Wide Net Stiffness Variation and Safety Concerns with the 2 cm Height Tolerance in Junior Volleyball

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Abstract

A volleyball net's stiffness, the force applied at a given point on the net divided by the resulting displacement at that point, is proportional to the tension in the top cable for a taut net. Currently, the rule book regulates neither stiffness nor tension. Instead, it regulates the height at the center and allows the net to be up to 2 cm higher over the sidelines. We measured the displacement of the center of the net with a 1.1 kg load using a net height chain on 48 courts across four junior tournaments. First, stiffness varied widely across courts: 146 to 354 N/m, a factor of 2.4 overall and of 1.7 to 2.4 within every tournament. The height tolerance cannot detect this variation, because the height difference depends on the net's weight as well as its tension. Second, tightening the nets to meet the 2 cm tolerance could pose a tipping risk for freestanding supports. As set, estimated cable tensions of 365 to 885 N were all below the 250 lb comparison value, while 45 of the 48 nets exceeded the height tolerance. Meeting the tolerance would take an estimated median tension of about 1,200 N, above the comparison value on 30 of the 48 courts, including every court at two tournaments. For the two ballast positions examined in Figure 5b, the estimated tension would reach the modeled tipping threshold of a 700 lb base on 34 to 44 courts. We propose evaluating a load check using the existing height chain. Under a 1.1 kg load, a displacement of at least 7 beads corresponds to an estimated tension below 250 lb for spans up to 11 m.

Keywords: volleyball net; effective stiffness; cable tension; field measurement; freestanding net system; sports equipment regulation

1 Introduction

In volleyball, the net is part of the playing surface. Balls can clip the top of the net or rebound and still be in play. This creates a need for players to be able to anticipate how the net will affect the ball. How the net responds depends on how taut it is, which we describe by the net's stiffness: the force applied at a given point on the net divided by the resulting displacement at that point. In this study, we measured stiffness by loading the top band at midspan(Figure 2a). Tension, the pulling force carried along the top cable, is different from stiffness, but the two are related. For a taut cable of span L, its midspan stiffness equals

$4T/L$ in the point-load model(Section 2.5). The FIVB (International Volleyball Federation) recognizes this and has guidelines instructing the first referee to check the net by throwing a ball into it, because "the ball must bounce off the correctly taut net" [1]. In one experiment, Ogawa et al. shows that the tension in competition nets rose by 280 to 350 N for a fraction of a second when a ball struck the net at attack speed[2]. However, how much the net's tautness changes the path of the ball has not been measured.

While the rules do not give a number for tautness, the USA Volleyball and FIVB rules[3,4] require, in Rule 2.1.2, that the net height be measured at the center of the court, and that the heights over the two sidelines equal each other and be no more than 2 cm above the official height. Additionally, the rules do describe a flexible cable inside the top band that "keeps the top taut", but they specify neither its tension nor its stiffness[3,4]. Nevertheless, the height tolerance constrains the tautness indirectly. We call the difference between the net's height over a sideline and its height at the center the *edge-to-center height difference* (Figure 2a). A cable that sags only slightly compared with its span, as a net does (2 cm over about 10 m), hangs in a parabola[5]. If the net's weight W_n is spread evenly between posts a distance L apart, the cable sags at the center by $s = W_n L/(8T)$ at tension T, so capping s sets a minimum tension, $T \geq W_n L/(8s)$, proportional to the weight of the net. The posts stand just outside the sidelines, so a reading over a sideline sees most of this sag but not all of it. This changes the minimum tension by a fixed factor (Section 2.6) but not its proportionality to weight. The published weights of two competition nets differ by 75%[6,7]. A height tolerance alone therefore cannot make nets of different weight equally taut.

Tension also matters for a separate reason: it pulls the two posts toward each other at net height (Figure 2b). Besides the increase in tension during impact, the same study recorded the steady tension the nets carried, 1.56 to 2.26 kN, on steel posts set in floor sockets. Ogawa et al. calculated that those posts would begin to yield near 2.8 kN, and noted that posts have been damaged in practice[2]. At the tournaments in this study, however, the posts were not in floor sockets. They stood on ballasted, freestanding bases (Figure 1c), systems that manufacturers describe as designed for tournament settings[8]. The cited Sports Imports setup manual instructs users not to tension the top cable beyond 250 lb (1,112 N)[9]. Bison's Arena II specification states that its bases take at least 250 lb of net tension without moving[10]. The former is an operating limit for the equipment covered by the manual. The latter describes resistance to movement at the stated load. We use 250 lb as a comparison value. The nets that Ogawa et al. measured carried 1.4 to 2 times that. While tension gauges for volleyball nets exist[11], and one tournament system ships with a gauge set to 250 lb[12], the four tournaments in this study did not check for tension. The height rule implies a minimum tension that is higher for heavier nets. Whether a support can carry that tension depends on the specific system and its setup.

Ogawa et al. measured tension directly, by placing a load cell in the top cable[2]. That method is impractical for surveying an entire tournament because a load cell would have to be installed in the top cable of every net. As a result, we are not aware of any published measurements of how taut nets are from court to court under tournament conditions. Tension can, however, be estimated indirectly. A load hung at the midspan of a taut cable pulls it down by an amount inversely proportional to the tension, so the tauter the net, the less it moves. Ogawa et al. proposed a handheld gauge based on this principle[2]. This study applies it with a known load and the bead chain already used to check net height. Because it needs

only one item beyond what is already used to check height, the method can be applied to every court at a tournament.

This study asks two questions. First, on playing consistency, how much does the stiffness of the net vary from court to court, and does the height tolerance detect that variation? Second, on support safety, how much tension would each net need in order to meet the 2 cm tolerance, and can the freestanding supports carry it? If not, what standard could they meet? The answers to these questions are this paper's findings. Stiffness varied widely between courts at every tournament in a way the height tolerance could not detect (Sections 3.1 and 3.2). The estimated tension needed to meet the 2 cm tolerance exceeded the 250 lb comparison value on most courts. For some base configurations, it also reached the modeled tipping threshold (Sections 3.3 and 3.4). A check of the displacement under a known load, using the bead chain already used to check height, could address both problems (Sections 3.5 and 4.2). The measurements are static, and no ball was tested. Cable tension was estimated from the displacement under a load applied perpendicular to the cable.

2 Methods

2.1 Study design and sample

To find out how taut nets are under real tournament conditions, we measured them at the tournaments themselves. This was an observational field study of 48 courts at four junior tournaments in three states, held in March and April 2026 (Table 1). Each court was measured once, after play on that court had finished: 8 courts at the first tournament, 18 at the second, 9 at the third, and 13 at the fourth. Courts were measured as they became free, and courts still in play at the time were not measured, so the courts were not a random sample. All nets were set to 2.24 m, the height USA Volleyball specifies for girls from 13U to 18U[3].

Table 1: The four tournaments and the number of courts measured at each.

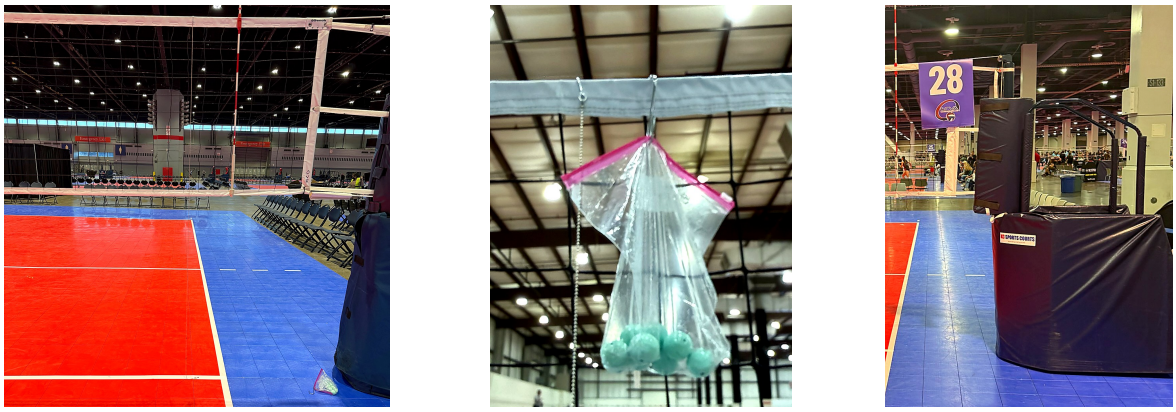
Tournament	Event	Location	Date	Courts
1	Power League 2	San Mateo, CA	8 March 2026	8
2	Red Rock Rave	Las Vegas, NV	15 March 2026	18
3	Power League 3	Sacramento, CA	21 March 2026	9
4	Windy City	Chicago, IL	5 April 2026	13

2.2 Apparatus

Net height at the tournaments was checked with a metal bead chain supplied with the net system. The chain is hung from the top of the net so that it reaches the floor, and the height is read as a count of beads (Figure 1a). We used the same chain as our measuring scale, reading every displacement as a count of beads and converting it to length using the bead spacing c. The chain has four red markers at the maker's preset net heights for men, women and juniors, so the distances between the markers are known, and dividing them by

the number of beads between the markers gave $c = 4.372\,\text{mm}$. The markers are not perfectly consistent: straight-line fits through them give 4.30 to 4.41 mm, depending on which markers are used and whether the heights are taken in inches or in metres. The value used lies within 1.6% of every fit, so uncertainty in bead spacing changes the estimated stiffness and tension by no more than 2%, which is too small to affect the findings, and it does not affect the tension needed to meet the 2 cm tolerance at all.

The load consisted of a bag of nine fishing weights, and an S-hook with a total mass $m = 1.105\,\text{kg}$ and weight $W = mg = 10.84\,\text{N}$. The mass was measured using a kitchen scale with a resolution of 1 g. It was hung from a hook on the top band at midspan (Figure 1b).



(a) (b) (c)

Figure 1: Equipment (a) Edge reading: the bead chain hangs from the top of the net over the sideline, just inside the antenna, and reaches the floor. (b) The 1.1 kg load hooked to the top band at midspan, with the chain hanging from its own hook beside it. (c) A freestanding base: the post stands at the court end of a padded ballast box that extends away from the court. Photographs by the author.

2.3 Procedure

Three readings were taken on each court (Figure 2a):

- *edge*: the chain hung from the top of the net at one end, with the net free;
- *free middle*: the chain hung at midspan, with the net free;
- *loaded middle*: the chain at midspan with the load hooked beside it.

The edge readings were taken over the sideline, the same place the rules measure height. Measuring over the sideline ensures that the readings can be compared with the 2 cm tolerance. If the measurement had been taken closer to the post, the readings would be slightly different. The effect of the reading location is analyzed in Section 2.6. Photographs were taken of each reading, and the beads were counted by hand. This means that anyone can check the measurements. When two photographs of the same reading differed, which they did by at most one bead, the value from the clearer photograph was used. Further, in the photographs the load's hook and the chain's hook are about 10 cm apart (Figure 1b). At

this offset, the chain recorded approximately 98% of the midspan displacement. As a result, the calculated stiffness and model-based per-court tensions are about 2% high. Correcting for this would lower the number of courts above 250 lb at the 2 cm tolerance (Section 3.3) from 30 to 28 and not change the findings. The chain itself weighs 39 g. The chain hangs from the net during every reading, so the weight of the chain cancels from the displacement, and the height difference is measured exactly as the tournaments measure it, with the same chain.

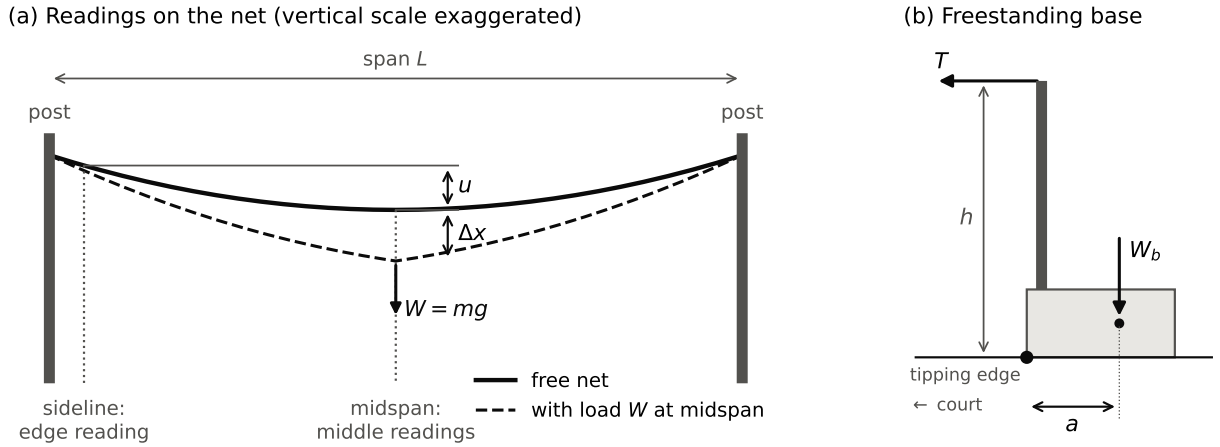


Figure 2: (a) The three readings and the two quantities formed from them: the edge-to-center height difference u and the load-induced midspan displacement Δx. Vertical scale exaggerated. (b) The forces on a freestanding base: the net tension T at height h tends to tip the base about its court-side edge, and the ballast weight W_b, acting a distance a from that edge, resists it.

2.4 Variables and resolution

From the three readings, we calculate two differences. The *edge-to-center height difference* u is the difference between the edge reading and the free middle reading. This is the quantity the 2 cm tolerance limits. The *load-induced midspan displacement* Δx is the difference between the free middle reading and the loaded middle reading. The *effective midspan stiffness* is then

$$k = \frac{W}{\Delta x}, \tag{1}$$

the static force per unit vertical displacement at midspan. Hereafter, k and references to measured stiffness denote this effective midspan stiffness. It describes the installed net as a whole (top cable, mesh, bands, bottom cord and supports) under this load. It is not a property of the net material, and it describes a static load rather than the impact of a ball.

Every reading is a whole number of beads, so each one is rounded to the nearest bead. Assuming independent, uniformly distributed rounding errors, each reading has a standard uncertainty of $1/\sqrt{12}$ bead, giving Δx a standard uncertainty of 0.41 bead (1.8 mm). The

observed displacements were 7 to 17 beads, corresponding to a relative standard uncertainty in k of 2.4 to 5.8%, largest for the stiffest nets.

2.5 Point-load model: tension from the load

The first model we use is the point-load model. We treat the top cable as a flexible string between supports a distance L apart, carrying a horizontal tension H, with $y(x)$ as its depth below the line joining the supports, and x measured from midspan. For a string with a small slope carrying a load $w(x)$ per unit length, vertical equilibrium gives[5]

$$H\,\frac{d^2y}{dx^2} = -w(x). \tag{2}$$

Before the load is hung, the net already sags under its own weight, so the measurement has to separate the load's effect from that sag. Equation (2) makes this possible: at a fixed H, the equation is linear, so the displacements caused by two loads add. The net's own weight bends the cable into a shallow parabola, and a weight W at midspan adds a V-shaped displacement $\frac{W}{2H}\left(\frac{L}{2} - |x|\right)$ on top of the parabola. Taking the difference between the free middle and loaded middle readings therefore leaves only the V-shaped displacement, whose depth at midspan is the measured Δx. We write T for both, giving

$$\Delta x = \frac{WL}{4H}, \qquad T_{\text{model}} = \frac{WL}{4\,\Delta x} = \frac{kL}{4}. \tag{3}$$

Balancing the forces at the load point, with each half of the cable taken as straight, gives $T = W\sqrt{(L/2)^2 + \Delta x^2}/(2\Delta x)$, which differs from Equation (3) by less than 0.02% here. This is also the formula of Ogawa et al.'s proposed gauge[2].

Three simplifications in the point-load model make T_{model} an overestimate. First, Equation (3) assumes that hanging the load does not change H. In reality, the load stretches the cable slightly, raising H. Second, the mesh, side bands, and bottom cord also help hold the load, but the model credits all of the stiffness to the top cable. Third, the chain was hung about 10 cm from the load and so the displacement was read about 2% low (Section 2.3), which makes the tension about 2% high.

2.6 Self-weight model: tension to meet the 2 cm tolerance

The second model addresses how tight each net would need to be to meet the 2 cm tolerance. The tolerance limits the edge-to-center height difference u, which comes from the net sagging under its own weight. This model links the sag to the tension. We assume that the part of the net's weight carried by the top cable, W_c, is spread evenly along the cable. The result is that the tension needed to meet the tolerance equals the current tension times $u/(2\,\text{cm})$.

With the weight spread evenly, Equation (2) gives a parabola[5] with midspan sag $s = W_cL/(8T)$, measured from the posts. A reading taken a distance d in from a post sees only a fraction $f = (1 - 2d/L)^2$ of the sag: $f = 1$ at the post and 0.64 to 0.83 over the sidelines. For a given net, W_c, L and f are fixed, so the height difference varies with $1/T$, doubling

the tension halves the height difference. Bringing a net's height difference down to 2 cm therefore takes the tension

$$T_{2\,\mathrm{cm}} = T_{\mathrm{model}}\,\frac{u}{2\,\mathrm{cm}}. \tag{4}$$

Equation (4) uses only the readings from that court. Because $T_{2\,\mathrm{cm}}$ is built on T_{model}, $T_{2\,\mathrm{cm}}$ is also an upper estimate.

The same $1/T$ scaling, run the other way, gives the smallest height difference each net could reach without the tension exceeding a limit T_{lim}:

$$u_{\mathrm{lim}} = u\,\frac{T_{\mathrm{model}}}{T_{\mathrm{lim}}}. \tag{5}$$

The value u_{lim} is the tightest height tolerance that net could meet within the limit.

A large height difference can come from a slack net or from a heavy one. The sag and the load-induced displacement share the same tension, so dividing the height difference by the displacement gives the *apparent net mass*

$$m_{\mathrm{app}} = 2m\,\frac{u}{\Delta x}, \tag{6}$$

which needs neither the span nor the bead size. For a sideline reading, m_{app} equals f times the mass carried by the top cable, multiplied by the factor (≥ 1) by which Equation (3) overestimates the tension.

For comparison, we also computed the tension the 2 cm tolerance implies if the whole catalogue weight of a net hangs from the top cable, $T = W_n L f/(8 \times 2\,\mathrm{cm})$, using the lightest and heaviest competition nets whose weight the manufacturer publishes[6,7], 3.63 kg (HD2) and 6.35 kg (PBN2).

2.7 Freestanding bases

The two models above estimate, for each net, the tension the top cable carries and the tension needed to meet the 2 cm tolerance. The remaining question is whether a freestanding base can hold the tension.

The net pulls the top of each post toward the court with tension T at height $h = 2.24$ m (Figure 2b). Let W_b be the weight of the ballast, a the horizontal distance from the ballast's center of mass to the court-side edge, and μ the coefficient of friction between base and floor. Taking moments about the tipping edge, and comparing the pull with the friction available, the base stays in place while

$$T \leq \frac{W_b\,a}{h} \quad \text{(tipping)}, \qquad T \leq \mu\,W_b \quad \text{(sliding)}, \tag{7}$$

so tipping comes first, before sliding, whenever $a < \mu h$. The model ignores the weight of the post and base frame, which also resists tipping. It also ignores the brief additional tension from balls or players hitting the net. No manufacturer publishes a or μ. The published bases are 45 to 52 in (1.1 to 1.3 m) long[10,12–14], with the ballasts on the side of the posts away from the court (Figure 2b), so we report results for $a = 0.3$, 0.5 and 0.7 m and for μ from 0.3 to 0.7. Table 2 lists the ballast, base length and any stated tension limit of several systems.

Table 2: Freestanding volleyball systems: ballast per base, base length and manufacturer tension guidance or resistance specification.

System	Ballast per base	Base length	Published tension specification
Spalding Freestanding One-Court[15]	800 lb	–	–
Spalding Freestanding II[8]	1,100 lb	–	–
Sports Imports Portable[16]	1,100 lb	–	–
Sports Imports Tournament Portable[9,12]	800 lb	45 in	not to exceed 250 lb
First Team Horizon[13,17]	700 lb	48 in	–
Bison Arena II[10,18]	not stated	48 in	holds at least 250 lb without moving

2.8 Data analysis

We measured the relationship of the height difference u with the displacement Δx and the stiffness k using Pearson's correlation coefficient r, which runs from -1 (one quantity falls as the other rises) through 0 (no straight-line relationship) to $+1$ (both rise together), with 95% confidence intervals. Because the tournaments may have used different nets, we also computed a pooled *within-tournament* correlation, subtracting each tournament's mean from both variables before correlating the two. Differences between tournaments are reported descriptively. The data was analyzed in Python using NumPy and SciPy.

2.9 Ethical considerations

The study involved no human participants and collected no personal data. The tournament crews gave permission for the measurements, which were made on each court after play on that court had ended. The load was removed immediately after each reading, and the photographs contain equipment only.

3 Results

3.1 Finding 1: net stiffness varies widely from court to court

Across all 48 courts, the effective midspan stiffness ranged from 146 to 354 N/m, a factor of 2.4. Nets set up at the same event were far from alike: within every tournament the stiffest net was 1.7 to 2.4 times as stiff as the softest (1.7, 1.9, 1.7 and 2.4 at tournaments 1 to 4), and 25 of the 48 courts were more than 20% away from the median stiffness of their own event, a margin larger than the resolution of one bead. The overall median was 275 N/m, with an interquartile range of 221 to 321 N/m and a coefficient of variation of 24% (Table 3).

The tournament means were 290, 264, 300 and 242 N/m (the horizontal bars in Figure 3), all within 12% of the overall mean of 269 N/m, while the courts at each tournament differed by a factor of 1.7 to 2.4. The variation among courts within tournaments was therefore larger

than the variation in tournament means. The estimated relative standard uncertainty in a single stiffness due to rounding is 2.4 to 5.8% (Section 2.4), much smaller than the observed spread.

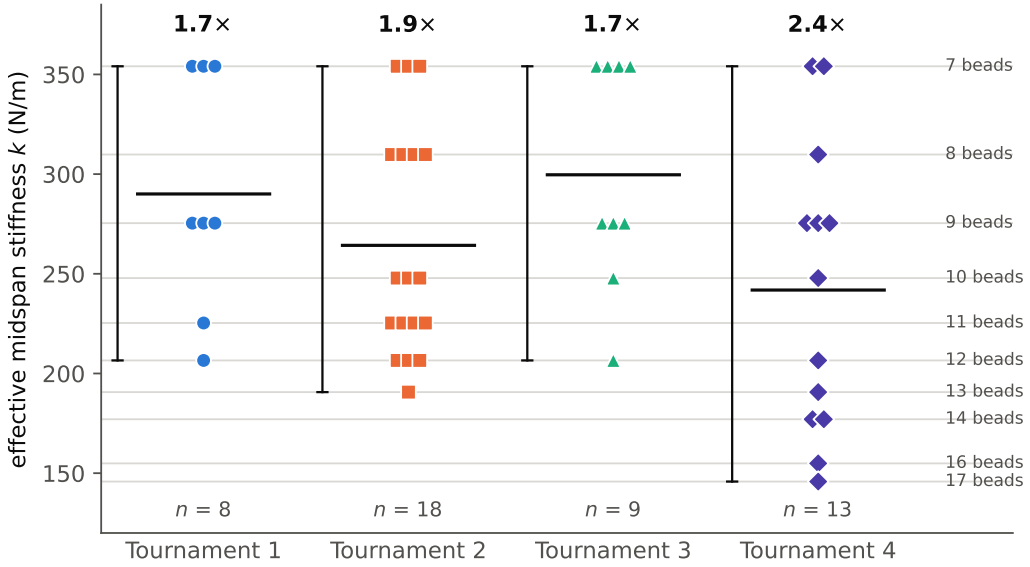


Figure 3: Finding 1: effective midspan stiffness k of each court, by tournament. The bracket beside each tournament spans its softest to its stiffest net, and the bold figure above it is their ratio; horizontal bars mark tournament means. Because readings are whole beads, k takes only the values marked on the right, and courts sharing a value are spread sideways. By Equation (3) the point-load tension estimate is $T_{\text{model}} = kL/4$, that is, 2.5 m times k on a 10 m span.

Table 3: Results by tournament: means of the edge-to-center height difference u and the load-induced displacement Δx; mean ± standard deviation of the effective stiffness k; and medians of the apparent net mass m_{app} (Equation (6)), the point-load tension estimate T_{model} (Equation (3)) and the tension $T_{2\,\text{cm}}$ that would bring u to 2 cm (Equation (4)).

Tournament	n	u (cm)	Δx (cm)	k (N/m)	m_{app} (kg)	T_{model} (N)	$T_{2\,\text{cm}}$ (N)
1	8	5.4	3.9	290 ± 59	2.7	689	1,656
2	18	3.1	4.3	264 ± 57	1.5	620	924
3	9	5.6	3.7	300 ± 56	3.2	689	1,935
4	13	4.0	4.9	242 ± 72	1.8	620	1,129
All	48	4.2	4.3	269 ± 63	2.0	689	1,241

3.2 The height tolerance does not detect this variation

The edge-to-center height difference, the quantity the 2 cm tolerance limits, did not show how stiff a net was. The height difference had a median of 4.4 cm (range 1.3 to 7.4 cm), and across all 48 courts the height difference and the displacement under the load were

essentially unrelated ($r = 0.08$, 95% CI -0.21 to 0.36; Table 4, Figure 4). In fact, four courts had exactly the same height difference, 4.8 cm, yet their stiffnesses spanned the whole range of the study, from 146 to 354 N/m. However, after accounting for tournament means, the two were modestly related ($r = 0.40$, 95% CI 0.12 to 0.62): nets with a larger height difference than others at the same event tended to be softer. Even so, within a tournament the height difference accounted for only about a sixth of the court-to-court variation in displacement ($r^2 = 0.16$).

Table 4: Correlation of the edge-to-center height difference u with the load-induced displacement Δx (with 95% confidence interval, Fisher's z) and with the effective stiffness k. "Within tournaments" correlates the residuals after each tournament's mean is removed.

	n	$r(u, \Delta x)$	95% CI	$r(u, k)$
Tournament 1	8	−0.34	−0.84 to 0.48	+0.45
Tournament 2	18	+0.55	0.11 to 0.81	−0.47
Tournament 3	9	+0.58	−0.13 to 0.90	−0.63
Tournament 4	13	+0.47	−0.11 to 0.81	−0.42
Pooled	48	+0.08	−0.21 to 0.36	−0.05
Within tournaments	48	+0.40	0.12 to 0.62	−0.36

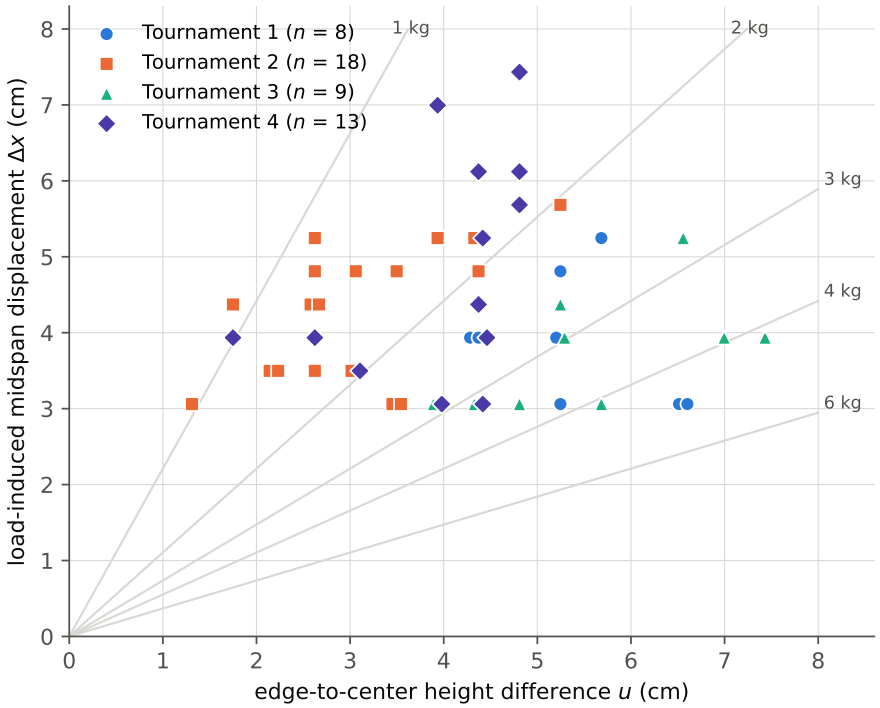


Figure 4: Load-induced displacement Δx against edge-to-center height difference u for each court. Grey rays mark constant apparent net mass $m_{\text{app}} = 2m\,u/\Delta x$(Equation (6)); under the model, a net with fixed weight, geometry, and load sharing moves along its ray as its tension changes. Courts with identical readings are offset slightly.

The height difference does not track the stiffness because the height difference depends on the weight of the net in addition to the tension. A heavier net sags more at the same tension. The mean height differences at tournaments 1 to 4 were 5.4, 3.1, 5.6 and 4.0 cm, nearly a factor of two apart, while the mean stiffnesses remained similar (Table 3). Further, the apparent net mass (Equation (6)) followed the height difference, with medians of 2.7, 1.5, 3.2 and 1.8 kg; in Figure 4, nets with the same apparent mass lie along one grey line. The apparent net mass was below the lightest catalogue net, 3.63 kg, on 42 of the 48 courts. Therefore, the height difference records mainly which kind of net is up, not how tight the net is, and the variation in stiffness of Finding 1 passes a height check unnoticed.

3.3 Finding 2: estimated tension to meet the 2 cm tolerance exceeded the comparison value on most courts

As the nets were set, the point-load model gave tensions of 365 to 885 N, with a median of 689 N (Table 3, Figure 5a), all below the 250 lb (1,112 N) comparison value. However, 45 of the 48 nets exceeded the 2 cm tolerance. Bringing the nets within the tolerance would take about twice the tension they had. The tension needed to reach 2 cm (Equation (4)) had a median of 1,241 N, 1.8 times the median tension as set, and exceeded the comparison value on 30 of the 48 courts (Figure 5b).

At tournaments 1 and 3, where the apparent net masses were greatest, the estimated tension needed exceeded the comparison value on every court, and at tournaments 2 and 4 it exceeded that value on 13 of 31 courts. These tensions are similar to the 1.56 to 2.26 kN that Ogawa et al. measured on nets with floor-socket posts[2]. If ball strikes added the 280 to 350 N reported by Ogawa et al. to these estimated static tensions, 40 to 42 of the 48 courts would exceed 250 lb at the 2 cm tension. Applying the same increments to the estimates as set would put 12 to 17 courts above 250 lb.

There are two assumptions that affect these counts. First, the edge readings were taken over the sidelines; had they been taken at the posts, the estimated tension needed would exceed the comparison value on 13 to 22 courts instead of 30. Second, assigning the whole catalogue weight of a net to the top cable instead would raise the needed tension further, to 1.4 to 4.3 kN, so the per-court estimates above are the lower of the two approaches.

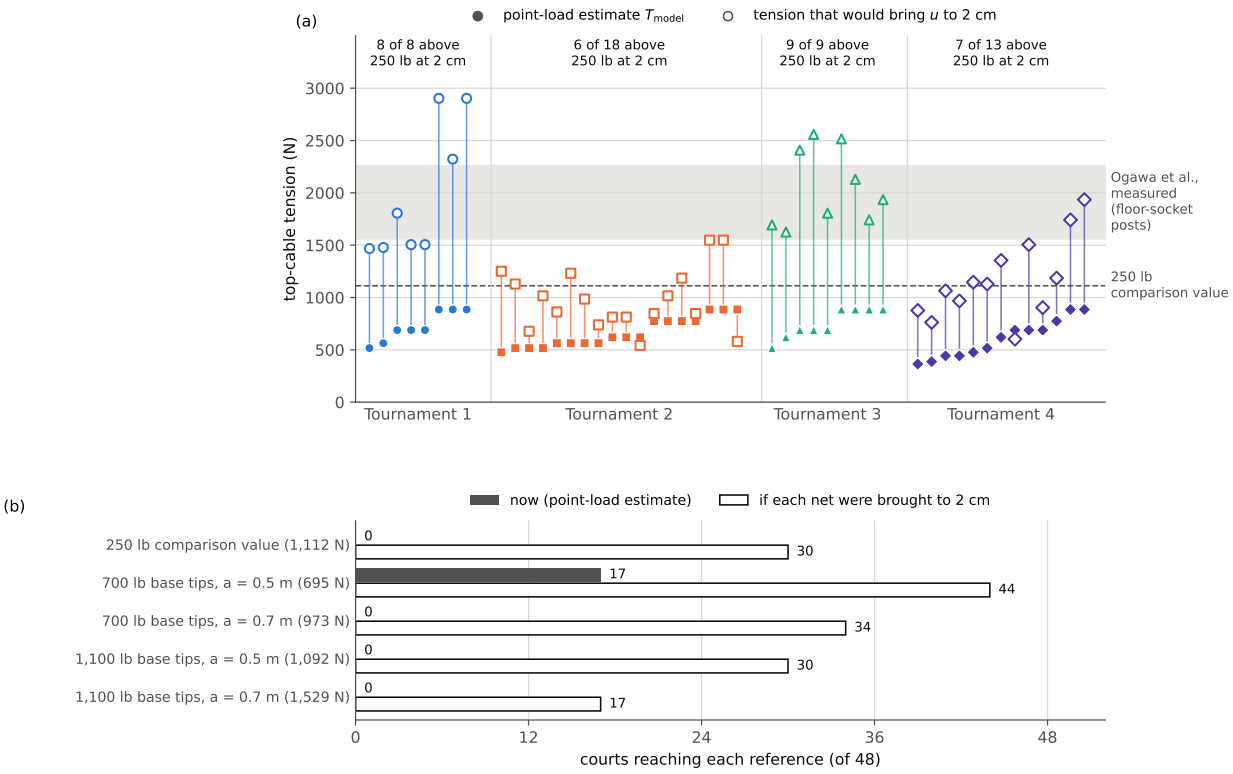


Figure 5: Finding 2. (a) For each court: the point-load tension estimate T_{model} as the net was set (filled) and the tension $T_{2\,\text{cm}}$ that would bring its height difference to 2 cm (open), grouped by tournament and sorted by T_{model}. The dashed line is the 250 lb comparison value, and the counts above each tournament are the courts whose $T_{2\,\text{cm}}$ exceeds it. The shaded band is the range of steady tensions Ogawa et al. measured with floor-socket posts. (b) Number of the 48 courts whose estimated tension reaches the comparison value or the modeled tipping threshold $W_b a/h$ of a 700 or 1,100 lb base for moment arms of 0.5 and 0.7 m (Equation (7)), as set (filled) and if brought to 2 cm (open).

3.4 The bases under the tension the tolerance requires

At the estimated tension needed to meet the 2 cm tolerance, some modeled base configurations would reach their tipping thresholds on most courts (Figure 5b, Table 5). For instance, a 700 lb base would reach the threshold on 34 to 44 of the 48 courts, for moment arms of 0.7 and 0.5 m, and even the heaviest ballast listed, 1,100 lb, on 17 to 30. As the nets were set, the same 700 lb base would reach the threshold on 0 to 17 courts and the 1,100 lb base on none. The counts depend on the unknown moment arm a (Table 5), but at the 2 cm tension many courts reach the threshold for every moment arm considered.

In the modeled scenarios, tipping generally occurs before sliding. Tipping comes first in every case considered except a slippery floor ($\mu = 0.3$) with $a = 0.7$ m, where a 700 lb base would slide at 934 N, just before tipping at 973 N. These counts come from the model and the published ballast weights: no base was tested, and a and μ were not measured.

Table 5: Tipping tension $T_{\text{tip}} = W_b a/h$ for three ballasts and three moment arms a ($h = 2.24\,\text{m}$), and the number of the 48 courts whose point-load estimate T_{model} and 2 cm tension $T_{2\,\text{cm}}$ reach it.

	$a = 0.3\,\text{m}$			$a = 0.5\,\text{m}$			$a = 0.7\,\text{m}$		
Ballast	T_{tip} (N)	T_{model}	$T_{2\,\text{cm}}$	T_{tip} (N)	T_{model}	$T_{2\,\text{cm}}$	T_{tip} (N)	T_{model}	$T_{2\,\text{cm}}$
700 lb	417	46	48	695	17	44	973	0	34
800 lb	477	44	48	794	12	42	1,112	0	30
1,100 lb	655	26	45	1,092	0	30	1,529	0	17

3.5 Height tolerance and a proposed load check

We considered two ways to keep estimated tension below the 250 lb comparison value. The first is a looser height tolerance. Equation (5) gives, for each net, the smallest height difference the net could reach without exceeding 250 lb in the model (Table 6). The model estimates that the comparison value would allow a 2 cm tolerance to be met by 18 of the 48 nets, 3 cm by 34, 4 cm by 42 and 5 cm by 46; leaving room for a ball strike[2] lowers the net counts to 6, 20, 31 and 39. Most nets would need a tolerance of about 4 cm, and the heavier nets at tournaments 1 and 3 up to 5.2 cm.

The second is a minimum displacement under a known load, which does not depend on the weight of the net. In the midspan point-load model, $k = 4T/L$, so 250 lb corresponds to a displacement of 5.6 beads under the 1.1 kg load on a 10 m span and 6.1 beads on an 11 m span. A displacement of at least 7 beads therefore keeps the estimated tension below 250 lb on spans up to 11 m, whatever the net weighs. Every net measured met this: the smallest displacement was 7 beads, on 12 courts. A maximum displacement, which would keep nets taut enough for consistent play, cannot be set from these data, because no ball was tested (Section 4.2).

Table 6: Height tolerances, and the number of the 48 nets that could meet each without their tension exceeding 250 lb (1,112 N), or 250 lb less the 350 N a ball strike can add (762 N), from Equation (5).

Height tolerance	2 cm	3 cm	4 cm	5 cm
Nets that could meet it within 250 lb	18	34	42	46
... leaving room for a ball strike	6	20	31	39

4 Discussion

4.1 What the findings mean

A known load and the bead chain already used to check net height are enough to measure the stiffness of a volleyball net. Net stiffness varied widely between courts at the same event.

The model also suggests that the tension needed to meet the 2 cm tolerance could reach the tipping threshold of some freestanding base configurations.

The first finding matters for play. If the tautness of the net affects how the ball leaves the net, as the referee's check assumes[1], tournaments did not offer consistency. A team could move from one court to another and meet a net more than twice as stiff, with nothing in the pre-match check to show the difference. The height check cannot catch the difference, because the height difference depends on the weight of the net as well as on the tension. The tournaments appear to have used nets of different weight, but the net systems were not recorded, so this remains a hypothesis.

The second finding matters for safety. On 30 of the 48 courts, the estimated tension needed to meet the height tolerance exceeded the 250 lb comparison value. The base model indicates that tightening the nets to meet the tolerance could also bring some base configurations to their tipping thresholds. Ogawa et al. found tensions of this size on floor-socket posts and reported that posts have failed in practice[2]. On freestanding systems, resistance to tipping depends on the weight and geometry of the base. Direct tension measurements and stability tests on identified systems are needed to establish when the height requirement and the equipment's operating limits conflict.

4.2 Recommendations

A tolerance of about 4 cm would allow most measured nets to meet the height requirement at an estimated tension below the 250 lb comparison value (Table 6), but it would also allow lighter nets to hang looser. A check of how far the net moves under a known load measures effective midspan stiffness directly and, through the midspan point-load model $k = 4T/L$, provides an estimate of cable tension without needing to know the net weight. The following are our recommendations for evaluating that check.

For tournament crews. In a supervised validation trial, a known weight can be hung at midspan and the displacement read on the bead chain. Under a 1.1 kg load, a displacement of at least 7 beads corresponds to an estimated top-cable tension below the 250 lb comparison value on spans up to 11 m (Section 3.5). The equipment manufacturer's setup instructions govern adjustments. A maximum displacement for consistent play would require ball-response tests.

How reliable the check is. Two errors of the method always push the estimated tension up: the point-load model overestimates the tension, and the chain, hung beside the load, reads the displacement about 2% low. Both effects make the model estimate conservative under its assumptions. Rounding to whole beads is a third error, but rounding is unbiased; the margin between the 7 beads required and the 6.1 beads corresponding to the comparison value at 11 m covers the typical rounding error of 0.41 bead.

For manufacturers. The check needs only a calibrated weight with a hook and a tag on the chain marking the allowed range, both of which could be supplied with the net system. This weight does not have to be the same as the one used in this paper. For example, a 2.2 kg weight would approximately double the displacement and halve the relative effect of bead resolution if the response remains linear over this load range.

For rule makers. The 2 cm tolerance warrants review for freestanding systems. Where direct testing confirms that meeting the tolerance requires more tension than an approved

system can carry, options include a different height tolerance or equipment rated for the required tension. Rule makers could also evaluate a cable-tension check or a validated minimum displacement under a standard load, with any limit based on the equipment in use.

4.3 Limitations

- The courts were measured as they became free after play at four events and were not chosen at random, so the results may not generalize to other events or net systems.
- Measurements were made after play. Cords and cables relax under load, so these tensions may be lower than at set-up.
- No ball was tested; the link between stiffness and play rests on referees' practice.
- Stiffness was measured only at midspan; variation in stiffness along the net was not assessed.
- All tensions are model-based upper estimates; neither model was checked against a tension gauge or load cell.
- The cable model treats the net as a single string: the mesh, bands, bottom cord, and supports are not modelled.
- The manufacturers and model numbers of the net and base on each court were not recorded.
- Readings are whole beads, and repeatability was not tested by hanging the load more than once.
- The chain hung about 10 cm from the load.
- The moment arm a and the floor friction μ are unknown; results are given for ranges of each.

4.4 Future work

1. Hang a 1.1 kg load and then a 2.2 kg load on the same net. If the displacement doubles, the tension did not change under the load, which tests Equation (3) directly; the heavier load also halves the size of one bead relative to the displacement.
2. Repeat the readings on one net several times, and at the start and end of a day, to measure repeatability and relaxation.
3. Record the net and base model on every court, and measure net mass or obtain a documented mass for each net model, to test whether net weight explains the difference between events.

4. Measure the ballast position of one real base, and how far the top of a post moves when the net is tensioned.

5. Measure the tension of a few nets directly with an in-line gauge or load cell, as Ogawa et al. did[2], at several tensions.

6. Measure the ball's response through controlled contacts at the top band of nets of known effective midspan stiffness, following the design of rebound experiments of tennis string beds[19]. A string bed is about as stiff as a tennis ball, whereas a net is far softer than a volleyball, so the tennis results are a template for the experiment rather than a prediction.

4.5 Conclusion

A volleyball net is part of the playing surface. The 2 cm height tolerance does not reliably detect differences in stiffness. The model suggests that tightening a net to meet the tolerance could also reach the tipping threshold of some freestanding base configurations. The bead chain that already checks the height, with a known load added, measures what the height rule cannot. Confirming the tensions directly and testing how the ball responds are the next steps toward a standard that keeps nets both consistent and safe.

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