7th AAAA Congress
on Sound and Vibration
22-23 September 2016, Ljubljana, Slovenia

Slovenian Acoustical Society

Comparison of characterization methods for B-flat clarinet reeds*

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ABSTRACT

Clarinet reed makers label the reed strength of a reed according to the playing ease. For the labeling reed makers primarily use two methods. They use reed characterization machines which either (1) measure the mechanical stiffness or (2) the material's hardness. Nowadays also synthetic materials are used for clarinet reeds. In this study both characterization methods will be compared, using 27 B-flat clarinet reeds (3 different strength, manufacturers, and materials). First, a reed hardness tester was used to measure the compliance of three materials (cane, oriented polymer, fiber-reinforced polymer) at three different positions (reed tip, 8 mm, and 16 mm from reed tip). Second, a force-displacement measuring setup was built, consisting of a XYZ translation stage and a force measurement head. Each reed was mounted on a stand. Adjusting the stages caused the measurement head to bent each reed, a read-out displayed the corresponding force. The force was measured at the same three positions. The reeds were bend for 0.25 mm and 0.5 mm and ranked by the measured force. Third, a professional clarinetist played and ranked the reeds by the playing ease. The results indicate that the mechanical stiffness is a better indicator for the playing ease of natural and synthetic reeds than the hardness of the material.

* Updated version with minor corrections (spelling and typos), no changes in the content of the originally published paper have been made.

1. INTRODUCTION

When a clarinetist is blowing into the instrument, the characteristics (stiffness, mass, material density) of the vibrating reed have a strong influence on the sound (e.g. intonation, the timbre, the tonal attack) and on the playing ease [1, 2]. Figure 1A shows the eight different parts of a clarinet reed [3]: the heel or butt end, the stock or bark, the shoulder, the vamp, the heart or spine, the left and the right rail, the tip and the table or flat side.

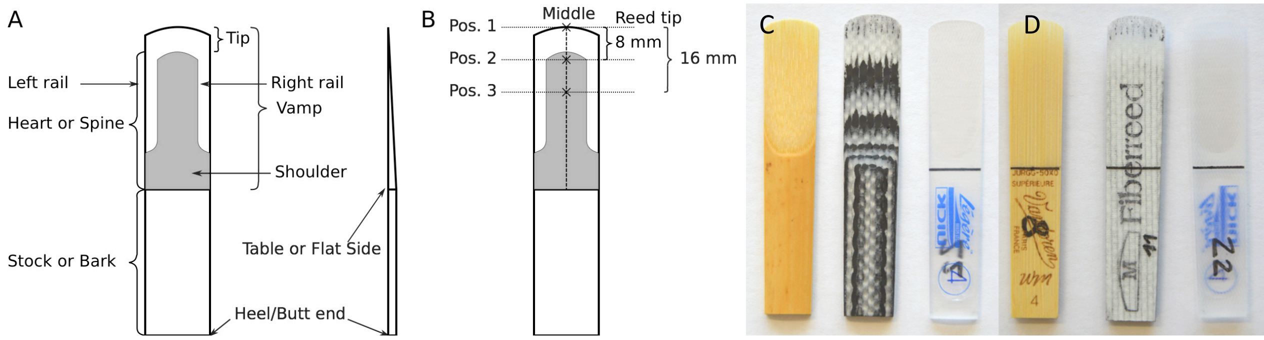

Figure 1. A: The parts of a clarinet reed. **B:** Three measuring positions: Pos.1: reed tip, Pos.2: distance: 8 mm, Pos. 3: distance: 16 mm. **C:** Front view of clarinet reeds. **D:** Table of clarinet reeds

Today's clarinet single reeds are made out of different materials, including natural cane, and synthetic materials like oriented polymer or fiber-reinforced polymer. A cane reed is cut out of a plant called Arundo donax L. (Graminae). These plants are cultivated in southern France, Spain, Italy, Turkey, China, Mexico, California, Chile and Argentinia [4, 5, 6, 7, 8]. The tissue [7] of a cane reed comprises three parts (see Figure 2A): The small outer part (epidermis), the middle part (fiber band) and the thick inner part (inner cortex). Small vascular bundles separate the epidermis and fiber band along its border. The inner cortex is filled with stem tissue (parenchyma cells) and larger vascular bundles. Every vascular bundle itself comprises three tissues: xylem, pholem and a thick fibre ring (sclereid), which is either continuous or discontinuous. A high number of viscular bundles with continuous fibre rings make the cane more rigid/stiffer. Clarinetists [9, 10] have complained of the limited durability and the change on the reeds characteristics due to saliva, moisture and temperature. Therefore, since the 1930's there has been vast interest in finding alternative materials to replace the sensitive cane reeds. In early experiments cane reeds were treated with plastisol and nitrocellulose [11], synthetic resin [12] and other materials in an attempt to maintain their sustainability. Later in the 1960's, completely synthetic reeds were invented comprising plastic filled fibers [13] or cemented layers of different materials [14]. However, the sound quality of these synthetic reeds was not satisfying for professional players. Backus [13] stated that the reed properties (density and Young's modulus) of synthetic reeds must be similar to that of cane reeds in order to have the same sound and playing quality. In his investigations cane reeds had a Young's modulus (elastic modulus) between 700,000 and 2,000,000 pounds per square inch with a density of 0.8 to 1 grams per cubic centimeter (wet). Synthetic reeds had a Young's modulus between 200,000 to 500,000 with a density of 1.3 to 2 grams per cubic centimeter.

Today's oriented polymer reeds have an equal sound quality to that of cane reeds and are played by professional musicians [15, 10]. Reeds by the company Légère (used in the following study) are manufactured in primarily three steps. In the first step, polymer composites are machine melted, using processes [16] such as hydrostatic extrusion, ram extrusion, tensile drawing, die drawing or compression. In these processes the polymer molecules are formed at a temperature below the melting point. Hereby, the stiffness of the material is influenced by the drawing direction and can therefore be controlled by the reed maker (see Figure 2B).

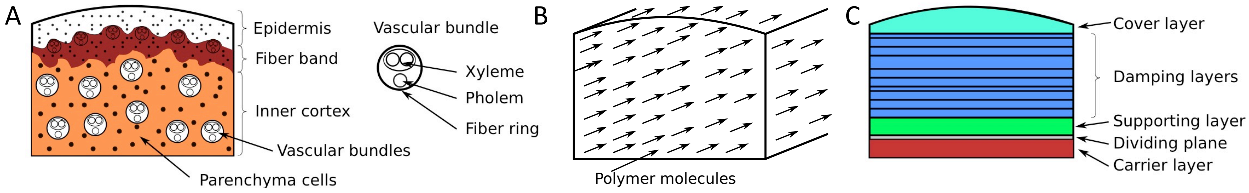

Figure 2. A: Cross section of a clarinet cane reed subdivided into different parts (left). More vascular bundles (right) makes a reed stiffer. **B:** Cross section of a clarinet oriented-polymer reed. The molecules alignment and material influence the material's stiffness. **C:** Cross section of a fiber-reinforced plastic reed subdivided into several layers and one dividing plane.

In a second step, numerically controlled machines mill the cut (e.g. German Cut) on the reed. Then the flat side of the reed is polished to ensure that mouthpiece and reed close entirely. Still the materials properties and characteristics (stiffness, density, viscous damping, Young's modulus, molecular alignment) are different from those of natural cane. Polymer-composite materials (e.g. carbon fiber-reinforced epoxy) have higher densities than metals. To compensate this, oriented polymer reeds are made thinner than cane reeds. Finally, the reeds are sorted towards their strength by a computer-controlled bend test.

Fiber-reinforced plastic reeds, invented by Harry Hartmann [9], consist of four different layers (carrier layer, supporting layer, multiple damping layers, and a cover layer) and a dividing plane (between carrier layer and supporting layer) which are agglutinated together on large boards by heating the material. Figure 2C shows a schematic cross section of the different layers. The layers comprise strands of fibers embedded into a plastic compound of epoxy resin or phenolic resin. Each fiber strand has a thickness of approx. 0.12 mm (a fiber bundle close to 1mm). The carrier layer comprises primarily carbon fibers. Damping layers have unidirectional or transverse fiber strands of different materials (hollow glass fibers, kevlar fibers, glass fibers, aramid fibers, microtubes of flexible ceramics, osmotic fibers) which can be interwoven or layered on top. Fibers running transversely to the reeds are softer and therefore reduce tearing and internal damping. Fibers running longitudinal are much stiffer and have the same characteristics as vascular bundles in cane reeds. Finally, the reed is cut from the large boards of compound material. Different clarinet reed cuts are produced e.g. for German clarinets or Boehm/French clarinets.

Several methods are used to characterize the quality of cane reeds. In order to preselect the cane for single or double reeds, it is recommended for students or professional musicians [17] to test the materials stiffness and hardness, the materials flexibility or specific gravity/denisty [19, 20, 21, 22]. The oldest and most simple method [17, 4] to test the hardness of cane reeds is called the fingernail test. Hereby, the fingernail is pressed into the reed's heel (inner cortex) to check the hardness of the material. Softer cane reeds show a larger and deeper fingernail print than harder reeds (see Figure 3A). However, this method cannot be applied to synthetic reeds because of the hard materials. Today, oboists and bassoonists use a hardness tester based on a gauge design (e.g. by reed's and stuff) to test the material's hardness. Such a gauge might also be useful to investigate clarinet reeds. Another method [17] investigates the material flexibility, when twisting both ends of a reed in opposite directions. This method assumes that softer reeds bend more than harder reeds.

The third method measures the specific gravity or density of cane reeds [18, 19, 20]. In some experiments cane reeds were dropped from certain distances on a rigid surface to compare the

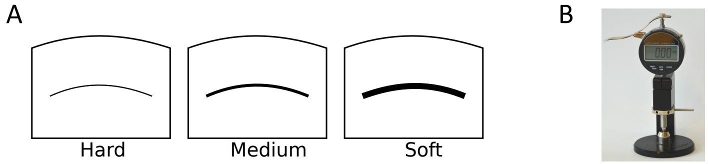

Figure 3. A: The fingernail-test. Cross section of clarinet reed. The print of the fingernail tells you how hard the material is. Soft cane will show you a larger and deeper print. **B:** Reeds'n Stuff Hardness tester.

different resulting pitches [21]. Professional clarinet reed makers [23, 8] use spring or mass-loaded gauges to sort the cane reeds into different strengths (static-force-displacement measurements). These gauges are bending the reeds (of the same cut) at the reed tip with a certain force and simultaneously measure its displacement (static stiffness). The reeds are then sorted by their displacement. Softer reeds show a larger displacement, harder reeds a smaller displacement. However, no reed strength characterization method for both cane and synthetic reeds exists so far. Furthermore non of the existing methods has been empirically tested on a collection of synthetic reeds and cane reeds. In this study, 27 reeds (9 cane, 9 synthetic, 9 fiberreeds) with three different strengths will be measured (hardness, stiffness), and their playing ease will be categorized by a professional clarinetist.

2. METHODS

In this paper, three methods are used to categorize 27 clarinet reeds by its mechanical stiffness, hardness and playing ease. Table 1 gives an overview of the reeds which are used in all three experiments. Figure 1C and 1D exemplary show the three different reed types (cane, fiber-reinforced, oriented polymer). The reeds are numbered from 1 to 27 (see Table 2).

Table 1. Reed makers, reed types, material, reed strength and ID-labels of the 27 different reeds for B-flat clarinet which were used in the experiments.

Reed maker	Type	Material	Strength	Reed ID
Vandoren	White Master German Cut	cane	3; 3.5 ; 4	1–9
Hartmann's Fibereeds	NC German Cut	fiber-reinforced plastic	medium, medium hard, hard	10–18
Légère	Classic German Cut	oriented polymer	3.45; 4; 4.25	19–27

Table 2. Strength of reeds (soft, medium, hard) and their ID numbers.

Strength	Soft	Medium	Hard
Cane reeds	1–3	4–6	7–9
Reinforced-fiberreeds	10–12	13–15	16–18
Oriented polymer reeds	19–21	22–24	25–27

Hardness of the clarinet reeds

In the first experiment we measured the hardness of the material (compliance) for the 27 clarinet reeds. All reeds were measured at three different positions: reed tip, 8 mm and 16 mm from the reed tip (see Figure 1B).

Equipment/Setup The setup consisted of a reed hardness tester (Reeds'n Stuff Hardness tester for oboe 'RnS', digital, see Figure 3B), which is pressing a spring with a certain force into the reed material. The compression of the material can be read out on a digital display.

Procedure In order to determine the geometry of the reeds, the width of each reed was measured with the digital micrometer. With the hardness tester, the width was measured with and without the spring. The raw data (width of the reed without (1) and with (2) the spring) was taken to calculate the resulting difference, using the following equation: width(1) - width(2). This procedure was applied to all three positions (tip of reed, 8 mm from tip, 16 mm from tip). Finally, a mean value of these three measurement points was calculated.

Results The results of the hardness measurements showed that cane reeds (Nr. 1-9) are softer than reinforced-fiber (Nr. 10-18) and oriented polymer (Nr. 19-27) reeds. Figure 4A shows the results of the hardness measurements, indicating how much the reeds were compressed at the three different measuring positions. The black solid line illustrates the measurements at the reed tip, the red line 8 mm inside the vamp and the green line 16 mm inside the vamp. The blue line shows the average values. Hardness measurements at the reed tip (black line, solid, cross) show that the material of cane reeds (Nr. 1-9) is easily compressible. The cane reed's tip (first measuring position) was compressed by -0.05 mm up to -0.1 mm. In contrast, the tip of the reinforced-fiberreeds and oriented polymer reeds are more rigid. These tips were compressed by less than -0.03 mm. However, using this method, no systematic differences between the reeds of different strength (soft, hard, medium) were found. Hardness measurements at the second measuring position (8 mm from reed tip, red line) showed again that the cane reeds are softer than the synthetic reeds. Here, cane reeds (red line) were compressed by -0.13 mm up to -0.18 mm. Synthetic reeds were compressed by -0.03 mm and -0.04 mm. No differences were found between the reeds labeled with different reed strength. The results of the third measuring position (16 mm from reed tip, green line) showed that the material of cane reeds is much softer compared to the synthetic reeds. The cane was compressed by -0.18 mm and -0.28 mm. Similar to the cane reeds, the synthetic reed types were softer at this position in comparison to the first and second measuring position. The synthetic reeds were pressed in between -0.08 mm and -0.13 mm (Nr. 10-27) at the third measuring position. Taking a look at the reinforced and oriented polymer reeds (Nr. 10-27, green line), there is a tendency that harder reeds can were less compressible at the third measuring position than softer reeds of the same type (Nr. 1-9). The results of all (static) measurements show the same trend, that the material of all synthetic reeds is harder than that of cane reeds. It remains the question if all the synthetic reeds chosen for this study might also be harder to play than the cane reeds. However, we assume it to be unlikely that all synthetic reeds are harder to play than the cane reeds.

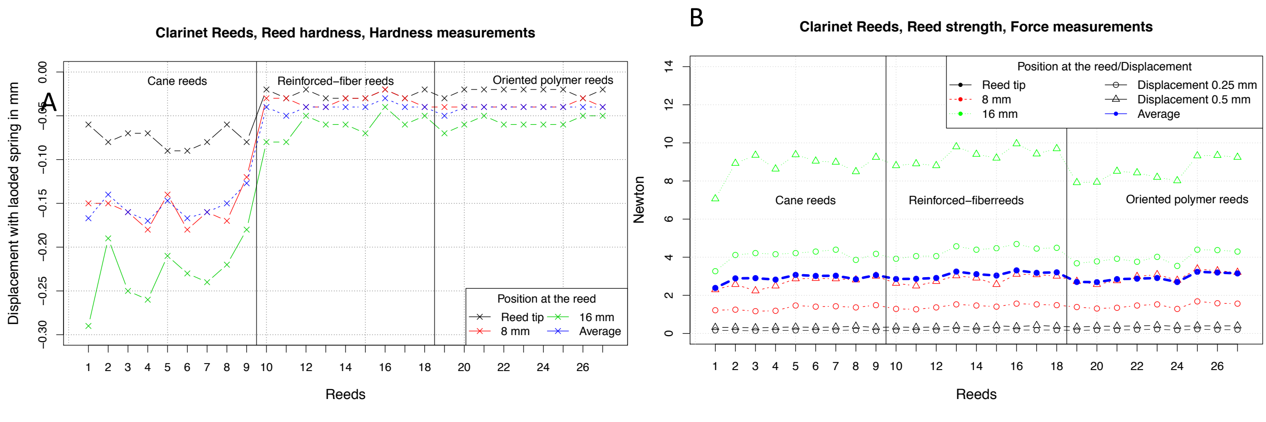

Figure 4. A: Hardness measurements of 27 different clarinet reeds. The raw values show how much the spring loaded measuring head compressed the material. **B:** Force measurements of 27 different clarinet reeds, showing the measured force for bending 0.25 mm and 0.5 mm.

Stiffness of the clarinet reeds

For the second measurement the stiffness of the same 27 reeds was measured by bending the reed for 0.25 mm and 0.5 mm at the same three measuring positions used in the first experiment (see Figure 1A). Therefore a customized static stiffness tester was built to measure the occurring forces during the process of bending the reeds.

Equipment/Setup The measuring setup consisted of two translation stages (PT3: XYZ translation stage with three standard micrometers, by Thorlab), a weighbeam (rod with two strain-gauge sensors), and a control panel measuring amplifier for process control (Hottinger Baldwin Messtechnik, MVD 2510). The two strain gauges were calibrated using standardized. The reed was mounted to one of the translation stages (01). The second stage (02) was used to press the weight-beam to the reed. Figure 5A schematically illustrates the reed static stiffness tester and Fig. 5B/5C shows the original setup.

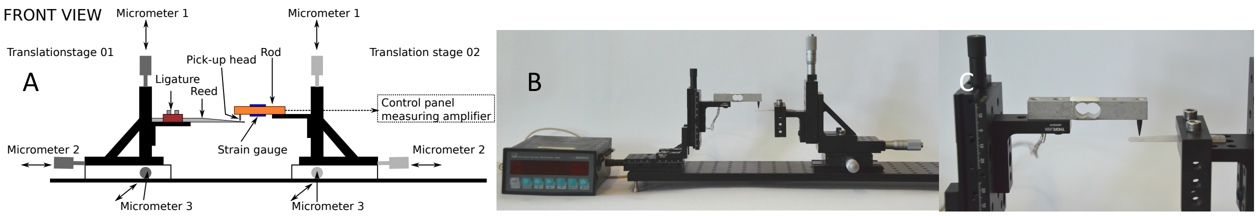

Figure 5. A: Schematic illustration of the static stiffness tester. **B:** Original measuring setup. **C:** Zoom.

Procedure Each reed was mounted on the bench of the first translation stage. One half of the reed was laying on the bench and the other half hang over to be flexible for bending. We adjusted the pick-up head with micrometer 1 (translation stage 02) to contact the reed using a pre-weight of 0.1 N. For the actual measurement at the reed's tip, the reed was displaced with the micrometer 1 (translation stage 02) for 0.25 mm and for 0.5mm. Force values were transcribed from the display of the control panel. The same procedure was repeated for two more measuring positions on the reed (8mm and 16mm from reed tip), for each of the 27 reeds.

Results When bending the tip of the reed, a force between 0.1–0.25 N was measured for a displacement of 0.25 mm and forces between 0.3–0.45 N for 0.5 mm displacement. At the second measurement position (8 mm from the tip), forces between 1.2–3.4 N were measured for 0.25 mm displacement and 2.3–3.4 N for 0.5 mm displacement. At the third position (16 mm from the tip), forces between 3.2–4.8 N were measured for 0.25 mm displacement (8.5–10 N for 0.5 mm displacement). Figure 4B shows the results of the force measurements of the 27 clarinet reeds. The black lines (triangular and circular) refer to the measurements done at the reed tip (first measuring position), the red dotted lines (triangular and circular) to the measurements 8 mm inside the reed (second measuring position) and the green dotted lines (triangular and circular) to the third measuring position (16 mm inside the reed tip). Circular separated lines indicate that the reed has been displaced for 0.25 mm, triangular separated lines that the reed has been displaced for 0.5 mm. We found, that especially for the measuring position 8 mm (red lines), there were differences between soft reeds (e.g. Reed Nr. 1-3, 10-12 and 19-21) and hard reeds. Forces measured with soft reeds were in a range of 1.2–1.4 N, harder reeds are in a range of 1.4–1.7 N. However, this was not the case for all reeds, outliers (Reed Nr. 4 and 24, medium strength) imply that some reeds might be softer than labeled by the reed makers.

Playing ease of the clarinet reeds

In a third experiment, a professional clarinetist (first author) tested all reeds and sorted them towards the playing ease.

Equipment/Setup The reeds were played on a B-flat clarinet (by O. Hammerschmidt, type: OH 320) with a mouthpiece by MAXTON (mouthpiece lay: NA, material: PMMA) with the according silver ligature.

Procedure Each reed was mounted to the mouthpiece. Cane reeds were soaked with saliva for some seconds to be in playing condition. A simple scale covering the range of the instrument (C major scale, C4–C6) was played. First, the player categorized the reeds towards the playing ease into three different groups: easy, medium and hard to play. Second, the reeds were ranked from 1 (easiest to play) to 27 (the hardest to play).

Results Figure 6A shows the clarinet reeds sorted towards the playing ease. We were interested in the relationship between the hardness measurements, the stiffness measurements and the playing ease of the reeds. Therefore we calculated an individual One-Way Analysis of Variance (ANOVA) for each of the measured parameters and used the categorization of the *playing ease group* as a factor. Table 3 shows the results of each independent statistical test. The p-values on a significance level $p < 0.01$ are highlighted in the table. From this analysis we found a significant effect of *playing ease group* for the measured stiffness at the tip and 8 mm away from the tip of the reed. For all other measurements the statistical test did not reach the level of significance.

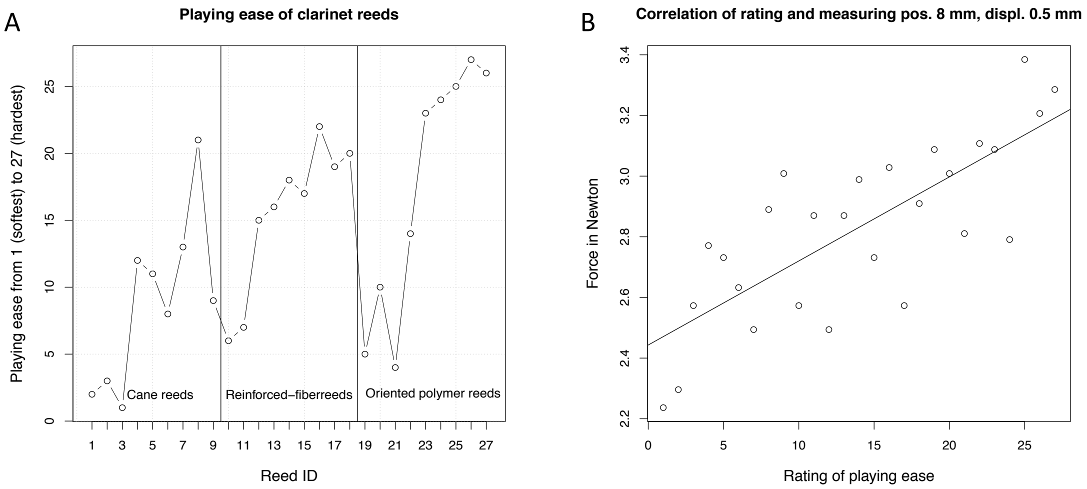

Figure 6. A: Playing ease of the different clarinet reeds. **B:** Correlation between the rating of the playing ease and the measurements done at a position 8 mm from reed tip with displ. of 0.5 mm.

Table 3. Results of independent One-Way ANOVA for the 10 different static measurements from experiment 1 and 2 by the playing ease group factor.

	Df	Sum Sq	Mean Sq	F value	Pr(<F)
Hardness (Tip)					
Group	2	0.00	0.00	2.70	0.0874
Residuals	24	0.01	0.00		
Hardness (8 mm f. Tip)					
Group	2	0.01	0.01	2.19	0.1343
Residuals	24	0.08	0.00		
Hardness (16 mm f. Tip)					
Group	2	0.04	0.02	0.06	0.0656
Residuals	24	0.15	0.01		
Hardness - (Average)					
Group	2	0.01	0.01	2.73	0.0857
Residuals	24	0.06	0.00		
Stiffness (Tip), .25 mm displ.					
Group	2	0.00	0.00	7.31	0.0033
Residuals	24	0.01	0.00		
Stiffness (Tip), .50 mm displ.					
Group	2	0.01	0.01	7.68	0.0026
Residuals	24	0.02	0.00		
Stiffness (8mm), .25 mm displ.					
Group	2	0.19	0.10	8.85	0.0013
Residuals	24	0.26	0.01		
Stiffness (8mm), .50 mm displ.					
Group	2	1.10	0.55	12.67	0.0002
Residuals	24	1.04	0.04		
Stiffness (16mm), .25 mm displ.					
Group	2	0.58	0.29	2.92	0.0732
Residuals	24	2.37	0.10		
Stiffness (16mm), .50 mm displ.					
Group	2	1.93	0.97	2.45	0.1079
Residuals	24	9.48	0.39		

To further investigate the relationship between the playing ease and the stiffness measurements, we correlated the measured stiffness with the ranking of the reeds (see Table 4). Here we found a significant correlation on a $p < 0.001$ level for all stiffness measurements at the tip and 8 mm away from the tip. For the case of measuring at 8 mm and bending the reed for 0.50 mm, Figure 6B depicts the positive correlation between measured force and the ranking of the reeds from the easiest to the hardest to play.

Table 4. Results of the correlation tests between the stiffness and the rating of the playing ease.

Positions	p-value	corr. value
Reed tip, dip. 0.25	< 0.001	0.728596
Reed tip, dip. 0.25	< 0.001	0.737853
8 mm from reed, displ. 0.25 mm	< 0.001	0.721622
8 mm from reed, displ. 0.5 mm	< 0.001	0.768137
16 mm from reed, displ. 0.25 mm	< 0.05	0.400624
16 mm from reed, displ. 0.5 mm	= 0.083	0.339863

3. DISCUSSION

This study investigated the stiffness, the hardness and the playing ease of 27 B-flat clarinet reeds (cane reeds, reinforced-fiberreeds, oriented polymer reeds). In the first experiment we measured the hardness of the reeds at three different measuring positions with a hardness tester and found that cane reeds are more compressible than reinforced-fiberreeds and oriented polymer reeds. Synthetic composites are supposed to have a higher density and mass than cane reeds to make them more durable. This might explain the results of the measurements [13] but makes this method not suitable to compare reed strengths in general. In the second experiment we measured the stiffness of the same reeds with a self-built static stiffness tester. Here, the results showed differences between the reeds labeled with different strengths. As professional reed makers use gauges working with a similar principle to characterize their reeds [23, 8], it would be interesting for the future to compare the data of our stiffness measurements with the measurements of such a professional mass or spring loaded gauge. However, we would expect similar results, as both measurement techniques investigate the force-displacement relationship. From the playing test we were able to group the reeds into three main categories of *playing ease* and finally ranked them from the easiest to the hardest reed to play. Here, a significant effect of the *playing ease* group on the measured stiffness was found, as well as a positive correlation between the *playing ease* ranking and the stiffness of the reeds. This preliminary result indicates that the stiffness of the reed is a more reliable parameter to compare reeds from different materials than the hardness. Playing tests with a larger panel of professional clarinetists are foreseen for the future to validate these observations and to further investigate similarities and differences between natural and synthetic reeds for wind instruments.

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