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Review

A Review on Ergonomics in Agriculture. Part II: Mechanized Operations

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Received: 23 February 2020; Accepted: 15 May 2020; Published: 18 May 2020

Abstract: Background: Musculoskeletal disorders (MSDs) have long been recognized as the most common risks that operation of agricultural machineries poses, thus, undermining the ability to labor and quality of life. The purpose of this investigation was to thoroughly review the recent scholarly literature on ergonomics in agricultural mechanized operations; Methods: Electronic database research over the last ten years was conducted based on specific inclusion criteria. Furthermore, an assessment of the methodological quality and strength of evidence of potential risk factors causing MSDs was performed; Results: The results demonstrated that ergonomics in agriculture is an interdisciplinary topic and concerns both developed and developing countries. The machines with driving seats seem to be associated with painful disorders of the low back, while handheld machines with disorders of the upper extremities. The main roots of these disorders are the whole-body vibration (WBV) and hand-arm transmitted vibration (HATV). However, personal characteristics, awkward postures, mechanical shocks and seat discomfort were also recognized to cause MSDs; Conclusions: The present ergonomic interventions aim mainly at damping of vibrations and improving the comfort of operator. Nevertheless, more collaborative efforts among physicians, ergonomists, engineers and manufacturers are required in terms of both creating new ergonomic technologies and increasing the awareness of workers for the involved risk factors.

Keywords: biomechanics; musculoskeletal disorders; ergonomics; risk factors; vibration; agricultural machinery

1. Introduction

Agriculture provides food, raw materials for other industries and employment opportunities. As a consequence, given the key role of agriculture in global economy, safety and health of its employees are regarded to be of major importance. However, rural occupation involves a considerable number of harmful illnesses. Epidemiological studies have identified several health problems such as cancers, respiratory and pesticide-caused diseases, hearing loss and musculoskeletal disorders (MSDs) [1–3]. The most widespread and alarming non-lethal disease among farmers is considered to be the MSDs [4]. Manual operations such as harvesting and pruning are very common, in particular in developing countries [5]. These tasks involve working in awkward postures, prolonged and repetitive trunk bending, kneeling, heavy carrying and lifting, which constitute the main risk factors for the pathogenesis of MSDs [6,7].

Nowadays, mechanization in agriculture covers most farming operations as a means to lessen intensive manual labor, optimize timeliness of the tasks and increase productivity [8]. Nevertheless, in many cases, the introduction of machinery did not eliminate the health problems of workers.

Operators of the agricultural machines, for example, are exposed to engine fumes, harvesting dust and whole-body vibration (WBV) effects [5].

The definition of WBV according to the European Directive 2002/44/EC [9] is: "*The mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine*". Experiencing of high levels of WBV can either cause or worsen back injuries. Intensive and frequent vibrations, long durations and severe shocks contribute to the aggravation of MSDs. Overall, WBV can be as vital as manual and repetitive carrying of heavy loads and awkward postures (such as stooping) in provoking low back pain and injury [10]. Taking also into account that usually agricultural workers are exposed to a series of risk factors, because of the both manual and mechanized nature of the executed tasks, the epidemic proportions of low back disorders among them appear to be plausible [5–7,11].

An illustrative example of exposure to WBV is the use of tractor. Tractor is considered to constitute a primary origin for severe musculoskeletal injuries to operators [5]. Similar observations have been noted for all-terrain vehicles and other agricultural machines with driving seats. These machines can be particularly dangerous when operating by young adolescents, since they lack the physical size, experience and strength required for the safe operation [12]. Other usually operated self-propelled machines are power tillers, grass trimmers and handheld olive beaters [13–15]. These machines can be very hazardous to the workers, mainly because of the high levels of vibrations at the upper extremities, resulting from the contact of the hand with the handles. The sustained exposure to this kind of stresses may provoke the well-known hand–arm vibration syndrome (usually abbreviated as HAVS in the relative literature) that can affect the blood vessels, muscles, nerves, joints and connective tissues of forearm and hand [16,17].

The vibrations, which are generated due to the engine operation and ground roughness, are transferred to the operator as a result of the body's contact with the seat, the cabin floor and handling operating tools [18]. WBV exposures regarding on-road vehicles are principally along the vertical axis (z). On the other hand, concerning the off-road vehicles, WBV is developed not only along z axis, but along the fore-aft (x) and lateral (y) axes [19] as well. Long-term high-level vibration can result in degenerative changes of joints, especially of lumbar spine [20]. Such multi-axial exposures of WBV can increase the rotational forces and shear in the spine as well as enlarge the muscle loads for the purpose of counterbalancing the head and torso inertia. Moreover, the long-lasting working period can lead to the impairment of the soft tissues of the neck and low back. These injuries are known as "precursor of musculoskeletal injuries" [21].

Manufacturers try to improve the comfort of tractors by designing active seats, front suspension as well as cab suspension systems. However, all these measures lack of a focused line to determine tractor comfort. Most seats do not take into account the multi-axial features of WBV during the operation of agricultural machines and commonly have a single-axial passive suspension system. This ascertainment may elucidate the concerning high incidence rates of low back injuries presented in operators of off-road vehicles [22]. Although suspension seats were developed to take into account the multi-axial nature of vibrations, their efficacy on reducing the muscle loads on the low back and neck has not been systematically evaluated [19].

Ergonomics includes the risk factors identification for the pathogenesis of MSDs, the examination of the root causes and also the development and evaluation of the resultant interventions to both production efficiency and workers' safety. In our recent review study [7], ergonomics in manual agricultural operations was investigated, including tasks such as harvesting, pruning, heavy carrying and lifting. The present comprehensive review study focuses on the overview of the most important results regarding ergonomics in agricultural mechanized operations. To this end, the recent scientific articles engaging with ergonomics were exploited to capture the current advancement and determine the main risk factors for MSDs. In addition, geographical distribution of all contributing research organizations is presented along with the research areas dealing with this topic, since ergonomics in agriculture is a relatively new scientific field. It was introduced due to the awareness of the health problems originated from MSDs and their epidemic proportions among farm workers worldwide.

The next section presents a brief description of the spinal anatomy, biomechanics and negative impacts of WBV and hand-arm transmitted vibration (HATV) on the health of agricultural workers, since the present literature survey demonstrated that vibration is the major risk factor. This section is necessary for the comprehension of the basic biomechanics and terminology, thus, making this work accessible to a large variety of readers. The implemented methodology together with the search engines and exclusive criteria are described in the "Methods" section that follows. In addition, the procedure performed for the assessment of the methodological quality of the reviewed studies is presented in this section along with that for strength of evidence of potential risk factors provoking MSDs. The "Results" section comes next, which is sub-divided into four subsections. These subsections refer to a preliminary data visualization, a brief presentation of the relevant studies, an assessment of their methodological quality and a summary of the methodologies, ergonomic interventions, main risk factors and other important aspects. Furthermore, since each agricultural machine involves dissimilar risk factors, a first classification based on the studied machinery was made and analyzed in a different subsection in pursuance of better investigation of the outcomes. Finally, concluding remarks are summarized in the "Discussion" section along with "Study strengths and limitations".

2. Spinal Anatomy, Biomechanics and Health Effects of Whole-Body and Hand-Arm Transmitted Vibration

Some fundamental description on the spinal anatomy, as well as biomechanics and health effects pertaining to WBV and HATV, is provided in this section for the sake of better comprehension of the terminology and the involved pathology.

2.1. Spinal Anatomy

As far as the machineries with driving seats are concerned, the principal support of the body is provided by pelvis, spine, feet and legs. More specifically, the spine allows for trunk flexion and twisting along with absorbing vertical shocks [23]. The spinal column is formed from 33 vertebrae, which are kept together by ligaments. As it can be depicted in Figure 1, the vertebrae are further subdivided into cervical, thoracic and lumbar vertebrae as well vertebrae attached to sacrum and coccygeal [23]. An intervertebral disc exists in between adjacent vertebrae. Each disc forms fibrocartilaginous cushions that serve as shock absorbers, thus, protecting the vertebrae. They also allow for slight motion of the vertebrae and function as ligaments for holding the vertebrae together [24]. Regarding the seat design, the positioning of the sacral and lumbar vertebrae is particularly significant since these vertebrae together with the muscles and discs support almost all the spinal load. One comfortable posture should guarantee the normal position of the lumbar curve, while the back muscles must be relaxed. Finally, blood has to circulate normally.

In addition, the vertebrae are held in place by muscles and tendons. Any change from the natural spinal position produces correspondingly stains on the spinal muscular system. The seat comfort of operator relies on providing muscular relaxation while, at the same time, stabilizing the trunk. It also depends on the extent at which the seat properly fits to the worker [23]. Anthropometric characteristics vary considerably with gender, height, mass, age and nationality of the operator. For example, studies such as [23,25] have concluded that there is an important discrepancy between the western anthropometric data and that of Indian workers. Not suitable seats and equipment can result in excessive physical effort that, in turn, may develop MSDs.

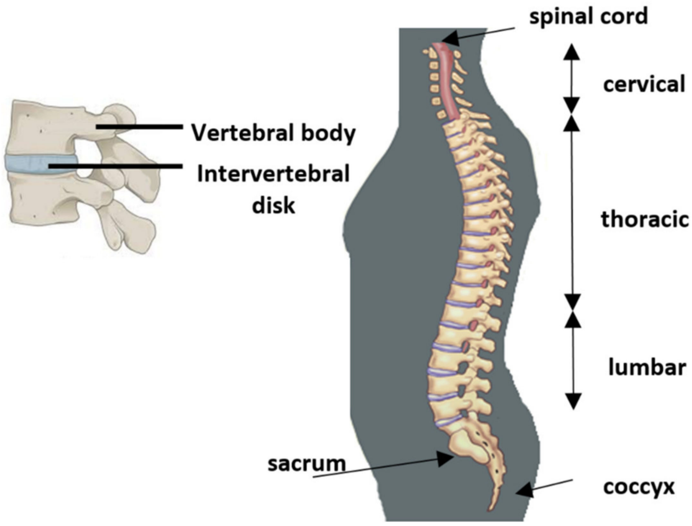

Figure 1. Basic spinal anatomy.

2.2. Biomechanics and Physiological Effects of Vibration Exposure

All objects have a characteristic vibration frequency, which is called resonant frequency. When this value is reached, the system oscillates with a larger amplitude compared to the cases at which an equal oscillating force is applied, but at other frequencies. This phenomenon is called resonance in physics. For human beings, due to the existence of different body parts, there are various resonant frequencies [26]. As regards the vertical vibration, the critical range is 4–8 Hz. Strong resonance is observed in the neck region between 3 and 5 Hz. As far as the low back is concerned, the range of the resonant frequencies is around 4.5 Hz [27]. As the levels of vibration gradually increase, the muscles tend to be unnaturally tensed for the purpose of dampen the vibration.

In a sitting position, values between 4 and 7 Hz tend to be the most harmful for the spine [28]. In addition, the transfer of the vertical vibration towards the spine appears to be higher at the standing posture than the seated one [29]. Vibration is transmitted from the source to the operator through the contact surfaces. In operating agricultural machineries with a seat, buttocks are the main contact surfaces. The effects of the exposure to vibration depend on different external factors, like the composition and the type of the seat, the kind of shoes as well as the entire body posture. The thresholds of resonant frequency also diversify among individuals. Overall, the consequences of vibration on operators rely on its magnitude, direction, frequency and duration.

Exposure to vibration for relatively short periods turns out not to be very harmful and usually results in increase of heart rate, loss of balance and headaches. On the other hand, prolonged and repeated exposure to WBV can lead to permanent physiological alterations. In particular, since the intervertebral disks and vertebral structures serve as springs and dampers so as to dissipate the energy from WBV, the human spine appears to be affected to a great extent. The two mechanisms that have been recognized are stiffening, as a response to shocks, and softening, as WBV enhances [30]. MSDs, especially in the region of low back, are the most frequently reported effects of WBV [31]. Investigations have demonstrated that at 4.5 Hz, around which the resonant frequency of low back exists, the fatigue of the muscles takes place. This, in turn, modifies the response of the muscles to sudden loads, thus, becoming more vulnerable to injury [27]. Focusing on the microlevel of the spine structure, prolonged movement of intervertebral discs owing to vibration can stress the annular fibers. Subsequently, the levels of pressures increase in the disks and the consequent forces may induce the material to fail. The material fail of the disk can make it to protrude from the vertebral system. This movement can press the spinal nerves and develop low back pain [32].

As far as the HAVS is concerned, it can be defined as a syndrome which includes circulatory disorders, such as "white finger", as well as sensory and motor disorders like numbness and clumsiness to carry out complex tasks. MSDs can be developed among workers who operate handheld agricultural machineries, as for example handheld olive beaters and power tillers [14,33]. All these components may not be presented in the worker at the same time. Diseases, such as carpal tunnel syndrome, osteoarthritis of the wrist, hand and elbows and bone cysts, have been attributed to HATV [34]. The main risk factor for HAVS is considered to be the duration of the exposure to intense vibration. If the exposure to vibration is discontinued, a partial recovery can occur [34]. Contributing risk factors involve also smoking and previous medical conditions, which can cause neurovascular pathology [35]. Pain in the region of upper limbs is an ordinary complaint of agricultural workers, especially when adverse ergonomic factors exist.

3. Methods

3.1. Identification of Relevant Studies

With the objective of seeking for recent articles related to ergonomics in agricultural mechanized operations, the common search engines of Google Scholar, Scopus, PubMed and ScienceDirect were used. In addition, Boolean keyword combinations of "agricultural machinery", "ergonomics", "biomechanics", "risk factors" and "musculoskeletal disorders" were conducted. Once we were identifying a study, we made a methodical survey within the website of the journal in which the study was published with the intention of detecting further studies. Subsequently, we scanned the references of the selected articles in order to find papers that had not been recognized via the initial search process. This procedure was repeated till no further investigation occurred. The last search took place on 15 December 2019. The title and abstract of the resultant journal papers were subsequently reviewed. Finally, the full text of each study was read to identify its appropriateness. All the co-authors discussed on the content of the selected papers and some of them were excluded, because they did not meet at least one of the inclusion criteria described below.

Overall, four basic inclusion criteria were considered: (a) the topic is associated with agriculture, (b) MSDs provoked by machinery operations are examined, (c) the article was published between 2010–2019 and (d) the journal has an impact factor larger than 1. Conference and non-English papers along with Master and Doctoral Theses were not included. Studies focusing on ergonomics in livestock, fishing and milking were also excluded. Consequently, peer-reviewed journal papers were only taken into account for the present investigation dealing with farming. In total, 32 journal papers were encompassed, while a first classification was accomplished in accordance with the type of the machinery they investigated. Different publishers contributed to this review, including Elsevier, Taylor & Francis and MDPI. Finally, older review studies, such as [16,31,36–41], were identified that constituted the sources for useful information. A flowchart regarding the present methodology and in which phase each criterion was imposed is illustrated in Figure 2.

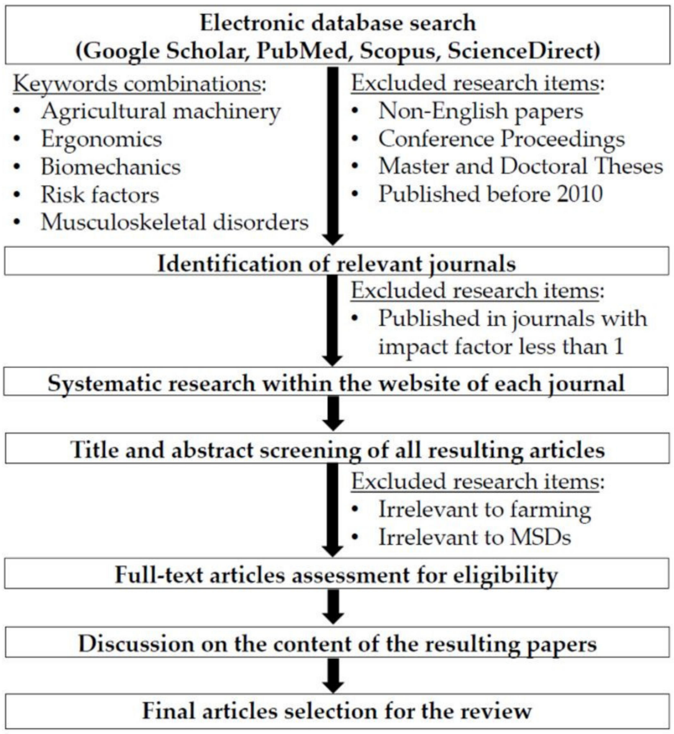

Figure 2. Flowchart of the present survey methodology.

3.2. Methodological Quality Assessment

Evaluating the risk of bias in the methodology of the selected studies is a key step in carrying out and interpreting systematic literature reviews. To this end, a rigorous assessment of the methodological quality can help to capture the possible causal distribution of the risk factors without overestimating or underestimating them. In the present systematic review, the risk of bias tool developed by Hoy et al. [42] was used similar to relevant studies such as [43]. This tool consists of 4 and 6 items concerning the external and internal validity of each study, respectively, as well as a summary item for the overall methodological quality assessment. In fact, these items are yes–no questions focused on identifying potential bias in sampling and measurement methods. If there is insufficient information to judge a particular item, the answer is "No" [42]. For articles not involving participants, such as those developing biomechanical models, some items were filled with "C" representing "Can't say" similar to [43]. These items were not taken into account in the final score of each study. Three reviewers (LB, DT and DB) answered all the questions of the aforementioned tool for each study independently. A consensus meeting was taken place to compare the results and discuss on the final answer. For the cases with "C" additional criteria, such as clearly stated objective, proper validation of the model, measurements in a standard and reliable way, were taken into account in the final decision.

Subsequently, the methodological quality of each study was rated as high (++), acceptable (+) or low (-), indicating low, moderate or high risk of bias, respectively, based on the approach followed by [44]. Each study could be scored from 0–100% depending on the number of "Yes" answers in the 10 questions of the tool of Hoy et al. [42]. The average method score of the 32 selected studies was defined as the limit point, beyond which high methodological quality was considered. The studies that scored between 50% and average value were rated as acceptable, whereas those below 50% were labeled as having low methodological quality.

3.3. Strength of Evidence of Potential Risk Factors Causing MSDs

Based on [45], the strength of evidence of potential risk factors for the development of MSDs among operators of agricultural machineries is classified as follows: *"(i) Strong evidence: consistent* *findings in multiple high-quality cohort or case-referent studies, (ii) moderate evidence: consistent findings in multiple cohort or case-referent studies, of which only 1 study was of high quality, (iii) some evidence: findings of 1 cohort or case-referent study, or consistent findings in multiple cross-sectional studies, of which at least 1 study was of high quality, (iv) inconclusive evidence: all other cases (i.e., consistent findings in multiple low-quality cross-sectional studies, or inconsistent findings in multiple studies). Inconclusive evidence was defined as findings of only 1 cross-sectional study, irrespective of the quality of the study*". Cross-sectional, cohort and case-referent (or case-control) studies are also called observational studies and sometimes are the only feasible method to investigate various problems [46]. Strong, moderate and some evidence of a risk factor gives high, moderate and low assurance, respectively, that the evidence demonstrates the true effect. In contrast, inconclusive evidence does not allow for a safe conclusion to be drawn.

4. Results

4.1. Preliminary Data Visualization Analysis

Graphical representation of data, via the use of pie or bar charts as well as maps and graphs, can offer an accessible approach to illustrate and comprehend the current trends and patterns of data. The so-called data visualization analysis has gained increasing attention recently. In particular, data visualization is critical when it comes to analyzing massive amounts of data and making data-driven judgments. Moreover, it can produce important results for the purpose of identifying: (a) the most contributing organizations at international level, (b) relevant international journals and (c) current trends [47]. In this subsection, a preliminary data visualization analysis is presented in order to fulfil the aforementioned aspects.

4.1.1. Geographical Distribution of All Contributing Research Organizations

First of all, the geographical distribution of the organizations engaging with the present topic was tried to be captured. For this purpose, the affiliation of the author was considered as an indicative specimen. In the studies involving more than one author, each nation participated only once. Figure 3 illustrates the geographical spread of the contributing organizations. Each color corresponds to different contribution, while the official country abbreviation codes were set.

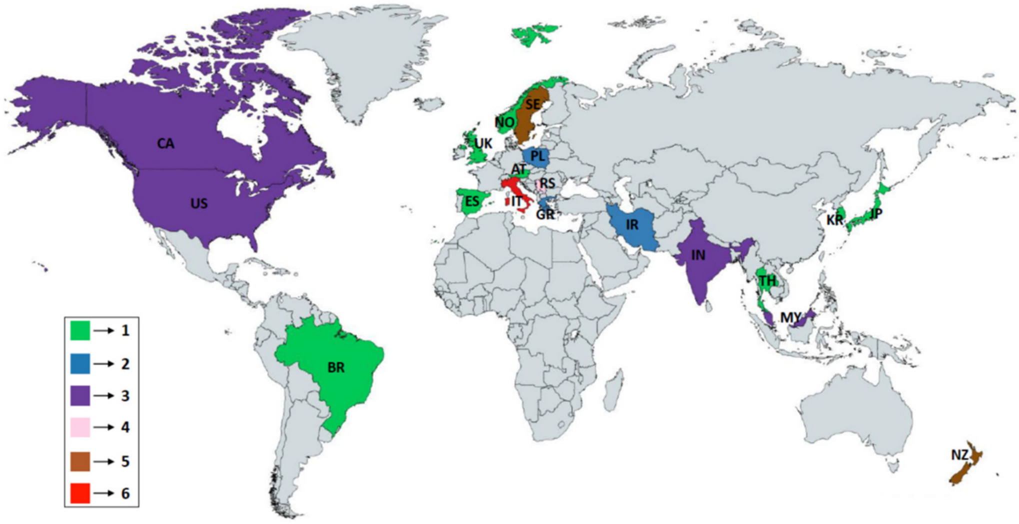

Figure 3. Geographical distribution of all contributing research organizations.

The concern of MSDs on account of agricultural mechanized operations seems to interest both developing and developed countries. Remarkably, no contribution was found from Africa, probably because most rural tasks there are still curried out manually as well as there are fewer existing research organizations compared to the developed countries. Considerable contribution was observed from Italy (IT, 6 papers), New Zealand (NZ, 5 papers) and Sweden (SE, 5 papers). Serbia (RS) followed with 4 articles, while India (IN), Malaysia (MY), USA (US) and Canada (CA) came next with 3. Greece (GR), Poland (PL) and Iran (IR) participated with 2 investigations, whereas Brazil (Br), Spain (ES), United Kingdom (UK), Norway (NO), Austria (AT), Thailand (TH), Korea (KR) and Japan (JP) contributed with one study. In total, the biggest source of the present literature survey was Europe whose organizations were involved in 23 papers. Finally, research on ergonomics in agricultural machinery spreads also in South Asia (9 papers), Oceania (5 papers) and North America (6 articles).

4.1.2. Distribution of All Contributing International Journal Papers

Subsequently, the international journals that included the selected articles were examined in order to identify the research areas engaging with ergonomics in agricultural machinery. As can be gleaned from Figure 4, the "International Journal of Industrial Ergonomics" is the central source of the present literature survey with 15 papers, which correspond to almost half of the references. This journal deals with ergonomics in various industries, design of equipment, humans in complex systems and occupational safety. "Applied Ergonomics" and "Ergonomics", which cover similar research areas, follow with much less contribution, namely 3 articles. The "Annals of Agricultural and Environmental Medicine" comes next with 2 contributions whose subject combines agriculture with medicine. Finally, nine international journals participate in this investigation with 1 article. Their research areas include agricultural topics, manufacturing of off-road vehicles, technology of sensors, ergonomics, computational modeling and interdisciplinary sciences that study agriculture in conjunction with medicine, occupational health and safety. As can be concluded from the wide range of research areas as well as the geographical distribution presented in Figure 3, ergonomics in rural machinery is an international, versatile and interdisciplinary issue.

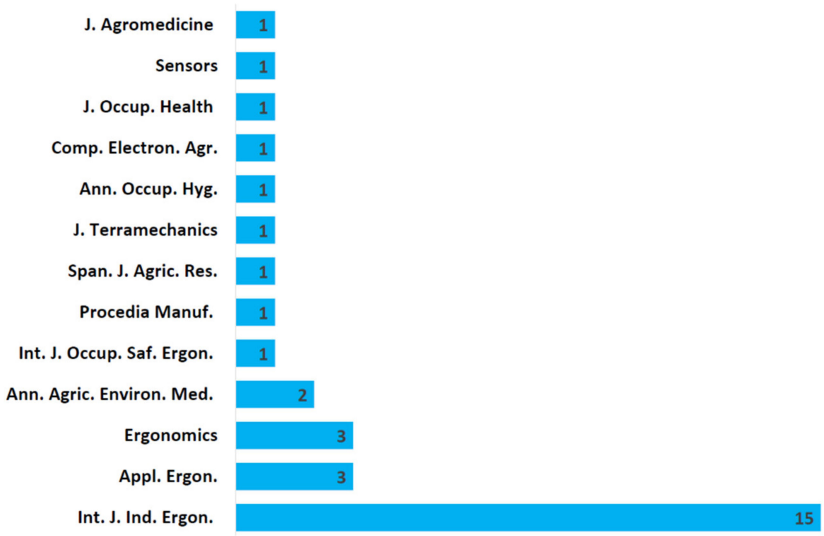

Figure 4. Distribution of all contributing international journals.

4.1.3. Keyword Information Clustering

The keyword information clustering is presented in this subsection in an effort to roughly capture the issues that are going to affect the present investigation. In addition, we got a first idea of the negative consequences of agricultural mechanized operations on operator's health and their root causes. To achieve these goals, at about 155 keywords were collected from the 32 selected articles, which are mentioned in the corresponding section of each journal. Then, out of these keywords the 10 most frequently used ones were identified, which are listed in Figure 5. In this figure, the size of the font corresponding to each word is proportional to its frequency, while the same color indicates equivalent occurrence.

Figure 5. Keyword information clustering of the relevant papers.

Clearly, "agriculture" is the most usual keyword due to the field of this study. The keyword "whole-body vibration", which follows divulged the main risk factor for the development of MSDs in agricultural machinery. The word "tractor", that comes next, seems to be the principal risky agricultural machine, probably owing to its versatile and frequent use. Apart from WBV, the "hand–arm transmitted vibration" appears to have contributed to a great extent, primarily because of the inclusion of machineries such as grass trimmers, handheld olive beaters and power tillers. These machines are notorious for the HATV. The "low back pain" that follows indicates the most affected body part during agricultural activities in general, which is in accordance with the relative published works [48–53]. The keyword "seat" that appears afterwards shows the efforts for ergonomically designed seats in order to improve the comfort of the operator. "Ergonomics" is plausibly presented, since it is the subject of this review study, however, with relatively small incidence than we expected. This is conjectured to occur as a result of the relatively smaller number of the existing ergonomic interventions comparing to the urgency of MSDs in agricultural workers.

Three keywords are presented with equal frequency which are depicted with the same color. The first one is associated with the "comfort", which an operator seeks for, "shock" with the frequent jolts, that an operator experiences, and "all-terrain vehicle" with the second most examined machinery of this review study. Finally, frequently presented keywords, however with less incidence, were "safety", "health" and "musculoskeletal disorders" which are obviously related with the injuries caused from mechanized operations. Moreover, "electromyography" was presented, which is a medical procedure for assessing the electrical activity of muscles, as well as "suspension" denoting the systems which are utilized for lessening the vibration levels.

In brief, there seems to be a strong relationship between the above keywords. Apart from agriculture that plausibly appeared, the riskiest agricultural machines were presented, namely tractor and all-terrain vehicle. The main risk factors were also gleaned from this analysis, namely WBV and HATV, the health impact of which was elaborated in the Section 2. The principal reported MSD for operators, namely low back pain, appeared that made physicians to engage with this field. Furthermore, ergonomists and manufacturers have cooperated with physicians to develop ergonomic interventions such as comfortable seats and suspensions justifying the words "comfort" and "seat". The analysis that follows supported the frequency of these keywords, while also other aspects were found and investigated.

4.2. Brief Review of Literature Classified into Agricultural Machinery Types

4.2.1. Tractor

The tractor is an engineering vehicle that was specially designed for the purpose of providing the power to automate several agricultural tasks. Operating a tractor includes a variety of actions such as operating levers, buttons, clutching and braking pedals, steering and looking behind as a means to maneuver and observe the machine. The above acts influence the sitting posture and loading on the parts of the body. Prolonged sitting on the seat of tractors along with the aforementioned factors seems to contribute to MSDs that workers complaint for. Finally, it is widely known that operators are exposed to high doses of WBV during common agricultural operations originated from both the engine and the ground [20]. High levels of vibration lead to the discomfort of the operator and the increased risk for low back, shoulders, neck, knees and spinal pains. The probability of experiencing these kinds of discomforts seems to increase with age. The host of MSDs, coming from the use of tractors, justify the relatively large number of journal papers found in the literature within the last decade that are going to be presented below in brief.

The importance of the anthropometric characteristics and isometric muscle strength was highlighted by Dewangan et al. [54] and Feyzi et al. [55], who investigated Indian and Iranian workers, respectively. In fact, the discrepancy between the existing standards for tractor controls and the real ones can lead to overexertion, which is a critical risk factor for the emergence of musculoskeletal injuries. In [54], the push and pull strength of the right hand as well as the strength of the right leg and foot were substantially higher as compared with their left sides. In [55], the results demonstrated the inappropriateness of the international standards. Furthermore, anthropometric features were used by Kuta et al. [56] as a means to improve safety through the adaptation of a steering panel. In particular, they measured the dynamic load of various body parts, such as the arms, wrists and forearms with surface electromyography by taking into account the steering column and the angle that is formed between the arm and the forearm. The results revealed that the most convenient position regarding the hands was at the elbow angle of 100° and when the inclination angle of steering column was close to 50°.

The measurement of WBV via triaxial accelerometers was the subject in [57] and [52] regarding farms in Poland and prairies in Canada, respectively. Solecki [57] evaluated the annual exposure to WBV in the x, y and z directions on the operator seat. It was noted that the highest total vibration doses took place in August and April, whereas the maximum mean daily exposure appeared during April, August, September and October. On one hand, the high values appeared in August were attributed to agricultural activities related to soil cultivation, cereal harvesting and transport. On the other hand, in April tedding and raking hay, spreading of fertilizers, disc harrowing, spraying and transport were responsible for the high vibration levels. Concerning Zeng et al. [52], they found that the maximal measurements were in the vertical axis. Interestingly, the 41.4% of the measurements in the vertical axis were within or above the caution zone of the health guidance. Furthermore, shocks occurred, which are considered to be the principal risk factor for the development of low back pain.

The influence of implements, which can be added to the tractor, on the vibration levels was studied by [18,58]. In [18], the longitudinal WBV occurring in tractors having a large square baler was assessed. Considerable WBV was observed during downhill driving with four-wheel drive. The authors suggested simple control of four-wheel drive operation for reducing the vibrations. In [58], different tractor types and speeds having three tillage implements (namely a plough, a disk harrow and a cultivator) were examined. The tractors seem to play the primary role in the development of vibration along the lateral axis, while the implements along the horizontal axis, with the plough displaying the highest vibration. Optimal combination between tractor and implement, tractor and speed as well as 3-point shock absorbers (designed for the implements) were suggested by the authors for attenuating the vibration levels. The significance of lateral vibration was also highlighted by Gomez-Gil et al. [48]. They inferred that the lateral vibration levels can be higher than the vertical ones, while the former tend to increase linearly with the height above the ground of the tractor seat. It was seen that a 30 cm reduction of the tractor seat height can decrease the lateral vibration by approximately 20%. In contrast, the vertical vibrations are hardly affected by the height above the ground.

The adjustment of electronic speed on the vibration levels of a tractor was investigated by Loutridis et al. [59]. The electronic regulator offers the opportunity for operation with a constant speed mode regardless of the load. Vibration levels on the seat were measured for the tractor driving on an asphalt road at different speeds, namely at 20, 25 and 28 km/h. The weighted acceleration was found to be larger for the case of electronic speed adjustment. Conversely, during cultivating at various speeds, namely at 6, 7.5 and 9 km/h, the vibration by utilizing the speed adjustment were observed to be lower comparing to the normal operation. The effect of different speeds as well as various surfaces with different tire pressures and tractor masses was investigated by Deboli et al. [60]. In particular, the vibration values along with acceleration transmissibility concerning the three axes were estimated on both the seat and the cabin platform. This investigation demonstrated that the accelerations of the seat along the x and y axes are affected by the pitching and rolling movements. According to authors, manufacturers should decrease these implications by using suspension systems in these directions.

Kim et al. [19] carried out a laboratory-based investigation in order to evaluate the effect of a single- and multi-axial suspension seat on lessening the exposure to WBV and physical fatigue of the major muscles of neck and low back during driving agricultural tractors. To this end, a motion platform simulated the tractor environment by applying the 24-minute field-measured profiles of vibrations. These data appertained to smooth paved and gravel roads, farm fields and extravagant off-road terrain. The outcomes showed that the multi-axial consideration can reduce the lateral vibration exposures and the associated muscular fatigue in the low back and the neck. The effect of the type of the terrain was also examined in [61], which aimed at assessing the convenience of tractor seats during harrowing and haying while driving the tractor on ridges and asphalted surface. Moreover, an approach relied on the pressure mapping was utilized to evaluate the comfort of the seats. The derived pressure indices were considered to be particularly useful tools for the seat mapping and comparing the seats that are available on market on the basis of the buttocks–seat interface under dynamic circumstances.

The influence of vibrations on the tractor operator was also investigated by biomechanical models in [62,63]. Mehta & Tewari [62] estimated the compressive and shear loads on the tractor operator lumbar vertebra while seating with different cushion materials for the back. Seven seat cushion materials with various thicknesses and compositions were tested. The maximal compressive forces were observed for the case of coir cushion having a thickness of 80 mm, whereas the minimum ones appeared when a high-density polyurethane foam was utilized with a thickness of 44 mm. In [63], the influence of vibrations on the operator was evaluated, via kurtosis and skewness approaches, with reference to their intensity and signal form. Two instances were studied, which were the cases without shocks and with several shocks (during transportation). Ground roughness was found to cause vibrations within the 0–30 Hz range. On the other hand, the engine generates vibrations at 50–200 Hz. Overall, kurtosis method was proved to better demonstrate the difference between the signals.

Ergonomic interventions that reduce the risks regarding older farmers were examined by Caffaro et al. [64] via questionnaires. Most participants reported some discomfort with mounting/dismounting the tractor, while an additional step was declared to be particularly helpful. Moreover, twisted postures, which are required for attaching trailers and implements, caused back pains. Introduction of rear-view cameras and mirrors was mentioned to be beneficial to prevent from awkward postures of neck and trunk. Remarkably, overconfidence, coming from their experience, was observed to decrease the risk awareness. In fact, it seems that WBV in conjunction with rotation of the trunk tends to be the reason for MSDs. This hypothesis was investigated by Morgan & Mansfield [49], who summarized the current opinion of experts. Results showed that simultaneous exposure increases the risk for low back pain. In addition, discomfort on the right shoulder and thighs was reported when exposed to combined risk factors.

Finally, the exposure risk to WBV originated from different type of tractors, namely six dissimilar track-laying tractors, was examined by Vallone et al. [65]. The experiments were carried out at three sites with different soil textures, namely lithosols, regosols and vertisols. It was demonstrated that the vibration values for 8 h per day were constantly larger than the action value of the daily exposure. Moreover, the characteristics of the soil did not affect the vibration in the x and y axes. However, in the z axis, vibration was affected by the soil type indicating higher levels for regosols and vertisols, i.e., as the soil texture becomes stronger.

4.2.2. Quad Bike

All-terrain vehicles, also named as quad bikes, are vehicles moving at low-pressure tires and having a seat for the driver along with a handlebar for the control of steering. They look like common motorcycles, but more stability is provided via the extra wheels at slower speeds. Quad bikes assist in a lot of operations in agricultural community, such as inspecting of livestock and crops, fertilizing and supervising crews. Additionally, they are frequently used as a substitute regarding the pick-up of horses, trucks and even walking. They are found in nurseries, orchards, forests, etc. Remarkably, they are particularly dangerous when operating by young adolescents, since they lack the physical size, experience and strength required for the safe operation. Operators of all-terrain vehicles were found to be exposed to shocks and WBV, thus, resulting in increased risk for MSDs development, mainly at the regions of low back and neck.

In [12,66–68], Milosavljevic et al. measured the exposure to WBV and mechanical shocks during operating quad bikes in New Zealand with triaxial accelerometers, while a whole-body health surveillance questionnaire was used in all studies. The findings were particularly ominous since the values appeared to exceed the permitted limits. Overall, the main reported pain complaints referred to the muscles of low back. Briefly, taller and overweight drivers, non-flat terrain, high driving velocities, increased distance as well as exposure to WBV were the major risk factors. The authors concluded that a combination of interventions is prerequisite for lessening the exposure to vibration and shocks. These factors should be carefully considered in the design of seats and suspension systems for the purpose of reducing vibration exposures.

Kociolek et al. [69] explored the exposure to head and neck vibrations when operating a quad bike in typically found terrains. The vertical axis acceleration was higher at the regions of head and neck when compared with the seat. In addition, a strong relationship was observed between the vertical vibrations on the seat with the corresponding ones on the head. In a different manner, Mani et al. [70] investigated several operations, namely the bipedal and unipedal stance and limits of stability as well as lifting in an effort to assess the postural control during functional activities. The postural control was derived from the center of pressure displacements. The outcomes indicated an important increase of the center of pressure regarding the lifting task.

4.2.3. Grass Trimmer

The grass trimmer, which is also known as weed whacker, is a handheld machine that utilizes a flexible polymer string that is mounted on the head of the cutter. An internal combustion engine powers this device, which is equipped with a shoulder strap, while the output engine flange is linked to a rigid shaft via a flexible shaft. Grass trimming is a thorough repetitive task that is usually operated in discomfort postures. Thus, MSDs can be developed mostly at the upper limbs. Finally, the HATV is known to provoke restricted flow of the blood and injury of the nerves of fingers, as it was described in the Section 2.2. Three journal papers were found in this field.

Hao & Ripin [15] applied a new method, namely a node technique, for lessening the vibration levels over a practical range. In their investigation, frequency analysis, miniature triaxial accelerometers, calibrator, FFT analyzer as well as a post-processing software were used. The results demonstrated that the two tuned vibration absorbers successfully decreased the large loop and rear handle deformations, where the node was displaced closer to the handle. Furthermore, field tests were carried out, which showed lessening of acceleration in all axes and total vibration values during cutting operation. In addition, Azmir et al. performed two studies [13,71] aiming at investigating the effect of vibration at hands and arms regarding grass cutter employees in Malaysia. A HAVS questionnaire was utilized in both studies. In [13], a dynamometer (for hand grip strength force measurement), as well as numerical scoring and sensori-neural assessment (through observation of finger phalanxes color alterations), was further used. In addition, in contrast with [71], the sample was divided into two groups, namely a group working from morning until evening and a part-time working group. The results of [13,71] revealed that most workers (interestingly, in both groups) exceeded the exposure action limit values with blanching and numbness of the fingers being noted.

4.2.4. Handheld Olive Beater

Harvesting of olives by using handheld beaters constitutes a time consuming, demanding and repetitive task. Workers use to operate it in awkward body postures and, as a consequence, they are exposed to risks for developing MSDs, especially at the region of upper limbs. Additionally, the vibration transfer via hands and arms can cause similar problems as the ones described in the Section 2.2. Two papers fulfilled the imposed criteria of the present bibliographic survey.

Lenzuni et al. [72] and Calvo et al. [33] investigated the experienced acceleration owing to the operation of the handheld olive beaters. Both studies performed field tests, while the former also used a simulator of the tree (a wooden frame with nine horizontal and nine vertical wires). In [72], laboratory data were found to be statistically consistent with the real field data regarding the front z axis as well as the front and rear x axis. There were significant discrepancies on the accelerations in the rear and front y axis and the rear z axis. In [33], three dissimilar devices were used, while the hand–arm vibration levels as well as the OCRA (occupational repetitive action) findings were beyond the exposure limit.

4.2.5. Power Tiller

Power tiller is a commonly utilized device in agricultural operations such as tillage, cultivation, sowing and weeding. It has a set of blades equipped with a wheeled housing that is powered via an electric motor or a gasoline engine. One of the main apprehensions pertaining to power tiller users is the exposure to high levels of vibration at the hands and arms. This happens because the handle is a cantilever beam and the power is produced via a diesel engine. As occurring in the use of the aforementioned handheld agriculture machines, the vibration is transferred through the hands to the arms and shoulders leading to fatigue and discomfort of the operator. Prolonged exposure for several months and years results in the development of MSDs [73]. One study was found that satisfies the inclusion criteria.

Chaturvedi et al. [14] carried out experiments under three different operational conditions, namely during moving on farm roads, tilling with the use of a cultivator as well as rototilling with a rotavator. The highest vibration levels were observed in x direction. The maximal x-direction rms vibrations were equal to 5.96, 6.81 and 8 m/s^2 during tilling, transportation on farm roads and rototilling, respectively. For the purpose of reducing the vibration, three materials were tested, namely polyurethane, rubber and a mixture of polyurethane and rubber. The results revealed that the maximum reduction was accomplished by implementing the rubber material in all agricultural tasks. Additionally, the average time for incidence of the syndrome of white fingers increased via adoption of the interventions.

4.2.6. Rice Plowing Machine

The rice plowing machine is a special designed power tiller for rice cultivation. The operation of it usually takes place with bare feet and hands that can lead to an ischemic effect in these parts of the body [74]. In addition, it involves HATV with its consequences already having been mentioned above. Moreover, the awkward postures of trunk and wrist during its operation as well as the repetitive movements are responsible for the appearance of some common MSDs, namely hand, wrist and low back disorders, to mention, but a few [5,75,76]. Swangnetr et al. [77] was the only journal study dealing with the subject of the present investigation.

In [77], it was postulated that uncomfortable postures of the whole body and upper extremities worsen the worker performance and constitute risk factors for the pathogenesis of MSDs. A new design with vertical plow handles was proposed for neutral wrist posture. This ergonomic intervention was compared with the horizontal handle design during working on level and uneven conditions of the ground with the use of simulated plowing task. The effect of plow handle and the position of the whole body on grip force along with arm muscle activity was evaluated. The results demonstrated that the proposed handles increase the upper-arm muscle usage between 47–70% for the two ground types compared to conventional handles. Nevertheless, participants felt greater discomfort when utilizing the new handles according to the requested design.

4.2.7. Agricultural Aircraft

The working conditions associated with the agricultural pilots are very demanding and singular, since they are not able to change, to a great extent, their posture. This fact, in connection with the WBV experienced by the pilots inside the cabin, can increase the MSDs mainly located in the low back. The increased fatigue is a risk factor associated with the performance of the pilots and accidents. Agricultural aircraft vibration exposure is a rarely studied field, which justifies the one and only study dealing with the purpose of the current search within the last decade.

Zanatta et al. [78] estimated the vibration levels experienced by pilots in four aircrafts frequently used by Brazilian farmers. Acceleration at the seat was measured with triaxial accelerometer during actual operations. Then, a questionnaire focused on spine musculoskeletal symptoms was filled in by the participants. During all the tests, no exposure of the agricultural pilot took place beyond the acceptable exposure limit value. Nevertheless, under certain circumstances, some over the limit values were reported. Approximately 62% of the participants declared some musculoskeletal discomfort of the spine throughout the last 12 months. According to the authors, actions aiming at controlling the vibration can be implemented such as decreasing the time of the flight and improving the runways.

4.2.8. Various agricultural machines with driving seats

Rice farming typically involves several kinds of agricultural machines with driving seats. Tsujimura et al. [79] conducted a field study in order to investigate the exposure to WBV over one year, which is originated from various agricultural machines in a rice farm. The daily levels were compared with the limits recommended by the European and Japanese societies for occupational health. The vibration accelerations were measured on the seat base and pan of 4 tractors having different implements attached, 2 combine harvesters, one rice-planting machine and one truck that is used for moving the machines. Moreover, the participant filled in a questionnaire about his labor (type of machinery, place, date and working hours). The levels of WBV were observed to be high enough in operations with a combination of high velocities and heavy implements.

4.3. Methodological Quality of the Reviewed Articles

Based on the methodology elaborated in Section 3.2, Table 1 was created. This table includes all the selected studies along with the 11 items (yes–no questions) of the tool developed by Hoy et al. [42] for the purpose of evaluating the risk of bias of the reviewed studies in sampling and measurement methods. The average score, which was utilized as a cutoff value to define articles of high methodological quality, was found to be approximately equal to 75%. According to the criteria analyzed in 3.2, 35.5% of the studies can be characterized as having a high methodological quality that is equivalent to a low risk of bias. Consequently, further research is believed to be very unlikely to alter the confidence in this estimate [42]. Furthermore, 64.5% of the selected studies were labeled as acceptable, which corresponds to moderate risk of bias. As stated in [42], further research is likely to show a significant impact on the confidence in the estimate and may modify it. Remarkably, no low methodological quality studies were found, a fact that is attributed to the relatively high quality of the journals that published the reviewed papers and reinforces the current results. The items that appeared to be the more questionable were those associated with the quality of the sampling. In particular, in several cases the sampling proved not to be a close representation of the national population, while many times only few persons participated in the survey, usually selected with a non-random way. However, in most cases the relatively high quality of the measurement method and the multiple investigated factors counterbalanced this disadvantage.

Table 1. Methodological quality scores of the selected journal papers; 1–4 items correspond to external validity criteria while 5–10 to internal validity criteria [42].

Reference	External Validity				Internal Validity						Overall, Quality
	1	2	3	4	5	6	7	8	9	10	11
Dewangan et al. [54]	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	++
Milosavljevic et al. [66]	N	Y	Y	N	Y	N	Y	Y	Y	Y	+
Loutridis et al. [59]	N	N	N	N	Y	Y	Y	Y	Y	Y	+
Milosavljevic et al. [67]	N	Y	Y	Y	Y	N	Y	Y	Y	Y	++
Milosavljevic et al. [12]	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	++
Chaturvedi et al. [14]	N	N	N	N	Y	Y	Y	Y	Y	Y	+
Milosavljevic et al. [68]	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	++
Solecki [57]	N	Y	N	Y	Y	Y	Y	Y	Y	Y	++
Hao & Ripin [15]	N	N	N	N	Y	Y	Y	Y	Y	Y	+
Gomez-Gil [48]	C	C	C	C	Y	Y	C	Y	C	Y	+
Morgan & Mansfield [49]	Y	Y	N	Y	Y	N	N	Y	Y	Y	+
Swangnetr et al. [77]	N	Y	Y	N	Y	N	Y	Y	Y	Y	+
Azmir et al. [71]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	++
Langer et al. [18]	C	C	C	C	Y	Y	Y	Y	Y	Y	++
Mehta & Tewari [62]	C	C	C	C	C	Y	N	Y	C	Y	+
Mani et al. [70]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Tsujimura et al. [79]	N	N	N	N	Y	Y	N	Y	Y	Y	+
Azmir et al. [13]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	++
Lenzuni et al. [72]	Y	N	N	Y	Y	Y	N	Y	Y	Y	+
Gialamas et al. [58]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Vallone et al. [65]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Zeng et al. [52]	N	Y	N	N	Y	Y	Y	Y	Y	Y	+
Caffaro et al. [64]	N	Y	N	Y	Y	N	Y	Y	Y	Y	+
Deboli et al. [60]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Taghizadeh-Alisaraei [63]	C	C	C	C	C	Y	Y	Y	C	Y	++
Calvo et al. [33]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Kim et al. [19]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Kociolek et al. [69]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Feyzi et al. [55]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	++
Kuta et al. [56]	N	N	N	Y	Y	Y	Y	Y	Y	Y	+
Romano et al. [61]	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	++
Zanatta et al. [78]	N	N	N	Y	Y	N	Y	Y	Y	Y	+

C: cannot say; N: no; Y: yes; ++: high quality (low risk of bias); +: Acceptable (moderate risk of bias); -: low quality (high risk of bias); 1: Was the study's target population a close representation of the national population in relation to relevant variables, e.g., age, sex, occupation?; 2: Was the sampling frame a true or close representation of the target population?; 3: Was some form of random selection used to select the sample, or, was a census undertaken?; 4: Was the likelihood of non-response bias minimal?; 5: Were data collected directly from the subjects (as opposed to a proxy)?; 6: Was an acceptable case definition used in the study?; 7: Was the study instrument that measured the parameter of interest shown to have reliability and validity (if necessary)?; 8: Was the same mode of data collection used for all subjects?; 9: Was the length of the shortest prevalence period for the parameter of interest appropriate?; 10: Were the numerator(s) and denominator(s) for the parameter of interest appropriate?; 11: Summary item on the overall risk of bias, [42].

4.4. *Synopsis of the Methodologies, Ergonomic Interventions and Risk Factors for the Development of MSDs*

The journal papers, which fulfilled the imposed criteria, are summarized in Table 2 in chronological order. This table includes various aspects of the articles, namely the year of publishing, the country where the investigation took place, the studied machinery, the number of participants and the implemented methodology. In Figure 6, the time distribution of the selected papers during the last decade as well as the scientific impact they have (via showing the number of citations) is illustrated. The quality of them is guaranteed from the total 509 citations they have. This is a considerable number, taking into account the recent year of publishing and the fact that almost 23% of them were published during the last two years (i.e., 2018, 2019). Also considering the increasing interest in ergonomics worldwide, their impact is anticipated to rise during the next decades. As far as the geographical distribution of all contributing research organizations is concerned, it has already been analyzed in Section 4.1.1.

Table 2. List of the selected journal papers along with the date of publishing, country that the survey was conducted, studied machinery, number of participants and methodology.

Ref.	Year	Country	Machinery	Part.	Methods
[54]	2010	India	Tractor	379	Handgrip dynamometer; 16 isometric strength parameters were measured
[66]	2010	New Zealand	Quad bike	12	TA, WBVHS Quest; WBV and mechanical shock measurements; Survey on seasonal use and spinal discomfort
[59]	2011	Greece	Tractor	1	Shock absorber, piezoelectric sensor; Vibration was measured for various terrains and operating conditions
[67]	2011	New Zealand	Quad bike	130	TA, WBVHS Quest; A seat pad mounted TA measured vibrations and shocks
[12]	2011	New Zealand	Quad bike	130	TA, WBVHS Quest; Field study and survey examined the prevalence of loss of control depending on various factors
[14]	2012	India	Power tiller	3	TA; Measurements in 3 cases (transportation on farms, rototilling with rotavator and tilling with cultivator); 3 materials at handles to reduce HATV
[68]	2012	New Zealand	Quad bike	130	TA, WBVHS Quest; A seat pad mounted TA measured vibrations and shocks; Personal, workplace and vehicle characteristics were collected
[57]	2012	Poland	Tractor	N/A	TA; The following variables were estimated: total monthly and mean equivalent vibration doses as well as mean equivalent everyday acceleration
[15]	2013	Malaysia	Grass trimmer	10	TA, FFT analyzer; Transversal deflection, nodal technique and operating deflection shape analysis of the grass trimmer
[48]	2014	Spain	Tractor	N/A	Piezoelectric accelerometer; Geometrical and experimental examination
[49]	2014	UK	Tractor	83	Quest; Experts' opinion on the influence of combined exposure to WBV and trunk rotation
[77]	2014	Thailand	Rice plowing machine	24	Grip force sensor, EMG; Simulated plowing operation including walking on uneven and even terrain with suggested vertical handles and conventional horizontal ones
[71]	2015	Malaysia	Grass trimmer	204	Dynamometer (for measuring hand grip strength), physical observation for color changes in the fingers, HAVS Quest
[18]	2015	Norway	Tractor	N/A	WB accelerometer; Experimental measurements on a specific vehicle for different combinations of driving uphill and downhill
[62]	2015	India	Tractor	N/A	Biomechanical model to calculate the shear and compressive loads at L4/L5 (lumbar vertebra) of the operator with seats having different backrest cushions and seat pans
[70]	2015	New Zealand	Quad bike	34	TA; The postural control was found from displacements of the center of pressure at 3 different time periods
[79]	2015	Japan	Various AMDSs	1	TA, Quest; Measurement of accelerations at the seat base and at the seat pan in 4 vehicles having various implements attached over one year
[13]	2016	Malaysia	Grass trimmer	168	HAVS Quest; Survey on HATV exposure and symptoms
[72]	2016	Italy	Handheld olive beater	60	TA, Round Robin test; Tasks typically done during olive harvesting were performed via a tree simulator and field tests

Table 2. *Cont.*

Ref.	Year	Country	Machinery	Part.	Methods
[58]	2016	Greece	Tractor	N/A	Piezoelectric accelerometer, shock absorber; Combinations of 3 different tractors, 3 implements and 4 speeds
[65]	2016	Italy	Tractor	1	TA, shock absorbers; 6 different track-laying tractors having identical rototilling machine
[52]	2017	Canada	Tractor	40	TA, Quest; Vibration measurements were performed at the operator-seat interface with a TA in a seat pad from rubber
[64]	2017	Sweden	Tractor	9	Quest, interview; Senior farmers' opinion about their working life quality, problems in interacting with technological innovations, risk and safety issues
[60]	2017	Italy	Tractor	1	TA; Field tests were performed with the tractor moving on various grounds, at 2 forward speeds and tire pressures and with dissimilar tractor masses
[63]	2017	Iran	Tractor	N/A	TA; Analysis of shocks transmitted from the tractor seat using statistical methods and vibration signals
[33]	2018	Italy	Handheld olive beater	5	TA, OCRA method; 3 dissimilar electric olive beaters whose head had oscillating sticks
[19]	2018	USA	Tractor	11	TA; Examination of the differences between a single- and multi-axial suspension seat and muscle activity of the low back, shoulders and neck
[69]	2018	Canada	Quad bike	10	TA, triaxial gyroscope; Measurement of vibration exposure at the head and seat
[55]	2019	Iran	Tractor	364	Quest, anthropometric measurement devices; Hand, leg and torque strengths were measured and compared against recommended values
[56]	2019	Poland	Tractor	10	EMG; The lowest workload regarding the arm, wrist and forearm was determined, taking into account the elbow angle and the position of the steering column
[61]	2019	Italy	Tractor	8	Pressure sensors; 3 different tractor seats were used during harrowing, ploughing and haying
[78]	2019	Brazil	Aircraft	4	TA, musculoskeletal quest; measurement of the pilots' exposure to WBV during the flight and survey on musculoskeletal symptoms on the spine

AMDSs: agricultural machines with driving seats; EMG: electromyography; FFT: fast Fourier transform; HATV: hand–arm transmitted vibration; HAVS: hand–arm vibration syndrome; N/A: not available; NM: Nordic musculoskeletal; OCRA: occupational repetitive action; Part.: participants; Quest: questionnaire; Ref.: reference; TA: triaxial accelerometer; WB: whole-body; WBVHS: whole-body vibration health surveillance.

Regarding the type of agricultural machine, it can be easily ascertained that out of the 32 relative journal papers, the most highly reported machine during the last decade was by far the tractor with 53.13% percentage, obviously due to its versatile usage. The second studied subject was the quad bike with 18.75%. Grass trimmer came next with 9.38%, while the handheld olive beater followed with 6.25%. Finally, for the cases of power tiller, rice plowing machine and agricultural aircraft only three papers were found, one for each of them, with the relative frequency being approximately 3.13%. The same percentage was found for a study that investigated various agricultural machines with driving seats in a rice farm. The aforementioned distribution of the agricultural machines pertaining to the 32 selected studies can be illustrated in the pie chart of Figure 7.

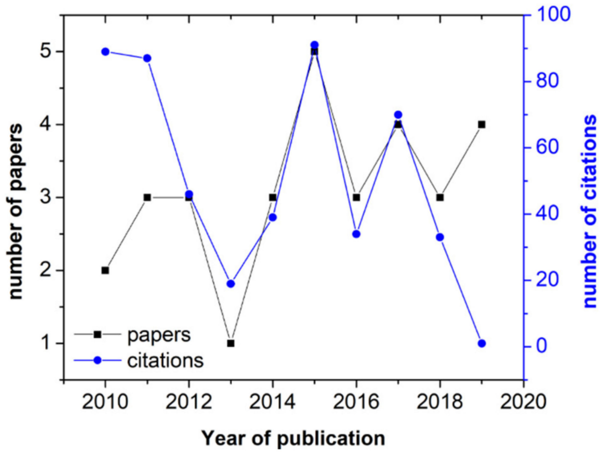

Figure 6. Time distribution of the selected papers along with their citations during 2010–2019 according to a Google Scholar search conducted on 2 April 2020.

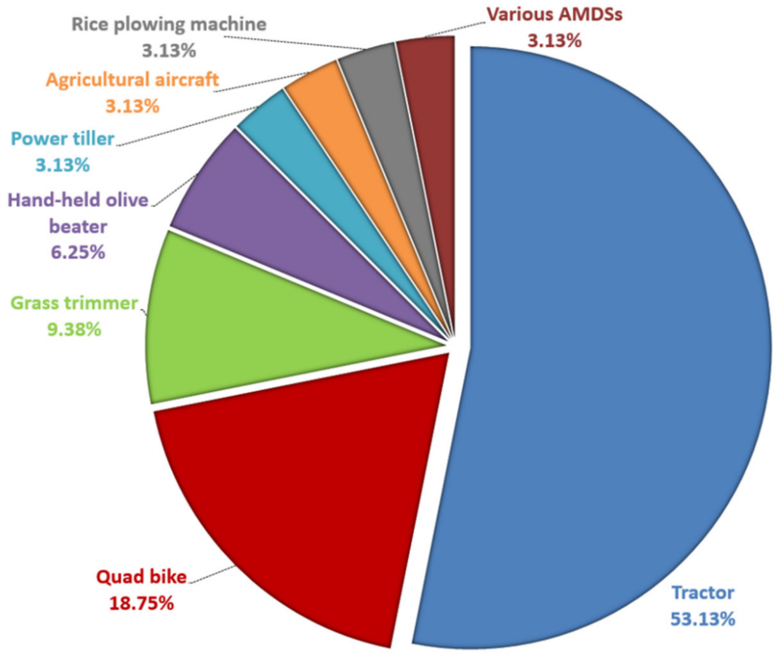

Figure 7. Distribution of the different kinds of studied agricultural machines causing musculoskeletal disorders; abbreviation AMDSs corresponds to agricultural machines with driving seats.

Concerning the methodology, the number of participants ranged from 379 to 1, since some studies wanted to investigate several aspects of the sample, such as age and gender and have a reliable amount of tests, whereas others wanted to test different risk factors with one worker. Additionally, the large number of studies dealing with vibration exposure justifies the frequency of the word "triaxial accelerometer", which is given by the abbreviation "TA" in Table 2. Triaxial accelerometers offer simultaneous measurements in all directions in order to analyze the experienced vibrations. Almost half of the investigating studies (53.13%) utilized triaxial, piezoelectric and whole-body accelerometers. Furthermore, most of the selected papers incorporated special questionnaires that investigate the consequences of operating agricultural machines. Questionnaires appeared in 34.38% of the studies. Special versions of the WBV health surveillance questionnaire [80] were adopted for gathering the mass, age and height of the participants as well as their experience on farming and operation of the machines. This type of questionnaire also collects data regarding the terrain of the farm, characteristics of the machinery, the distance, speed and duration of driving and work environment. It also involves the prevalence of various reported MSDs, including pains in the regions of neck, shoulders and low and upper back. Nordic questionnaire was also implemented with the intention of determining whether MSDs were developed in a given population. Evaluation of the incidence pertaining to the nine selected body parts is taken into account. Participants answer to yes–no questions. On one hand, if the response is "yes", further questions follow dealing with medical intervention, duration and frequency. On the other hand, when a negative answer takes place, the participant continues to the next part of the body [81]. Finally, special questionnaires about the hazardous consequences of machineries operated by hands were identified in the present literature survey. These questionnaires are associated with the high levels of vibrations that are transmitted at the upper extremities as a result of the contact between the hand and the handles of the machine. Examples of this type of machineries are grass trimmer, rice plowing machine and handheld olive beater.

Questionnaires can help to the filtering of MSDs for the purpose of producing useful results for the occupational health. However, it should be stressed that the role of questionnaires is not to offer medical diagnosis. Careful examination of the reported MSDs among a specific sample by experts can serve for optimizing the work environment and the seat, handle and other equipment design [82]. One of the weaknesses, which are associated with questionnaires, is that recent experienced MSDs are more likely to be remembered as compared with the older ones. In addition, it should be taken into account that MSDs are progressive and that participants can have some symptoms after physical findings [83]. The conditions at which the completion of the questionnaire takes place are very important and may influence the outcomes. For example, the presence of a researcher may affect answers. Additionally, it may be difficult for the questions to be phrased clearly and this could lead to different interpretations of questions.

In order to quantify the muscle activity, electromyography was adopted in the reviewed studies. Understanding of when as well as how much the muscles are active during the mechanized operation can be advantageous for physicians, in an effort to comprehend the mechanism of the injury. Moreover, handgrip dynamometers were used for estimating the isometric hand and arm strength as well as various sensors for measuring the grip force and interfacial pressures.

As can be gleaned from Table 3 and illustrated in the bar chart of Figure 8, the risk factors for the development of MSDs seem to be associated, to a great extent, with the "vibrations" (total percentage of 71.88%) which are produced either in the form of WBV (53.13%) or as HATV (18.75%). Biomechanics and physiological effects of vibration exposure were elaborated in the Section 2.2. According to the criteria presented in 3.3, there is a strong evidence regarding a positive relationship between exposure to vibrations and MSDs. In addition, some evidence exists for a positive relationship between "personal characteristics", such as mass, height and age and the pathogenesis of MSDs with a percentage of 18.75%. Age can be related with either accumulated musculoskeletal injuries or overconfidence. In addition, the discrepancy between the existing dimensions of seats and equipment of agricultural machines and the real individual ones from different nationalities can lead to overexertion, which is an additional risk factor for the development of MSDs. The "awkward postures" of trunk and wrist, which appeared in 12.5% of the studies, seem also to be potential indicators, with some evidence for a positive relationship.

Twisted postures of the trunk, which are required so as to attach trailers and implements, can provoke low back pain. Introduction of special mirrors and rear-view cameras would be helpful to prevent from awkward neck and trunk postures [64]. A further reason for acquiring awkward postures, except for the ignorance of the right ones, is the "seat discomfort" which was identified in 3 studies (with equivalent percentage of 9.38%) demonstrating some evidence for a positive relationship. Finally, the "mechanical shocks" were recognized with the same frequency as "seat discomfort", showing some evidence for a positive relationship with the pathogenesis of MSDS. Shocks are transferred to the seat and can be produced owing to uneven ground, while they use to grow with increasing the rpm of the engine [63].

Table 3. List of the selected journal papers along with their main results, identified risk factors and authors' suggestions.

Ref.	Main Results	Risk Factors	Authors' Suggestions
[54]	Isometric muscle strength of the right limbs was significantly higher than the corresponding left ones	Incorrect design of handling tools	Design of tractor controls based on isometric muscular strength data
[66]	The WBV and mechanical shocks were higher than the permitted limits; Low back pain was the most reported complaint	WBV, mechanical shocks	Shock absorbers
[59]	Electronic speed regulation is suggested in typical field tasks, while it should not be used in transportation on asphalt roads	WBV	Electronic speed regulation in typical field tasks
[67]	Vibration dose values and mechanical shocks exceeded standard limit thresholds; Lower and upper back pains were reported	WBV, mechanical shocks, age, body mass, driving duration	Shock absorbers, reduction of velocity and driving duration
[12]	Heavier and taller operators driving in difficult terrains and at high speeds should be particularly vigilant for risk of a loss of control	WBV, body height and mass, speed and distance, non-flat terrain	Management strategies for decreasing risks
[14]	The highest vibration was along x-direction; The maximum vibration reductions occurred with rubber handles; Interventions decelerated the occurrence of white finger syndrome	HATV	Rubber handles
[68]	A mixture of operator's height, mechanical factors and type of terrain can worsen the impact of body mass on vibration exposure	WBV, Body height and mass, sheep farms	Anthropometrics should be considered in the designing of seating and suspension systems
[57]	The highest total vibration doses occurred in August and April; The maximum mean daily exposure appeared during April, August, September and October	WBV	Management strategies for private farmers
[15]	Decrease of acceleration in all axes and total vibration values were noted by using the 2 tuned vibration absorbers	HATV	Control of handle vibration by node technique
[48]	Lateral vibrations can exceed the vertical ones, while they increase linearly with the tractor-seat height above the ground	Lateral vibrations	Lowering tractor-seat height above the ground
[49]	WBV and trunk rotation simultaneously exposure increases the risk for low back pain and discomfort in the right shoulder and thighs	WBV combined with trunk twist	Consideration of operators' feedback on equipment design
[77]	Tools facilitating a neutral wrist and symmetrical body postures can help to increase the efficiency of muscle use and reduce MSDs	Awkward wrist and body posture	Vertical handle design
[71]	Prolonged vibration exposure resulted in loss of hand grip strength, fingers' numbness and blanching	HATV	The chronic health effect should be considered when evaluating disabilities
[18]	The higher WBV was observed during downhill driving with 4-wheel drive	Longitudinal WBV	Manual or automatic control of 4-wheel drive
[62]	Coir cushion (80 mm thickness) and a high-density polyurethane foam (44 mm thickness) demonstrated the maximum and minimum compressive forces, respectively	Compressive and shear loads on lumbar vertebra	Biomechanical models for design of tractor seat, seat backrest cushion
[70]	Significant increase of the center of pressure for the lifting task	Postural control displacements	Postural control alterations to lessen acute exposures
[79]	WBV levels exceeded the Japanese and European threshold limits	WBV, heavy implements, high velocities	New health management strategies
[13]	Positive HATV symptoms relationships between the low-moderate and high exposure groups	HATV	Safety and health awareness programs
[72]	The simulated olive harvesting performed via this Round Robin test proved to be consistent with field tests	HATV	Round Robin test could be a viable basis for future research
[58]	Tractors play a key role in the development of lateral vibrations, while the implements in the horizontal ones; The plough showed the highest vibration	WBV	Optimal combination of tractor and implement
[65]	The daily vibration values were higher than the permitted ones; The characteristics of the soil affected only the vibration in the z axis	WBV, soil type	Soil type should be considered

Table 3. *Cont.*

Ref.	Main Results	Risk Factors	Authors' Suggestions
[52]	The maximum vibrations appeared in the vertical axis; 41.4% of these measurements were within or above the caution zone	WBV	Workplace information for the total work period
[64]	Mounting/dismounting the tractor as well as awkward trunk postures seems to cause back pains; An additional step and rear-view cameras and mirrors were mentioned to be particularly helpful	Mounting/dismounting the tractor, twisted postures, overconfidence	Training activities and design solutions for senior farmers
[60]	The vibrations on the seat along the x and y axes are affected by the pitching and rolling movements	WBV	Decrease of the rolling and pitching effects by using suspension systems
[63]	Ground roughness and engine generate vibrations within the 0–30 Hz and 50–200 Hz range, respectively; Kurtosis method better demonstrated the difference between the signals	WBV, mechanical shocks	Re-determining the practical limits
[33]	In all experiments both the HATV and OCRA scores indicated values beyond the admitted limits	HATV	Use of reliable vibration data, not only by subjective perceptions
[19]	Multi-axial suspension can decrease the lateral vibration and the associated pain in the neck and low back	WBV	Multi-axial seat suspension systems
[69]	The vertical vibrations were higher at head and neck than the seat.	Head and neck vibration	Suspension systems should consider both seat and head data
[55]	Inappropriateness of the international standards in the case of the isometric muscle strength in Iran	Seat discomfort	Design of tractor controls based on isometric muscular strength data
[56]	The most convenient position for the hands was at the elbow angle of 100° and when the steering column inclination angle was 50°	Seat discomfort	Design of tractor controls based on the comfort of the operator
[61]	The analyzed pressure indices are useful for comparing seats with the aim of assuring comfort in static and dynamic situations	Seat discomfort	Cushion-seat development based on intelligent automatic controller
[78]	In few situations, some over the limit values were observed; 62% of the participants reported some discomfort of the spine throughout the last 12 months	WBV	Improving the aircraft's cabin and controlling the flight time

HATV: hand–arm transmitted vibration; Ref.: reference; WBV: whole-body vibration.

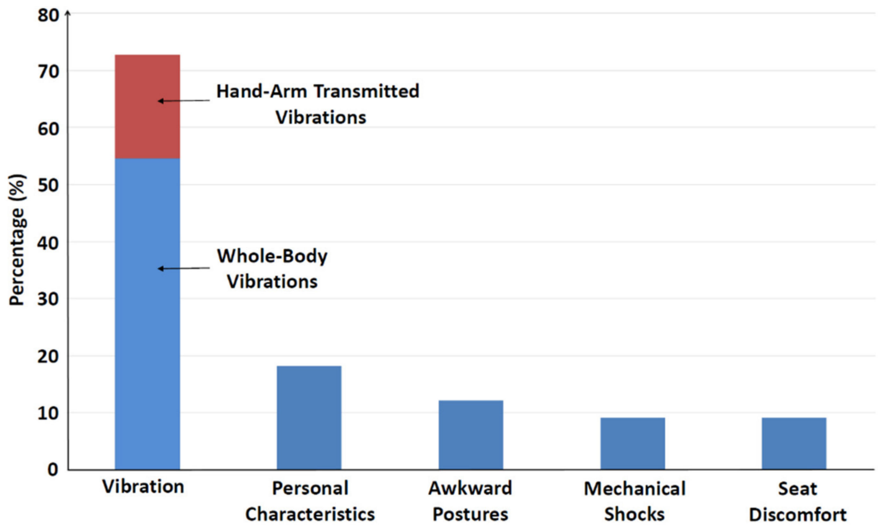

Figure 8. Percentage (%) of the main identified risk factors causing musculoskeletal disorders.

The ergonomic interventions that were suggested by the authors of the reviewed articles are closely related with the risk factors which they identified, as can be seen in Table 3. In brief, multi-axial seat suspension systems and shock absorbers are recommended for attenuating the experienced vibrations. In general, an ergonomically designed seat and handle should lessen the transfer of vibrations from the agricultural machinery to the human body and offer a comfortable operation. Overall, the optimal performance and comfort of seating system entails covers, cushion, damping and suspension mechanisms. Decrease of the levels of vibration on the seat is a key factor towards comfort and attenuating of MSDs. This can be accomplished via adjusting the spring characteristics to complement the characteristics of the machine. Furthermore, cushions of the seat may help as shock absorbers. They should be designed so as to provide minimum load transmission. In particular, they can be selected to have a specific dynamic stiffness and can undergo a considerably large deflection to get the mass to rest [36]. Based on research outcomes, there is no consistency in the selection of a certain material with verified suitability.

Moreover, design of tractor equipment based on anthropometric and isometric muscular strength data is suggested for avoiding awkward postures. Reduction of velocity and driving duration was also recommended for experiencing less vibration levels. Interestingly, most of the studies focused on the need for increasing the awareness of the risk factors associated with the subsequent MSDs among the workers, whose feedback is of major importance on evaluating the ergonomic interventions. For this purpose, new health management strategies are proposed for decreasing risks as well as reestablishment of vibration exposure limit values and everyday working hours in farms.

5. Discussion

Operation of agricultural machines contributes to the development of MSDs, which is an increasing international concern, since they constitute the most common non-fatal health problem among rural workforce [7,11]. Ergonomics is the research field that aims at fitting the task to workers by improving the workers-workplace environment and helping them to avoid awkward postures and vibrations. To this end, interventions are pursued by designing and evaluating ergonomic equipment as well as informing workers about the body postures that should not be acquired. The present systematic bibliographic survey identified 32 relevant journal papers regarding ergonomics in mechanized operations in agriculture. An additional criterion was imposed, namely all articles had to be published in the last decade, in order to capture the up-to-date progress in this field and determine the principal risk factors for MSDs.

The preliminary data visualization analysis, which was conducted, gave a sense of the geographical distribution of the most productive research organizations. It was ascertained that the present studied issue interests both developing and developed countries worldwide, with the major contribution being originated from Italy, Sweden and New Zealand. Ergonomics in agricultural machinery was proved to be a versatile and interdisciplinary topic concerning fields such as agrotechnology, occupational ergonomics, manufacturing, computational modeling and medicine. Furthermore, using the tool developed by Hoy et al. [42], the methodological quality of the studies was found to be either high or acceptable, thus, corresponding to low and moderate risk of bias, respectively.

The most investigated agricultural machines were, at decreasing order of frequency, tractor, quad bike, grass trimmer and handheld olive beater, as well as power tiller, rice plowing machine and agricultural aircraft. The three last machineries were presented with equal percentage. Each machinery was described in a different subsection in order to examine the investigated ergonomics in depth. Triaxial accelerometer was the main instrument that was utilized to measure the vibration levels during operating the machines under various conditions. In addition, a lot of the selected studies implemented special questionnaires, which investigate the consequences of operating agricultural machines. In particular, special forms of the WBV health surveillance questionnaire [80], Nordic questionnaire [81] and other MSDs-related questionnaires were implemented. Useful results can be derived from these questionnaires. However, they cannot offer medical diagnosis and a careful examination by experts is required.

A risk assessment analysis was also performed with the intention of identifying and evaluating potential factors that can negatively impact agricultural workers. Risk assessment is definitely an inherent portion of a wider management strategy for the purpose of introducing control measures and developing ergonomic interventions to attenuate any risk-related concerns. It was observed that WBV and HATV are the main risk factors among the operators of agricultural machines having driving seats and handgrips, respectively. A special section was introduced prior to the results section, namely Section 2, regarding the involved biomechanics and health effects of vibration for the sake of better comprehension of the present analysis. On one hand, the agricultural machineries with driving seats, such as tractors and all-terrain vehicles, were seen to be related to painful disorders of the low back and neck. Important factors affecting the WBV are the ground unevenness, driving speed and implements. On the other hand, handheld agricultural machines, such as grass trimmer and power tiller, are responsible for disorders at the upper extremities. Commonly reported disorders are the white finger syndrome, numbness and clumsiness to perform complex operations. Generally, the effect of vibration exposure on operators strongly depends on its magnitude, duration, frequency and direction.

However, most of the time, it is not easy to distinguish the effects of vibration from those originated from usual risk factors like prolonged awkward postures and intensive static postures. In other words, it is the interaction of improper long-term body postures and manual materials handling and vibration exposure that is responsible for the precipitation of MSDs. The wrong postures of trunk, arm and wrist may lead the muscles to be less tolerant to vibration stresses. Overextension, owing to the poor matching of the equipment with the anthropometric characteristics of the operator, along with seat discomfort is also a key factor for developing or aggravating the experienced MSDs. Body posture ergonomics and WBV are well founded research fields in several occupational sectors. Nevertheless, the crossover area that covers both factors is less developed, especially in agriculture that is a labor-intensive field and occupies most of the working population worldwide. As a consequence, to advance the knowledge, experts' opinion from both areas as well as more systematic experimental and computational investigations is necessary. Modern design of agricultural machines is an interdisciplinary mission based on the state-of-the-art advances in ergonomics, biomechanics as well as structural mechanics. Overall, these design parameters should meet three criteria, namely comfort, health and safety of the operator. The comfort deals with the ergonomic considerations like seat and handle dimensions, cushioning materials and the perception of comfort of the operator. The health and safety correspond, for example, to the extended spinal support during operating a machinery with a seat and damping of vibrations.

In a nutshell, taking also into account the results of the recent article regarding ergonomics in manual agricultural operations [7], low back pain was proved to be the major reported MSD. Rural workers are engaged in both manual and mechanized operations. Hence, concerted and systematic strategy is suggested with the intention of increasing the awareness of the related risk factors and designing of ergonomic equipment for protecting this body area. This strategy could be accomplished through international safety and health awareness programs by providing simple guidelines to workers for acquiring the less intensive posture for each agricultural machinery. More targeted effort is also required on the base of the anthropometric characteristics of each nation because improper equipment can cause additional MSDs. Frequent rest brakes can also be a viable solution in order to assist the viscoelastic connective tissues to recover from either repetitive fatigue [84] characterizing the manual tasks, such as harvesting and weeding, or vibration exposure [34].

Finally, the experience of the operators themselves will add a unique perspective since they are the most crucial members of this kind of surveys. Their contribution is paramount for developing sustainable ergonomic interventions by providing feedback on comfort and socio-cultural issues, which can influence their acceptance and adoption barriers. We still have a long way to make a safe agricultural environment, since the progress that has been made does not correspond to the gravity of this matter. Therefore, more collaborative efforts are required among physicians, ergonomists, engineers, manufacturers and international organizations concerning occupational health.

Study Strengths and Limitations

The main limitation of this study is considered to be the fact that non-English articles were not taken into account. Nevertheless, agriculture is regarded to be the main occupation of workers from developing countries who speak, for example, Spanish as well as African and Asian languages. In addition, papers published in journals with impact factor less than one were excluded, a factor that does not necessarily mirror the quality of single works. Consequently, considerable information is speculated to have been lost. This was compensated from the wide geographical distribution of the contributing research organizations and the high impact factor of the selected journals that guaranteed, to a great extent, the overall reliability of the current outcomes.

The major strength of the present literature survey is that thoroughly reviewed the recent progress regarding ergonomics in agricultural machinery by covering several aspects of it for the first time, at least to authors' knowledge. It is anticipated that this investigation is going to contribute towards more systematic investigation on ergonomics in agriculture for the purpose of improving the well-being of rural workers.

Author Contributions: Conceptualization, L.B., D.T. and D.B.; methodology, L.B., D.T. and D.B.; investigation, L.B., D.T.; writing—original draft preparation, L.B.; writing—review and editing, L.B., D.T. and D.B.; visualization, L.B.; supervision, D.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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