

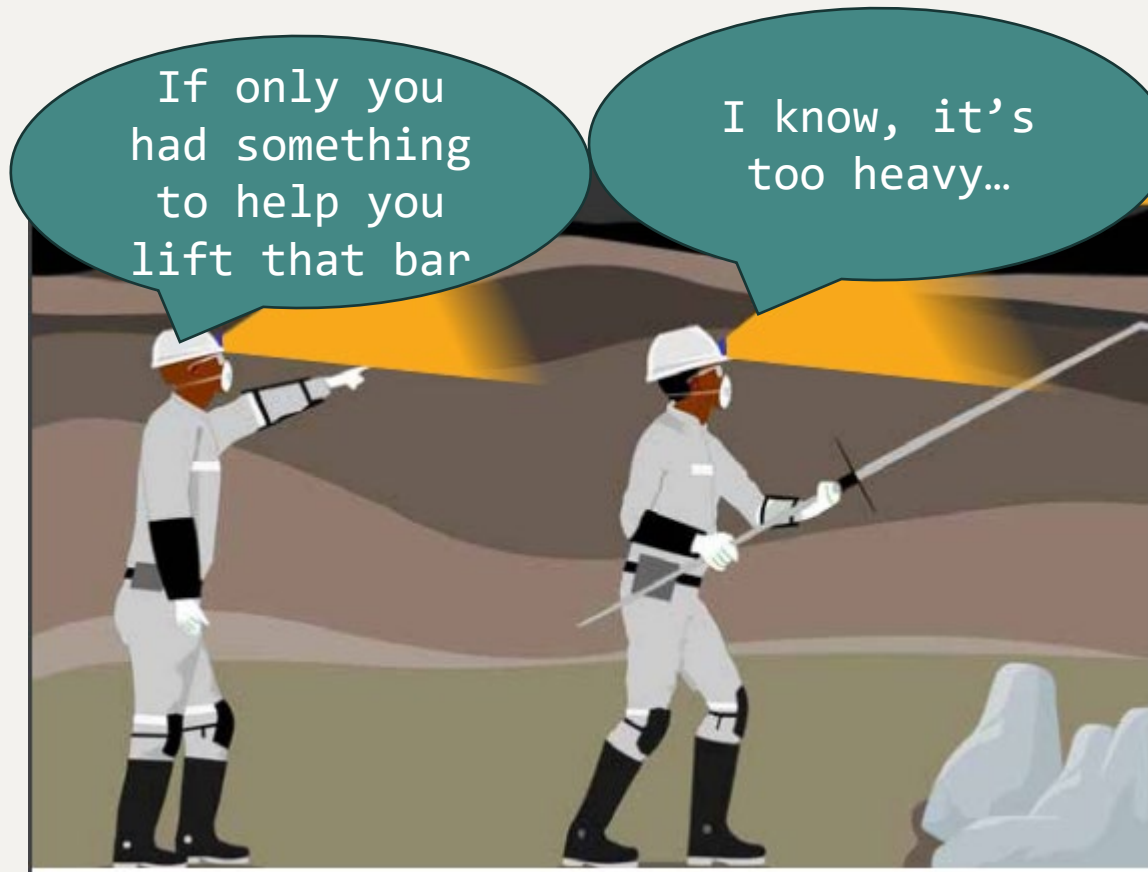
The use of exoskeletons in mining



Taygan Nadar
Sport Scientist



Problem: Barring underground is difficult...



Solution

- What if we use an exoskeleton...



What is an exoskeleton?



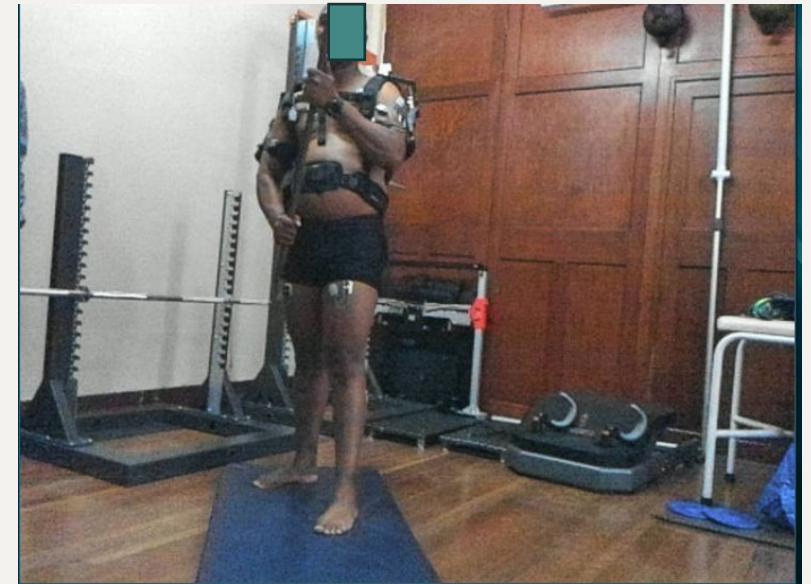
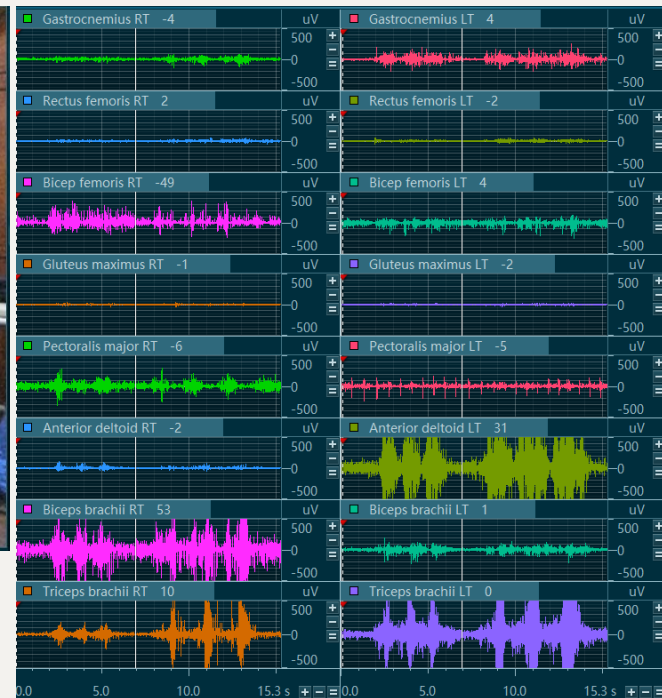
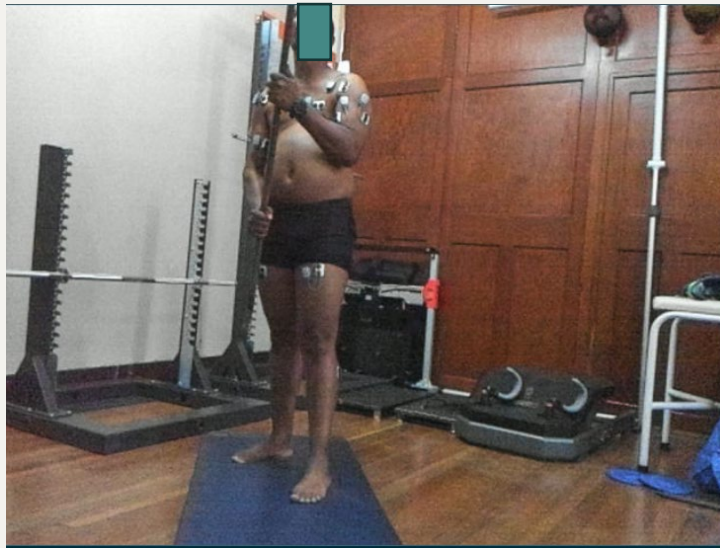
- External “skeleton” device worn on the outside of the body.
- Aims to assist with joint movements of the body.
- Provides strength and stability to the moving joints.



Would an exoskeleton make the work easier? Let's find out.

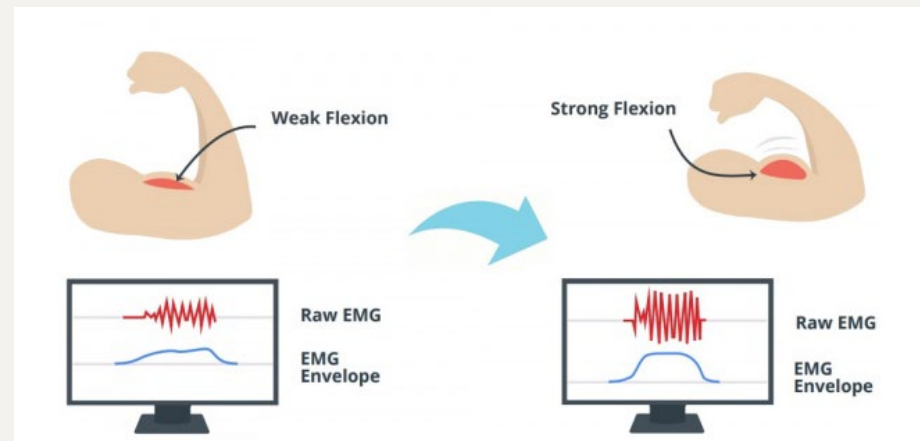


An EMG study was conducted to determine the effects of using an exoskeleton while barring



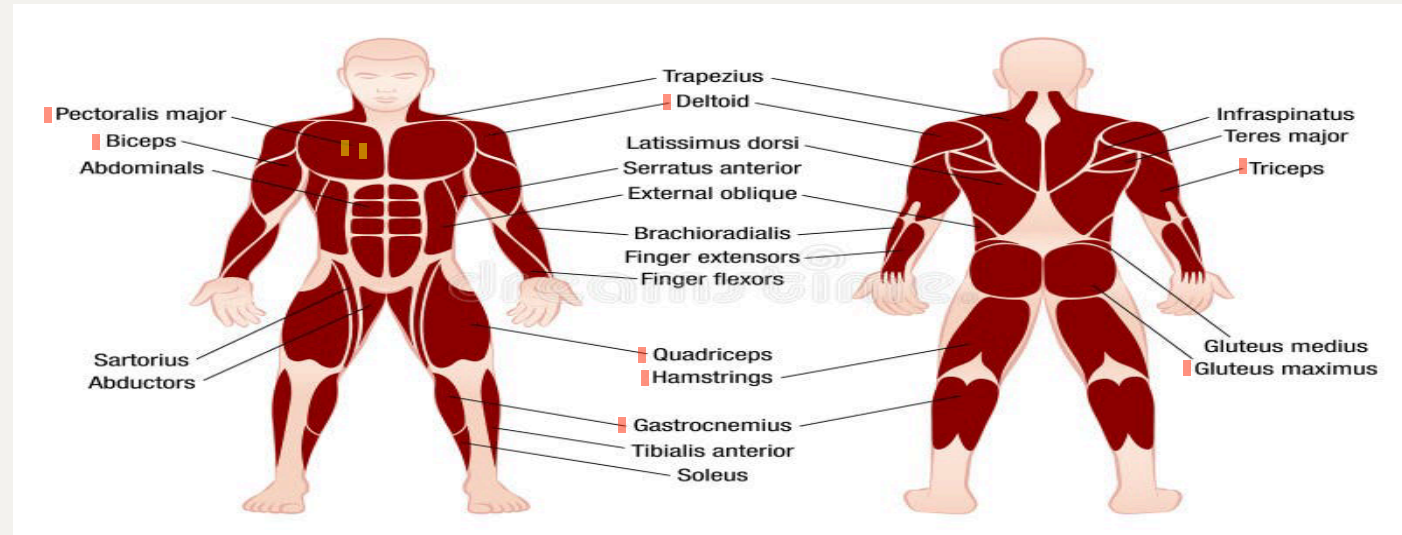
EMG (Electromyography)

- Measures the electrical activity produced by skeletal muscles.
- The harder the muscle must work = more electrical activity.



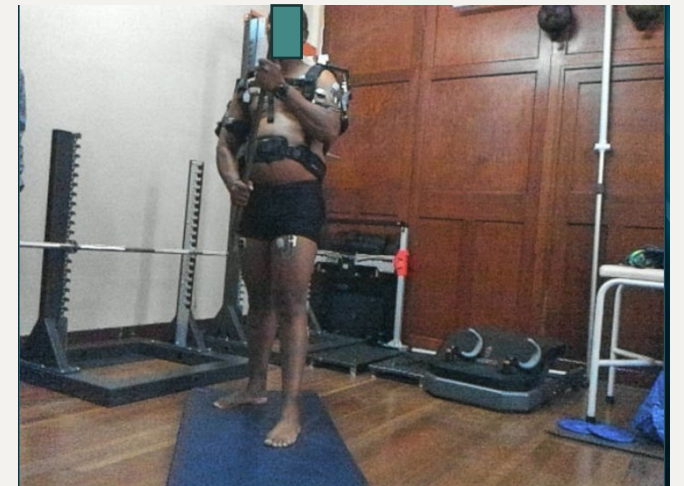
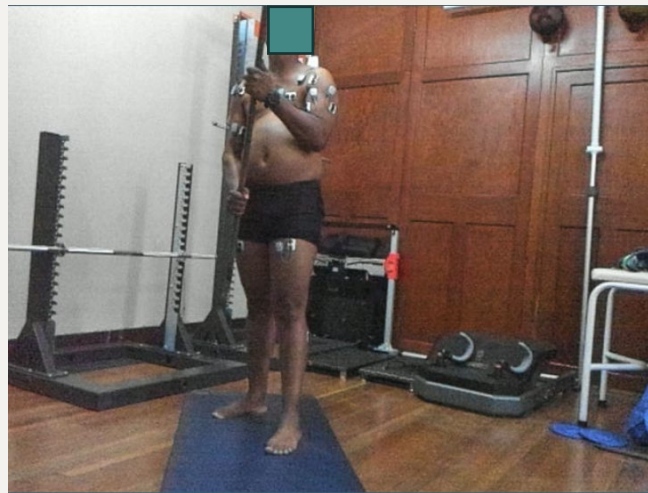
Hypothesis of exoskeleton testing for barring in the mine

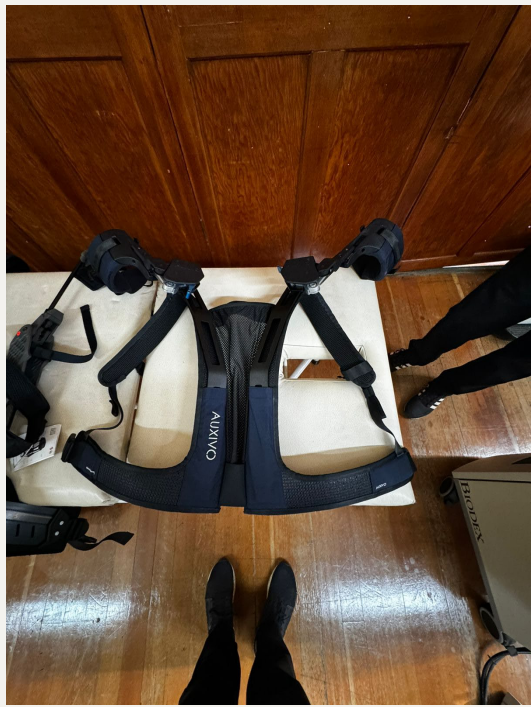
- The exoskeleton will provide support and stability to the joints while having to lift the heavy pinch bar.
- It is expected that the muscles will require less effort, resulting in lower electrical activity detected by the EMG.
- 8 different muscles were tested (triceps brachii, biceps brachii, pectoralis major, anterior deltoid, biceps femoris, rectus femoris, gluteus maximus, gastrocnemius)



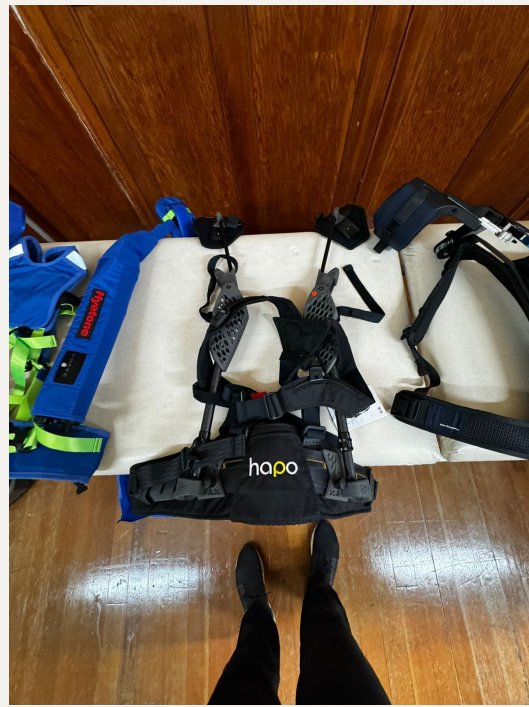
Testing protocol

- 6 miners were tested
- Each miner was required to perform 2 standing and 2 kneeling tests (barring with a 6kg long bar and a 3.7kg short bar).
- Each test was repeated 4 times. Once without wearing an exoskeleton, followed by another 3 times for 3 different exoskeletons.

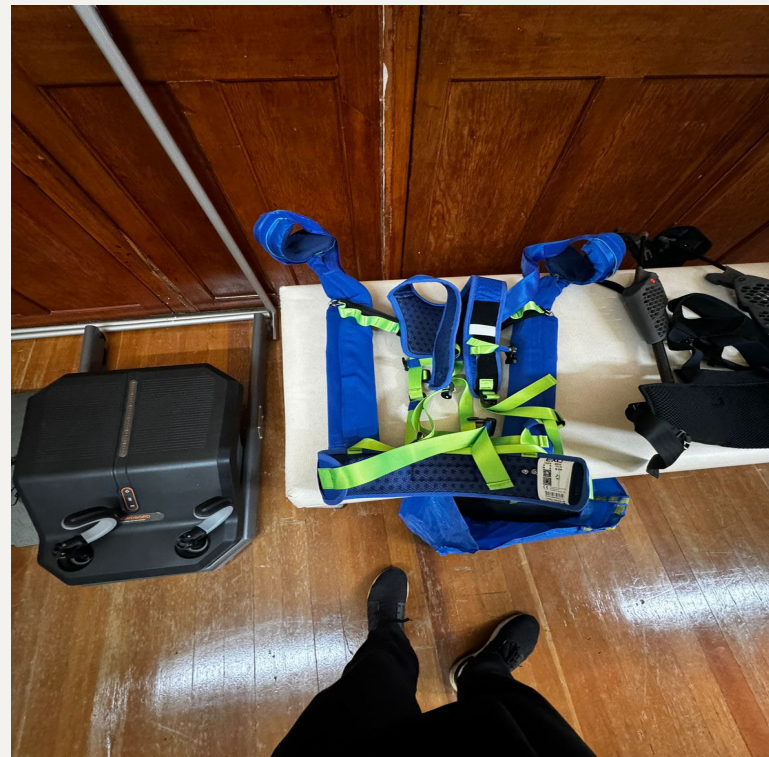




Exoskeleton 1



Exoskeleton 2



Exoskeleton 3



Pinch bars



Results

- Each test subject's muscle activation was tested while barring without the use of an exoskeleton. This measurement acted as a baseline for measuring the 3 different exoskeletons against it.
- Scoring system: a point was allocated to an exoskeleton each time the tested EMG value was below the baseline result. As mentioned earlier, lower EMG values indicates a lower amount of muscle activation, meaning that the exoskeleton is reducing the amount of activation required by the working muscle.



Example of EMG recordings

- In this specific case, exoskeleton 1 was the winner.
- Lowest amount of electrical activity recorded
- Most number of muscles detected that had a lower EMG value in comparison to the baseline values (test with no exoskeleton)

Muscle groups	Mean muscle activation (uV)			
	No exoskeleton	Exoskeleton no.1	Exoskeleton no.2	Exoskeleton no.3
Gastricnemius RT	1,323	1,835	4,67	2,22
Gastrocnemius LT	2,58	1,839	1 3,256	5,072
Rectus Femoris RT	8,87	9,654	15,717	11,933
Rectus Femoris LT	5,958	3,432	1 6,469	6,864
Bicep Femoris RT	4,889	7,294	12,033	6,903
Bicep Femoris LT	7,426	8,146	7,124 1	8,484
Gluteus Maximus RT	10,152	11,569	18,079	14,024
Gluteus Maximus LT	3,566	3,049	1 12,075	54,159
Pectoralis Major RT	35,313	28,17	1 50,265	43,059
Pectoralis Major LT	14,234	10,521	1 15,051	16,02
Anterior Deltoid RT	94,324	61,65	1 57,913 1	61,6 1
Anterior Deltoid LT	145,183	108,186	1 99,726 1	85,024 1
Biceps Brachii RT	76,832	82,43	108,413	87,623
Biceps Brachii LT	90,402	59,875	1 82,119 1	79,185 1
Triceps Brachii RT	66,354	77,082	65,062 1	68,414
Triceps Brachii LT	32,251	36,345	65,114	49,662
Total	599,657	511,077 8	623,086 5	600,246 3



Results
continued
(summary)



Subject 1	Exo 1	Exo 2	Exo 3
Test 1	8	4	4
Test 2	10	1	4
Test 3	8	5	3
Test 4	13	9	8
Points	39	19	19
Subject 2	Exo 1	Exo 2	Exo 3
Test 1	8	8	8
Test 2	7	5	5
Test 3	10	10	8
Test 4	11	10	6
Points	36	33	27
Subject 3	Exo 1	Exo 2	Exo 3
Test 1	11	6	10
Test 2	10	8	10
Test 3	7	7	6
Test 4	12	10	7
Points	40	31	33
Subject 4	Exo 1	Exo 2	Exo 3
Test 1	15	14	13
Test 2	15	13	13
Test 3	14	14	13
Test 4	12	13	13
Points	56	54	52
Subject 5	Exo 1	Exo 2	Exo 3
Test 1	1	10	3
Test 2	2	7	4
Test 3	1	6	0
Test 4	3	3	3
Points	7	26	10
Subject 6	Exo 1	Exo 2	Exo 3
Test 1	14	12	15
Test 2	11	5	12
Test 3	14	16	12
Test 4	9	11	6
Points	48	44	45

Total points for each exoskeleton

Exo 1	Exo 2	Exo 3
226	207	186
(58.6%)	(53.9%)	(48.4%)

Key:

- Test 1: Standing and barring with a long bar
- Test 2: Standing and kneeling with a short bar
- Test 3: Kneeling and barring with a long bar
- Test 4: Kneeling and barring with a short bar

Exo: Exoskeleton

Points: Points allocated to an exoskeleton each time the tested EMG value was below the baseline result

Results continued (discussion)

- Rankings: 226 points- Exoskeleton 1
207 points- Exoskeleton 2
186 points- Exoskeleton 3
- Exoskeleton 1 ranked to be the most effective. It showed to reduce muscle activation **58.6%** of the time. Exoskeleton 2 showed to reduce muscle activation **53.9%** of the time and lastly exoskeleton 3 showed to reduce muscle activation **48.4%** of the time.
- Even though exoskeleton 3 was ranked last, the device can still be considered effective as it reduced muscle activation **48.4%** of the time.



Additional tests

- **Isokinetic:** Muscle strength is assessed by providing resistance by an isokinetic dynamometer throughout the range of motion at a constant velocity.
- **Static hold (endurance):** Recording the maximum amount of time that the test subject can hold up a heavy object.



Isokinetic results

Measuring the force produced by the shoulder without and with using an exoskeleton

Results:

Average torque produced without the use of exoskeleton **82** Newton metres

Average torque produced with the use of exoskeleton **98** Newton metres



Static hold test (bicep strength)

Endurance shoulder test
by measuring how long the
test subject can hold a
heavy object in the
'barring' position.

Results:

Without the use of
exoskeleton **41 seconds**

With the use of
exoskeleton **1 minute, 13
seconds**

Final comments and areas for improvement of the exoskeletons

- Pros

Increases force output

Increases strength endurance

Provides more joint stability

- Cons

Can be uncomfortable (depending on the individual)

Not custom fit (does not fit all body types/physiques)

