

**Comparative analysis  
of nine gripping configurations for aerial straps  
TECHNICAL REPORT**

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Montreal, January 31, 2019

## Comparative analysis of nine gripping configurations for aerial straps

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### 2) Introduction

The aerial straps discipline is an aerial discipline, meaning it involves an apparatus suspended from above. The straps consist of two parallel bands that are several metres long. Aerial strap performers can perform various holds with their arms and legs, as well as hanging moves, rolling moves, drops and floor work<sup>1</sup> (Figure 1). They can also use the straps to spin and dangle over great distances above the ring or the audience. The acrobats can swing themselves by either going around in a circle or in a back-and-forth motion.

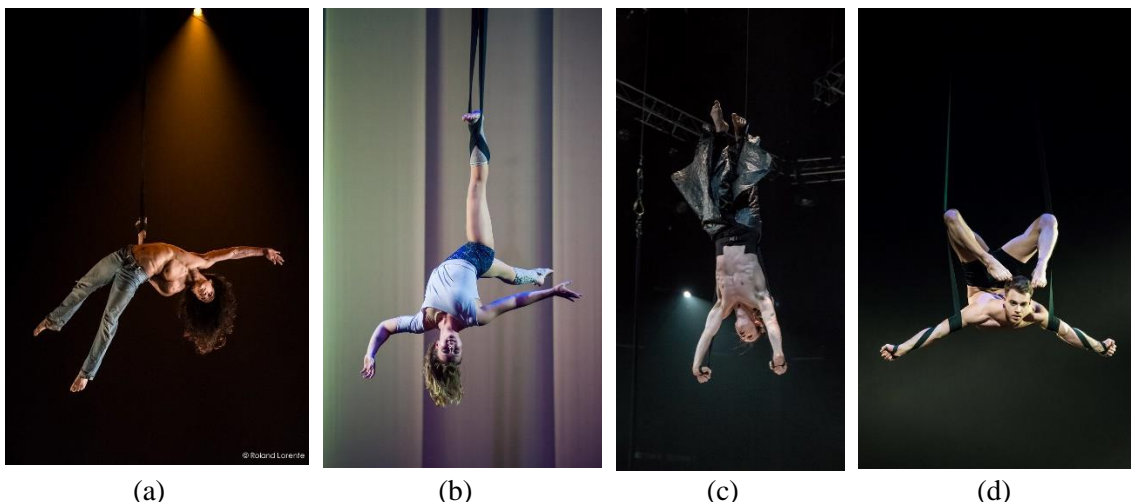


Figure 1: (a) hanging from one arm; (b) hanging from one foot; (c) handstand; (d) arm roll-down, École nationale de cirque Montréal (National Circus School) | Photos by Roland Lorente.

The aerial straps discipline requires athletic and esthetic skills, and it is very physically demanding. The acrobats endure heavy loads as they perform a wide variety of suspended moves. In a 2017 study on the discipline conducted in Montreal, researchers measured forces that were 8 times the body weight of the acrobats<sup>2</sup>. The physical demands are comparable to those of gymnastics, where the range of movement and the forces involved are associated with a risk of injury<sup>3</sup>. For example, for rings, forces of nine times the gymnasts' body weight have been measured<sup>4</sup>. The main risk with aerial straps is falling, as with all the aerial disciplines. However, there is very little scientific literature on the subject. Of all the studies on injuries in the circus world<sup>5</sup>, none focus specifically on aerial straps. The discipline is often lumped into a more general category such as acrobatics<sup>6</sup>, aeriels<sup>7</sup> or acrobatics using equipment<sup>8</sup>.

The FEDEC manual<sup>1</sup> explains the difference between several different types of gripping techniques:

- With stitched and adjustable textile rings: the rings are used to tighten the loop and the strap is held in the hand. The FEDEC manual recommends using adjustable rings ("coulisseau" in French) for work at height to "making grips safe [...] For work with stitched loops you use stitched and adjustable textile rings that you can tighten around your wrists. You can also create a slip knot by passing the strap through the loop (very secure but less comfortable)."

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Figure 2: The adjustable ring (image from <http://www.fedec.eu/file/252/download>)

- A secure hand lock is used for straps without stitched loops and to ensure hand grips are safe for work at height. It consists of tying a knot that will stretch with the load. (Note: This technique can also be used with straps with loops);



Figure 3: A secure hand lock (image from <http://www.fedec.eu/file/252/download>)

- Another secure hand lock for straps without loops: the strap is held in place in the acrobat's hand by the tension in the strap and by the grip. This position is not considered safe and cannot be used for dangling or dropping. (Note: This technique can also be used with straps with loops);

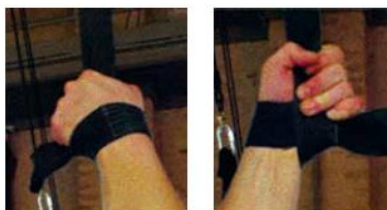


Figure 4: Another hand lock (image from <http://www.fedec.eu/file/252/download>)

Another gripping technique that is not in the FEDEC manual, but that is also popular is the choke loop. There are two ways to set it up: make a cow hitch knot with a strap with a loop or use straps that have an integrated choke loop.

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Figure 5: Strap with an integrated choke loop (stitched) and strap with loop and choke loop.

### Background

In the course of their usual practice, aerial strap performers will never purposely lose their grip on the strap. In normal circumstances, they always try to keep a firm grip on the strap. The risk of falling depends on how well they are holding the strap and what gripping technique they are using. However, there is no data on the effectiveness of the gripping techniques commonly used when the hand is not holding the strap.

### Objectives

The purpose of this report was to assess three criteria for strap gripping techniques. To do so, nine gripping techniques, which are described in the methodology section, were selected or created for this project. The techniques were then compared based on these three criteria. The project aimed to answer the following questions:

1. What is the "effectiveness," in terms of safety, when the gripping technique is in place and the hand is not holding the strap?
2. Is the gripping technique comfortable?
3. Does it take a long time to put the gripping technique in place?

A test protocol was implemented to measure the participants' ability to free their hand when on the ground and not holding on to the strap for the nine gripping techniques selected. Comfort and setup time were also measured for each gripping technique.

## 3) Work methodology

### Test protocol

The study participants were ten aerial strap acrobats who were either professionals or National Circus School students. The test had three parts and it was carried out for each of the nine gripping techniques.

1. Setup period: The acrobats were asked to set up the gripping technique when the signal was given. The setup time was measured.

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2. Time to free the hand: A strap with the selected gripping technique was placed on participants' wrists. The participants remained on the floor. They were asked to free their hands within a certain amount of time (30 seconds). A load cell measured the tension force in the strap throughout the test (Figure 6). The time to free the hand and the maximum tension force when the hand was freed were measured.

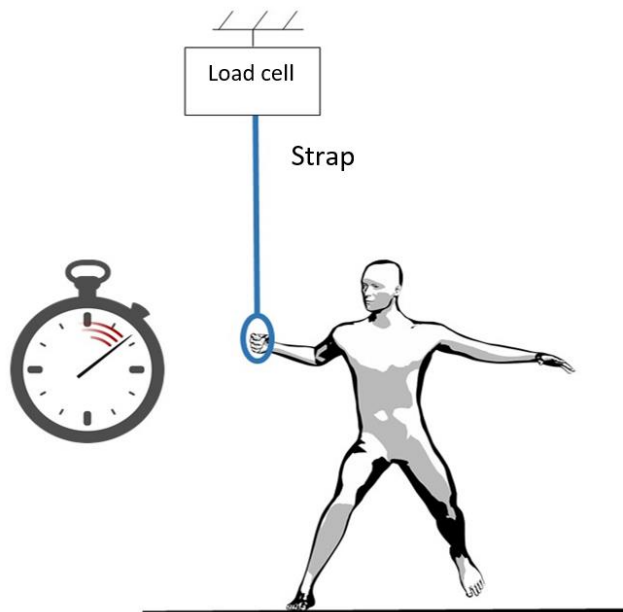


Figure 6: Illustration of the hand-freeing test

3. Notes about comfort and comments: Participants were asked to rate how comfortable the gripping techniques were on a scale from 1 to 5 (with 1 being very uncomfortable and 5 being very comfortable). They were then asked for their comments about the gripping techniques. Were they familiar with it? Did they use it? If yes, why? And if no, would they use it? What were the pros and cons for each type of grip?

The three criteria were evaluated as follows: the safety criterion was measured based on how long it took for participants to free their hands, the comfort criterion was measured based on the score given by participants, and the setup criterion was measured based on the time it took to set the gripping technique up.

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### The nine grips tested

- 1) The choke loop: With this technique, the more tension the acrobats put on the strap, the tighter the knot gets around the wrist.

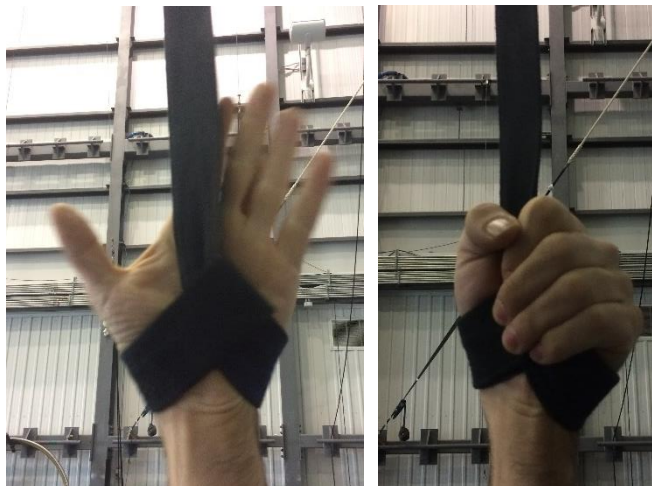


Figure 7: Choke loop with the hand open and the hand closed

- 2) First hand lock: You make a half hitch knot, meaning you wrap the strap around your wrist.



Figure 8: First hand lock position



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- 3) Second hand lock: You wrap the strap around your wrist then wrap it around itself. This technique is a round turn and a half hitch.

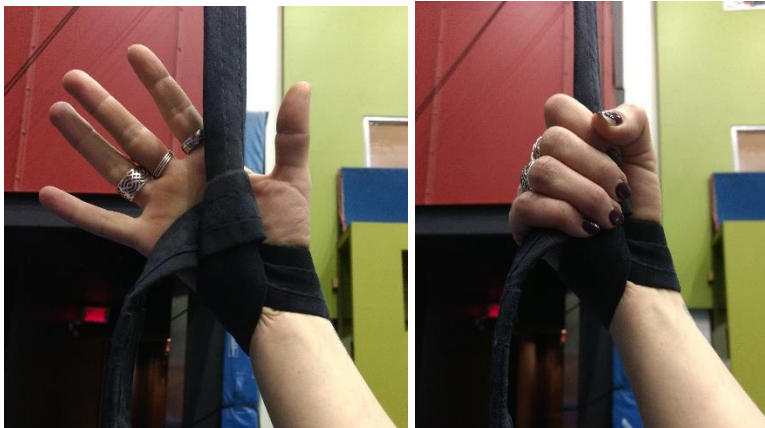


Figure 9: Second hand lock position with the hand open and the hand closed

- 4) Third hand lock: You wrap the strap around your wrist then tuck the end back into the loop that you created around your wrist. This type of knot is called a four-in-hand.



Figure 10: Position of the third hand lock with the hand open.

- 5) Adjustable ring: We asked the *Cirque du Soleil* Costume-making Workshop to make the smallest and narrowest adjustable ring possible.

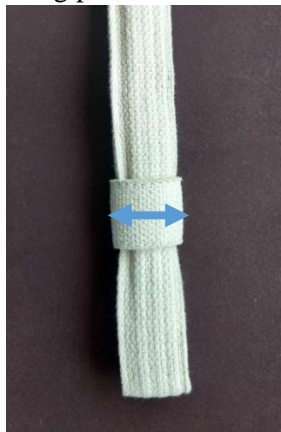


Figure 11: Adjustable ring, showing the width



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- 6) Sleeve: The sleeve is like the adjustable ring but longer. To make it, the Costume-making Workshop stitched four adjustable rings together.

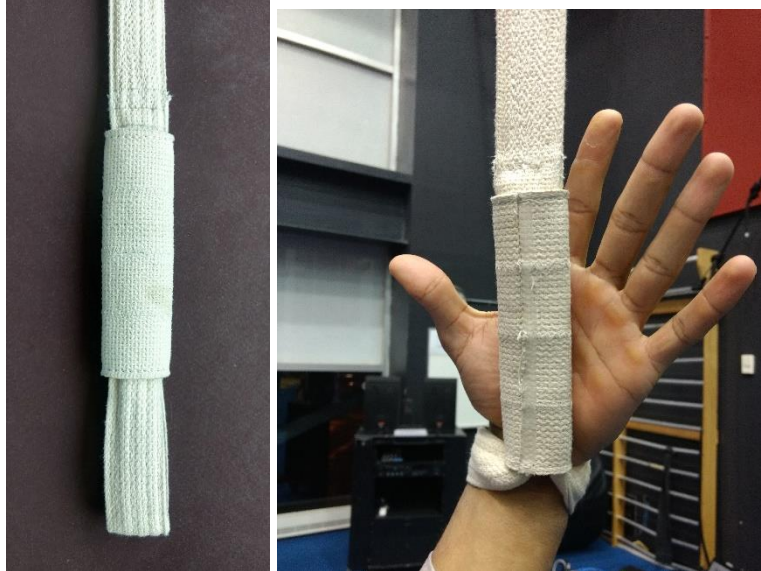


Figure 12: Sleeve and position of the sleeve with the hand open

- 7) Stitched choke loop: The choke loop is stitched in place so it does not tighten around the wrist. This is a new design whose prototype is shown in Figure 13.



Figure 13: Stitched choke loop and position of the stitched choke loop with the hand open

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- 8) Strapped choke loop: A strap blocks the choke loop, preventing it from tightening around the wrist. This is a new design whose prototype is shown in Figure 14.



Figure 14: Strapped choke loop and position of the strapped choke loop with the hand open

- 9) Adjustable ring with Velcro: This is a standard adjustable ring with Velcro inside the loop. This is a new design whose prototype is shown in Figure 15.



Figure 15: Adjustable ring with Velcro and position of the adjustable ring with Velcro with the hand open

### Decision matrix

A decision matrix was used to categorize the nine gripping techniques based on three criteria: safety, comfort and setup time. A decision matrix is a common decision-making tool. It allows us to rank the solutions and determine which is the best alternative, based on several criteria<sup>9</sup>. The criteria were assigned weights as follows: safety – 5; comfort – 2; and setup time – 1. These weights were discussed and chosen by a team of experts. It was determined that safety was 5 times more important than the setup time and 2.5 times more important than comfort. Each criterion received a score from 1 to 5 based on the procedure in Table 1.

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Table 1: Equivalent 1-5 scores for the three criteria

Safety: time to free the hand	Comfort	Setup time	Equivalent score
Impossible	5	0-1.6 s	5
22.5-30 s	4	1.6-3.2 s	4
15-22.5 s	3	3.2-4.8 s	3
7.5-15 s	2	4.8-6.4 s	2
0-7.5 s	1	6.4-8 s	1

## 4) Results

### General Comments

The tension force was measured for only nine of the ten participants due to a technical issue. Consequently, the tension force average found in the results is the average for nine participants. The stitched choke loop and strapped choke loop techniques are not one size fits all. Only one size of each of those gripping techniques was made; the stitched choke loop was too big for five people and the strapped choke loop was too big for seven people. Only the results of the participants whose wrists were the right size for those gripping techniques were included in the safety criteria section.

### Safety criteria

Table 2 ranks the gripping techniques by the average time it took the participants to free their hands ( $\infty$ : the participants were unable to free their hands within the allocated time range; 0: it took an average of 0 seconds for the participants to free their hands). The techniques that did not allow participants to free their hands appear at the top of the table. It also shows the average maximum force generated.

Table 2: Time to free the hand

Ranking	Gripping technique	Time to free the hand (in s)	Maximum force generated (in lbf)
1	Choke loop	$\infty$	130
1	Stitched choke loop	$\infty$	141
1	Strapped choke loop	$\infty$	146
2	Third hand lock	28	144
3	Sleeve	14	120
4	Adjustable ring with Velcro	9	114
5	Adjustable ring	8	108
6	Second hand lock	2	34
7	Third hand lock	0	50

Participants whose wrists were the right size for the strapped and stitched choke loops were unable to free their hands when using any of three types of choke loops. Participants whose wrists were too small for the blocked choke loops were all able to free their hands (average of 7 s for the stitched choke loop and of 5 s for the strapped choke loop). For the third hand lock, only one out of ten

Comparative analysis of nine gripping configurations for aerial straps participants was able to free their hand. For all other techniques, all participants were able to free their hands within the allocated time.

The average force generated varied between 34 lbf and 146 lbf, which almost, but not quite, represents the average body weight of the participants. Being on the floor, it was difficult for the participants to generate high forces or forces that were as high as they would be if they were doing dynamic moves in the air. The forces when the hands were freed varied from 5 to 166 lbf.

### Comfort;

Table 3 ranks the gripping techniques based on the average comfort scores from the participants. The grips were ranked from 1 to 5 (1: very uncomfortable; 5: very comfortable).

Table 3: Comfort (1: very uncomfortable, 5: very comfortable)

Ranking	Gripping technique	Score
1	Choke loop	4.02
1	Strapped choke loop	4.02
2	Adjustable ring	4.01
3	Stitched choke loop	3.58
4	Sleeve	3.61
5	Third hand lock	3.48
6	Adjustable ring with Velcro	3.18
7	Second hand lock	2.98
8	Third hand lock	2.75

The average comfort scores varied from 2.75 to 4.02 out of 5, which means that most participants found the grips fairly comfortable. The most comfortable were the choke loop, the strapped choke loop and the adjustable ring.

### Setup time

Table 4 ranks the gripping techniques based on the 10 participants' average setup time.

Table 4: Setup time

Ranking	Gripping technique	Setup time (s)
1	Adjustable ring	1.5
2	First hand lock	1.6
3	Sleeve	2.1
3	Strapped choke loop	2.1
3	Adjustable ring with Velcro	2.1
4	Choke loop	2.2
5	Stitched choke loop	2.5
6	Second hand lock	4.5
7	Third hand lock	8

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It took 2.5 seconds or less to setup for seven of the techniques. It took longer for the second and third hand locks, with 4 and 8 seconds respectively.

### Final ranking

Table 5 presents the decision matrix results with the three criteria—safety, comfort and setup time. Each criterion received a score from 1 to 5 based on the results from the preceding sections. They were weighted as follows: 5 for safety, 2 for comfort and 1 for setup time. The final score was calculated by adding each weighted score. The gripping technique that received the highest final score is considered to be the best option.

Table 5: Results of the decision matrix

Gripping technique	Safety	Comfort	Setup time	Score	Final ranking
	(5)	(2)	(1)		
Choke loop	5	4	4	37	<b>1</b>
First hand lock	1	3	5	16	<b>6</b>
Second hand lock	1	3	3	14	<b>7</b>
Third hand lock	4	3	1	27	<b>2</b>
Adjustable ring	2	4	5	23	<b>3</b>
Sleeve	2	4	4	22	<b>4</b>
Stitched choke loop	5	4	4	37	<b>1</b>
Strapped choke loop	5	4	4	37	<b>1</b>
Adjustable ring with Velcro	2	3	4	20	<b>5</b>

The three choke loop techniques obtained the highest score and are, consequently, considered to be the best solutions based on these three criteria. These gripping techniques are the choke loop, the stitched choke loop and the strapped choke loop.

### Participant comments

Most participants were very excited to see research being done on aerial straps. The pros and cons of each gripping technique are presented in Table 6.



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Table 6: Pros and cons according to the participants

Gripping technique	Pros	Cons
Choke loop	<ul style="list-style-type: none"> <li>• Safe</li> <li>• Comfortable</li> </ul>	<ul style="list-style-type: none"> <li>• There's a lot of pressure on the wrist, it's really tight</li> <li>• A strap for the left hand and the right hand, it takes some time to figure out which is which</li> </ul>
First hand lock	<ul style="list-style-type: none"> <li>• Easy to wrap and unwrap</li> <li>• Good for moves close to the ground</li> <li>• Good when you're not high up</li> </ul>	<ul style="list-style-type: none"> <li>• Not safe</li> <li>• Requires a lot of strength to close the hand</li> </ul>
Second hand lock	<ul style="list-style-type: none"> <li>• Good for moves close to the ground</li> <li>• Good when you're not high up</li> </ul>	<ul style="list-style-type: none"> <li>• Not safe</li> <li>• It's bulky in the hand</li> <li>• Takes a long time to set up</li> </ul>
Third hand lock	<ul style="list-style-type: none"> <li>• Good when you're not high up</li> <li>• The wrapping is artistic</li> </ul>	<ul style="list-style-type: none"> <li>• Takes a long time to set up</li> <li>• The more you pull, the tighter it gets</li> </ul>
Adjustable ring	<ul style="list-style-type: none"> <li>• Comfortable</li> <li>• Practical</li> </ul>	<ul style="list-style-type: none"> <li>• Not safe (the ring slides back up)</li> </ul>
Sleeve	<ul style="list-style-type: none"> <li>• Comfortable</li> <li>• Safe</li> </ul>	<ul style="list-style-type: none"> <li>• Too stiff to do rolling moves</li> </ul>
Stitched choke loop	<ul style="list-style-type: none"> <li>• Safe</li> <li>• Doesn't tighten like the choke loop</li> <li>• Comfortable</li> </ul>	<ul style="list-style-type: none"> <li>• Be careful about the size of the loop, it needs to be adjusted</li> <li>• The stitching is annoying</li> <li>• A strap for the left hand and the right hand, it takes some time to figure out which is which</li> </ul>
Strapped choke loop	<ul style="list-style-type: none"> <li>• Safe</li> <li>• Doesn't tighten like the choke loop</li> <li>• Comfortable</li> </ul>	<ul style="list-style-type: none"> <li>• Be careful about the size of the loop, it needs to be adjusted</li> <li>• A strap for the left hand and the right hand, it takes some time to figure out which is which</li> </ul>

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		<ul style="list-style-type: none"> <li>Concerns about the strap's life span</li> </ul>
Adjustable ring with Velcro	<ul style="list-style-type: none"> <li>Barely any difference with or without Velcro</li> </ul>	<ul style="list-style-type: none"> <li>The Velcro is irritating</li> <li>Too stiff</li> <li>Concerns about the Velcro's life span</li> </ul>

## 5) Discussion and interpretation of the results

In this study, we tested and compared three criteria for nine types of aerial strap gripping techniques. The three criteria were safety, comfort and setup time.

### Safety

The safety criterion was assessed based on how long it took for participants to free their hands while on the ground. The challenge, however, is to know if it would take the same amount of time if they were in the air. The forces generated while on the ground, for example, were the same as the participants' body weight, while forces measured when they perform dynamic strap moves in the air can be up to eight times their bodyweight<sup>2</sup>. In normal circumstances, acrobats keep a firm grip on the straps. But if they lose hold of the strap while in the air, the gripping technique is the only thing keeping them up there, and we could not confirm, with this test, what would actually happen in such a case. We can note that certain configurations make it easier or faster to get the hand free, like with the force from an impact (rather than a continuous force, like when dangling from the strap) and with the base of the thumb aligned with the loop (Figure 15).



Figure 15: Left: the thumb is perpendicular to the loop. Right: the thumb is aligned with the loop.

Participants were unable to free their hands when using the three choke loop techniques. Nine out of ten participants were unable to free their hands when using the third hand lock. Thus, based on this test, these are the three safest techniques. However, the choke loop technique was uncomfortable for some people; four out of ten participants said it put too much pressure on the wrist. The long-term consequences of such pressure on the wrist is unknown. The stitched choke loop and the strapped choke loop could be a good compromise. However, these must be tailored to the size of the wrist. If the loop is too big for the wrist, the acrobat's hand can slip out easily, as evidenced by the tests. They will have to be adjusted very carefully, as shown in Figures 16 and



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17. In addition, since they are both prototypes, the techniques have not been used in training or in shows; consequently, we do not know how long they will last or how well they will work. Further testing is required.

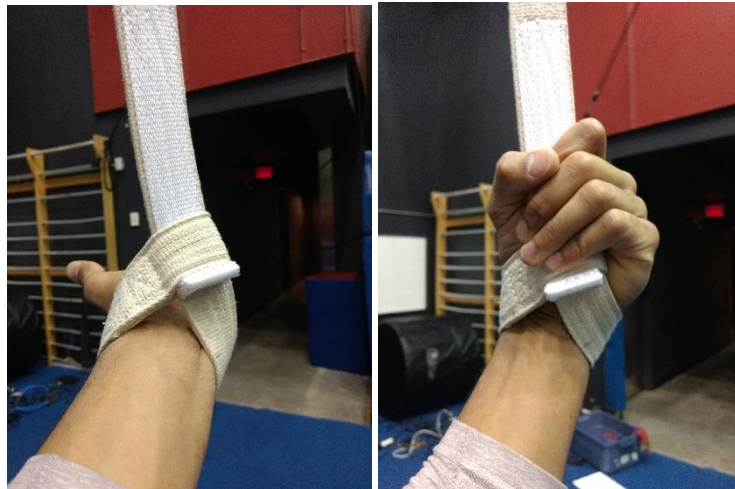


Figure 16: Proper adjustment of the stitched choke loop: very little room between the wrist and the strap (left) and thumb is well above the sliding loop (right).



Figure 17: Improper adjustment of the stitched choke loop: too much room between the wrist and the strap (left) and thumb is below the sliding loop (right).

#### Comfort and setup time

The comfort and setup time criteria were skewed because the participants were already familiar with some of the gripping techniques and were used to them. The most commonly used were the choke loop and the adjustable ring. Conversely, most of the participants had never used the second and third hand lock techniques, and it took longer to set those up. With practice, the acrobats would undoubtedly get quicker at setting up some of these techniques. Lastly, seven of the nine configurations that were tested were fairly quick to set up, under 2.5 seconds on average. The setup time criterion may not be a decisive factor in ranking the nine configurations. It was a similar scenario for comfort. Some participants clearly expressed the fact that they were used to their usual gripping technique and that the other techniques did not feel right. That is why the choke loop and

Comparative analysis of nine gripping configurations for aerial straps adjustable ring techniques were ranked highest, in first and third position respectively. Lastly, the study involved ten circus acrobats, which is a respectable number for a study on aerial straps, but it is not representative of the entire aerial straps discipline throughout the world. Most of the participants have studied at the National Circus School, which narrows the scope of judgment.

### The decision matrix

The advantage of the decision matrix is that it allows us to quantify, in an objective and systematic manner, the different gripping techniques based on several criteria. For this tool to work, however, it is crucial to choose the right criteria and give them the appropriate weight. In this study, only three criteria were selected—safety, comfort and setup time—but other criteria could have been added, like cost, look or life span. Weights were assigned to the criteria by a team of experts that determined that safety was 5 times more important than setup time and 2.5 times more important than comfort. The weighting gives much greater importance to safety and this shows in the results; the techniques where the participants were unable to free their hands were ranked as the best solutions. But these weights could be different for other acrobats or another circus company, based on their preferences. As such, this tool is not meant to replace professional judgment, but to enhance general knowledge. Nothing is dictated by the results of this tool.

### Limitations

As mentioned earlier, the limitations are as follows:

- It was impossible to measure the actual safety of the gripping techniques when acrobats are in the air, so it was difficult to tell if the results of the tests conducted on the ground would be the same in the air;
- The results were skewed based on what the participants were used to;
- There was not enough representation of the different ways aerial straps are used throughout the world;
- There was a limited number of criteria used;
- The weighting may differ depending on the acrobats' priorities;
- There was not enough usage data about the two new prototypes (stitched choke loop and strapped choke loop);
- The long-term consequences of the choke loop on the wrist are unknown.

These limitations are food for thought and could be the basis of further research.

### Recommendations

Another aspect that was not taken into consideration in this study, but that is very relevant when choosing a gripping technique is the acrobat's performance style. Indeed, participants brought this up several times, as they explained how they use the straps and which gripping techniques work best for them. There are many different ways of using the straps: one-arm techniques, dynamic movements, floor work, working in pairs, etc.

In addition, for advanced acrobatics, the equipment is adapted or tailored to the acrobats' needs. With this study, we compared nine techniques based on the averages of the tests done by ten acrobats. Yet it is important for acrobats to try different strap configurations and be aware the pros and cons of each so that they can choose the one that best satisfies their criteria. Safety is, of course,

Comparative analysis of nine gripping configurations for aerial straps a crucial criterion when choosing a gripping technique, which is why it is difficult to recommend techniques that did not pass the hand-freeing test—all techniques except for the three choke loop techniques and the third hand lock—unless they are used in specific circumstances like floor work.

Lastly, one of the participants mentioned that there was a lack of awareness regarding the issue of gripping techniques, both in circus companies and circus schools. We hope that this study, which supplements the FEDEC's approach, provides more information to aerial strap performers and leads to more discussion on the subject. Any additional research or data on the aerial straps discipline would be immensely helpful in allowing this discipline to evolve.

## 6) Acknowledgement

This project was supported by the Centre for Circus Arts Research, Innovation and Knowledge Transfer (CRITAC) and *Cirque du Soleil*.

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