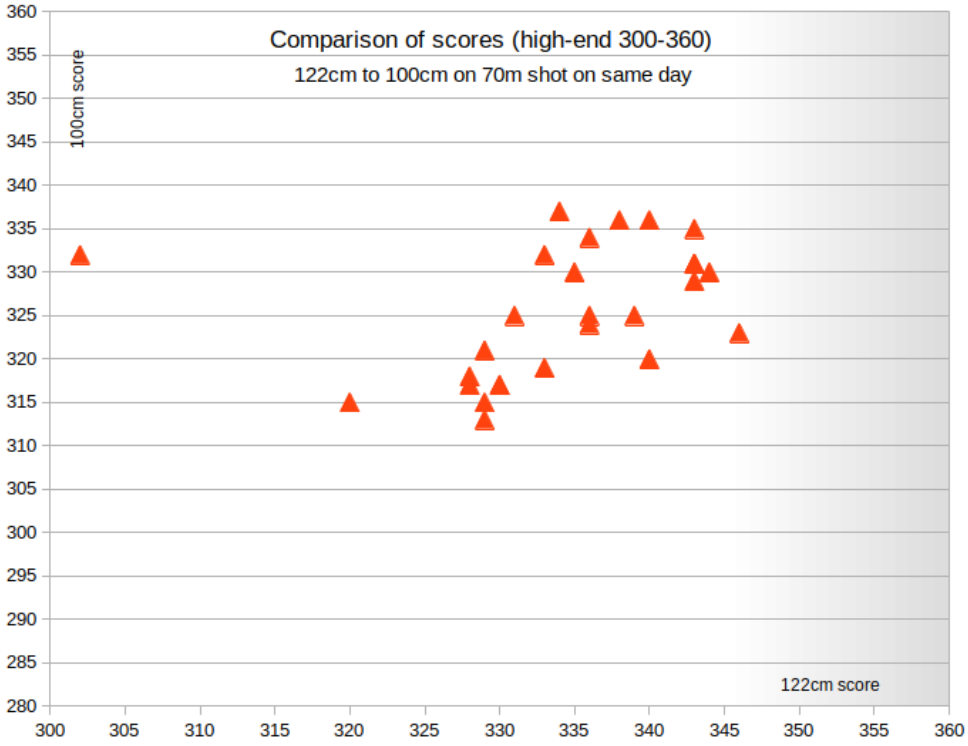
- Shooting distance is 70m.
- Conditions are controlled (preferably indoors, but if outdoors, then with same conditions).
- 36 arrows on 100cm followed by 36 arrows on 122cm in the same session (alternating the order of 100/122cm if doing more than 1 session per archer).
- Male and female of high international level.
- Accurate recording of arrow impacts and scores with photos or Artemis (archery app).
- All scores to be shot in the period January-February 2021.
- All participants fill in a questionaire afterwards.

The assumption for this test protocol is that an archer is able to keep exactly the same skill level (i.e. shoot with the same ability or skill for the whole day), in order to get a relation between the two scores (on 122cm and 100cm).

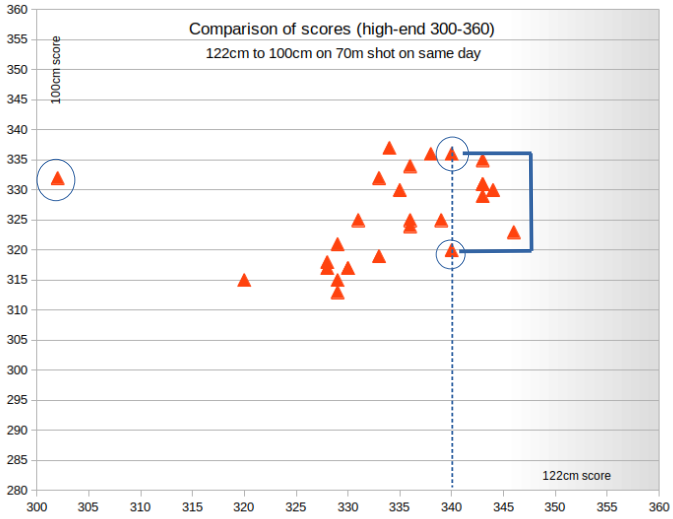
3. Results and preliminary analysis

16 individual archers from the Netherlands, Germany and Italy participated in these trials. 6 recurve women and 10 recurve men. With several men and women in the top 20 of the World Ranking. All members of national teams or talent team. In total 28 sessions where an archer shot a score on a 100cm target face and in that same session shot a score on a 122cm target face under perfect conditions (indoor 70m).

These 28 results are shown below, where each symbol represents 1 session with 2 scores. On the horizontal axes the 122cm score and on the vertical axes the 100cm score that was shot the same day by the same archer in the same controlled environment.



Most striking is the outlier on the far left, where a female archer shot a 302 (with a miss) on 70m at 122cm and with only a break of less than half an hour managed a 332 on a 100cm target face; a huge difference and not a representative result.



But even if this is considered an outlier, there are other remarkable scores that can be observed in the data.

Example 1; two archers managed a 340 at 122cm but one scored a 319 on the 100cm whilst the other shot a 336. Both in the same session and on the same day.

Example 2; one archer (who shot two sessions on two different days) managed the highest score difference (346@122cm / 323@100cm) and one of the lowest score differences (340@122cm / 336@100cm).

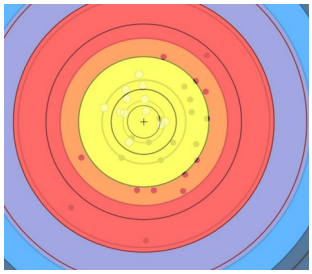
From these results it is hard to find a fixed relation between the 122cm score and the 100cm score. Partially because it is difficult, even for top-archers under controlled conditions shooting on the same day, to keep a constant performance.

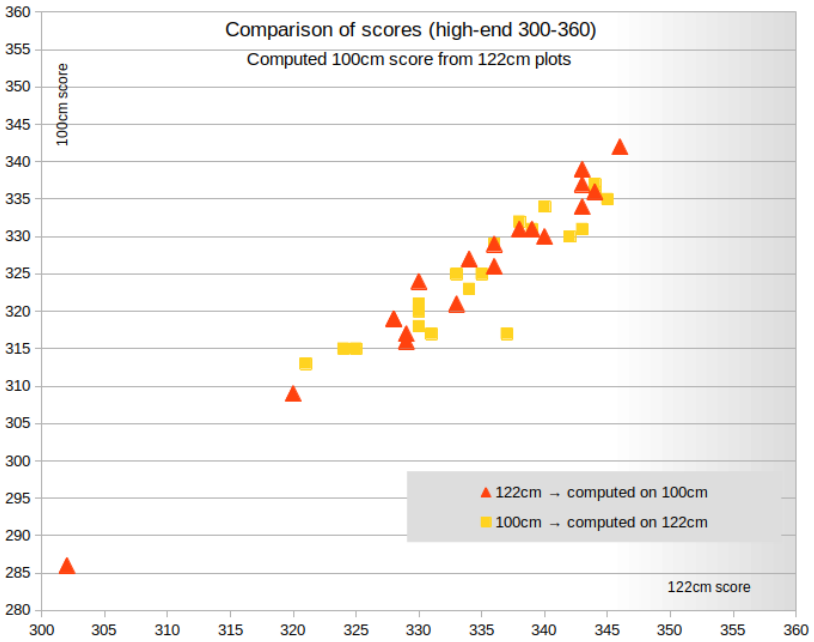
4. Further Analysis

Using a score/plot computer program (Artemis), the patterns shot on one target face size can be used to derive the results as if they were shot on a different sized target face. Artemis uses the exact positions plotted in mm's X and Y direction on one target and draws them on exactly that position on the second target and computes the score.

In this way, for every archer, the 122cm grouping pattern can be used to compute the 100cm score, and vice versa.

(Image on the right is not to scale)





These results are shown in the graph on the left.

This graph shows in yellow, the **actual shot** 100cm score compared to the **derived from the pattern** 122cm score.

And in red the **actual shot** 122cm scores compared to the **derived from the pattern** 100cm score.

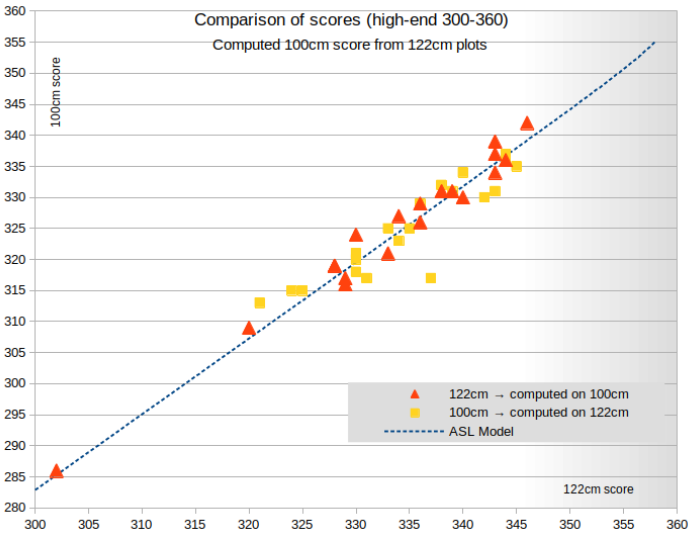
With the 122cm score on the horizontal axis and the 100cm score on the vertical axis.

It needs to be emphasized that no modelling takes place to get these results. The actual arrow position data was simply projected on another target face size.

4.1 The Archers Skill Level model

The Archers Skill Level model (ASL) is a performance model developed by James Park (AUS) and used quite extensively. Its math is very complex but what it does is; it can compute a skill level (a number) based on a score (=performance) and using that skill level it can compute a new score (performance) that would have been shot, when shooting on a different target face (with different size and/or different scoring rules) but with the same ability.

> *For example; The score 326 shot on a 122cm target at 70m equals a skill level of 95.5. With that same skill level (95.5) the archer would have shot a score of 314 on a 100cm target at 70m.*



In the figure to the left, the skill level model is drawn in as a dotted line and shows a perfect fit with the measured data.

The dotted line is the skill level model. It very accurately represents the relationship between scoring on 122cm versus scoring on 100cm.

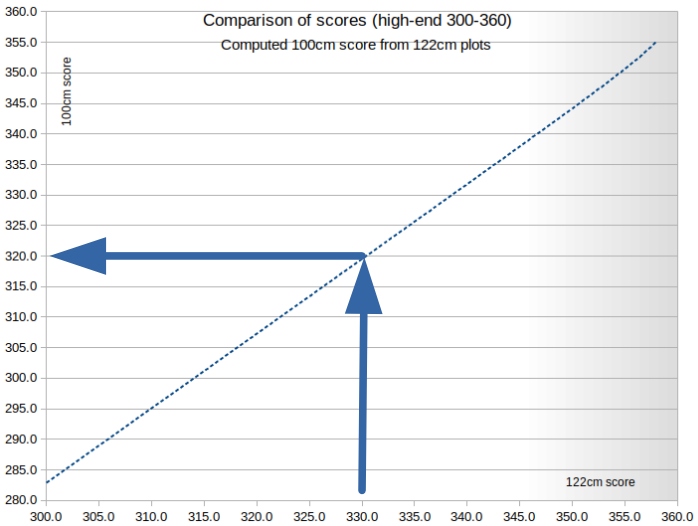
Note that it looks like a straight line, but it actually is not. On the very ends (near 360) it curves upwards and at lower score (240 and below) it curves horizontally. But that is outside the scope if these tests.

4.2 Estimate your new score on a 100cm target face at 70m

To estimate the score when using a 100cm target face instead of the 122cm target face at 70m (but also at 60m) the graph below can be used.

Find the current 122cm score and move up and left to find the 100cm score.

Example; If the archer currently shoots 330 on 122cm at 70m, find that score on the horizontal axis. Move up to the dotted line. The point where you cross the dotted line, go left towards the Y-axis and find the score you would have shot on 100cm (in this case around 320).



4.3 Why use a computer model?

Predicting how the results and score distributions of competitions will change with new target face sizes, can be done in two ways;

1. Do many real-life test-competitions, with typical archer performance distributions. Note that simply doing one or a few test competitions does not have any statistical relevance in this case. The change in target face is too small to be able to detect any changes and draw conclusions.
2. Or, use a small number of real-life test scenarios (with real archers under supervised conditions) to validate the use of a computer model (validate = proof that the computer model can accurately predict the archers performance), and then use that computer model in thousands of simulations to predict the results of

competitions shot on new target faces or new rules. Thousands of competitions, including elimination rounds, can be simulated to get statistical relevance.

In the remainder of this report, it is assumed that the skill level model can correctly predict the score of archers shooting 70m at different target faces (as was shown by the perfect fit of the model to the test data in section 4.1)

4.4 Computer simulation

Using computer simulations 3 questions can be answered;

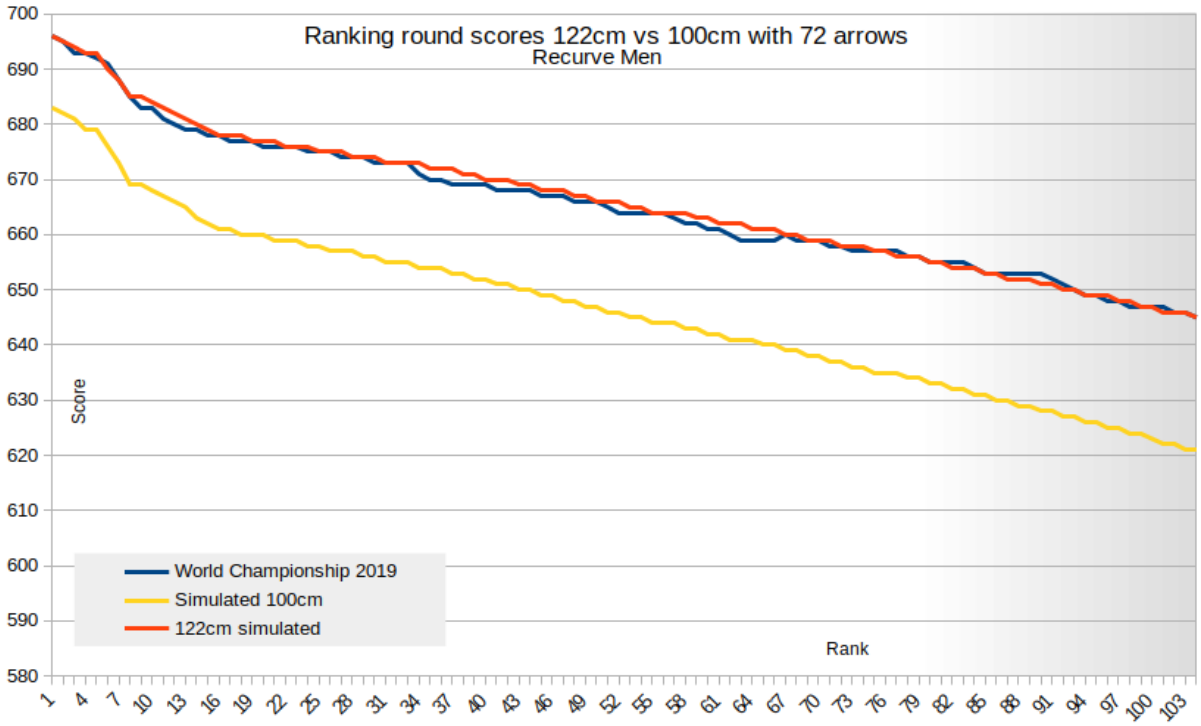
1) What will be the effect of a 100cm target face in qualification round score?
2) What will be the effect of a 100cm target face in elimination rounds?
3) What will be the effect of a ranking round of 60 arrows instead of 72 arrows?

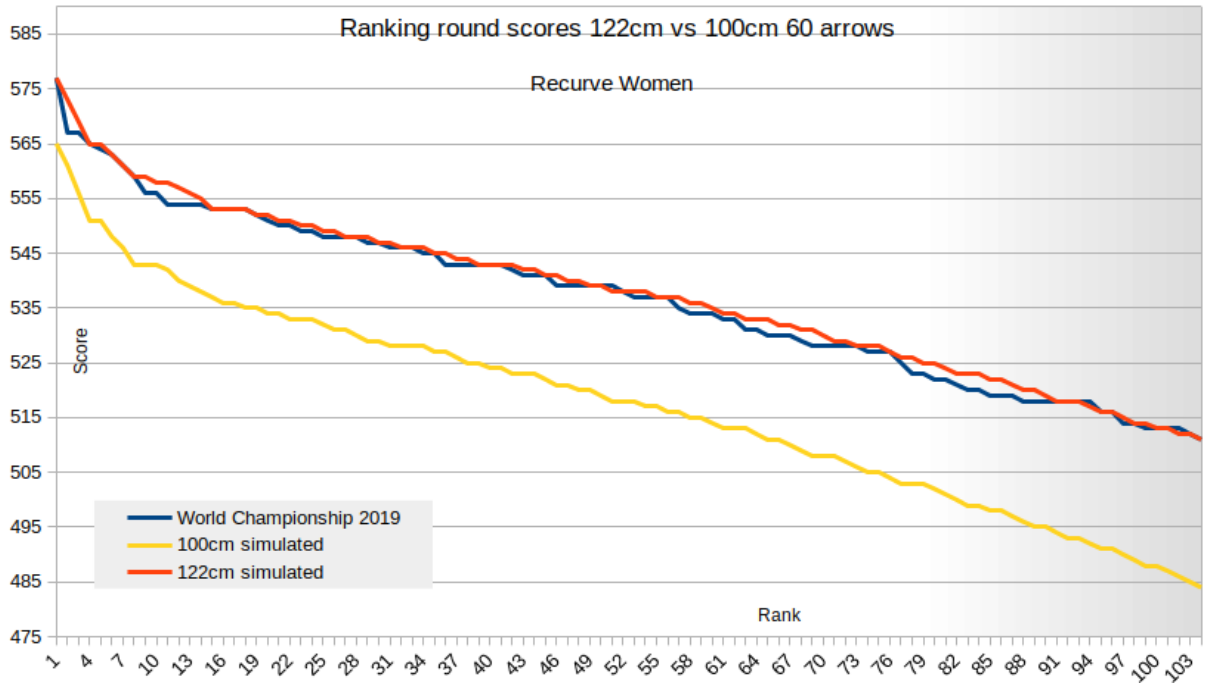
4.4.1 Effects of 100cm target face in 720 round ***ranking*** rounds

To represent the current skill levels in a population of archers, a reference competition is used; the ranking round of the World Championships 2019. Note that the scores (from 1st to 104th) during this competition were closer than any World Cup in that same year.

In simulation runs (with N=1.000.000 runs) the qualification round was simulated using the 122cm target face (red line) and using the new 100cm target face (yellow line) and all data is compared with the actual results from the World Championships in 2019 (the blue line).

The red line (simulated 122cm) is to show that the results of the computer simulation - with the skill level distribution of 2019 - have a very good match with the actual ranking round of 2019 (blue line).





Tied scores (equals scores)
If we have a field of archers, all with a slightly different skill levels, the number of ties in a qualification round based on an (integer) scoring format can be considered a `quality` metric of the ranking round competition format. See the next two examples:

> Example-1: Suppose in a 104-cut ranking round the format would be; shooting only a single arrow instead of 72. The highest score would be 10, the 104th score would probably be an 8 and we'd have more than 100 tied scores (the ranking would not be a very good representation of the skill levels of the archers). There is not enough differentiation in score to rank the archers correctly.

> Example-2: Suppose in a 104-cut ranking round the format would be; shooting 288 arrows, instead of 72. Then the top score for recurve men would be around 2780 and the 104th score would be around 2580. There are 200 points between 1st and 104th place, so there would hardly be any ties. The ranking would be a very good representation of the archers true skill levels.

Conclusion: The number of ties is a measure of how good the format of the qualification round is[1].

At the World championship 2019 in 's Hertogenbosch in recurve men, the 1st and 104th score were 696 and 645. From 1st to 104th rank score spreads (696-645) 51 points over 103 ranking positions. This means there needs to be a minimum of 52 ties in score.

During the World championships in 2019 there were actually 58 ties for recurve men.

For recurve women, the 1st and 104th score were, 692 and 613. A score spread of 79 points means a minimum of 24 ties is expected.

During the World championships in 2019 there were actually 53 ties for recurve women.

The reason for both actual number of ties (especially the recurve women) to deviate from the minimum is that the skill level of the archers is not a linear spread. The athletes have 'bunches' of similar (but not exactly the same) skills (and thus scores). For example the top 8 already differ 20 points among 8 archers. Leaving only 60 points to be divided by the remaining 96.

1 Besides number of ties there are many other requirements for a good (and practical) qualification format. Duration for example, qualification formats of 288 arrows, although very good in finding the 'correct' ranking are unpractical.

The number of ties in an actual competition will always be higher than the theoretical lower bound:

$$min\left(N_{ties}\right) = position_{cut} - \left(score_{1\,st} - score_{cut} + 1\right)$$

To reduce the number of ties the score difference (in integer scoring) between the 1st and the 104th (or cut) score needs to increase. There are many ways to accomplish this; shooting more arrows, using more than 10 rings on the same target face or reducing the target face diameter.

From the computer simulations we see that the scores have a higher spread. The difference between the 1st ranking score and the 104th ranking score is much higher for the 100cm compared to the 122cm.

	1st score	104th score	Score difference	Minimum number of ties needed
Recurve Men (from World Championship 2019)	696	645	51	52
Recurve Women (from World Championship 2019)	692	613	79	24
Recurve Men (from simulation 100cm)	683	621	62	41
Recurve Women (from simulation 100cm)	678	581	97	6

Changing to a 100cm target face increases the score spread by 21% for recurve men and 23% for recurve women. Number of tied scores in qualification round will reduce significantly as well, making the ranking round a higher score-differentiating round.

It has to be noted that the reference scenario is the World Championships of 2019 in which the 104th score is high compared to other International Events. The spread (and thus score-differentiation) will only increase (which is good) for World Cups or other international events.

4.4.2 Effects of 100cm target face in ***elimination*** rounds

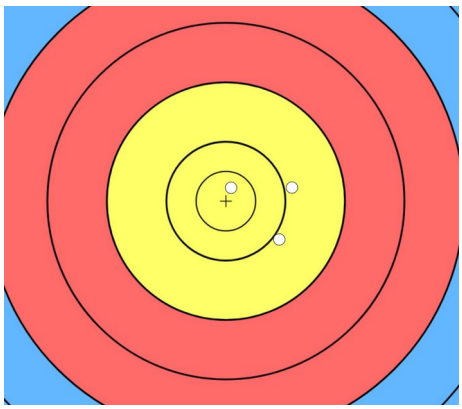
The effect of a 100cm target face in elimination rounds is somewhat harder to show. On average, the better performing (=smaller grouping) archer always wins independent of the target face size or scoring rules. However, the 'feeling' of archers and coaches that a better performing archer (= shooting smaller groups) doesn't always get rewarded needs to be addressed. An often heard argument in favor of smaller target faces goes along these lines;

Situation 1: In an elimination set, if 'A' shoots 3 really good arrows; X, a 9 (very close to the 10 ring) and another 9 (very close to the ten ring), 'A' gets a score of 28 which is the same as the opponent 'B' who shot a liner 10, and two liner 9's. If the target face becomes smaller, 'A' would have won that set (which would be more 'fair' because of the higher performance=smaller group), now its a draw.

Situation 1

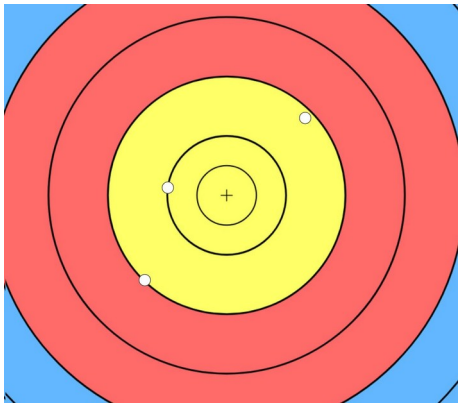
Archer A

Scores 28 on 122cm, and would still score 28 on 100cm as well



Archer B

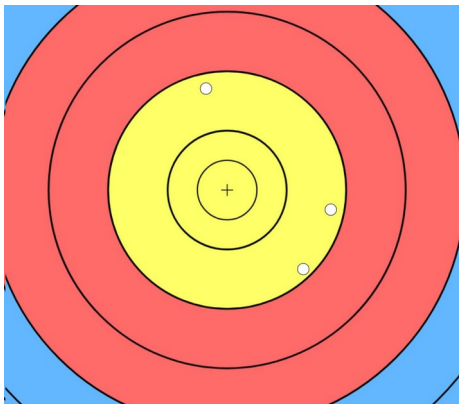
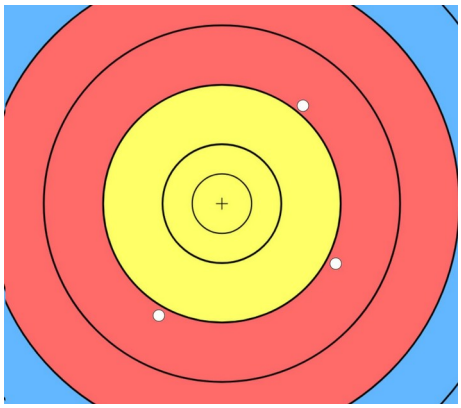
Scores 28 on 122cm but would have score 25 on 100cm



In this first particular case, the smaller target face 'selects' the better performing archer more correctly. But that is not always the case, it may turn out to be dis-advantageous as well, because along the same lines;

<u>Situation 2:</u> If 'A' shoots 3 just inside 9's, and the opponent 'B' shoots 3 8's (but very close to the 9 ring) in the case of the 122cm target face, 'A' would be the winner, with the 100cm they split the set points.'

Situation 2

Archer A	Archer B
Scores 27 on 122cm, but would have scored 24 on 100cm as well	Scores 24 on 122cm and would still score 24 on 100cm
	

It is difficult to find out if the situation in the first example will happen more often than the situation in the second example. The distribution of arrows is higher towards the center so it might be the case that the smaller target face favors the better archer a bit more.

It is much easier to look at how often elimination rounds are won after 3 sets, 4 sets or 5 sets (or a shoot-off), and if this changes with the introduction of the 100cm target face. Using the same simulation program, an entire competition is simulated. This includes all rules for top-8, shoot-offs at cut-positions, set-system elimination rounds including shoot-offs, and every arrow that is shot is simulated according to the archers skill level model. All relevant statistics are saved.

If the 100cm target face is really better at differentiating who is the better skilled archer, then the results should show that;

- Matches are (on average) decided earlier (with less required sets), especially in the earlier rounds when archers are paired up having relatively big skill level differences.
- Matches will less likely be decided by shoot-offs (for the same reason as above)
- The final ranking will represent the archers skill level distribution more closely.

That last item needs some extra explanation;
Start with a typical population of 104 recurve men archers (much like the 2019 World Championship) and look at their all-season arrow-averages and call that their skill-level (= what they are capable of). Not all archers have the same arrow average; some well-known top-archers have shot consistent high scores and high arrow-averages (like 9.5..9.6 average) and some archer score considerably less (9..9.1 average).

A ranking of the archers based on this arrow-average (skill level) can be made.

Now shoot a new competition and consider two options; A) All archers shoot 72 arrows, B) all archers shoot only 2 arrows. And a new ranking of these results can be made.

Ranking round A will probably show a better 'correctness' with respect to the skill-level of the archers than that of of ranking round B. It will be more in line with the skill level than round B. This correctness can be expressed with a 'fitness' function. An often used function for this in mathematics is a quadratic function[2]

$$Fitness = \frac{1}{N}\sqrt{\sum_{i=1}^{N=104}\left(Rank(i)_{skill\,level} - Rank(i)_{competition}\right)^2}$$

2 In words; fittness is a kind of average of the difference in ranking of the archer based on his/her skill-level and the ranking he/she gets in the competition. These two rankings should be close to each other (thus, fitness function is smaller is better)

The computer simulation calculates this quadratic fitness function that shows how close the end-result (the final ranking of each individual archer) was to what it should have been, based on their skill levels. Note that the fitness function is a 'smaller is better' number.

Recurve Men 122cm

```
Qualification: 70.0m at World Archery 122cm, 10 rings target face, Scoring system: Cumulative 72 arrows (q_rm_72a_70m_122cm10rings)
Elimination  : 70.0m at World Archery 122cm, 10 rings target face, Scoring system: Set-system 3 arrow sets, best of 5 sets
(e_rm_3abo5_70m_122cm10rings)
Skill level distribution: 117.0 115.0 110.6 107.2 105.0 101.2 ("RM)

           Elimination round statistics
=============================================================================================================================
|                            |   1/48   |   1/24   |   1/16   |    1/8   |    1/4   |    1/2   |   FG+FB  |   total n-matches |
+----------------------------+----------+----------+----------+----------+----------+----------+----------+-------------------+
| # total simulated matches  |  4800000 |  2400000 |  1600000 |   800000 |   400000 |   200000 |   200000 |         104       |
| # avg wins after  3 sets   |   19.69% |   15.50% |   17.75% |   16.63% |   13.18% |   11.11% |   10.85% |   18.31   17.60%  |
| # avg wins after  4 sets   |   34.84% |   33.42% |   35.16% |   35.28% |   33.60% |   32.58% |   32.21% |   35.83   34.45%  |
| # avg wins after  5 sets   |   45.47% |   51.08% |   47.09% |   48.09% |   53.22% |   56.31% |   56.94% |   49.86   47.94%  |
| # avg wins after S/O       |     6.33 |     3.73 |     2.22 |     1.14 |     0.66 |     0.36 |     0.36 |   14.79   14.22%  |
| # avg wins equal score !S/O|     1.26 |     0.76 |     0.44 |     0.22 |     0.13 |     0.07 |     0.07 |    2.95    2.83%  |
| # avg wins with lower score|     0.91 |     0.47 |     0.23 |     0.10 |     0.04 |     0.02 |     0.02 |    1.72    2.83%  |
| # avg expected wins        |   74.85% |   68.59% |   74.53% |   74.45% |   67.87% |   62.07% |   61.14% |    0.50  104.00%  |
=============================================================================================================================

Number of archers that qualified top  4, also ends in top  4 =   2.0
Number of archers that qualified top  8, also ends in top  8 =   5.1
Number of archers that qualified top 16, also ends in top 16 =  10.4

Qualification ranking fit to theoretical ranking (lower is better): 1.332670

Final ranking fit to theoretical ranking  (lower is better)       : 1.768448
```

Recurve Men 100cm

```
Qualification: 70.0m at Experimental 100cm, 10 rings target face, Scoring system: Cumulative 72 arrows (q_rm_72a_70m_100cm10rings)
Elimination  : 70.0m at Experimental 100cm, 10 rings target face, Scoring system: Set-system 3 arrow sets, best of 5 sets
(e_rm_3abo5_70m_100cm10rings)
Skill level distribution: 117.0 115.0 110.6 107.2 105.0 101.2 ("RM)

           Elimination round statistics
=============================================================================================================================
|                            |   1/48   |   1/24   |   1/16   |    1/8   |    1/4   |    1/2   |   FG+FB  |   total n-matches |
+----------------------------+----------+----------+----------+----------+----------+----------+----------+-------------------+
| # total simulated matches  |  4800000 |  2400000 |  1600000 |   800000 |   400000 |   200000 |   200000 |         104       |

| # avg wins after  3 sets   |   21.99% |   17.62% |   20.24% |   19.07% |   15.53% |   13.30% |   13.16% |   20.70   19.90%  |
| # avg wins after  4 sets   |   34.46% |   33.33% |   34.73% |   34.89% |   33.31% |   32.38% |   32.23% |   35.51   34.15%  |
| # avg wins after  5 sets   |   43.54% |   49.05% |   45.03% |   46.04% |   51.15% |   54.32% |   54.61% |   47.79   45.95%  |
| # avg wins after S/O       |     5.91 |     3.50 |     2.08 |     1.07 |     0.62 |     0.34 |     0.34 |   13.86   13.33%  |
| # avg wins equal score !S/O|     1.16 |     0.72 |     0.41 |     0.21 |     0.13 |     0.07 |     0.07 |    2.78    2.67%  |
| # avg wins with lower score|     1.22 |     0.64 |     0.33 |     0.14 |     0.07 |     0.04 |     0.04 |    2.38    2.67%  |
| # avg expected wins        |   75.04% |   68.76% |   74.68% |   74.68% |   68.00% |   62.08% |   61.38% |    0.50  104.00%  |
=============================================================================================================================

Number of archers that qualified top  4, also ends in top  4 =   2.0
Number of archers that qualified top  8, also ends in top  8 =   5.2
Number of archers that qualified top 16, also ends in top 16 =  10.4

Qualification ranking fit to theoretical ranking (lower is better): 1.309230

Final ranking fit to theoretical ranking  (lower is better)       : 1.752835
```

Recurve Women 122cm

```
Qualification: 70.0m at World Archery 122cm, 10 rings target face, Scoring system: Cumulative 72 arrows (q_rw_72a_70m_122cm10rings)
Elimination  : 70.0m at World Archery 122cm, 10 rings target face, Scoring system: Set-system 3 arrow sets, best of 5 sets
(e_rw_3abo5_70m_122cm10rings)
Skill level distribution: 117.0 115.0 110.6 107.2 105.0 101.2 ("RM)

           Elimination round statistics
=============================================================================================================================
|                            |   1/48   |   1/24   |   1/16   |    1/8   |    1/4   |    1/2   |   FG+FB  |   total n-matches |
+----------------------------+----------+----------+----------+----------+----------+----------+----------+-------------------+
| # total simulated matches  |  4800000 |  2400000 |  1600000 |   800000 |   400000 |   200000 |   200000 |         104       |
| # avg wins after  1 sets   |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00    0.00%  |
| # avg wins after  2 sets   |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00    0.00%  |
| # avg wins after  3 sets   |   19.69% |   15.50% |   17.75% |   16.63% |   13.18% |   11.11% |   10.85% |   18.31   17.60%  |
| # avg wins after  4 sets   |   34.84% |   33.42% |   35.16% |   35.28% |   33.60% |   32.58% |   32.21% |   35.83   34.45%  |
| # avg wins after  5 sets   |   45.47% |   51.08% |   47.09% |   48.09% |   53.22% |   56.31% |   56.94% |   49.86   47.94%  |
| # avg wins after S/O       |     6.33 |     3.73 |     2.22 |     1.14 |     0.66 |     0.36 |     0.36 |   14.79   14.22%  |
| # avg wins after D-S/O     |     0.00 |     0.00 |     0.00 |     0.00 |     0.00 |     0.00 |     0.00 |    0.00    0.00%  |
| # avg wins equal score !S/O|     1.26 |     0.76 |     0.44 |     0.22 |     0.13 |     0.07 |     0.07 |    2.95    2.83%  |
| # avg wins with lower score|     0.91 |     0.47 |     0.23 |     0.10 |     0.04 |     0.02 |     0.02 |    1.72    2.83%  |
| # avg expected wins        |   74.85% |   68.59% |   74.53% |   74.45% |   67.87% |   62.07% |   61.14% |    0.50  104.00%  |
=============================================================================================================================

Number of archers that qualified top  4, also ends in top  4 =   2.0
Number of archers that qualified top  8, also ends in top  8 =   5.1
Number of archers that qualified top 16, also ends in top 16 =  10.4

Qualification ranking fit to theoretical ranking (lower is better): 1.332670

Final ranking fit to theoretical ranking  (lower is better)       : 1.768448
```

Recurve women 100cm

```
Qualification: 70.0m at Experimental 100cm, 10 rings target face, Scoring system: Cumulative 72 arrows (q_rw_72a_70m_100cm10rings)
Elimination  : 70.0m at Experimental 100cm, 10 rings target face, Scoring system: Set-system 3 arrow sets, best of 5 sets
(e_rw_3abo5_70m_100cm10rings)
Skill level distribution: 117.0 115.0 110.6 107.2 105.0 101.2 ("RM)

           Elimination round statistics
=============================================================================================================================
|                            |   1/48   |   1/24   |   1/16   |    1/8   |    1/4   |    1/2   |   FG+FB  |   total n-matches |
+----------------------------+----------+----------+----------+----------+----------+----------+----------+-------------------+
| # total simulated matches  |  4800000 |  2400000 |  1600000 |   800000 |   400000 |   200000 |   200000 |         104       |
| # avg wins after  1 sets   |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00    0.00%  |
| # avg wins after  2 sets   |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00% |    0.00    0.00%  |
| # avg wins after  3 sets   |   21.99% |   17.62% |   20.24% |   19.07% |   15.53% |   13.30% |   13.16% |   20.70   19.90%  |
| # avg wins after  4 sets   |   34.46% |   33.33% |   34.73% |   34.89% |   33.31% |   32.38% |   32.23% |   35.51   34.15%  |
| # avg wins after  5 sets   |   43.54% |   49.05% |   45.03% |   46.04% |   51.15% |   54.32% |   54.61% |   47.79   45.95%  |
| # avg wins after S/O       |     5.91 |     3.50 |     2.08 |     1.07 |     0.62 |     0.34 |     0.34 |   13.86   13.33%  |
| # avg wins after D-S/O     |     0.00 |     0.00 |     0.00 |     0.00 |     0.00 |     0.00 |     0.00 |    0.00    0.00%  |
| # avg wins equal score !S/O|     1.16 |     0.72 |     0.41 |     0.21 |     0.13 |     0.07 |     0.07 |    2.78    2.67%  |
| # avg wins with lower score|     1.22 |     0.64 |     0.33 |     0.14 |     0.07 |     0.04 |     0.04 |    2.38    2.67%  |
| # avg expected wins        |   75.04% |   68.76% |   74.68% |   74.68% |   68.00% |   62.08% |   61.38% |    0.50  104.00%  |
=============================================================================================================================

Number of archers that qualified top  4, also ends in top  4 =   2.0
Number of archers that qualified top  8, also ends in top  8 =   5.2
Number of archers that qualified top 16, also ends in top 16 =  10.4

Qualification ranking fit to theoretical ranking (lower is better): 1.309230

Final ranking fit to theoretical ranking  (lower is better)       : 1.752835
```

To summarize these results;

When changing from 122cm to 100cm in elimination rounds with a typical skill level distribution (equal to the 2019 World Championships) on average the number of elimination matches that are decided in 3 sets is expected to increase, whilst the number of elimination matches that are decided in 5 sets is expected to decrease. The number of elimination matches that are decided through shoot-off is expected to decrease as well.

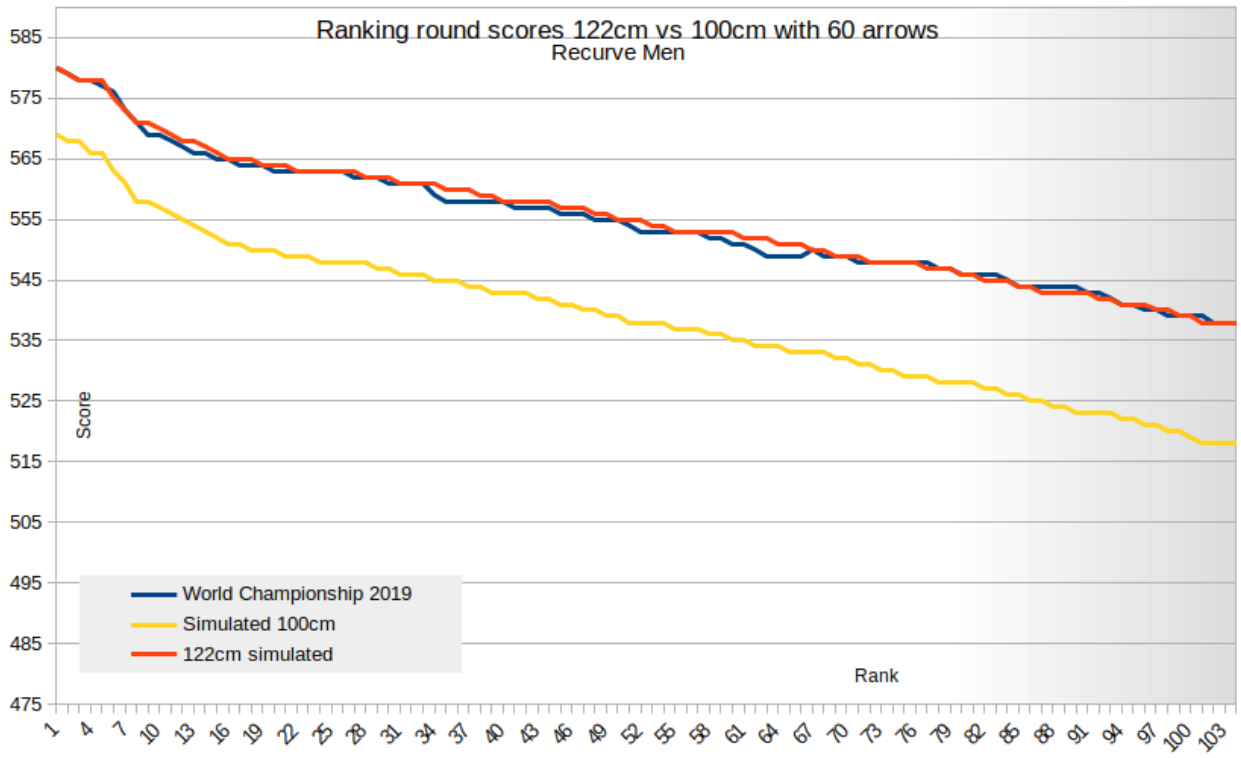
The fitness (how good the final ranking represents the archers skill level) improves when using the 100cm target face.

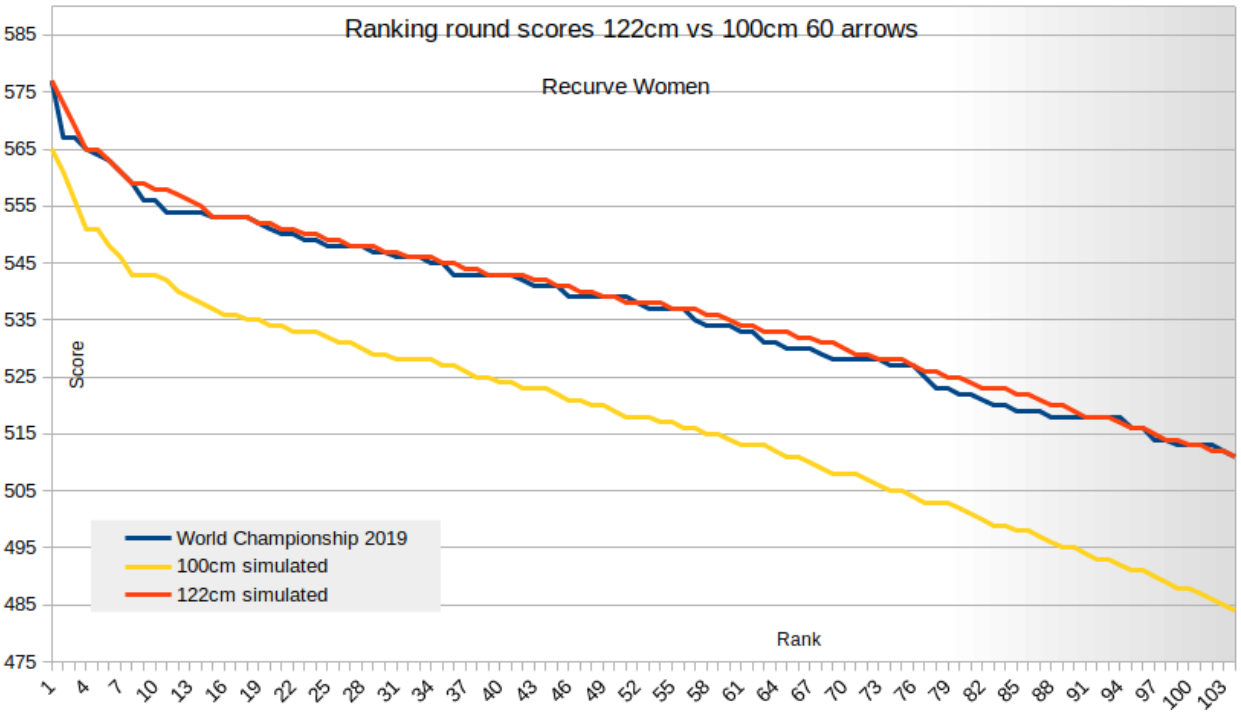
4.4.1 Effects of 60 arrows instead of 72 in ***ranking*** rounds

A ranking round with only 60 arrows instead of 72, will reduce the score difference between the 1st and 104th score and thus be less differentiating. How much the gap between 1st and 104th will close can be estimated by using the real 2019 World Championship scores and factor them by 60/72. The same for the computer simulation results for the 100cm.

	1st score	104th score	Score difference	Theoretical minimum number of ties
Recurve Men				
72 arrows on 122cm	696	645	51	52 (= reference)
72 arrows on 100cm	683	621	62	41 (-22% ties)
60 arrows on 122cm	580	538	42	61 (+17% ties)
60 arrows on 100cm	570	518	52	51 (-2% ties)
Recurve Women				
72 arrows on 122cm	692	613	79	24 (=reference)
72 arrows on 100cm	678	581	97	6 (-75% ties)
60 arrows on 122cm	577	511	66	37 (+54%)
60 arrows on 100cm	565	485	80	24 (0%)

The figure below shows what a typical World Championships ranking round with 60 arrows look like


Ranking round scores 122cm vs 100cm with 60 arrows
Recurve Men
Score
Rank
World Championship 2019
Simulated 100cm
122cm simulated


Ranking round scores 122cm vs 100cm 60 arrows
Recurve Women
Score
Rank
World Championship 2019
100cm simulated
122cm simulated

4.5 Results of the questionaires

The survey was filled out by 16 participants, and consisted of 9 questions.[3]

In the first question – Do you think the competition on the 100cm target face you tested is fair? – 88% answered yes, and is a positive statement towards a change.

The second – Do you think that your position in the ranking round will change if WA uses this target face – showed a 56-44% ratio. Also this can be considered a positive fact, cause the thought of the archers is only relevant if compared to the data: and these prove that the 100cm is as fair as the 122cm

The third question asks, how many arrows have been shot on 100cm targets: according to the request, most shot between 61-90 arrows (75%). 2 archers shot more the 180+ arrows at the 100cm target face.

4th question: Was aiming a bigger challenge for you while shooting on the 100cm face? Clear 81% say yes: it shows that the 100cm target is a bigger challenge and therefor a positive fact for an agonist.

5th question: male or female, shows that 81% of testers answered male and 19% female.

In the 6th question we wanted to know which the highest result on a 122cm target face was.
>349 12,50%
345-349 31%
340-344 25%
335-339 19%
330-334 6%
325-329 0%
320-324 6%

The following question refers to the highest scores in training, to see the difference between a high score in tournament and a high score in training
>349 31%
345-349 44%
340-344 13%
335-339 6%
330-334 6%
325-329 0%
320-324 0%

And finally the highest score on the 100cm face shot during the tests
>349 0%
345-349 0%
340-344 0%
335-339 31%
330-334 25%
325-329 0%
320-324 19%
<320 25%

There were no extra comments made during the survey.

5. Other effects of these format changes

This is a (incomplete) list of side effects which the authors wanted to mention as well;

Any change will involve a complete reset of all World, Continental and National records, which is why these changes should preferably all happen at once, instead of gradually.

The different scores will have an impact on the archers and coaches (and in a lesser sense) non-sport-specific spectators. There will be less comparison material in the beginning after the change.

3 Thanks to World Achery (and Thomas Aubert in particular) for hosting and helping with the survey.

When changing to a 100cm target face

Changing to 100cm target face will probably change the cost of the target face.

Besides differentiation in scores, the 100cm target face may become the biggest target face used in World Archery competition. And if compound is going to use 4 targets of 80cm but only up to the 6 ring instead of the 5 ring, these both changes could reduce the cost of target butts and stands as they can become smaller as well.

Target face replacement cost w(due to wear) will be less of a issue since the arrows will be equally spread out, the same as they are now, and the impact on the lines (although the circumference of the 10 is smaller) is extremely small.

There could be some more misses. If the target-butts and stands stay the same, there is no extra time for arrow retrieval because the misses will still be in the target. But if the target-butts and stands are reduced in size as well, more time will be spend in arrow retrieval. How much needs to be assessed.

Training methods (and perhaps equipment: sight) may need to change as well.

When changing to a ranking round of 60 arrows

Time spend for ranking rounds will be less.

6. Conclusions

This study shows the expected (scoring and ranking) consequences of changing the target face size from 122cm to 100cm without and in combination with changing the number of arrows for the ranking round from 72 to 60.

Results show that the 100cm target face will reduce scores (as expected) on both the high end and the lower end of the ranking round. In the reference comeptition (the World Championships in 's Hertogenbosch in 2019), recurve men top score 696 would become 683 and the 104th score of 645 would change to 621. For recurve women the top score 692 becomes 678 and a score of 613 becomes 581. The score difference between the 1st and 104th score will increase going to 100cm which will result in 22% less tied scores for the recurve men in the ranking round. For women recurve the number of tied scores will reduce significantly more.

Visually, the 100cm target face will reflect almost a 122cm target face at 90m (actually 85m) and thus changes the sight picture and might require a different aiming dot or circle and archers will need some time to adjust. The survey under 16 test athletes showed that they found it more challenging to aim at the 100cm than at the 122cm.

For the elimination rounds the effect of changing to 100cm results in more matches that will be decided in 3 sets and less in 5 sets and slightly less matches will be decided by shoot-off. This indicates that the 100cm is a slightly better differentiater than the 122cm target face.

The correctness (or fitness) metric that was used indicates how well the end-result represents the skill-levels. This fittness metric will decrease slightly. The format becomes slightly better in selecting the best performing archer.

Introducing a ranking round of 60 arrows without changing the target face size, will close the gap, or score difference, between the 1st and 104th score. The number of tied scores in the ranking round will rise significantly. However, when introduced in combination with the smaller 100cm target face this will result in the same number of ties as we have currently.

7. Acknowledgements

Many thanks to all archers and coaches that participated in this study!

And thanks to World Archery Thomas Aubert for hosting and helping with the survey.

The software that was used was created by Marcel van Apeldoorn and is freely availaible on github

https://github.com/mvapldrn/ArcheryCompetitionSimulation