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Research Article

Titreşime Maruz Kalan İnşaat İşçileri İçin Optimal Emeklilik Yaşı: Türkiye'de Bir Vaka Çalışması

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Öz

Titreşimler yani; ses dalgaları, belirli bir süre içinde belirli sayıda tekrar eden dalgalardır. Ses dalgalarından farkı, sesin hava yoluyla iletilmesidir, titreşim ise vücudun katı kısımlarını kullanır. Titreşimler, operatörlerin el ve kollarına ve hatta tüm yapılarına bina operasyonlarında kullanılan makine ve ekipmanlardan geçer. Titreşimler birçok rahatsızlığa neden olur. Özellikle inşaat sektöründe, yüksek frekanslı titreşim yayıcı makina ve ekipmanlarda çalışan işçilerde ciddi sağlık sorunları gözlenmektedir. Bu sağlık sorunlarından en yaygın olanı orta ve uzun vadede ciddi mesleki ve bazı sağlık sorunlarına neden olan titreşimli bir sendromdur. Titreşim sendromu hastaları özellikle inşaat işlerinde fonksiyonel, sosyal ve psikolojik sakatlık yaşarlar. Bu nedenle, bu mesleklerin sigortaları ve amortismanları diğer çalışanlardan farklı olmalıdır.

Bu çalışmada inşaat işçilerinin titreşim sendromu risk sınıflamaları yapılmıştır. Sıkı kavanoz açma zorluğu, el kavrama zayıflığı ve parmak rengi değişiklikleri çalışanların genel sorunları arasında öne çıkmaktadır. Ankete göre parmak soğukluğu ve parmak uyuşukluğu daha az ortaya çıkmaktadır. Bu sonuca göre gerekli önlemler ve yasal mevzuat önerileri sunuldu. Titreşime maruz kalan inşaat işçilerinin emeklilik yaşı için Taguchi metoduna dayalı bir optimizasyon yapıldı. İnşaat işçilerinin çalışma sürelerinin analiz sonuçlarına göre yeniden incelenmesi gerektiği sonucuna varılmıştır. İlgili mevzuat, her meslek için önerilen emeklilik yaşı uyarınca güncel tutulabilir.

Anahtar Kelimeler: Titreşim sendromu, çalışma koşulları, inşaat işçileri, sağlık sorunu, optimum emeklilik yaşı, anket çalışması.

Optimal Retirement Age for Construction Workers Exposed to Vibration: A Case Study in Turkey

Abstract

Vibrations namely; sound waves are the waves that have a certain number of repetitions in a period. The difference from the sound waves is that the sound is transmitted through the air, while the vibration uses the solid parts of the body. Vibrations pass to operators' hands and arms and even to all their bodies from machinery and equipment used in building operations. Vibrations cause many discomforts. Especially in the construction sector, serious health problems are observed in workers working in high-frequency vibration-emitting machines and equipment. The most common of these health problems is a vibratory syndrome, which causes serious occupational and some health problems in the medium and long term. Vibration syndrome sufferers especially in construction works experience functional, social and phycological disabilities. Hence, the insurances and the depreciation of these occupations must be different from those of other employees.

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In this study, construction workers' vibration syndrome risk classifications were conducted. Difficulty in tight jar opening, weak hand grip and finger color changes are among the general problems of the employees. According to the questionnaire, finger coldness and finger numbness are less common. According to this results suggestion on necessary precautions and legal legislation were presented. A Taguchi method-based optimization was performed on the retirement age of construction workers exposed to vibration. It is concluded that the working time of construction workers should be re-examined as per the analysis results. Related legislations can be kept up with the date as per the recommended retirement age for each occupation.

Keywords: Vibration syndrome, working conditions, construction workers, health problem, optimum retirement age, questionnaire study.

1. Introduction

In recent years, construction projects have increasingly developed into a complex and challenging structure. Construction workers require a variety of skills to achieve the objectives of construction projects within specified time and budget. Even though, health and safety regulations are currently active in many countries including Europe, organizations are ineffective to protect their workers' health and safety (Verra, Benzerga, Jiao, & Ruggeri, 2018). Electrical plate compactor (Misir & Laman, 2017), roller operations, vibrator operations and hand compactor operations are some of the usage areas for the vibration for the compaction of construction materials. And construction workers are often forced to work for a long time using their physical strength to the fullest. Some diseases start to appear in workers who work for a long time in this way. These diseases are Musculoskeletal Disorders (MSDs), Hand-Arm Vibration Syndrome (HAVS) and Noise-Induced Hearing Loss (NIHL)(Handford et al., 2017; R. A. House, Sauvé, & Jiang, 2010; Nath, Akhavian, & Behzadan, 2017; Thompson, Turcot, Youakim, & House, 2011).

Vibration syndrome in the construction industry is a condition associated with the utilization of vibrating tools during the working time. Recent study indicates that workers who are exposed to vibration at great risk of having MSDs of shoulder and neck (Charles, Ma, Burchfiel, & Dong, 2018). In Europe there are millions of workers who face with this problem. Consequently, this disease costs huge amount of money to the employers (Anyfantis & Biska, 2018).

Hand-arm vibration syndrome (HAVS) and Carpal Tunnel Syndrome (CTS) are the disease involving vascular, neurologic and musculoskeletal systems and can also be coexisted together (Falkiner, 2003). HAVS can be the result of using pneumatic and electric building tools such as grinders, drills, jackhammers, chainsaws, which transmit vibration with high frequency to workers' body (Ragnhild Cederlund, Isacsson, & Lundborg, 1999). Mining, forestry, and metalworking workers up to 50 % may be affected by HAVS (Handford et al., 2017). In advanced cases, HAVS may cause extremity disability(Ron House et al., 2009; Ronald House, Holness, Taraschuk, & Nisenbaum, 2017; Poole & Mason, 2005). HAVS usually manifest pale and cold hand. The condition is called secondary Raynaud's syndrome. An example of Secondary Raynaud's syndromes effect on a human body is shown in Fig. 1 (Falkiner, 2003). Vascular spasms in secondary Raynaud's syndrome is related to the intensity and duration of vibration exposure (Bovenzi, 2010; Vihlborg, Bryngelsson, Lindgren, Gunnarsson, & Graff, 2017). Early diagnosis and avoidance of HAVS is the critical factor, since advanced disease results in permanent impairment (Kurozawa, Nasu, Hosoda, & Nose, 2002; Pelmear & Taylor, 2006).

Fig. 1. Secondary Raynaud's syndrome

Current researches have been focused on the biomedical perspective such as arm disabilities, shoulder and hand problems (R. Cederlund, et al. 2001; R. House et al., 2012; Ron House et al., 2009; Poole & Mason, 2005; Sauni et al., 2010). The best known and

Table 1. Vascular symptoms classification according to The Stockholm Workshop Scale

Vascular Symptoms	0	No symptoms recorded
	V_1	Symptoms only have impacts on the tips of the distal phalanges of one or more fingers
	V_2	Symptoms on whiteness of fingers affecting the distal and middle) phalanges of one or more fingers (Occasional)
	V_3	Symptoms on whiteness of fingers affecting the distal and middle) phalanges of one or more fingers (Frequent)
	V_4	V_3 with additional trophic changes
Neurological Symptoms	NS_0	No symptoms recorded
	NS_1	sporadic numbness and/or tingling with a sensorineural loss
	NS_3	sporadic or continuous numbness and/or tingling with reduced sensory perception
	NS_4	Continuous numbness and/or tingling along with reduced manipulative dexterity

Although there are many studies on HAVS, there is no overall perspective on the effect of HAVS on disability. No information is available on the HAVS impacts on the construction workers in Turkey. This research was conducted in order to contribute to the related studies for addressing symptom management and work safety strategies to minimize the effect of HAVS and similar health problems in Turkey.

2. Literature review

According to the literature, there are three existing data collection types widely utilized concerning Vibration syndrome and its effects on workers:

- Self-reported method: workers fill out a questionnaire to identify their risk factors for their jobs. Through this approach, both physical and psychosocial factors are obtained with interviews and surveys such as the Nordic Musculoskeletal Questionnaire and Borg Scale. This approach provides advantages such as low cost and ease of application at the construction site (Borg & Löllgen, 2001; David, 2005; Kuorinka et al., 1987). However, this approach has some disadvantages such as workers' self-reports shows that are often uncertain, unstable (Balogh et al., 2004; Spielholz, Silverstein, Morgan, Checkoway, & Kaufman, 2001).
- Observation method: a job analyst generally observes risk factors on the construction site, and direct observation on construction site or a video recording analyzing is required (Teschke et al., 2009; Valero, Sivanathan, Bosché, & Abdel-Wahab, 2016). Despite being inexpensive and applicable to a wide range of workplace, this approach is disruptive in nature and time-consuming (David, 2005).
- Measurement method: Some measurement tools such as Inertial Measurement Units (IMUs) and Surface Electromyography (SEMG) Sensors are generally attached to workers' body to collect data (Alwasel, Elrayes, Abdel-Rahman, & Haas, 2017; Maxwell Fordjour Antwi-Afari, Li, Yu, & Kong, 2018), but construction workers' body movements of a few muscles can be recorded, and it is difficult to monitor the whole body (D. Chen et al., 2018; J. Chen, Qiu, & Ahn, 2017). Besides, attached sensors can make workers feel unrestful and disturbing while fulfilling their duty (M. F. Antwi-Afari et al., 2017; Maxwell Fordjour Antwi-Afari, Li, Edwards, et al., 2018; Umer, Li, Szeto, & Wong, 2016).

Measurement and Observation method are not preferred in this study due to their high cost and difficulty in application. Hence, the self-reported method was selected in this study.

Taguchi method was used to analyze the questionnaires in this study. Taguchi method is commonly used by experts with the purpose of analyzing experimental results such as compressive strength, flexural strength and sulfate resistance properties (Yildizel & Calis, 2019). In this methodology, the product/process is affected by; environmental factors, and components of the product. The components used to create the product are classified as; controllable and uncontrollable (Turkmen, Gul, & Celik, 2008). The uncontrollable components cannot be intervened by the researcher. Taguchi method seeks the way to get the best result by keeping the uncontrollable parameters the same and tries the different values for the controllable components. The aim of this method is to investigate the interrelations between the variables and the product/result. Based on the data available, the method can optimize the system by using the optimum values for the parameters to get the desired results.

This method enables the research to minimize variability around the investigated parameters while optimizing the performance. As it uses numerous experimental results, it gets a deep view to understand the structure of the system and how the results change. Therefore, the findings of Taguchi are applicable in the real environment. This method keeps the cost of the experiment at a low level by giving an opportunity to get the optimum result without doing many experiments (Sevinc, Durgun, & Eken, 2017).

There some studies, review the day and night shift conditions of workers, however in this study only day shift workers have been investigated (Kim, 2018).

3. Methods

3.1. Survey design

In this paper, vibration syndrome symptoms on construction workers were classified. Interviews were conducted with 175 construction workers including concrete breakers, impact drillers, steel cutters, grinder, roller operator, truck driver, vibrator operator, and hand compactor operator. The questionnaire is given in Table 2. Content validity is applied to determine if these questions are asked to the adequate number of workers. Content validity is the level which determines the sufficient number of construction workers per each occupation in the questionnaire (Gleason, Harris, Sheean, Boushey, & Bruemmer, 2010). Survey results were validated with the Lawshe content validity method. Lawshe content validity ratio is reliable to determine the validity of components and whole questionnaire (Ayre & Scally, 2014). And this method is one of the most accepted methods for content validity determining processes (Barton, Wrieden, & Anderson, 2011). Content validity ration is calculated with the Eq. (1)(Forman & Damschroder, 2007). In this method, 5-10 respondents are considered adequate by some researchers (Gilbert & Prion, 2016); however, other researchers study in various areas such as; health nutrition, economy, academic, family study suggest that using a larger number of samples (minimum n=30)(Markovina et al., 2015).

Table 2. Survey design

1.General information				
Occupation				
Age				
2. Questions				
Health problem	Health Problem Severity (1-4)	Vibration Exposure Time (h per day)	Working Experience (years)	First syndrome diagnosis age
Finger color change				
Finger tingling				
Finger numbness				
Upper limbs problem				
Neck problems				
Hand grip weakness				
Finger coldness				
Difficulty in handling small objects				

Lawshe content validity ratio, $(CVR)=\frac{N_1-(N_2/2)}{(N_2/2)}$ (1)

, where N_1 is the number of respondents who answered the questionnaire for the same occupation, N_2 is the total number of the respondents. According to the validation scale, if CVR is lower than 0.50, it is unacceptable, between 0.50-0.59, it is counted as poor, between 0.60-0.69 is questionable, and 0.70-0.79 is acceptable, higher than 0.80 is evaluated as good (George & Mallery, 2013).

3.2. Taguchi orthogonal array design

Taguchi orthogonal method was utilized to study the optimal retirement age for construction workers, who faced with vibration in their daily working times. A standard L_{16} array was proposed to study the effects of three factors at four levels. Health problem severity(H), vibration exposure time (V) and working experience (W) on the same jobs were selected as important factors effecting the retirement age as seen in Table 3. Analysis of variance (ANOVA) was also conducted to determine the most significant factors on the retirement age optimization. Vascular problems were considered at four levels as 1,2,3 and 4 (Vihlborg et al., 2017) within the health problem severity classification during the optimization. Vibration exposure time and working experience as codified as illustrated in Table 4. Minitab software was used during the analyses. Only 16 average retirement age output was required for the L_{16} orthogonal array design (Table 4). Finger numbness was not considered in the optimization studies, since it is a neural disease and its symptoms can be easily confused with other diseases.

Table 3. Taguchi L_{16} orthogonal array factors and their levels.

Factors	Level 1	Level 2	Level 3	Level 4
Health problem severity	1	2	3	4
Vibration exposure time(hours)	2(0-2)	4(2-4)	6(4-6)	8(6-8)
Working experience (years)	5(0-5)	10(5-10)	15(10-15)	20(15–20)

Table 4. Taguchi L_{16} orthogonal array

Trial number	Factors and their levels		
	Health problem severity	Vibration exposure time (hours)	Working experience (years)
1	1	2	5
2	1	4	10
3	1	6	15
4	1	8	20
5	2	2	5
6	2	4	10
7	2	6	15
8	2	8	20
9	3	2	5
10	3	4	10
11	3	6	15
12	3	8	20
13	4	2	5
14	4	4	10
15	4	6	15
16	4	8	20

The other parameters that can influence a person's health condition such as: smoking habit, diet, sleep habit have been excluded in this study. In this respect it should not be considered as a biological study.

4. Results and discussion

4.1. Survey results

Participant and vibration syndrome symptom quantities are presented in Fig. 2. No female worker was interviewed. 175 construction workers are participated in the questionnaire. Difficulty in opening tight jars, hand grip weakness and finger color changes are the main parts of the general worker answers. Finger coldness and finger numbness are less suffered according to the questionnaire.

Vibration syndrome symptoms were classified according to the worker occupation and given in Fig. 3. Concrete breakers and drillers mostly suffer from finger color change and hand grip weakness. Steel cutters suffer from difficulty in opening tight jars and handling small objects. Main symptoms for grinders were obtained as difficulty in opening tight jars and finger color change. Roller operators suffer from upper limbs problem and finger tingling. Vibrator operators complained about upper limbs problem and neck problems. Hand compactor operators' main symptoms are finger numbness, finger tingling and finger color change. Truck drivers were obtained as the less vibration effected workers in construction industry; however, they have vibration sourced health problems as neck problems and upper limbs problem.

Vibration syndrome sufferers especially in construction works experience functional, social and phycological disabilities. Only applicable evidences are the disease symptoms and they are presented in Fig. 3.

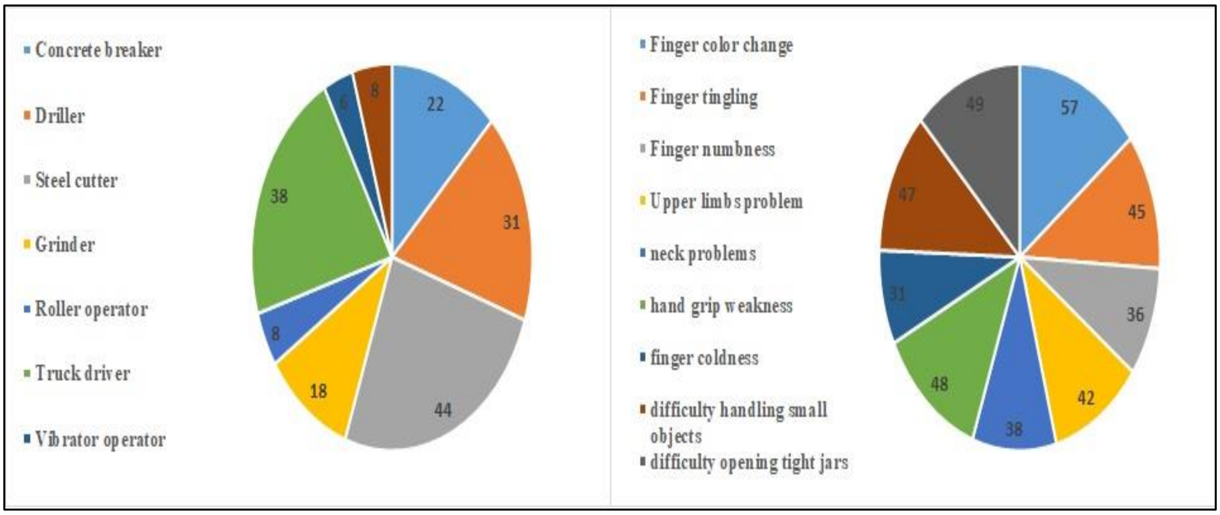

Fig 2. Number of responses and symptom quantities

Severity index analysis result for positive answers are given in Table 5. Mostly suffered symptoms are classified according to their severity index. Finger color change was obtained as mostly suffered symptoms.

Table 5. Severity Index (S.I.) analysis results

Symptoms	S.I. (%)	Rank
Finger color change	77.01	1
Difficulty opening tight jars	71.21	2
Hand grip weakness	65.14	3
Difficulty handling small objects	64.53	4
Finger tingling	63.27	5
Upper limbs problem	59.92	6
Neck problems	57.23	7
Finger numbness	56.77	8
Finger coldness	51.13	9

Table 6. Content validity analyses results

Occupation	Ne	N	N/2	Ne /N	CVR
Concrete breaker	20	22	11	0.91	0.82
Driller	30	31	15.5	0.97	0.94
Steel cutter	43	44	22	0.98	0.95
Grinder	17	18	9	0.94	0.89
Roller operator	8	8	4	1.00	1.00
Truck driver	36	38	19	0.95	0.89
Vibrator operator	6	6	3	1.00	1.00

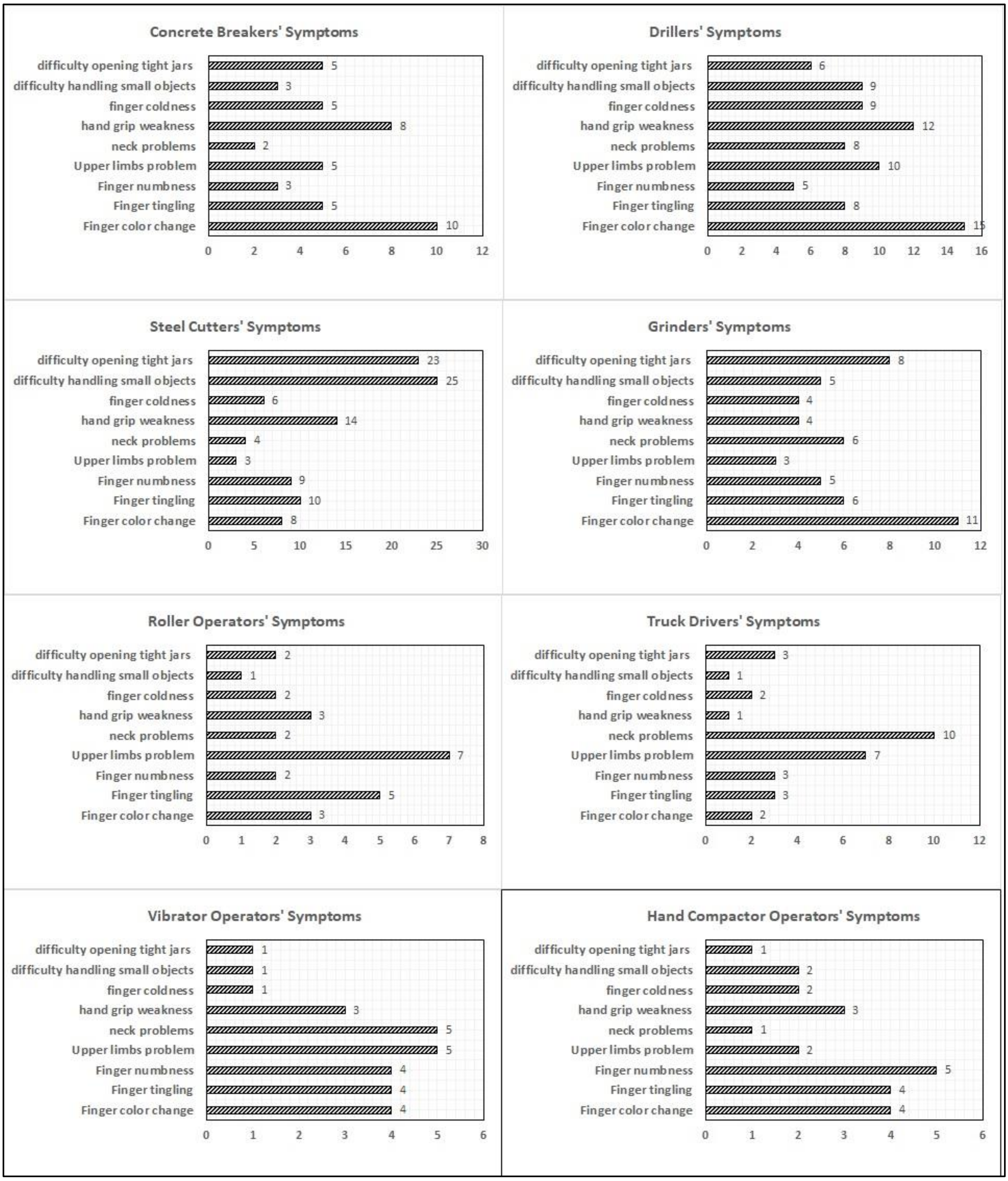

Fig. 3. Symptoms distribution according to the workers occupation

Lawshe content validity results are presented in Table 6. All calculated CVR were found as higher than 0.80. These good results can be contributed to the workers who reported to the survey provided good feedbacks, and the essential number of responses are received.

4.2. Taguchi optimization results

Taguchi retirement age optimization results are given in Fig. 4. The signal to noise ratio represents the quality characteristic transformation, and this ratio as considered as smaller is better to obtain the minimum retirement age. According to the Taguchi design results, optimum conditions for finger color change, finger tingling was $H_1V_4W_{20}$. For finger coldness, neck and upper limb problems optimum conditions was obtained as $H_1V_2W_{20}$. Analysis results showed that for the handing grip weakness and difficulty in handling small objects problems optimum conditions was $H_2V_2W_{10}$. And the optimum working conditions for difficulty in opening tight jar was $H_2V_4W_5$.

Table 8 shows the ANOVA results for retirement age and parameters contribution to the analysis. Health problem severity was obtained as the most effecting factor on the retirement age in all analyses since it has F-Value compared to the other factors. Working experience obtained as the second important factor for finger color change, finger tingling, upper limbs problem, neck problem and finger coldness on the optimized ages. However, vibration exposure time was the second most effective factor for difficulty in opening tight jars and hand grip weakness problems. It is known that the vibration exposure time and health problem severity significantly contributed to the progress of the difficulty in opening tight jars and hand grip weakness problems (Bovenzi, 2005; Walker-Bone & Palmer, 2002).

Optimum retirement ages recommendations for every health problem are presented in Table 7.

Table 7. Recommended Retirement Ages according to the Taguchi Design

Health Problem	Recommended retirement age
Finger color change	43
Finger tingling	41
Upper limbs problem	39
Neck problems	41
Hand grip weakness	52
Finger coldness	39
Difficulty in handling small objects	54
Difficulty in opening tight jars	55

Minimum retirement ages were obtained as 39 for finger coldness and upper limbs problem. On the other hand, the maximum retirement age was 55 for difficulty in opening tight jars. Higher vibration exposure rate directly related to the musculoskeletal complaints, especially upper limb problems. Acquired Amputation is one of the treatment methods of advanced musculoskeletal complaints. Employment rates of the worker are slightly lower, on condition that AA is required as a cure (Postema et al., 2016). For this reason, the optimal age for upper limbs problem can be significantly evaluated to prevent these types of job losses. Finger coldness disease is generally treated by preventing the circumstances which cause flare ups (Sakakibara et al., 1988). For construction workers, there is almost no way to stay away from this environment except retirement, since another profession that they can do is very limited. Difficulty in opening tight jars disorder is tolerable compared to the other occupational disease, and the analysis results were obtained in parallel with the literature studies (R. Cederlund et al., 2001; Hua, Lemerle, & Ganghoffer, 2017; Pelmear & Taylor, 2006).

Table 8. ANOVA results

Finger color change					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	167.69	55.90	2	0.216
Vibration exposure time	3	48.69	16.23	0.58	0.649
Working experience	3	113.19	37.73	1.35	0.345
Error	6	167.88	27.98	-	-
Total	15	497.44	-	-	-
Finger tingling					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	200.19	66.73	2.40	0.167
Vibration exposure time	3	47.19	15.73	0.57	0.658
Working experience	3	143.19	47.73	1.72	0.262
Error	6	166.88	27.81	-	-
Total	15	557.44	-	-	-

Upper limbs problem					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	271.687	90.562	2.04	0.210
Vibration exposure time	3	8.688	2.896	0.07	0.976
Working experience	3	183.688	61.229	1.38	0.337
Error	6	266.875	44.479	-	-
Total	15	730.938	-	-	-
Neck problems					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	394	131.333	2.63	0.145
Vibration exposure time	3	16.50	5.50	0.11	0.951
Working experience	3	125.50	41.833	0.84	0.521
Error	6	300	50	-	-
Total	15	836	-	-	-
Hand grip weakness					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	310.69	103.563	5.39	0.039
Vibration exposure time	3	52.19	17.396	0.90	0.492
Working experience	3	19.69	6.563	0.34	0.797
Error	6	115.37	19.229	-	-
Total	15	497.94	-	-	-
Finger coldness					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	344.19	114.73	5.43	0.038
Vibration exposure time	3	63.69	21.23	1	0.453
Working experience	3	113.69	37.90	1.79	0.249
Error	6	126.88	21.15	-	-
Total	15	648.44	-	-	-
Difficulty in handling small objects					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	282.75	94.083	3.69	0.081
Vibration exposure time	3	21.25	7.083	0.28	0.840
Working experience	3	45.25	15.083	0.59	0.643
Error	6	153	25.500	-	-
Total	15	501.75	-	-	-
Difficulty in opening tight jars					
Factor	df	Sum of Square (SS)	Adj mean of square (MS)	F-Value	P-Value
Health problem severity	3	347	124.667	3.78	0.078
Vibration exposure time	3	66.50	22.167	0.67	0.6

Working experience	3	27.50	9.167	0.28	0.84
Error	6	198	33	-	-
Total	15	666	-	-	-

df: Degree of freedom SS: Adj. Sum of square VA: Adj. Mean Square F: F value.

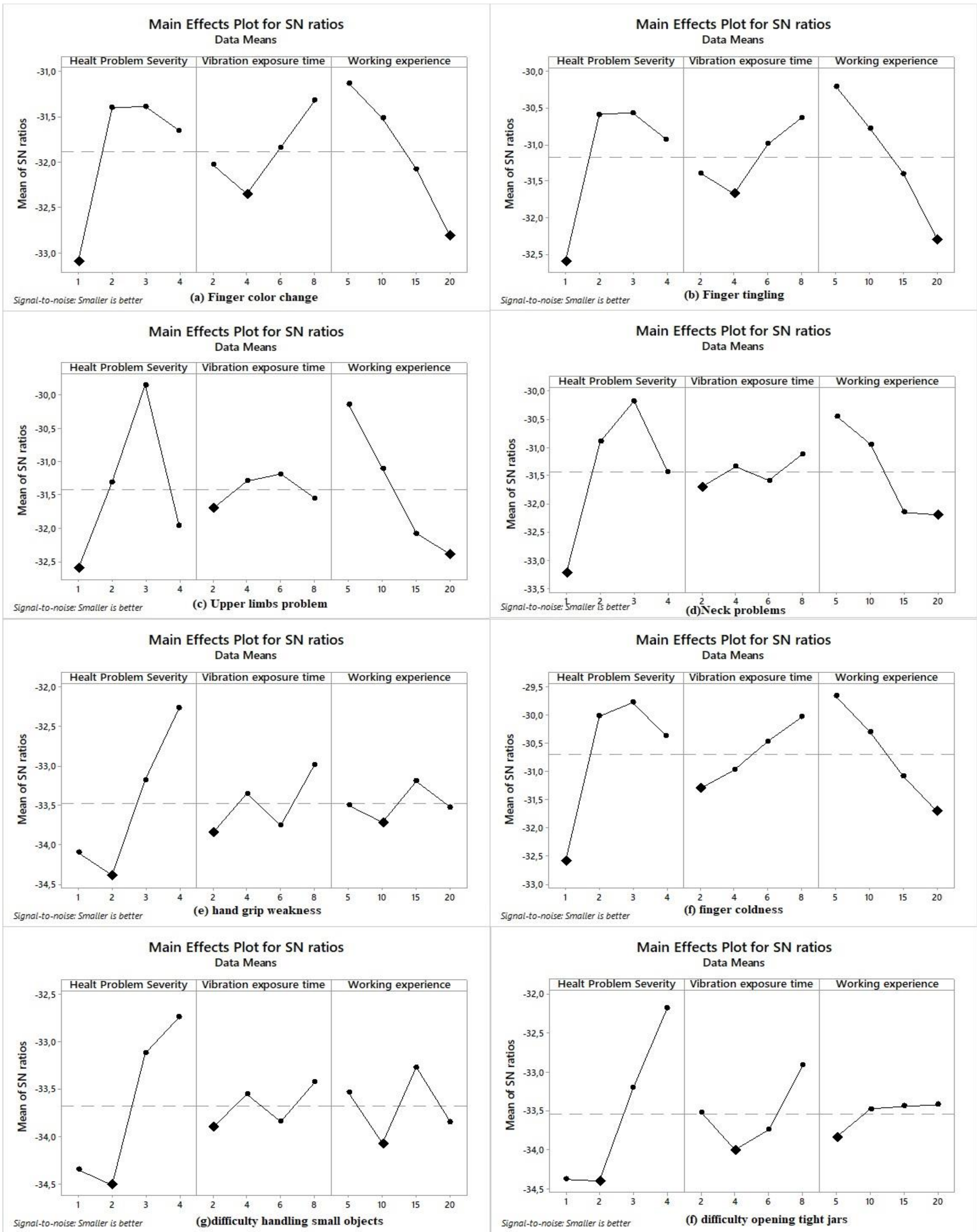

Fig. 4. Taguchi optimization results

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5. Conclusion

Various symptoms that occur in construction workers who are exposed to vibration due to their daily working activities, have been investigated and the retirement age optimization were also conducted in this research. Following conclusion can be drawn:

- According to the occupational groups of the employees, the working time should be re-examined.
- It is necessary to provide additional wage payments to the employees concerned.
- Work equipment to prevent these diseases should be developed and their usage should be followed regularly.
- Related norms and regulations can be kept up with the date as per the recommended retirement age for each occupation.
- The evaluation has been made based on the statistical data. It is recommended that further investigations might be done by including more parameters and maybe some doctors as well. By doing so deeper view can be obtained.

Conflict of interest

All authors declare to have no financial or personal relationships that could inappropriately influence the research described.

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