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# VEGETATION PRUNING ACTIVITY PERFORMED BY A LIVE LINE ELECTRICIAN: AN INTEGRATION OF WORK ANALYSIS, CLUSTER ANALYSIS AND BIOMECHANICS

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## Summary

This study consisted of understanding the activity of conventional pruning (poda_Conv) and pruning with the support prototype (poda_ProtSup) with hydraulic pruning of vegetation of Live Line Electricians (ELV) in an integrated way between work analysis, cluster analysis and biomechanics. The analysis was conducted in a laboratory environment. The cluster analysis of the present study was performed using the k-means method. During pruning with the support prototype (poda_ProtSup), the angle values related to the movements of the neck joint (sagittal plane) were lower, which suggests a more appropriate posture during the pruning activity. The cluster analysis indicated the formation of two groups (Silhouette Index of 0.7874), one associated with conventional pruning (poda_Conv) and the other with pruning with the support prototype (poda_ProtSup). Cluster analysis provided a refined understanding of the patterns of neck joint movements and proved to be an effective tool to identify intrinsic patterns from the biomechanical and ergonomic data of vegetation pruning activity. Fundamentally, the support prototype acts to reduce the load of the implement (motoprune), on the other hand it reduces the angular range of the neck joint, evidencing its relevance to the health and safety of electricians who perform this activity.

**Keywords**: Ergonomics of the Activity, Biomechanics, Live Line Electrician.

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## Abstract

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This study aimed to understand the activity of conventional pruning (pruning_Conv) and pruning with the support of a prototype (pruning_ProtSup) using hydraulic pruning of vegetation by Live Line Electricians (ELV), in an integrated way involving work analysis, analysis of cluster and biomechanics. The analysis was carried out in a laboratory environment. Cluster analysis in this study was performed using the k-means method. During pruning with the prototype support, lower angle values were observed, suggesting a more adequate posture during the pruning activity. Cluster analysis indicated the formation of two groups (Silhouette Index of 0.7874), one associated with conventional pruning and the other with pruning using the prototype support. Cluster analysis provided a refined understanding of cervical movement patterns and proved to be an effective tool for identifying intrinsic patterns from biomechanical and ergonomic data from vegetation pruning activities. Fundamentally, the support prototype acts to reduce the load on the implement (pruning tool); on the other hand, it reduces the angular amplitude of the cervical joint, highlighting its relevance for the health and safety of electricians who carry out this activity.

**Keywords:** Activity Ergonomics; Biomechanics; Live-Line Electrical Worker.

## 1. Introduction

The research presents partial results of a Research and Development (R&D) Program. It is known that this type of initiative stands out as an essential driving force in conducting the complete cycle of the research, development, and innovation chain in the Brazilian electricity sector scenario (Traldi et al., 2022). His vision goes beyond the simple search for knowledge, encompassing the materialization of innovative ideas, successful laboratory experiments, and the practical application of mathematical models, all converging on tangible results. In this way, R&D Programs play a key role in boosting collaboration between companies, providing an appropriate scale to transform concepts into tangible improvements, both in organizational performance and in people's quality of life (ANEEL, 2022).

In this context, cluster analysis emerges as a valuable tool. Over the decades, this technique of multivariate statistics has played an increasing role in several disciplines. During the 1950s, statisticians such as Robert R. Sokal and Edward F. Sneath introduced methods of numerical classification and data visualization, laying the initial foundations of this approach (Sokal, 1963). As one moved into the 1960s, cluster analysis established itself as a preeminent multivariate statistical technique, permeating areas as diverse as biology, taxonomy, and psychology. During this period, the hierarchical approach and the method of agglomerative linkage were developed, providing the construction of dendrograms that represent the structure of data grouping (Sokal, 1963). This time advance outlines not only the evolution of cluster analysis, but also highlights its growing relevance as an important tool in several areas of study, including ergonomic investigations such as the present one.

In the decades since, cluster analysis has expanded into areas such as computer science and pattern recognition. Partitioning methods, such as k-means, were introduced to create fixed partitions of data into clusters, with this, the method became more accessible and with the advancement of computing, clustering algorithms became more sophisticated. In the 1990s, there was a surge of interest in data mining and machine learning, and cluster analysis became a core technique for knowledge discovery in large data sets. Since then, cluster analytics has continued to be widely used in various areas, driven by data growth and advances in computing (Geng & Hamilton, 2006; Jain, 2010).

Cluster analysis is defined as a statistical technique used to identify patterns and structures in complex data sets, with the aim of grouping similar objects into groups or *clusters*. It is an unsupervised learning technique, which means that there are no pre-defined labels or categories for the data, and the algorithm is responsible for identifying patterns and grouping them based on their characteristics (Jain et al., 1999).

The medical field already makes use of this technique because large and complex biomedical datasets present challenges to conventional hypothesis-based analytical approaches. Since, data-driven unsupervised learning can identify intrinsic patterns in these datasets (Eckardt et al., 2023). Many of these studies use *cluster* analysis as a tool for exploring patterns with cardiovascular diseases and this can contribute to improving risk stratification and management of these patients (Guedon et al., 2023; Kim et al., 2023; Lee et al., 2023; Mohammadi et al., 2023).

In the context of ergonomics, *cluster* analysis has been used to identify patterns, groups and relevant characteristics in the improvement of ergonomic conditions in work environments.

The study by Jacquier-Bret et al., (2023) applied this technique to analyze lymphatic massage performed by physiotherapists, decomposing it into generic postures (PG). Seven PGs were identified based on joint angles, variability, and relative frequency. The most common postures were PG6, PG4 and PG2, and it was observed that the trunk and neck region had predominant flexion, while shoulder flexion and abduction varied. The analysis of the RULA score also showed differences between the generic postures. These results highlight the importance of monitoring massages and ensuring the use of proper postures to prevent musculoskeletal disorders. Thus, it is possible to evaluate massages quickly through a combination of generic postures for ergonomic analysis (Jacquier-Bret et al., 2023)

Another study, conducted by Andersen et al., (2021) looked at the importance of combined ergonomic exposures at work for the development of musculoskeletal pain. Using the Study of the Work Environment and Health in Denmark, the researchers investigated 18,905 employees over the course of four years. Through a *cluster* analysis using *k-means,* they identified nine *clusters* based on seven ergonomic factors. Using a weighted regression model, they observed that clusters with high combined ergonomic exposures showed the greatest increase in neck-shoulder and lower back pain intensity. In addition, *clusters* with high exposure to specific ergonomic factors also significantly increased pain. The results underscore the importance of combined ergonomic occupational exposures in the development of musculoskeletal pain and highlight the need for preventive approaches in the workplace (Andersen et al., 2021).

In the study by Hu et al., (2022), the patterns of balance recovery after slips and their association with the probability of slip-induced falls were investigated. Sixty young people participated in the study, who were subjected to unexpected slips while walking on a walkway. Hierarchical *cluster* analysis was used to classify the patterns of balance recovery based on the kinematic measurements of both feet during the period of 100 to 300 ms after heel contact of the slippery foot. Three distinct patterns of balance recovery were identified, which were related to different levels of probability of falling. These findings contribute to a better understanding of the mechanisms of balance recovery in slip situations and may aid in the development and evaluation of fall prevention interventions.

Cluster analysis has been increasingly explored as a robust tool in the area of biomechanics. Thus, the use of this tool together with the area of ergonomics points to a way of looking at a given problem in an interdisciplinary way. Thus, the objective of the study was to understand the activity of conventional pruning (poda_Conv) and pruning using the support prototype (poda_ProtSup) with hydraulic pruning of vegetation of Live Line Electricians (ELV) in an integrated way considering the analysis of the work, cluster analysis and biomechanics.

## 2. Methodology

The study presents partial data from a Research and Development (R&D) Project, carried out in partnership between a private electric energy company located in the interior of São Paulo, the Faculty of Applied Sciences (FCA) of UNICAMP and a manufacturer of tools for the sector.

A 38-year-old right-handed male Electrician (ELV) who has been working directly on a live line for 6 years and belonging to the electric power company's own staff participated in the research. The Electrician agreed to voluntarily participate in the research through an Informed Consent Form. The study was approved by the Research Ethics Committee of

UNICAMP – State University of Campinas, CAAE: 33462920.3.0000.5404. Opinion number: 4.151.017.

First, the application of the Ergonomic Analysis of Work (AET) (Guérin, et al., 2001) was used as a method to understand the nature of the activity performed by the ELV. Through a collective meeting held with 12 ELVs, it was identified that vegetation pruning was considered the most critical in terms of difficulty, duration and frequency. Based on this, global and open observations of the activity in a real situation were carried out, recorded in a field notebook and validated through an interview after the task was performed, due to the degree of danger of interaction with the workers during its execution.

For the biomechanical analysis of the movements performed in the activity, data collection was carried out with an experienced ELV, in a controlled environment, in the biomechanics laboratory of FCA/UNICAMP. In the laboratory, an environment was set up to enable the activity of pruning vegetation in a simulated way by the electrician. To this end, a structure1 that resembles a pole with a crosshead and tree branches was assembled, using wooden handles and screws (Figure 1).

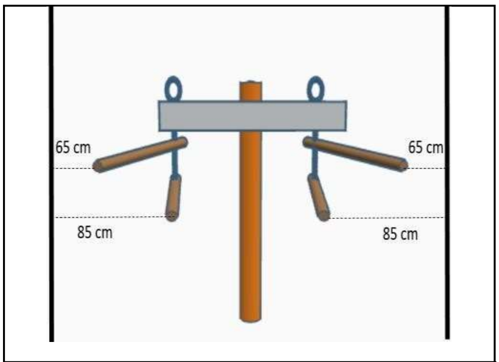


**Figure 1.** Structure assembled in the laboratory to be used in the simulation of vegetation pruning activity.

Data collection was divided into two distinct moments. At first, the ELV was instructed to perform the vegetation pruning movements according to its conventional pruning work routine (poda_Conv) by starting the pruning movement at the bottom of the branch and advancing towards the top (Figure 2a). In the second moment of collection, the ELV performed a simulation of the vegetation pruning activity similar to the first collection, but this time it performed the movements with the aid of a support prototype (poda_ProtSup) for hydraulic pruning (Figure 2b). During the vegetation pruning operation with hydraulic pruning, the ELV made cuts in the branches in stages, so that the branch could be pruned in the proximal and distal cutting zones, with zones E1 and E2 (left side of the ELV) and D1 and D2 (right side).

[1] The construction of this structure was based on the knowledge previously developed in the previous phase, by the field of ergonomics, through the analysis of the study of the ergonomics of the activity.

Each cutting zone (15 cm long) consists of the location of the branch to be pruned that has been properly identified for a standardization of the cutting location and easy visualization. Throughout the collection, the ELV performed 11 series of complete movements, simulating the movements of vegetation pruning by touching the branches from bottom to top and from top to bottom, in 04 predetermined zones along the branch, each measuring 15 cm.

For data collection, a motion capture system (*Optitrack*) was used, consisting of 12 17W prime cameras, configured with an acquisition rate of 200 Hz, to cover the entire capture area (Figure 2a; 2b). The whole-body model used was proposed by (Leardini et al., 2011), for the orientation of the upper limbs (Wu et al., 2002) and lower limbs (Wu et al., 2005), following the recommendation of the International Society of Biomechanics (ISB) (Figure 2d).

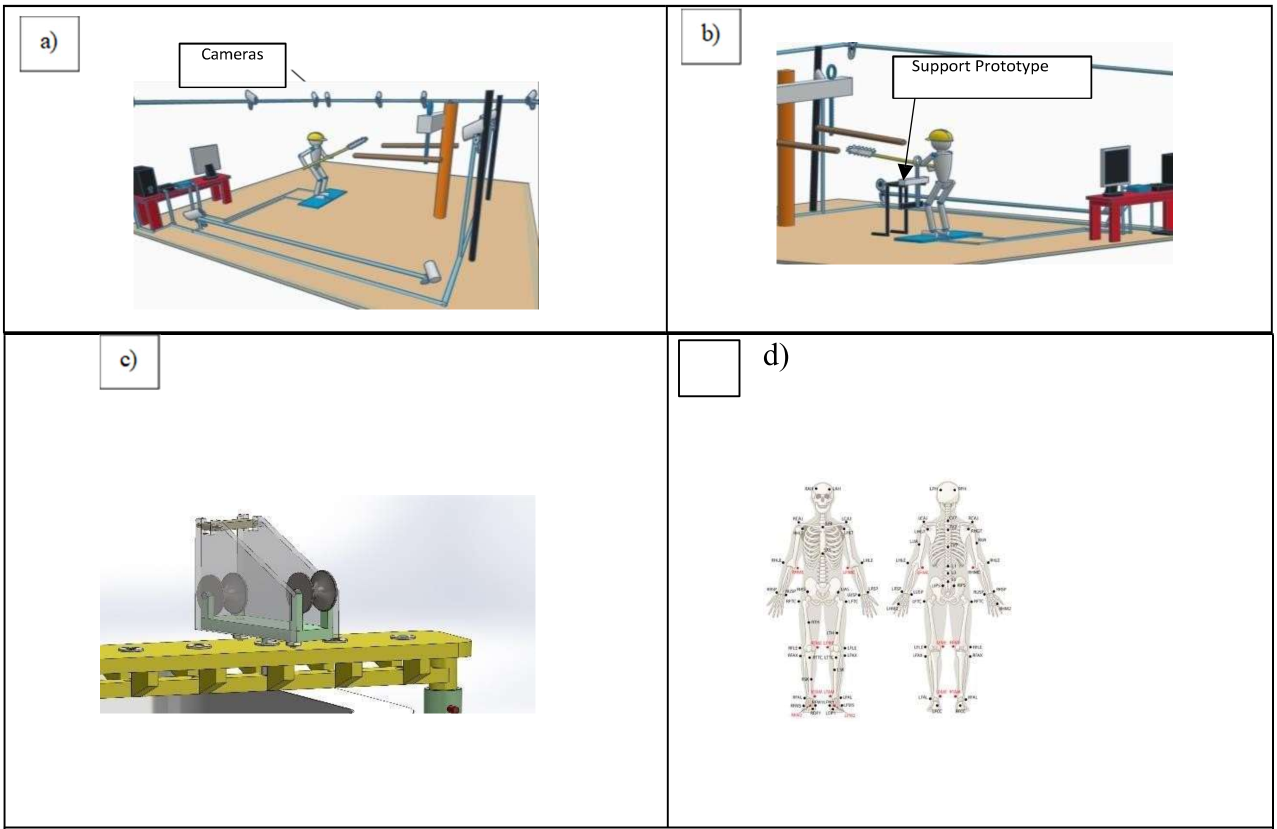


**Figure 2:** a) 1st day of collection without the use of the hydraulic pruning support; b) 2nd day of collection with the use of the hydraulic pruning support; c) Image of the prototype of hydraulic pruning support; d) Scheme with the bone accidents to be used as a reference for the positioning of the surface markers.

The 4th-order Butterworth digital filter, with a cutoff frequency of 10 Hz, was used for the smoothing process of the kinematic data. The Visual3D® software was used to calculate the kinematic variables, while the other processing was carried out in the Matlab® environment.

The *cluster* analysis of the present study was performed using the *k-means method* and the number of *clusters* was defined using the *silhouette* method (Hair et al., 2005; Rousseeuw, 1987). RStudio software (version 4.1.2; RStudio Team, 2021) was used for multivariate analysis.

## 3. Results and Discussion

### 3.1. The task of pruning vegetation

The task of pruning vegetation consists precisely of cutting different plant species that may cross the electricity grids, impairing their operation. This task is performed by ELV of the electric power company and it uses a hydraulic pruning. ELVs are operators that work directly in energized networks, which give them even greater risks of electric shock and accidents that can be fatal.

As a result, it is mandatory for the electricians of the company studied to use various Personal Protective Equipment (PPE) such as special clothing, boots, gloves and others to protect against risks (Figure 3).


**Figure 3:** ELV dressed with PPE to carry out the tree pruning activity

The work performed by these electricians is always carried out in pairs. The executing electrician is the one who gets on the crane truck to carry out the vegetation pruning operation. The second electrician works on the ground, observing the activity performed by the executor and warning of any risk that may emerge in the operation.

**Figure 4:** ELV executor in the activity of vegetation pruning.

Through interviews conducted collectively and individually with the ELV, it was identified that the activity confers a high degree of physical effort. Firstly, because, in terms of duration, this is an activity that can take from 1 to 3 hours or even days, depending on the tree.

Regarding physical exertion, the ELV reported that they are associated with the intensification and repetition of movements, data that corroborate the study by Moriguchi et al., (2009). In relation to the ELV in the survey, this factor affects a greater overload, especially in situations in which the company includes pruning as a daily activity in the weekly schedule.

For ELVs, the movements of the hands and arms are hampered by the PPE used, such as glove thickness and protective hoses. They also report great physical exertion in relation to movements with one arm extended and the other flexed, or both extended or both flexed, above the level of the shoulders and trunk flexion. At the time of the research, all ELV interviewees mentioned injuries and pain in the arms, forearms, wrists, elbows, and shoulders associated with vegetation pruning, as also pointed out by Gonçalves et al., (2021).

Added to this factor are the physical implications for the body as a result of constant exposure to climatic conditions of high temperature, heat, humidity, wind, and others, enhancing work overload (Traldi, 2022).

Although there is a standard step, as an organizational norm that describes how the execution of the task should occur, it was identified that the postures adopted by electricians are due to the contextual variabilities of the work, such as type of vegetation – thick, thin, longer or shorter branches and trunks, reach of vegetation, reach of the crane, presence of venomous animals or bird nests, unevenness of the asphalt, power of the pruning, others. Within this analysis of real work (Guérin*,* et al*.,* 2001), it is also possible to consider human variabilities that are centered on the worker's age, fatigue due to exposure to overload factors, experience and others.

The research by Traldi et al., (2023) carried out in the electricity sector points out that the adaptation of postures and the way of performing ELV work in jobs like this are fundamental for the quality of work and the preservation of health and safety.

### 3.2. Cluster analysis

The ELVs reported the difficulties inherent to the activity of pruning vegetation and the occurrence of injuries directly related to this activity. However, other body parts can be greatly affected without a direct relationship being perceived considering this activity. In this context, the kinematic data, especially on the neck joint, pointed to an important influence when using the support prototype.

When performing the *cluster analysis*, two distinct clusters were identified . These *clusters* were named *Cluster* 1 and *Cluster* 2 and the analysis was focused on the angles of the neck joint in the sagittal plane.

**Cluster 1: "poda_Conv"** This cluster gathers observations associated with conventional pruning with hydraulic pruning. The values of angles grouped in this cluster are characterized by the execution of conventional pruning. These observations present characteristics and behaviors of conventional pruning that is close to conventional pruning in a real situation, as reported by ELV itself.

**Cluster 2: "poda_ProtSup"** In this cluster, values of angles in which the support prototype was used are grouped The observations in this cluster present common characteristics that indicate the use of the hydraulic pruning support prototype.

With the application of *cluster analysis*, the identification of these two *clusters* offers an approach to understand different trends or patterns in the data, associated with the adoption or not of the support prototype. This analysis plays an important role in supporting objective decisions for the identification of distinct subgroups within the study population (Figure 5).

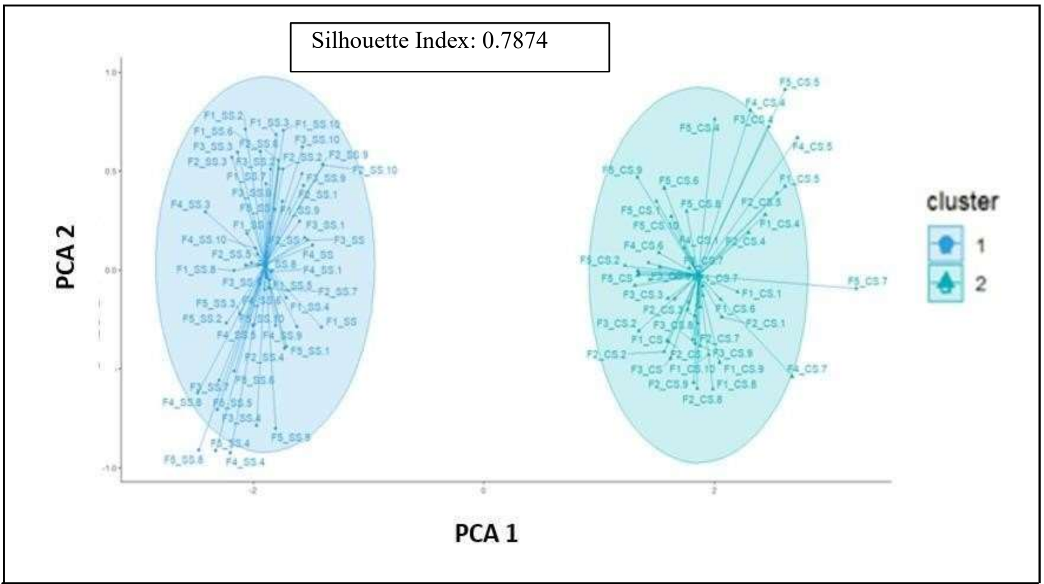


**Figure 5:** Cluster Analysis: Patterns Identified in Pruning Activities - Cluster 1: poda_Conv, Cluster 2: poda_ProtSup

The *cluster analysis* applied to the data resulted in the formation of two *distinct clusters*, with a Silhouette Index of 0.7874. This value indicates a good separation and compaction of the *clusters*, reflecting the similarity of the observations within each *cluster* and the dissimilarity between the *clusters*. The high value of the Silhouette Index suggests that the data were grouped coherently and that *cluster* analysis was effective in identifying patterns and structures in the data. These results allow a deeper and more refined understanding of the relationships and characteristics present in the data set under study, contributing to future investigations and decision-making based on the findings obtained through *cluster analysis*.

The results showed that when using the support prototype (poda_ProtSup), the ELV (a) performed the activity according to the pruning protocol and (b) during this procedure the angle values (figure 6) were lower in relation to conventional pruning (poda_Conv). Thus, considering that the main function of the prototype is to reduce the load of the pruning instrument, the longer permanence in these conditions ('a' and 'b') indicates that the ELV will have less physical wear, as well as the reduction of injury occurrences.

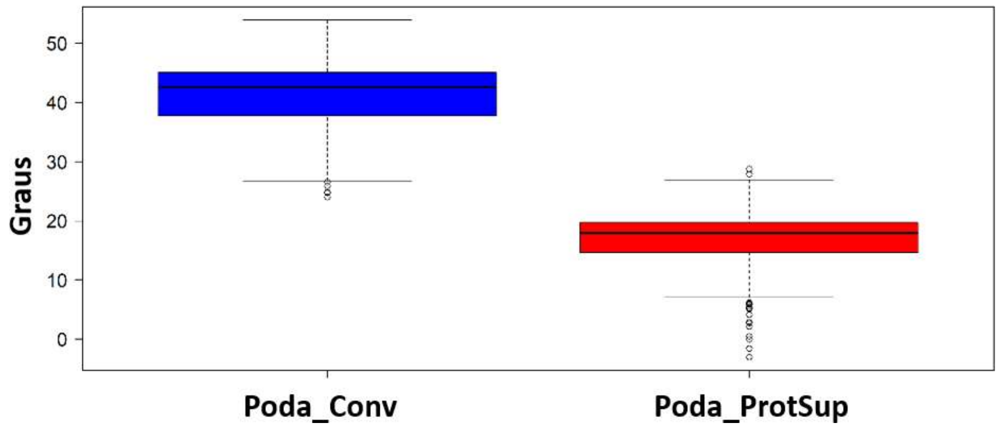


**Figure 6:** Angle variability (*Boxplot*) in the sagittal plane during pruning activity (poda_Conv and poda_ProtSup)

It was found that neck joint angle values (median, figure 6) in the poda_Conv was approximately 147% higher than the values obtained with the poda_ProtSup. This discrepancy highlights the importance of the support prototype in reducing the angles of the neck joint and highlights its relevance in the context of ergonomics and safety of workers who use hydraulic pruning. The results of this study provide a solid basis for the implementation of preventive measures and intervention strategies aimed at minimizing the risks associated with postures that are harmful to health during the operation of hydraulic pruning.

The study (Jacquier-Bret et al., 2023) employed the cluster analysis technique to examine common postures during lymphatic massage sessions performed by physical therapy professionals. By discerning different postures based on joint angles, variations, and relative frequency, a more accurate ergonomic assessment was made possible, resulting in the mitigation of potential musculoskeletal problems. The findings highlight the effectiveness of *cluster* analysis in identifying significant patterns and clusters, with applicability to optimize ergonomic conditions in work scenarios.

Similarly, another study (Andersen et al., 2021) investigated the effects of combined ergonomic exposures on the development of musculoskeletal pain. Through *cluster* analysis using *k-means*, the researchers identified nine *clusters* based on ergonomic factors and observed that clusters with high combined ergonomic exposures had higher pain intensity. The identification of these *clusters* provides a way to understand the different trends and patterns related to the use or not of the support prototype, contributing to more robust decision-making and to the identification of distinct groups within the population of interest (Andersen et al., 2021). Thus, they underscore the importance of combined ergonomic occupational exposures and highlight the need for preventive approaches in the workplace. These results are consistent with the findings of the present study, which identified two distinct *clusters* based on the angles of the neck joint during vegetation pruning, conventional pruning and the use of the support prototype.

In the context of another study (Hu et al., 2022), an examination of the patterns of balance restoration after slips was carried out, and their link with the possibility of falls resulting from these slips. Using the hierarchical cluster analysis approach, the researchers were able to discern three discrete patterns of balance recovery, associated with different levels of fall risk. These findings broaden the understanding of the mechanisms underlying balance recovery in slip scenarios, and have the potential to inform the creation of fall prevention strategies. (Hu et al., 2022).

Similarly, the results of the present study show the existence of two distinct groupings based on the angles of the neck joint during the activity of vegetation pruning. These groupings suggest the presence of varied behaviors and characteristics, possibly related to the adoption or not of a support device under development. The use of *cluster analysis* in this context provides a more precise apprehension of the relationships and traits intrinsic to the data, contributing to the identification of relevant patterns and structures.

From a methodological point of view, *cluster* analysis proved to be an effective approach in identifying intrinsic patterns and relevant groups in the analyzed datasets, contributing to a better understanding of the phenomena studied and providing important insights for the prevention of musculoskeletal disorders and informed decision-making. In terms of results, the present study presented data that corroborate studies in the literature, which used *cluster* analysis in different contexts, such as the analysis of generic postures in lymphatic massage and the investigation of the effects of combined ergonomic exposures and balance recovery patterns.

## 4. Conclusion

The task of vegetation pruning, as it is performed in the electricity company studied, has considerable impacts on the ELV, especially in terms of physical overload due to the frequency, intensity and repetitiveness with which it occurs. The research presents how the real work of electricians and the postures and movements adopted by them in the execution of the work result from the contextual and human variabilities present in the work situations.

The *cluster analysis* revealed the existence of two distinct groups. One composed of actions in the poda_Conv and the other with the use of the support prototype (poda_ProtSup).

The identification of *clusters* provided robust insights into the trends and patterns present in the data, allowing for a deeper understanding of the characteristics and behaviors related to the utilization of the support prototype. These findings may provide the basis for preventive measures and intervention strategies aimed at minimizing the risks associated with postures that are harmful to health during the operation of hydraulic pruning. Thus, cluster analysis using the K-means method, with a Silhouette Index of 0.7874, confirmed the effectiveness in identifying patterns and structures in the data, providing a solid basis for future investigations and decision-making based on the results obtained.

The results of this study focused on the values of neck joint angles (sagittal plane) during vegetation pruning. When using the support prototype (poda_ProtSup), the angle values were lower in relation to conventional pruning, indicating a more adequate posture and less overload on the neck joint. This finding points out positive aspects of the support prototype from the point of view of biomechanics and ergonomics, aiming at the safety of workers who use hydraulic pruning. [2]

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