How to cite: Öz, E., Jakob, M. 2020. Ergonomic Evaluation of Simulated Apple Hand Harvesting Using 3D Motion Analysis, Ege Üniv. Ziraat Fak. Derg., 57 (2):249-255 DOI: 10.20289/zfdergi.650787

Araştırma Makalesi
(Research Article)

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Keywords:

Apple; posture; upper arm; ergonomics; 3-D motion

Anahtar Sözcükler:

Elma; postür; üst kol; ergonomi; 3-D hareket

Ege Üniv. Ziraat Fak. Derg.,2020, 57 (2):249-255
DOI: 10.20289/zfdergi.650787

Ergonomic Evaluation of Simulated Apple Hand Harvesting Using 3D Motion Analysis

Simüle Edilmiş Elle Elma Hasadının 3 Boyutlu Hareket Analizi ile Ergonomik Değerlendirmesi

Alınış (Received): 25.11.2019 **Kabul Tarihi** (Accepted): 16.01.2020

ABSTRACT

Objective: The objective of this study was to conduct experiments by using 3D motion analysis system to reveal ergonomic exposures during apple hand picking.

Material and Method: The study was carried out in the ergonomics laboratory located at ATB (Leibniz Institute for Agricultural Engineering and Bioeconomy Potsdam e.V.) in Germany with an artificial dwarf apple tree. Body postures, especially upper arm elevation, were determined by a 3D motion capture system. Evaluations were made according to ISO 11226 standard and RULA classification.

Results: Average upper arm elevation changed between 27.86° and 33.60°. Time spent with elevated arm above 20°, the base limit suggested by standards was found to be significant for entire experiments as 77% on average of the process time. It was estimated that 5 to 6 hours within 8 hour shifts per day may be spend with elevated arms more than 20°.

Conclusions: More detailed information was obtained in comparison to observational methods. This technique allows to determine the exact values of the arm positions depending on time intervals. It can also be used to find out other awkward postures such as trunk and head inclination and for any other work process.

ÖZ

Amaç: Bu çalışmada elle elma hasadındaki ergonomik etkilenmelerin ortaya konulması için 3 boyutlu hareket analizi sisteminin kullanılabilirliğinin belirlenmesi amaçlanmıştır.

Materyal ve Metot: Çalışma, ATB (Leibniz Institute for Agricultural Engineering and Bioeconomy, Potsdam-Almanya) enstitüsü ergonomi laboratuarında yapay cüce elma ağacı ile yürütülmüştür. Beden duruşları, özellikle üst kol yükselmesi 3 boyulu hareket analizi sistemi kullanılarak belirlenmiştir. Değerlendirmeler ISO 11226 standardı ve RULA ölçeğine göre yapılmıştır.

Bulgular: Ortalama üst kol yükselmesinin 27.86° ve 33.60° arasında değiştiği belirlenmiştir. Standartlar tarafından temel kısıt olarak belirlenen 20° nin üzerinde yükselmiş kol ile geçirilen süreler tüm denemeler için önemli bulunmuş ve işlem zamanının ortalama %77 sini oluşturduğu belirlenmiştir. 8 saatlik bir çalışma süresinde 5-6 saatin kolların 20° den daha yüksekte olacak şekilde harcandığı tahmin edilmektedir.

Sonuç: Gözlemsel yöntemlere göre çok daha detaylı sonuçlar elde edilmiştir. Bu yöntem zaman aralıklarına bağlı olarak kol pozisyonlarına ilişkin kesin değerler alınmasını sağlamaktadır. Bu sistem vücut ve baş eğilmesi gibi biçimsiz çalışma duruşlarının değerlendirilmesi için elma toplama dışında herhangi bir iş düzeni için de kullanılabilir nitelikte bulunmuştur.

INTRODUCTION

Ergonomic work place design is important for human health in rural areas as well as in cities (Yoruk et al, 2006). Agriculture is one of the areas where ergonomic problems are most commonly seen. Several researchers pointed out that there is a prevalence of ergonomic hazards associated with musculoskeletal diseases in agricultural production (Silvetti et al., 2007; Kirkhorn et al., 2010), especially in labor intensive practices such as fruit picking or fresh vegetable production (Meyers et al., 1997; Villarejo, 1998; Villarejo and Baron, 1999; McCurdy et al., 2003).

Harvesting processes in orchards, vineyards and of fresh vegetable are characterized by the needs of intensive manual labor with awkward body postures like leaning forward, stooping and holding both hands above shoulder level for an indefinite period of time which in consequence may lead to musculoskeletal disorders. Several studies revealed that back, neck and shoulder strains and pains are very common in this process (Sakakibara et al., 1987; Earle-Richardson et al., 2004; 2005; 2006; Freivalds et al., 2006).

Studies on orchard ergonomics mainly focused on apple harvesting due to having unfavorable body postures that include overhead working, leaning and trunk inclination due to standing under the tree or climbing up a ladder, reaching to the apples usually with both arms, gripping them with fingers. Among those, working with hands above shoulder level has the highest impact on the development of shoulder disorders. Studies showed that time spent in this position ranged from 40% to 60% of total harvesting time (Sakakibara et al., 1987; Earle-Richardson et al., 2005) and pickers were found to be working in these positions for approximately 63% of the work day (NYCAMH, 2006). In another study, it was concluded that working in this position even for a short period may cause abnormal scapular positions and may lead to strain and pain in the shoulders (Yoo, 2013).

Ergonomic exposure studies related to apple picking workers utilized different measurement techniques that can be categorized in three groups such as self-reporting, observational methods and direct measurements. Although observational techniques are frequently used, there are some limitations as the accuracy of observation depends on the viewing angle of the observer, and is limited to assessable variables (Pinzke, 1997; David, 2005). To get more accurate data on a large range of variables, direct measurement methods such as electromyography (EMG) and motion capture techniques are very common and favorable.

Electromyography (EMG) and surface electromyography (sEMG) are the techniques widely used in agricultural ergonomic studies (Stal et al., 2000, 2003 Pinzke et al., 2001; Jakob and Liebers, 2011; Jakob et al., 2012) including orchard ergonomics (Earle-Richardson et al., 2006; Freivalds et al., 2006). Using motion capture and 3D motion capture techniques to determine the ergonomic exposures for agricultural jobs is quite new. There are a few studies conducted by Jakob et al. (2003, 2009); Jakob and Liebers, (2011) and Marinello et al. (2015), but it has been widely used in medical based studies.

There was no study found in the literature analyzing the ergonomic exposures by using motion capture techniques especially in orchard ergonomics. Hence, the objective of this study was to determine the usability of 3D motion analysis technique to determine ergonomic exposures such as upper arm elevation, time spent with elevated arms and arm opening angle in the orchard harvesting in particular with apple hand picking. This is the first study conducted in orchard ergonomics with the above mentioned method.

MATERIAL and METHOD

The study was carried out in the ergonomics laboratory located at ATB (Leibniz Institute for Agricultural Engineering and Bioeconomy Potsdam e.V.) in Germany. An artificial and two meter high dwarf apple tree with artificial leaves was used for the experiments. The tree had apple like replicates attached to it in between 1.20 and 1.68 m height from the ground.

In order to determine body postures, a 3D motion capture system was used. The system included two digital video cameras (Canon XM2) with a rate of 50 frames per second. Capturing motions of the arm was performed by using optical markers. For this purpose, a male volunteer, 1.83 m tall wore a tight fitting black garment for marker application. Three optical markers were fixed to shoulder, elbow and wrist on the left arm. The captured images, while five of the replicates were randomly picked, were rendered in three-dimensional computer space with SIMI Motion® (Unterschleiβheim, Germany) software. Experiments were repeated 4 times (Figure 1).

The collected data were analyzed with the same software to determine upper arm elevation. Elbow-shoulder line in relation to XZ axis was chosen to determine these angles. The data were evaluated according to ISO 11226 standard from the point of

upper arm elevations limits regarding to posture and movement frequency and RULA classification which is the most common used observational method to determine exposure level (McAtamney & Corlett 1993; ISO 2000).

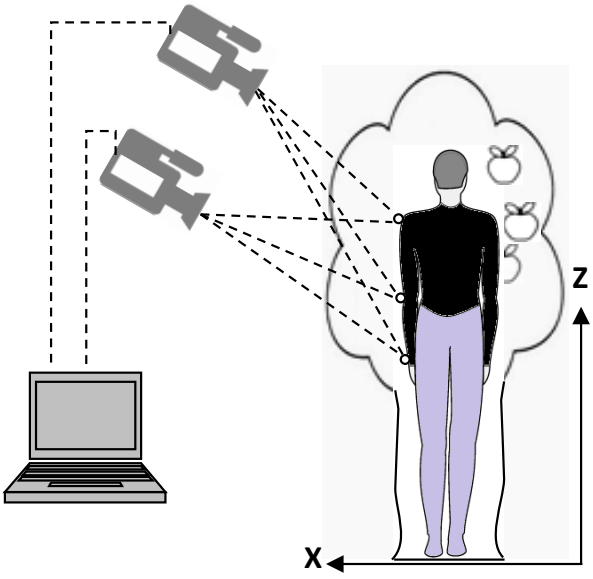


Figure 1. Design of 3D motion capture system
Şekil 1. *3 boyutlu hareket yakalama sisteminin dizaynı*

RESULTS and DISCUSSION

The preliminary findings from the experiments are tabulated in Table 1.

Table 1. Preliminary results obtained from experiments.
Çizelge 1. *Denemelerde elde edilen ön sonuçlar*

	Exp-1	Exp-2	Exp-3	Exp-4
Overall Duration (s)	15.58	19.80	19.34	15.99
Picking Duration (apple.s^{-1})	3.12	3.96	3.87	3.20
Movement Frequency (min^{-1})	19	15	16	19
Frequency Level (ISO 11226)	High	High	High	High

Picking durations and movement frequency obtained in the experiments were found to be very close to obtained values under practical conditions (Thamsuwan et al., 2015). High frequency movements were observed in the entire experiments according to ISO 11226 standard (more than 2 movements per second). Movement frequency is an important parameter with regard to reveal the magnitude of repetitive motions. To examine possible effects, the absolute velocities of shoulder, elbow and wrist were measured (Figure 2).

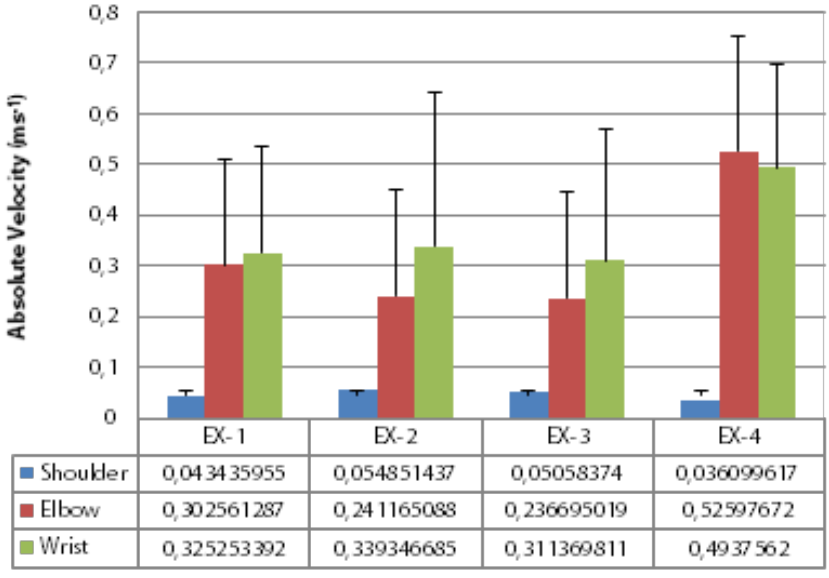
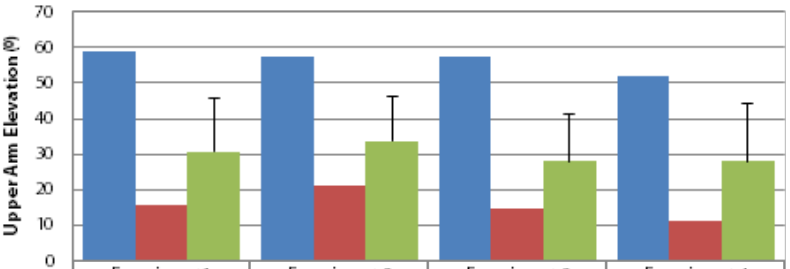


Figure 2. Average absolute velocities obtained from the experiments
Şekil 2. *Denemelerde elde edilen ortalama mutlak hızlar*

Higher velocity values were observed for elbow and wrist in comparison to the shoulder. Shoulder movements were very limited since the artificial tree was only 2 m high. Depending on the arm elevation, higher values were measured in elbow and wrist. In all experiments, the highest values were obtained for the wrist probably due to twisting and picking actions. Studies revealed that more muscle effort was required when working with intensive repetitive motions (Kruizinga et al, 1988) and trauma may occur in frequent repetitive motions even in safe and low-powered work situations (Putz-Anderson, 1988). Arm reach with high frequency was found to have a negative effect on whole body discomfort especially for female workers (Lin et al., 2010). Thus, these results indicated to the possible musculoskeletal problems, especially in the wrists due to high velocities.

Movement frequency also is a decisive factor to evaluate the upper arm elevation in ISO standard. Upper arm elevations between 20° and 60° are conditionally accepted while elevations higher than 60° are not acceptable. In this context, the measured upper arm elevations are depicted in Figure 3.



	Experiment1	Experiment 2	Experiment 3	Experiment 4
Max.	58,7	57,23	57,28	52,09
Min.	15,56	21,01	14,64	11,37
Avg.	30,62	33,6	27,98	27,86

Figure 3. Measured upper arm elevations in degrees

Şekil 3. *Derece cinsinden ölçülen üst kol yükselme açıları*

Average upper arm elevation was found to be greater than 20° although a dwarf type apple tree was used. In many studies, the long-term arm elevation is considered a risk factor for shoulder pain (Mayer et al, 2012; Hanvold et al. 2015), disorders (Kilbom, 1994; Finsen and Christensen, 1998; Fischer et al., 2008; van Rijn et al., 2010), shoulder muscle fatigue (Hagberg 1981; Earle-Richardson et al., 2006) and musculoskeletal disorders (Bjelle et al., 1979; Sakakibara et al., 1995; Pinzke, 1997; Meyers et al., 1998; Pan et al., 1999; Calisto and Kleisinger, 2001). Overhead working with both arms elevated and inappropriate neck positons, are very common in apple picking but it is considered to be more risky as compared to work with one arm only (Shin et al., 2012).

The acceptability of upper arm elevation over 20° according to the standard is given if full arm support is provided. Unfortunately, it is impossible to use a full arm support for apple picking operations. In this case, it is recommended to consider the duration of the posture in this position. To determine the duration with elevated arms, the time spent in the relevant angular sectors was calculated (Figure 4).

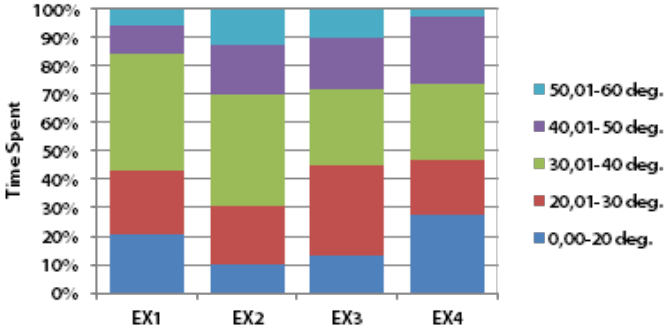


Figure 4. Time spent in angular sectors

Şekil 4. *Açısal sektörlerde harcanan zaman*

As seen from the figure, time spent with elevated arm over 20° ranged from 78 to 90% of the duration in the experiments. The most frequent upper arm elevations were observed between 20° and 40°. Considering an eight-hour work shift, at least six hours would exceed the recommended posture for upper arm elevation. However, the assessment may not be realistic if the time spend is considered only. Holding times in these positions are as important as the duration. According to the standard the holding time must be reduced if upper arm elevation increases. For arms elevated above 20°, holding time longer than 3 minutes is not recommended. In this respect, the calculated holding times for the experiments are presented in Figure 5.

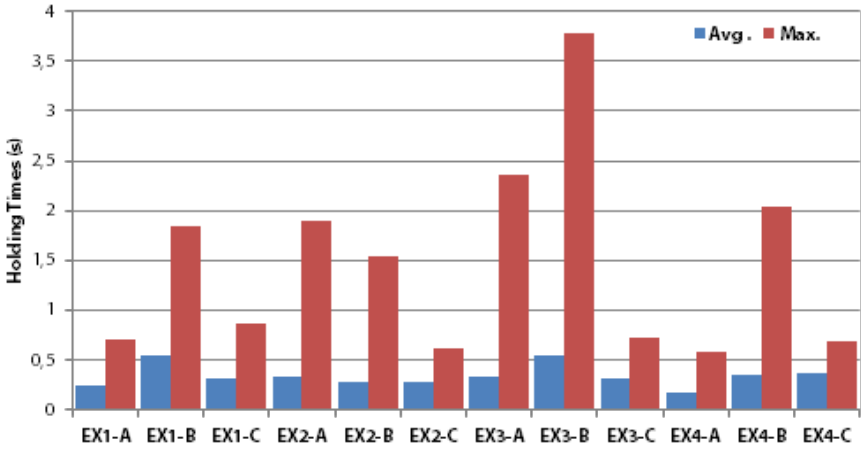


Figure 5. Average and maximum holding time regarding to upper arm elevations (A= 20.00⁰-30.00⁰ - B= 30.01⁰-40.00⁰ - C= 40.01⁰-50.00⁰)
Şekil 5. *Üst kol yükselmesine bağlı olarak ortalama ve maksimum tutma süreleri (A= 20.00⁰-30.00⁰ - B= 30.01⁰-40.00⁰ - C= 40.01⁰-50.00⁰)*

Maximum holding times regarding upper arm elevations were found to be considerably lower than the limits stated in the standards. This situation was expected since apple picking is a high speed operation. Although short durations were measured, many studies revealed that working 1 hour or more in a day with elevated arms increases the likelihood of a specific disorder in the shoulder (van Rijn et al., 2010) and creates discomfort in the back and neck probably due to no possibilities to support arm or hands (Kruizinga et al., 1988). It was found that the holding duration affected the whole body discomfort including shoulder flexion, holding weight, and reaching frequency (Lin et al., 2010) and increased holding duration lead to arm fatigue (Sjogaard et al., 1988). In some studies, between 10% and 30% of strength losses in a day were observed even for moderate work (Byrne and Eston, 2002; Clarkson and Hubal, 2002; Mullaney et al., 2005).

Although the highest percentage of time was recorded between 20° and 40° in the experiments, movements exceeding 40° were found noteworthy. This elevation was accepted to be critical according to RULA method. RULA determines postures as highly risky if the upper arm is elevated above 45° while 20°-45° are classified as moderate risk. Short durations were observed above 45° probably due to the fact that the experiments represent only a very short time. However, under real harvesting conditions, these values will be very meaningful. Considering high percentages, a worker who works 8 hours a day may spend 5 to 6 hours in this position if we extrapolate the measured values (Table 2).

Table 2. Time spent with elevated arms according to RULA method
Çizelge 2. *RULA yöntemine göre yükselmiş kollarla harcanan zaman*

	Elevation	Exp-1	%**	Exp-2	%	Exp-3	%	Exp-4	%
Measured	20⁰-45⁰	**11.18s**	***71.8***	**13.08s**	***67.6***	**10.94s**	***57.3***	**9.08s**	***60.1***
	> 45⁰	**1.56s**	***10.0***	**3.62s**	***18.3***	**2.60s**	***13.4***	**1.26s**	***7.9***
	Elevation	Exp-1	%***	Exp-2	%	Exp-3	%	Exp-4	%
Estimated*	20⁰-45⁰	**5.7h**	***71.3***	**5.4h**	***67.5***	**4.6h**	***57.5***	**4.8h**	***60.0***
	> 45⁰	**1.2 h**	***15.0***	**1.5 h**	***18.8***	**1.1 h/**	***13.8***	**1.0 h**	***12.5***

*Working shift for 8 hours a day
**Within experiment duration
***Within working shift

Although maximum holding times were found to be within desirable interval in the entire experiments it seems inevitable that the workers get exposed to the risk of suffering from MSD's by taking into account the long working hours in an awkward position. The results also showed that the amount of time spent with an arm elevated above 20° and undermine the importance of recovery times.

During the experiments, some adductive movements of the upper arm and rise of the shoulder were observed besides some twisting effects of the wrist while picking. It is difficult to measure twisting by using image analysis techniques because of the reduced visibility of markers. If markers are located very close to each other, analyzing hand movements, automatic recognition would not be very reliable. Other measurement devices such as inclinometer or goniometer should be used for this.

Different techniques were used to reveal the relationship between arm elevation and ergonomic exposures. However, the number of studies that use the objective methods to measure upper arm elevation limits of elevation and process duration (Hanvold et al., 2015) are limited using. The 3D motion analysis technique used in this study provided very detailed information about the parameters as mentioned above. Fully mechanized apple picking is not expected in the near future due to process complexity and economic reasons (Mlotek et al., 2015). Hence, the values obtained from this study may be helpful and motivating for developing interventions.

CONCLUSIONS

The followings were concluded from the study conducted:

- The 3D motion analysis can be employed to objectively measure the ergonomic exposures in apple hand picking process especially in terms of upper arm elevation.
- The results presented give more detailed information in comparison to observational methods. The average upper arm elevation measured ranged between 27.86° and 33.60° and thus exceeds the acceptable limit.
- From an ergonomic point of view, the time spent with elevated arm was found to be significant. It was estimated that 5 to 6 hours may be spent within an 8 hour shift with elevated arms above 20°.
- 3D motion analysis allows to determine the exact values of the arm positions depending on time intervals. It can also be used to determine other awkward postures such as trunk and head inclinations and it could be used for other tree crops besides apple.

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