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Research Article

Ergonomic Risk Analysis for Drone Pilots

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ABSTRACT

The use of drones has increased due to various circumstances in recent years: the uses and applications they offer, the ease of piloting them and their increasing accessibility are perhaps the most important reasons. New applications are emerging, increasing professional interest in these small aircraft. The operator who pilots the drone never boards it and, therefore, the pilot does not suffer the consequences of its movements. However, there is an interaction with a specific interface that, together with the need to always control the aircraft, directly affects the operator's posture. This article stems from this postural analysis, to determine the conditions that this new job should provide to avoid musculoskeletal disorders. Starting from the identification of dangerous postures in real flights, the article applies the RULA methodology to determine the need for action and the possible corrections to be adopted. Thus, it must be verified that there are awkward postures that pilots (workers of a flight operator company for this study) should avoid, and that above all preventionists should study to avoid injuries during certain drone operations.

Keywords: Drone, ergonomics, awkward postures, RULA method, musculoskeletal disorder, UAS, RPAS.

INTRODUCTION

An Unmanned Aerial System (UAS) or Remotely Piloted Aircraft System (RPAS), commonly known as drones, is a set of one or more unmanned aircraft and the equipment that controls them remotely, as can observed in Fig. **1**. This definition includes all unmanned aerial vehicles, whether autonomous (without human intervention during the flight) or remotely controlled.

The technology is more than a century old, although it was mostly limited to military uses for most of this time [1]; initially limited capacities and high economic costs delayed its application to the civil sphere. In recent years, the development of technology and telecommunications have lowered the cost of the equipment and made it easier to use, leading to increasing interest and adoption for more diverse uses. Thus, new applications are emerging for all kinds of industries, including companies that had never previously considered incorporating this type of tool into their usual operations or services [2].

As an example, the author of this article (pilot, instructor, and flight examiner) has used these devices to carry out inspections in civil works structures [3, 4] (Fig. **1**). However, drones can be used in many other professional activities, such as mining [5, 6, 7], agriculture [8, 9, 10], the audiovisual industry [11, 12, 13], archaeology [14, 15, 16, 17], the environmental sector [5, 18, 19, 20], or emergency and rescue services [21, 22, 23, 24], to name just a few.

The growing presence of drones in various professional fields has increased social concern about the operability of these systems, whether they are operated directly or programmed [25]. Compared to traditional aviation, aircraft control remains static on the ground, either by a human pilot who manipulates the controls from ground control or by a programmed automated system that transmits orders from the centre of operations. This entails new environments with needs and tasks that require specific skills. Added to the technological complexity of handling these vehicles correctly and safely over long distances is the challenge of interaction with a specific interface and the dissociation of the perception of movement, beginning to be experienced in a completely new and unnatural way.

Fig 1 presents an image taken during the preparations for an inspection of a viaduct with a Parrot Anafi drone. In the photograph the complete equipment is displayed: the Anafi drone, the control unit, a smartphone and a display tablet, and binoculars for locating the drone in distant positions (photo by the author).

Fig. 1. Complete equipment of the unmanned aerial system

The growing presence of drones and the proliferation of applications for them have given them great prominence. However, this protagonism is not always positive: certain interventions, some failed, have revealed the complexity of the operating environment, which is the airspace [26, 27]. To guarantee safe flights, especially for the population outside the flight operation, a restrictive regulation has been developed that, together with safety protocols and standards for each type of operation and aircraft, guarantees safety in flight and airspace [28]. The simpler handling and lower costs of drones pose a great challenge, since they give access to airspace, already complex, to many people, with or without specific training, complicating traditional operations. This situation has led to the regulation of the handling of unmanned aircraft, establishing three types of flight operations, represented in Fig. **2**, depending on technical capabilities and limitations according to the environment and the permit [29, 30], establishing:

- Visual Line of Sight (VLOS). In this situation, the pilot always has the aircraft in sight.
- Extended Visual Line of Sight (EVLOS). In this situation, an observer supports the pilot in the visual control of the aircraft, extending the scope of the operation, and it is possible for the pilot to lose direct visual communication for short periods.
- Beyond Visual Line of Sight (BVLOS). In this situation, the pilot does not have visual control of the aircraft, all operations being carried out through a positioning and remote-control system, resorting to the use of data display screens.

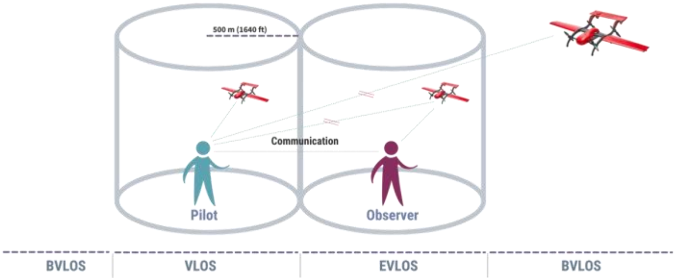


Fig. 2. Types of flight operations [31].

For this, certain requirements and specific training are required according to the desired and authorised operations [28].

As the legislation to regulate the massive new use of drones is increasingly restrictive and demanding, the simplest flights, and for which the fewest requirements are demanded, are those within the range of the pilot or VLOS. This form of flight determines the characteristics of the pilot's position since they must be outdoors, and the aircraft must be followed visually. The pilot needs to visually locate the aircraft most of the time, obliging them to adopt awkward postures in some situations.

With the versatility of these systems and the appearance of new applications, more and more companies are motivated to incorporate them into their production processes, thus creating new jobs, such as drone pilots. This is a very new profession with great prospects. Research about it is very scarce (even non-existent), especially in the field of pilots' health and safety. However, there is a need for research into the possible musculoskeletal disorders that it may cause. This is one of the most immediate injuries derived from the awkward positions pilots must adopt to keep the aircraft in view during the flight.

Ergonomics tries to adjust the characteristics of the task to the characteristics of the worker to prevent musculoskeletal damage or reduce it if it cannot be prevented [32, 33, 34, 35]. One of the risk factors most associated with the appearance of musculoskeletal disorders is excessive postural load [36]. Inappropriate postures while working lead to fatigue, and in the long run, this fatigue will lead to health problems [37, 38]. Thus, assessing the postural load or static load, and reducing it if necessary, is a fundamental measure for improving occupational health and safety [39].

When analysing a newly emerged profession, the bibliography on the subject is practically non-existent. Studies and research on the subject focus on the development of systems and the risks associated with their use [40, 41], which ignore the human element and the effect on the operator of the continued use of these aircraft. This justifies this research since it evaluates the posture adopted by a drone pilot during a flight operation and thus determine possible musculoskeletal disorders. It must be considered that the work is carried out standing up, moving the trunk and especially the head, constantly holding a light load.

As previously mentioned, there is no empirical evidence of previous research on this subject. The evidence of research on ergonomic problems refers to the use of smartphones [42, 43]; so, it is important to study ergonomic problems caused by the use of drones to find out about and prevent these possible injuries.

Thus, the main objective of this article is to determine the working conditions of drone pilots with the aim of reducing muscle strain in flight operations within the visual range, reducing postural loads and minimising possible musculoskeletal disorders. To do this, the process will include:

- Identify unsuitable or awkward postures during the work cycle and identify their causes.
- Analyse the influence of the environment, tools, and flight data, combined with the pilot's posture, to evaluate their influence on the postures adopted.
- Propose measures to correct posture based on the data obtained.
- Optimize flight operations to integrate the indicated postural corrections.

The author's interest in improving body position to reduce fatigue and pain experienced in these operations arose from personal experience in piloting drones within visual range, which prompted this research. Initially, it started with a simple search for information about the ideal conditions of a remote piloting post.

The concept of risk here is not limited to occupational risk prevention. Risk is not just the possibility that a worker will suffer harm; it is also the possibility that a flying object will cause damage due to its use [44]. Thus, some studies discuss the types of remotely controlled aircraft that exist, depending on multiple parameters such as shape, size, propellers, etc., proposing possible classifications of these [45, 46], thus helping to draft future regulations.

Among the possible ways to assess posture, one can distinguish between information records, observational methods, and biomechanical methods [47, 48]. The essential characteristics of the three are shown in Table 1:

Table 1. Comparative analysis between the different postural assessment methodologies.

	Information	**Observation methods**	**Biomechanical methods**
Precision	Very low	Optimal	High
Type of results	Subjective results	Objective results	Objective results
Tools	Surveys Interviews Questionnaires ……	Recordings	Accelerometers Inclinometers Goniometers ……
Sample size	Very large sample	Limited sample	Very limited sample
Cost	Very low cost	Low cost	Very high cost

Note: Own elaboration.

According to Table 1, the most desirable approach would have been an analysis by biomechanical methods. However, given the limited resources available, a biomechanical analysis was not possible. Therefore, to obtain objective data, an observational analysis was performed. The most widespread observation methods [49, 50] are the Ovako Working Analysis System (OWAS) [51], Rapid Upper Limb Assessment (RULA) [52], and Rapid Entire Body Assessment (REBA) [53, 54], whose main characteristics are highlighted in Table 2:

Table 2. Comparative analysis between different observation.

	OWAS	RULA	REBA
Type of job	Industrial	Requiring arm movement	Any
Body elements to study	Limbs (arms and legs) Trunk	Arms Forearms Wrists Trunk Neck Legs	Arms Forearms Wrists Trunk Neck Legs
Other aspects to study	Load or force	Load or force Time spent Repetition	Load or force Hand position Exercise

Note: Own elaboration.

RULA, therefore, turned out to be the most suitable, as shown in Table 2. As this profession is relatively new, with specific postures focused on the upper part of the body (high prominence of the head and neck), and involving the use of a tool of a certain weight held for long periods, for the present investigation RULA was used. In other words, OWAS was ruled out due to its limitations: the fundamental body parts could not be studied since the method does not cover them. REBA was also ruled out due to its excessive amplitude, since it analyses positions and segments that are not involved in the activity studied [55, 56].

RULA METHOD

As mentioned in the Introduction, there are various methods for assessing the risk associated with postural load, varying in the scope of application, the assessment of individual postures or groups of postures, the conditions of application or by the parts of the body assessed or considered for assessment. One of the most widespread observational methods for assessing postures in practice is the RULA method [57].

The RULA method was developed in 1993 by McAtamney and Corlett of the University of Nottingham's Institute for Occupational Ergonomics for assessing the exposure of workers to risk factors that cause a high postural load and that can cause disorders in the upper limbs of the body [56]. For risk assessment, the method considers the posture adopted, its duration and frequency, and the forces exerted when it is maintained.

For a certain posture, RULA will obtain a score which establishes a certain Performance Level. The Performance Level will indicate whether the posture is acceptable or to what extent changes or redesigns are necessary in the position [58]. In short, RULA allows the evaluator to detect possible ergonomic problems derived from an excessive postural load [59].

The RULA method assesses individual poses (it does not evaluate sets or sequences of poses). For this reason, the postures to be assessed must be selected from those adopted by the worker in the position (Table 3). Thus, the postures selected were those that apparently involve a greater postural load due to their duration, their frequency or because they present a greater deviation from the neutral position.

Table 3. Postures identified in the work cycles for further analysis.

Posture 1	Posture 2	Posture 3	Posture 4	Posture 5
				

For this, the first step was observation of the tasks performed by the worker / pilot. Table 3 shows several cycles of work, enabling to determine the best postures to evaluate, also considering the time spent by the worker / pilot in each posture.

The measurements of the postures adopted by the worker / pilot are fundamentally angular, meaning the angles of the different parts of the body with respect to certain references. To measure, the posture was captured with a photographic camera and, later, the angle was measured with a protractor on the photograph. To ensure the validity of the method, enough photographs from different points of view were needed. Therefore, five photographs were taken from different planes (Fig. **3**).

In this case, it was very important to ensure that the angles to be measured appeared accurately in the images; in other words, it was necessary to ensure that the plane of the angle to be measured was parallel to the plane of the camera (Fig. **3**). In addition, since it was unknown which side was subject to the greatest postural load, it was decided to apply the method to the right and left sides of the body, separately.

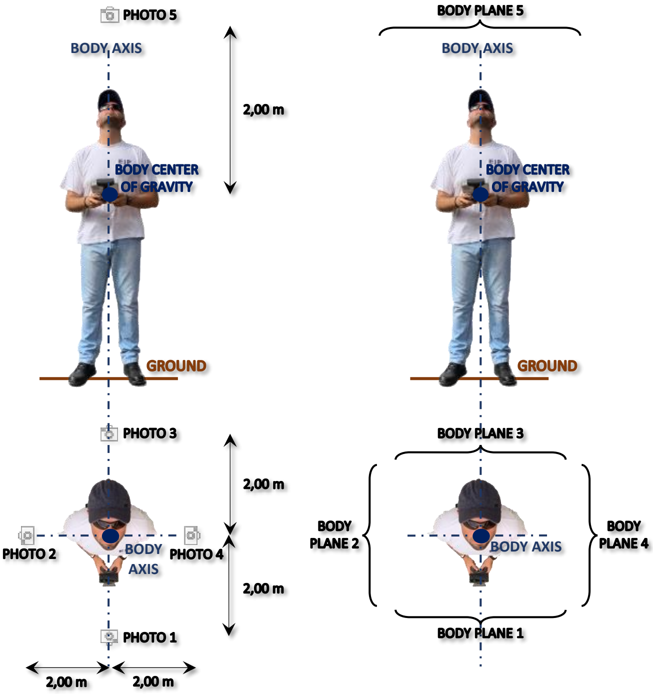
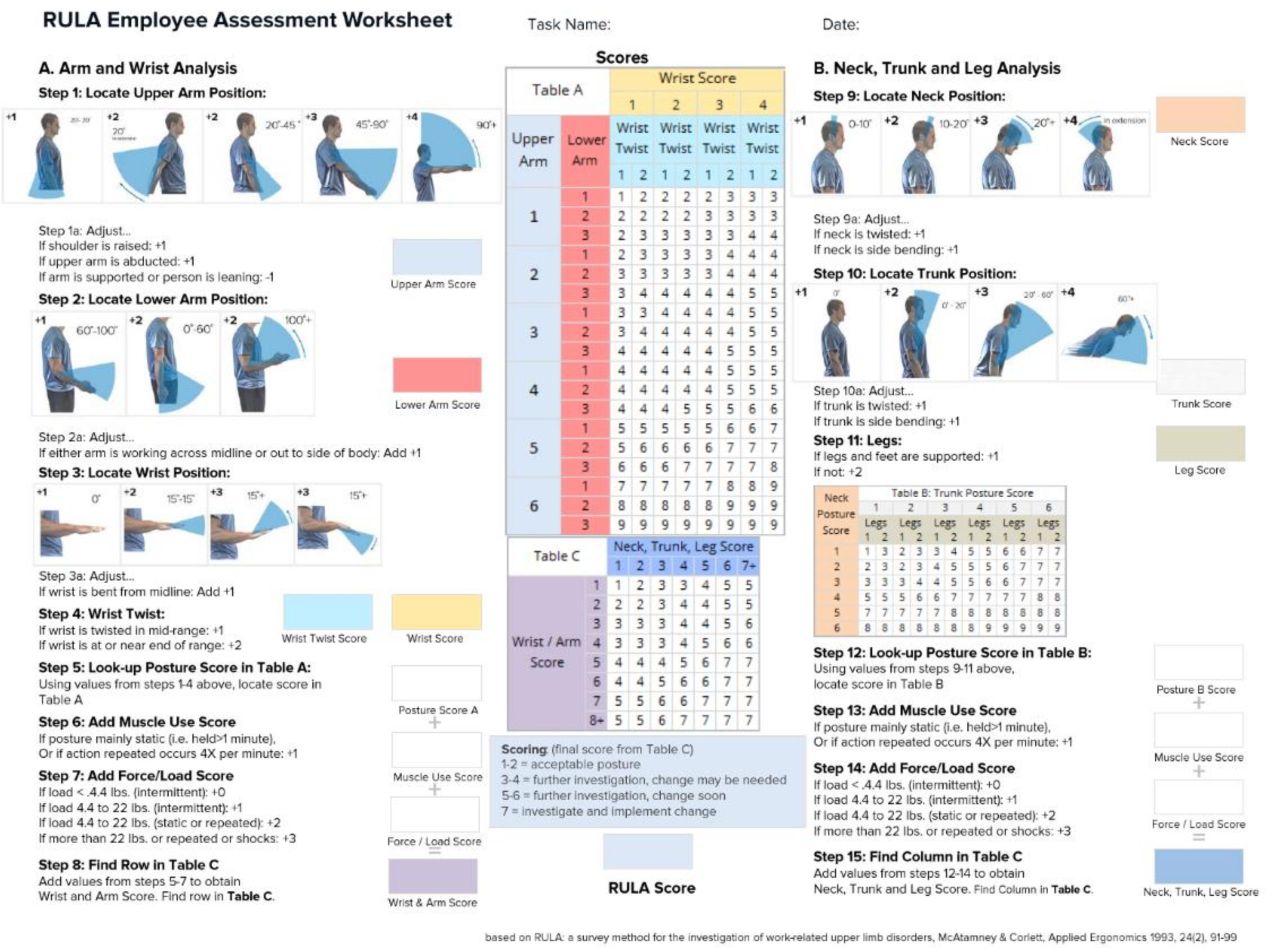


Fig. 3. Location of the camera for taking photographs and body plans to be recorded.

Having chosen the postures, RULA is the applied. The RULA method divides the body into two groups: Group A which includes the upper limbs (upper arms, forearms, and wrists); and Group B, which includes the legs, trunk, and neck [60, 61]. Using the tables associated with the method, a score is assigned to each body area (legs, wrists, arms, trunk, etc.) in order to assign overall values to each of groups (A and B, Fig. **4**) based on these scores.



RULA Employee Assessment Worksheet

Task Name:

Date:

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Step 2: Locate Lower Arm Position:

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

Step 7: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain
Wrist and Arm Score. Find row in **Table C**.

Scores

Table A		Wrist Score							
		1		2		3		4	
Upper Arm	Lower Arm	Wrist Twist		Wrist Twist		Wrist Twist		Wrist Twist	
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C		Neck, Trunk, Leg Score						
		1	2	3	4	5	6	7+
Wrist / Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

RULA Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Neck Posture Score	Table B: Trunk Posture Score											
	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above,
locate score in Table B

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

Step 14: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain
Neck, Trunk and Leg Score. Find Column in **Table C**.

based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

Fig. 4. Summarized scheme of application of the RULA method (ergo-plus scheme [62]).

Thus, the method following the established procedure is applied [55, 56, 57]: Study of work cycles. Depending on the tasks performed, individual postures were assessed, analysing the cycles and identifying the postures adopted by the worker. To do this, the researchers recorded workers during intervals of 25 minutes, which is the time that a flight operation lasts and/or the autonomy of the battery of the drone used in the investigation. In this way, they were able to record all their movements. Later, the movements that differed from the neutral posture and were repeated over the course of the working day were identified, ruling out fortuitous movements.

As a complement to the above, the study considered how static and how repeatable the activity was. In addition, the characteristics of the physical environment in which the activity takes place, and the tools and equipment used for the flight were recorded.

1. Posture selection. From the material obtained by recording the work cycles in the previous section, the postures were selected with the greatest postural load, considering duration, frequency, and deviation from a neutral position. With this selection, the different elements of the body involved were then analysed, where action would be required to reduce risks.

2. Angular data collection. After choosing the positions to study, they were analysed individually to catalogue the turns and angles of each body part, assigning each one a score. To do this, workers were photographed adopting the postures from five different angles (diagram in Fig. **3**): four to reflect the planes perpendicular to the ground and one for the plane parallel to the ground.

3. Score. Based on the cataloguing of the angular measurements, each body part was scored to obtain a partial score based on two groups (Fig. **5**):

A. The upper arm, the forearm, and the wrists.

B. The trunk, the neck, and the legs.

These partial scores are corrected based on the type of muscle activity and the force exerted, to give final scores for the group. Finally, based on the combination of the final scores of the groups, the overall score was obtained, which determines whether there is a risk. With this, the Action Level can be established. Fig. **6** shows how the groups are organized to obtain the level of action.

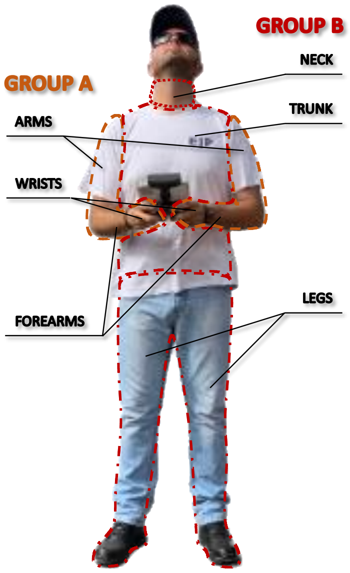


Fig. 5. Diagram of body groups.

Measuring the angles formed by the different parts of the operator's body is essential for assigning scores to them. The method determines how the angle is measured for each member. Subsequently, the overall scores of groups A and B are modified depending on the type of muscle activity developed, as well as the force applied during the performance of the task, and the final score is obtained from these modified overall values.

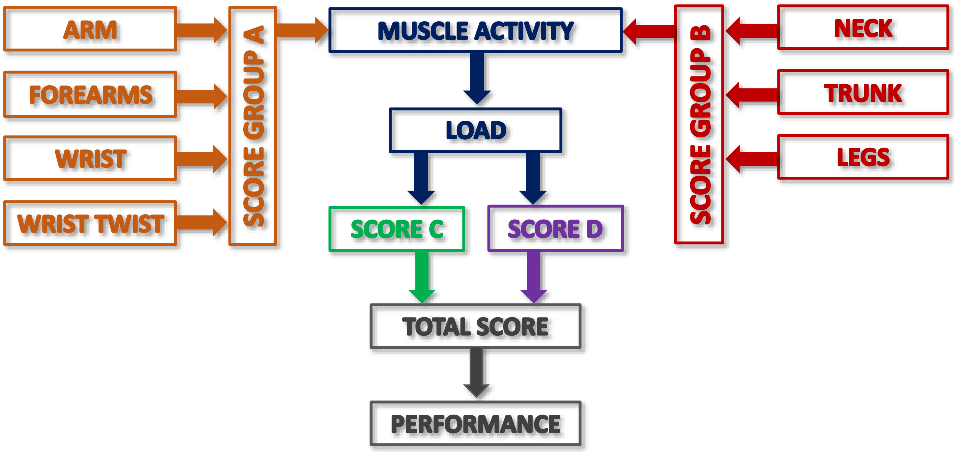


Fig. 6. RULA Method Scoring System Outline [52], adapted by the author.

4. Corrective measures. If necessary, the corrective measures to be adopted will be planned according to the results.

5. Task redesign. If the task requires, changes will be proposed to improve it ergonomically.

This method is an iterative process that must be repeated as often as needed (Fig. 7) to check the effectiveness of the correction measures (if they have been applied), adjusting the corrections if necessary.

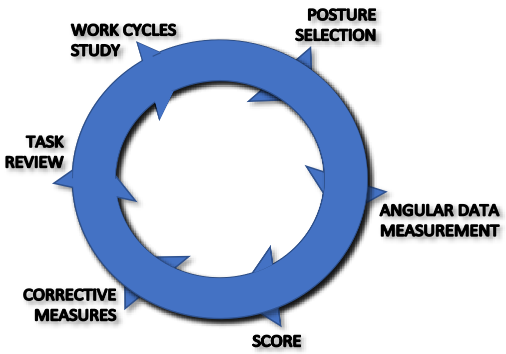


Fig. 7. The iterative process of applying the RULA method, represented in an endless cycle.

The final value provided by the RULA method is proportional to the risk involved in carrying out the task, so that high values indicate a greater risk of the appearance of musculoskeletal injuries. The method organizes the final scores into performance levels that guide the evaluator on the decisions to be made after the analysis. The proposed levels of action range from level 1, which considers that the assessed position is acceptable, to level 4, which indicates the urgent need for changes in the activity.

Subjects

For the study, two drone operators of different sexes were used. These two pilots performed four visual range flight operations on two different days, each lasting 25 minutes: two operations each day, under normal working conditions, with a five-minute rest period between consecutive operations.

The flights were a necessary part of the author's main activity: the visual inspection of two masonry bridges. Therefore, the distance between the pilot and the drone and the angle of observation was different on each flight. This allowed us to observe a greater number of postures.

Before the first operation, the two operators were interviewed. Both answered the same questions, the results of which are shown in Table 4.

Table 4. Compilation of the answers of the two workers to the previous interview.

	Worker 1	**Worker 2**
Age	39	40
Gender	Female	Male
Length of service	< 1 year	3 years
Pilot days per week	two (2) days /week	three (3) days a week
Daily effective pilotage time	two (2) hours / day	two (2) hours / day
Previous illnesses	Cervical contractures	Vertebral stenosis (low back)
Work-related ailments	Neck and wrists	Neck, back and wrists

MATERIALS

The flights were carried out with a Parrot drone, the Anafi model, as shown in Fig 1. This device is controlled by a console (also Parrot) to which a tablet or mobile phone is attached (Fig 7). On this device screen, the pilot can see all the aircraft information and all the flight information. Generally, the author tends to use a tablet because of the higher quality of vision that it provides (Fig. **1**). However, this is not always possible. For this reason, a mobile phone (iPhone XR model, Fig. **8**) was used in this case, to study a situation that offers almost complete mobility and, due to the load carried, has more unfavourable ergonomics. The control unit + mobile phone + connection cable were weighed and found to have a total weight of 520 g (Fig. **9**). The operator commanding the flight must hold this equipment throughout the flight.

Fig. 8. Radio control console used in flights.

Fig. 9. Weighing the radio control assembly carried by the flight pilot.

Duty cycle analysis

From the observation of the working hours, it can be determined that a work cycle coincides with the flight operation. Each of these operations follows the following protocol:

1. Checking the environment to locate possible risks during the flight and thus be able to start the operation and plan the best route.
2. Weather check.
3. Checking the physical and emotional state of the pilot.
4. Checking the aircraft and the electronic systems involved.
5. Aircraft situation in the take-off position.
6. Rotor ignition.
7. Take-off.
8. Planned flight.
9. Return to the place of origin.
10. Landing.
11. Rotor shutdown.
12. End of the operation.

From the recording of each cycle, a series of postures were extracted, as shown in Table 3, to be analysed using the RULA methodology. The choice was made according to the following criteria:

- The posture is adopted and maintained by both pilots.
- Significant deviation from neutral posture.
- The posture is held for a long period.

Each chosen position had its particularities. All postures were adopted due to the characteristics and needs of the flight, as explained below:

- Posture 1. Minimum posture time: 3’ 00”. The operators adopted this posture during the take-off operation when the aircraft was very far from their position. With this posture, pilots can visually follow the movement of the aircraft. Slight movements of the body parts sometimes accompany this posture.
- Posture 2. Minimum posture time: 1’ 45”. Many of the tasks involve the use of the data display screen coupled with the control knobs. This forces pilots to lean their heads forward many times during the operation, holding the consequently awkward tilt for long periods.
- Posture 3. Minimum posture time: 2’ 00”. When the drone flies over nearby targets or, above all, at a certain height, pilots have to lean their heads back to maintain visual contact with the aircraft.
- Posture 4. Minimum posture time: 1’ 30”. In flights that cover large areas of land, but in which the pilot is close to the target or the take-off point, the pilots turn their heads to follow the flight. The pilots maintain this awkward posture until the flight requires a postural change or it can be abandoned due to the approach of the aircraft.

- Posture 5. Minimum posture time: 1’ 00”. Similar to position 3, but even more exaggerated. The aircraft flies over the pilot's body axis and the pilot tries to maintain visual contact with the aircraft.

The neck and wrists are the body parts which are most forced into awkward positions and therefore suffer the most. This matches the information provided by the workers in the previous interview (last row of Table 3).

Posture analysis

Once the postures to be analysed are selected, the RULA methodology can be applied. For posture 1, the angular measurements of the body segments involved were taken, according to Fig. **10** and Fig**. 11**, for worker 1 and worker 2.

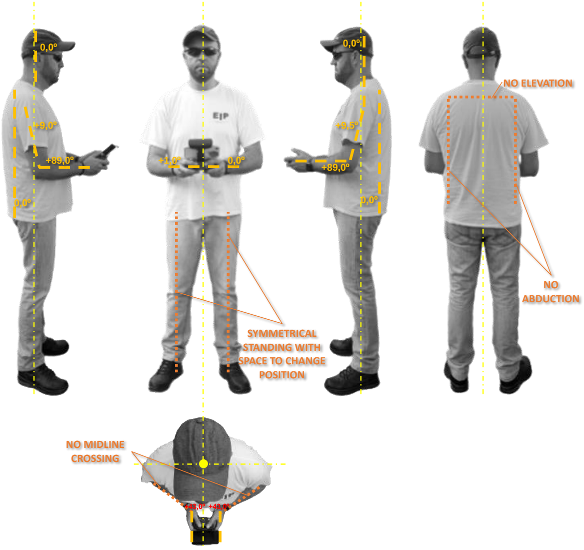


Fig. 11. Graphic analysis of posture 1, worker 2.

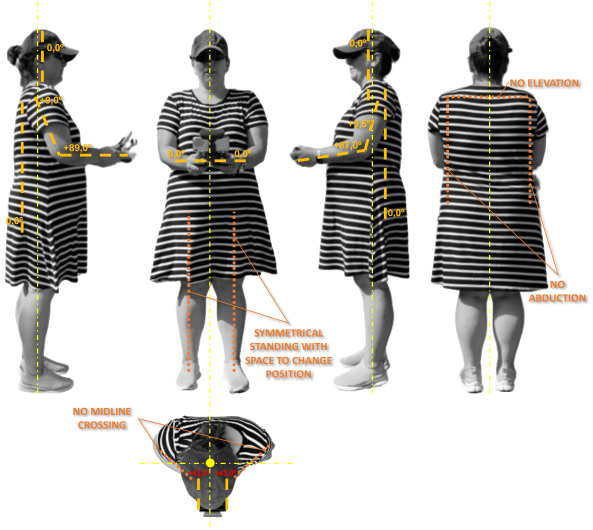


Fig. 10. Graphic analysis of posture 1, worker 1.

As can be observed, the values obtained are quite similar for both workers (Fig. **10** and Fig**. 11**). Therefore, the RULA method was applied to only one of them, because the final result will be the same.

Following the classification of groups in Fig. **5** and the diagram in Fig. **6**, the researcher proceeded to the score of posture 1 [52], obtaining the score of groups A, B, C, and D that was collect in Table 5.

Table 5. Posture 1 score according to the RULA method.

Group	Body Part	Factor	Assessment	Part. Score	Total Score
A	Upper arm	Upper arm score	From 20° extension to 20° flexion	1	3
		Modification of score	Neutral position		
	Forearms	Forearms score	Flexion between 60° and 100°	1	
		Modification of score	Neutral position		
	Wrist	Forearms score	Flexion or extension > 15°	4	
		Modification of score	Radial deviation		
	Wrist Twist	Wrist twist score	Medium pronation or supination	2	
B	Neck	Neck score	Flexion between 0° and 10°	1	2
		Modification of score	Neutral position		
	Trunk	Trunk score	Flexion between 0° and 20°	2	
		Modification of score	Neutral position		
	Legs	Legs score	Standing, with symmetrically distributed weight and free space to change position	1	
C	Activity	Activity type	Static (holds for more than a minute at a time)	1	4

	Load	Load or forces exerted	Load less than 2 kg	0	
D	Activity	Activity type	Static (holds for more than a minute at a time)	1	3
	Load	Load or forces exerted	Load less than 2 kg	0	

With these values, a final RULA score of value 3 was obtained [52, Table 17]. This indicates that, for posture 1, an in-depth study of the task is needed, because changes may be needed.

Next, posture 2 was analysed. To do this, the angular measurements of the body segments involved was taken, according to Fig. **12**, for worker 1, and Fig 13, for worker 2.

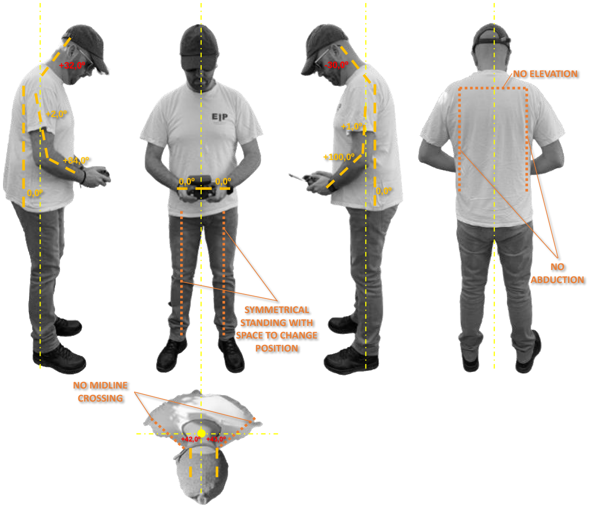


Fig 13. Graphic analysis of posture 2, worker 2.

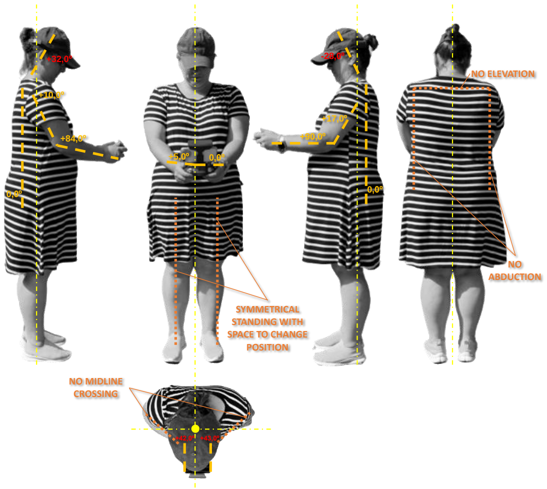


Fig. 12. Graphic analysis of posture 2, worker 1.

Following the classification of groups in Fig. **5** and the diagram in Fig. **6**, the analysis proceed to the score of posture 2 [52], obtaining the score of groups A, B, C, and D shown in Table 6.

Table 6. Posture 2 score according to the RULA method.

Group	Body Part	Factor	Assessment	Part. Score	Total Score
A	Upper arm	Upper arm score	From 20° extension to 20° flexion	1	3
		Modification of score	Neutral position		
	Forearms	Forearms score	Flexion between 60° and 100°	1	
		Modification of score	Neutral position		
	Wrist	Forearms score	Flexion or extension > 15°	4	
		Modification of score	Radial deviation		
	Wrist Twist	Wrist twist score	Medium pronation or supination	2	
B	Neck	Neck score	Flexion > 20°	3	3
		Modification of score	Neutral position		
	Trunk	Trunk score	Flexion between 0° and 20°	2	
		Modification of score	Neutral position		
	Legs	Legs score	Standing, with symmetrically distributed weight and free space to change position	1	
C and D	Activity	Activity type	Static (holds for more than a minute at a time)	1	4
	Load	Load or forces exerted	Load less than 2 kg	0	

With these values, a final RULA score of value 4 was obtained [52, Table 17]. This indicates that, for position 2, it is necessary an in-depth study of the task, because changes may be needed.

Next, posture 3 is analysed. To do this, the angular measurements of the body segments involved was taken, according to Fig 14 and Fig 15, for worker 1 and worker 2.

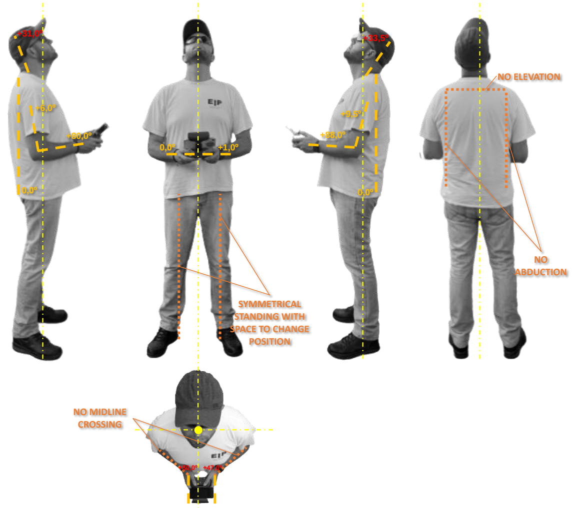


Fig 15. Graphic analysis of posture 3, worker 2.

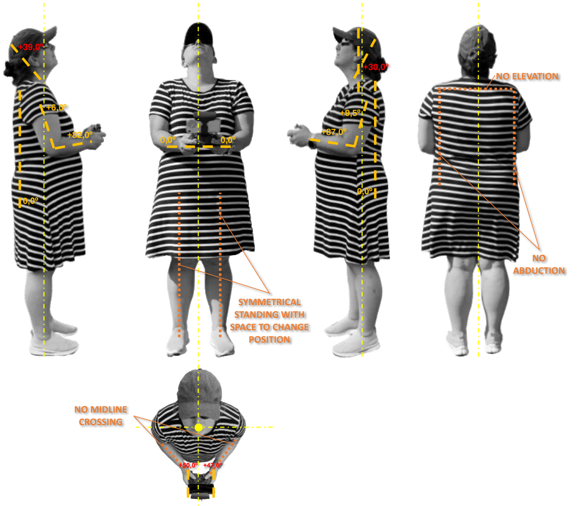


Fig 14. Graphic analysis of posture 3, worker 1.

As can be observed, the values obtained are quite similar for both workers (Fig 14 and Fig 15). Therefore, the RULA method was applied to only one of them, because the result will be the same.

Following the classification of groups in Fig. **5** and the diagram in Fig. **6**, the analysis proceeded to the score of position 3 [52], obtaining the score of groups A, B, C, and D that was shown in Table 7.

Table 7. Posture 3 score according to the RULA method.

Group	Body Part	Factor	Assessment	Part. Score	Total Score
A	Upper arm	Upper arm score	From 20° extension to 20° flexion	1	3
		Modification of score	Neutral position		
	Forearms	Forearms score	Flexion between 60° and 100°	1	
		Modification of score	Neutral position		
	Wrist	Forearms score	Flexion or extension > 15°	4	
		Modification of score	Radial deviation		
	Wrist Twist	Wrist twist score	Medium pronation or supination	2	
B	Neck	Neck score	Upper extension	4	5
		Modification of score	Neutral position		
	Trunk	Trunk score	Flexion between 0° and 20°	2	
		Modification of score	Neutral position		
	Legs	Legs score	Standing, with symmetrically distributed weight and free space to change position	1	
C	Activity	Activity type	Static (holds for more than a minute at a time)	1	4
	Load	Load or forces exerted	Load less than 2 kg	0	
D	Activity	Activity type	Static (holds for more than a minute at a time)	1	6
	Load	Load or forces exerted	Load less than 2 kg	0	

With these values, a final RULA score of 6 was obtained [52, Table 17]. This indicates that, for position 3, the task must be redesigned, because the operator is exposing himself to a significant risk that is not acceptable.

Next, posture 4 was analysed. To do this, the angular measurements of the body segments involved were taken, according to Fig 16 and Fig 17, for worker 1 and worker 2. In this case, each of the workers was analysed in a position different spin. Therefore, to obtain a reliable RULA score, the most unfavourable values were considered.

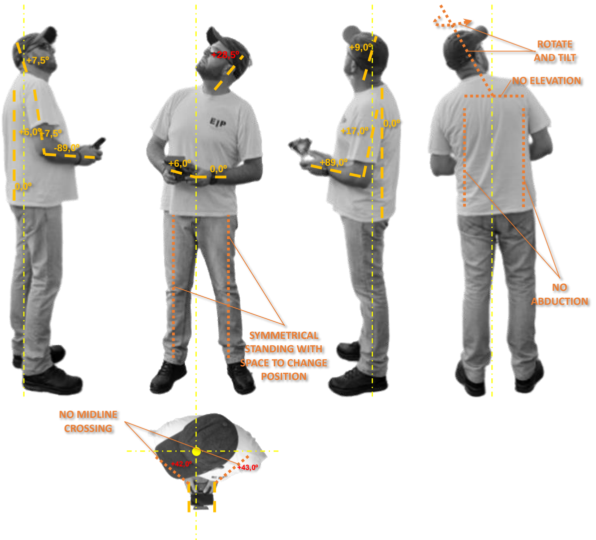


Fig 17. Graphic analysis of posture 4, worker 2.

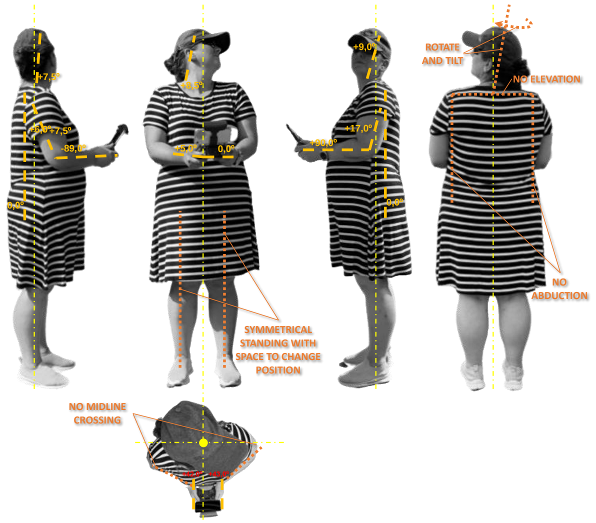


Fig 16. Graphic analysis of posture 4, worker 1.

As can be observed, the values obtained are quite similar for both workers (Fig 16 and Fig 17). However, unlike postures 1, 2, and 3, there is a different measurement: the cervical inclination of worker 2 is greater than the cervical inclination of worker 1. Therefore, the RULA method was applied to worker 2 because his posture is more unfavourable.

Following the classification of groups in Fig. **5** and the diagram in Fig. **6**, the analysis proceeded to the score of posture 4 [52], obtaining the score of groups A, B, C, and D that was collect in Table 8.

Table 8. Posture 4 scores according to the RULA method.

Group	Body Part	Factor	Assessment	Part. Score	Total Score
A	Upper arm	Upper arm score	From 20° extension to 20° flexion	1	3
		Modification of score	Neutral position		
	Forearms	Forearms score	Flexion between 60° and 100°	1	
		Modification of score	Neutral position		
	Wrist	Forearms score	Flexion or extension > 15°	4	
		Modification of score	Radial deviation		
	Wrist Twist	Wrist twist score	Medium pronation or supination	2	
B	Neck	Neck score	Flexion > 20°	5	7
		Modification of score	Head rotated and tilted		
	Trunk	Trunk score	Flexion between 0° and 20°	2	
		Modification of score	Neutral position		
	Legs	Legs score	Standing, with symmetrically distributed weight and free space to change position	1	
C	Activity	Activity type	Static (holds for more than a minute at a time)	1	4
	Load	Load or forces exerted	Load less than 2 kg	0	
D	Activity	Activity type	Static (holds for more than a minute at a time)	1	8

Load	Load or forces exerted	Load less than 2 kg	0

With these values, a final RULA score of 6 was obtaine [52, table 17]. This indicates that, for posture 4, the task must be redesigned, because the operator is exposing himself to a significant risk that is not acceptable.

Finally, posture 5 was analysed. To do this, the angular measurements of the body segments involved were taken, according to Fig 18, for worker 1, and Fig 19, for worker 2.

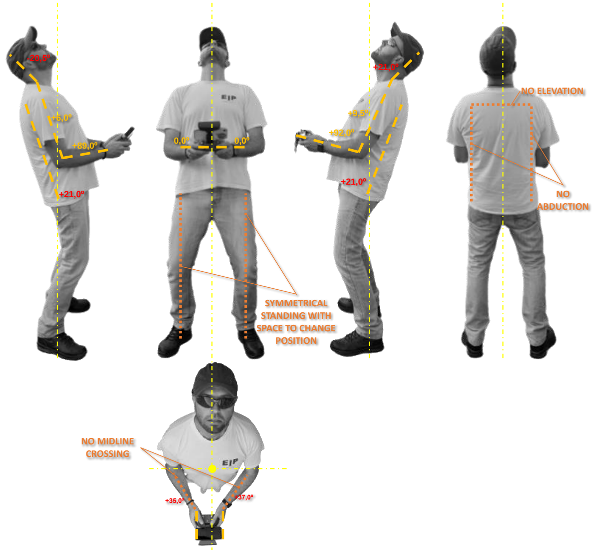


Fig 19. Graphic analysis of posture 5, worker 2.

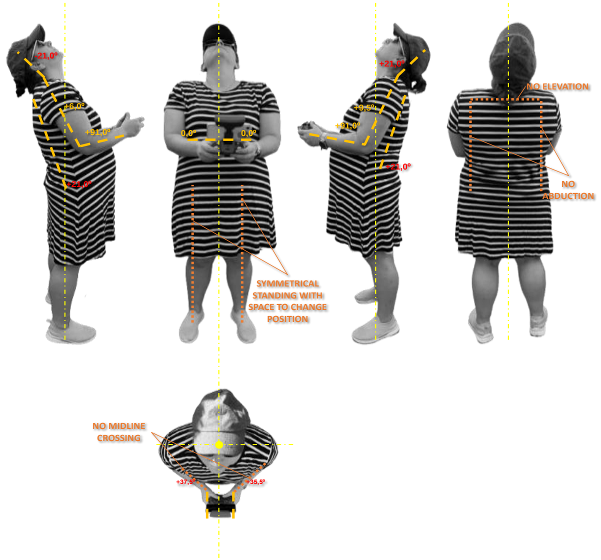


Fig 18. Graphic analysis of posture 5, worker 1.

Following the classification of groups in Fig. **5** and the diagram in Fig. **6**, the analysis proceeded to the score of posture 5 [52], obtaining the score of groups A, B, C, and D that was collect in Table 9.

Table 9. Posture 5 scores according to the RULA method.

Group	Body Part	Factor	Assessment	Part. Score	Total Score
A	Upper arm	Upper arm score	From 20° extension to 20° flexion	1	3
		Modification of score	Neutral position		
	Forearms	Forearms score	Flexion between 60° and 100°	1	
		Modification of score	Neutral position		
	Wrist	Forearms score	Flexion or extension > 15°	4	
		Modification of score	Radial deviation		
	Wrist Twist	Wrist twist score	Medium pronation or supination	2	
B	Neck	Neck score	Flexion > 20°	4	6
		Modification of score	Head tilted		
	Trunk	Trunk score	Flexion > 20°	3	
		Modification of score	Neutral position		
	Legs	Legs score	Standing, with symmetrically distributed weight and free space to change position	1	
C	Activity	Activity type	Static (holds for more than a minute at a time)	1	4
	Load	Load or forces exerted	Load less than 2 kg	0	
D	Activity	Activity type	Static (holds for more than a minute at a time)	1	7

Load	Load or forces exerted	Load less than 2 kg	0

With these values, a final RULA score of 6 was obtained [52, table 17]. This indicates that, for position 5, the task must be redesigned, because the operator is exposing himself to a significant risk that is not acceptable.

DISCUSSION

Of the five positions selected, three of them would require possible changes, and two the redesign of the task. The results obtained confirm that the segments initially identified as sensitive to posture do indeed suffer a high load, especially when maintaining the posture for continuous periods. As it continues during working hours, this effort can lead to muscle tension that can eventually cause some type of injury. The truth is that small variations in posture and a better flight technique can minimize the postural impact. In this sense, the resulting suggestions formulated were the following:

- Posture 1. We suggest raising your arms, trying to rest your elbows on your abdomen, raising the control console, and decreasing the angle of your wrists.

- Posture 2. We suggest raising the arms, trying to rest the elbows on the abdomen, raising the control console and reducing the angle of the wrists, and preventing the head from lowering excessively, compensating for the angle of the neck with the eyes.

- Posture 3. It is advisable to reduce the angle of the neck depending on the pilot’s space for movement. If possible, moving away from the inspected item reduces the viewing angle. In addition, we suggest raising the arms, trying to rest the elbows on the abdomen, raising the control console and reducing the angle of the wrists, and preventing the head from lowering excessively, compensating for the angle of the neck with the eyes.

- Posture 4. We suggest accompanying the trajectory of the aircraft with the body, moving all the segments as a block. In addition, we suggest raising the arms, trying to rest the elbows on the abdomen, raising the control console and reducing the angle of the wrists and preventing the head from lowering excessively, compensating for the angle of the neck with the eyes.

- Posture 5. Similarly to posture 3, in this case, we suggest limiting this position over time, trying to move the drone away from the body's axis.

Analysing the postures in more depth highlights that the most awkward segment is the wrist. Applying a correction in the position of the arms and the grip would improve the five postures significantly. In addition, they are all affected by the command console itself. The following characteristics determine the angle adopted by the hands when holding it:

- Console size. The dimensions of the controls and the screen force you to put your hands together, force the angle and flex your head.

- Position. When placing the transmitter in the abdomen area, the arms rotate towards the body axis, which forces the wrists to be extended to maintain a firm grip, thus forcing the angle.

The environment influences the posture that is taken, with muscle contraction being especially evident in environments with lower temperatures, observing the stiffest pilot. But it is the distance to the drone that is the determining factor in adopting an awkward posture. The closer it is, the more the neck has to bend.

Although the sample analysed was very limited in terms of the number of individuals, no influence of gender was observed. Both pilots adopted similar postures at similar times, based on the exposure characteristics.

CONCLUSIONS

Based on the results obtained, five awkward postures were identified, which were repeated throughout the working day, for prolonged periods. These five postures are the following.

1. Posture 1 is the one that forces the fewest body segments of the five. This posture concentrates the effort on the pilot's wrists.
2. In posture 2, the neck is subjected to an extension, in addition to forcing the wrists.
3. In posture 3, the neck is subjected to excessive flexion, in addition to straining the wrists.
4. In posture 4, the neck is bent while it is rotated, in addition to straining the wrists.
5. In posture 5, both the neck and back suffer an extension, in addition to straining the wrists.

Based on the characteristics of the flight, it is concluded that two possible causes are the origins of the unsuitable postures:

- The radio control console. Its dimensions require an awkward posture to correctly grasp the equipment. In addition, the pilot's physiognomy determines the angle of the arms, so when using smaller transmitters, the wrists are forced more.
- The spatial situation of the drone. Due to the characteristics of these flight operations, the pilot must keep the aircraft in line of sight. After observing the activity, it was noticed that the pilots' concentration on their observation influenced the movement of the neck, leaving the rest of the neck static. In addition, as the instrumental control of the flight requires attention to the data display screen, together with its dimensions, this causes the flexion of the head, maintaining the position, especially when the vehicle cannot be identified in the skies due to the distance.

In operations in different environments, the study identified the importance of adopting a proper posture. Depending on where the pilot is guiding the aircraft, the angle of the neck varies significantly. The flights that were carried out were inspecting different types of buildings. The higher and closer to the inspection site, the greater the angle when increasing the relative height of the drone. In operations that covered a greater distance or where the flight was further away, the extension of the neck was reduced, and the pilots were able to follow the trajectory of the vehicle with their eyes.

As has been shown, the size of the control device has a great influence on posture, but what was most striking was that the use of a smartphone as a data display screen was decisive; it was observed that this posture is related to the one adopted when consulting any current terminal of this type (standing upright with head fully flexed).

The large amount of information that is available to control the flight, as well as being able to have the drone's point of view through the cameras installed on it, attract the pilot's attention, keeping an eye on what is happening on the screen and, therefore, forcing the posture of the neck.

To correct the postures identified and consider the transmitter and the distance to the drone as generating causes, the following corrective measures are proposed:

- During flight planning, a section must be included to establish the piloting zone with sufficient distance to reduce the visual angle.
- If due to the characteristics of the environment, such as urban spaces, it is not possible to distance oneself from the inspection site, it is suggested to find a higher observation point, or reducing neck extension times by alternating the display on the screen with the visual location of the drone.
- During the postural observation, the pilots were required to correct their posture by raising their arms until their elbows rested on their sides. With this position, it was possible to raise the display screen. This reduced neck flexion and corrected the angle of the wrists.
- As an urgent measure, it is proposed to replace the smartphone with a tablet to increase the viewing space and thereby reduce the angle of flexion of the neck.
- If possible, replacing the transmitter with a larger one would increase the distance between the arms, which would reduce the angle of the wrists, significantly improving posture.
- There are specific harnesses for radio control. With the use of this element, the pilots would gain stability and would have a support point for the arms. In addition, by being able to adjust it, they could correct the angle of the arms, which would affect the position and flexion of the wrists.
- Due to the time spent on flights, accumulating throughout the day, a seat with back support could be used, allowing the pilots to move. This seat could even incorporate a tray for the control console, offering support to the different body segments.

The planning of the flight operation is essential. Thanks to this, aspects that affect body posture can be corrected. The way proposed to optimize the operation starts from the study of the flight. Using aerial photographs or cartography of the operation area, the flight path must be planned. This would optimize the flight time, avoid repeated or erratic trajectories, and allow for reducing possible awkward postures when searching for the drone based on the trajectory. In addition, correctly locating the observation point will help improve the viewing angle.

To guarantee postural correction, a flight protocol should be followed that establishes the actions to be taken into account before, during, and after the operation.

The body analysis reveals the influence of the control interfaces in posture correction. Due to its inevitable use, a suggested future line of research is the analysis of these interfaces to establish how they influence the musculoskeletal system and how they affect the dissociation of the perception of movement when using them.

Drone pilot work is often done in outdoor environments, which are not always safe, alternating with office work. In addition to the demands common to other jobs, in terms of results, others are added, such as great responsibility for the custody of high-value equipment, physical attacks by people who disagree with the presence of the aircraft, or the possible irruption into protected spaces, with the possible associated sanctions. These types of factors suggest the need to study the psychosocial factors of the job of drone pilot.

Related to the previous point, some operations are carried out in environments which are dangerous for the pilot, whether due to natural catastrophes, armed conflict, or another nature. It is proposed to analyse the mental strain and psychological risks of the job of drone pilot in emergency or pressure situations, which may be manifested in the postures adopted.

In the analysis of the angular study, a drone was used to take bird's-eye-view pictures, which motivated a line of thought on possible ways to apply drones as an evaluation and inspection tool related to the prevention of occupational hazards. This great technological development offers a wide range of possibilities, especially for planning and automation tools.

As a development of the previous suggestion and given the frequent news in the press on the multiple applications of laser object detection and measurement systems, another possible line of research could be its application in biometric studies for its ability to represent reality and the multiple possibilities of data analysis it offers as a non-invasive system.

As a new profession that companies are incorporating into their structures, but where risk analysis focuses on the interaction of the aircraft with the environment and the people in it, based on the development of postural analysis, further studies are suggested on how piloting drones can influence the health of the worker, possible injuries in the performance of the task, even possible diseases that could arise and in the future might be considered occupational hazards. In addition, health prevention and control strategies could be investigated and established.

To minimize musculoskeletal disorders, drone pilots' tasks must meet certain minimum conditions:

- Maintaining the proper distance from the drone, either moving away from the place of flight operation or gaining height, to minimize the visual angle and reduce the extension of the neck.

- Having a remote-control console of adequate dimensions with a large data display screen that allows information to be consulted comfortably, avoiding staring or locating small characters.

- Having a support point for the console, such as a harness, which can be adjusted to adapt to different physiognomies, thus managing to modify the angles of the arms, avoiding the effort of maintaining the posture.

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