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Article

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Modeling the Effects of Different Interventions on Kinesiophobia, Pain, and Quality of Life in Women with Lumbar Disc Herniation Using Artificial Neural Networks

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Abstract

This study aimed to examine the effects of swimming exercise, physical therapy, and a inactive lifestyle on pain, kinesiophobia, and quality of life in women diagnosed with lumbar disc herniation and to model the SF-12 physical health score using kinesiophobia and pain levels through Artificial Neural Networks (ANNs). A total of 54 female volunteers participated in the study. The participants had a mean age of 52.83 ± 13.30 years, a mean height of 162.18 ± 4.45 cm, a mean body weight of 75.37 ± 13.53 kg, a mean body mass index of 28.67 ± 5.11 kg/m², and a mean disease duration of 8.98 ± 7.85 years. Data were collected using a personal information form, the Visual Analogue Scale, the Kinesiophobia Scale, and the SF-12 Quality of Life Questionnaire. Normality was assessed using the Shapiro–Wilk test, group differences were evaluated by MANOVA, and the statistical significance level was set at $p < 0.05$. In the ANN models, the total kinesiophobia score and pain score were used as input variables, while the SF-12 physical health score was used as the output variable. A separate model was developed for each pairwise group comparison. A significant difference was found among the groups in terms of pain level ($p < 0.01$), with the swimming group exhibiting lower pain scores than the physical therapy and inactive groups. No significant differences were observed in kinesiophobia or physical quality-of-life scores. In the Swimming–Physical Therapy model, MSE was 0.675, MAPE was 3.242%, and R was 0.991. In the Physical Therapy–Inactive model, MSE was 0.705, MAPE was 3.410%, and R was 0.991. In the Swimming–Inactive model, MSE was 1.429, MAPE was 5.363%, and R

was 0.973. The results indicate that swimming exercise may support pain management and that ANN models can predict physical quality-of-life scores with a high level of agreement.

Keywords: Pain, Lumbar Disc Herniation, Kinesiophobia, Quality of Life, Swimming, Modeling, Artificial Neural Networks

INTRODUCTION

With digitalization and automation, daily life increasingly requires less physical effort, making physical inactivity a major public health problem worldwide. The World Health Organization identifies insufficient physical activity as one of the main risk factors for numerous chronic diseases, including cardiovascular diseases, diabetes, obesity, and musculoskeletal disorders [1]. Exercise is regarded as a fundamental intervention not only for the prevention and treatment of chronic diseases but also for improving overall quality of life, supporting psychological well-being, and maintaining functional capacity [2,3].

Low back pain and related conditions are among the clinical disorders that impose the greatest burden among musculoskeletal causes of pain [4,5]. Global Burden of Disease studies identify low back pain as one of the leading causes of work loss, functional limitation, and healthcare utilization in both developed and developing countries [6]. Lumbar disc herniation, one of the most common structural pathologies of the lumbar region, is characterized by the protrusion of the nucleus pulposus of the intervertebral disc through torn or weakened areas of the annulus fibrosus into the spinal canal, resulting in compression of the nerve roots [7,8]. As a result of this compression, pain, paresthesia, and functional limitation are frequently observed in the lumbar region, hips, legs, or distal extremities [8,9]. In a substantial proportion of patients, sleep disturbance, reduced performance of daily living activities, work loss, and a marked decline in quality of life have also been reported in addition to pain [7,10].

The etiology of lumbar disc herniation is explained by the interaction of occupational factors such as repetitive heavy lifting, prolonged sitting, poor posture, and exposure to vibration; sports activities involving excessive loading; personal factors such as obesity, smoking, and a inactive lifestyle; and psychological factors such as pain-related beliefs and fear-based avoidance of movement [7,8]. Prolonged sitting and physical inactivity increase mechanical loading, particularly at the L4–L5 and L5–S1 levels, accelerate disc degeneration, impair the structural integrity of the annulus fibrosus, and predispose individuals to herniation (Delisa &

Gans, 2007). In contrast, regular physical activity that imposes a moderate level of physiological loading on the spine has been reported to exert protective effects on the intervertebral discs and paravertebral muscles [2,3].

Avoidance of movement in individuals with low back pain is frequently associated with fear of pain and concern about reinjury. Kinesiophobia, as defined by SH, refers to an intense fear of movement arising from the belief that movement may cause reinjury or increase pain. It is considered an important psychosocial risk factor for the persistence of chronic pain and the progression of functional limitation [11,12]. In patients with lumbar disc herniation, high levels of kinesiophobia have been associated with greater pain intensity, reduced physical performance, and poorer quality of life [13,14]. Controlled mobilization and appropriate exercise initiated at an early stage have been reported to reduce pain and improve function, whereas prolonged inactivity may contribute to pain chronicity and increase psychological burden [15],[10].

Non-surgical conservative approaches used in the treatment of lumbar disc herniation include pharmacological treatment, physical therapy and rehabilitation, educational and behavioral interventions, and various exercise protocols [7-9]. Exercises such as McKenzie range-of-motion exercises, lumbar stabilization and core-strengthening programs, aerobic walking, and swimming have been shown to be beneficial for reducing pain and improving functional capacity [1,2,15]. Aquatic exercise and aquatic therapy provide a rehabilitation environment in which buoyancy reduces axial loading, while viscosity-related resistance that increases with movement speed improves muscular strength and endurance. They also reduce compressive forces on the joints and allow a greater range of motion [16]. These properties make aquatic exercise and swimming particularly suitable for patients with lumbar disc herniation who require limited mechanical loading on the lumbar region [16].

Swimming and aquatic exercises performed in deep or shallow water facilitate a return to activities of daily living with no pain or less pain after exercise because gravitational effects and joint compression are reduced to minimal levels [17]. In recent years, studies examining the effects of aquatic therapy, underwater treadmill exercise, and different swimming protocols on pain scores, functional status, and quality of life in patients with chronic low back pain and lumbar disc herniation have suggested that these approaches may provide a useful contribution to conservative treatment [15,17].

The effects of different exercise- and movement-based interventions on kinesiophobia, pain, and quality of life in women with lumbar disc herniation are shaped by the combined influence of numerous factors, including individual characteristics, physical fitness level, movement capacity, and the nature of the intervention program. The relationships among

these variables are often complex and nonlinear, which may make it difficult to explain the outcomes solely through conventional statistical methods. Artificial neural networks provide a modeling approach capable of learning hidden patterns in multidimensional data and predicting the possible effects of different interventions. Through this method, participants' baseline characteristics and post-intervention changes in kinesiophobia, pain, and quality of life can be evaluated together. This may support the prediction of the effects of different exercise interventions, the planning of movement and exercise programs suited to individual characteristics, and the development of physical education practices based on scientific evidence.

Within this context, the present study, entitled "Modeling the Effects of Different Interventions on Kinesiophobia, Pain, and Quality of Life in Women with Lumbar Disc Herniation Using Artificial Neural Networks," aimed to examine the relative effects of swimming exercise, inactivity, and physical therapy on kinesiophobia levels, pain threshold, and quality of life in women diagnosed with lumbar disc herniation and to model the relationships among these variables using artificial neural networks. The study also sought to contribute to the development of more effective, individualized, and evidence-based conservative treatment strategies for women with lumbar disc herniation.

MATERIALS AND METHODS

Study Design and Sample

This study was designed as a descriptive, comparative, and cross-sectional investigation. The aim of the study was to examine the effects of physical therapy, inactivity, and swimming exercise on kinesiophobia, quality of life, and pain levels in women with lumbar disc herniation.

A total of 54 female patients diagnosed with lumbar disc herniation who voluntarily agreed to participate in the study were included. The mean age, height, body weight, and body mass index (BMI) of the participants were 52.83 ± 13.30 years, 162.18 ± 4.45 cm, 75.37 ± 13.53 kg, and 28.67 ± 5.11 kg/m², respectively. The mean duration of lumbar disc herniation was 8.98 ± 7.85 years.

The study data were collected through face-to-face interviews with women diagnosed with lumbar disc herniation who resided in the Seyhan and Çukurova districts of Adana Province. The data collection instruments were prepared by the researcher based on the relevant national and international literature and were supported by standardized scales.

Participant Groups

Using purposive sampling, women diagnosed with lumbar disc herniation were divided into three groups. The swimming group (n = 18) consisted of women who had regularly participated in swimming exercises at Hayal Park Swimming Pool for at least six weeks. The mean demographic characteristics of this group were as follows: age, 48.33 ± 12.17 years; height, 163.05 ± 4.35 cm; body weight, 70.50 ± 13.37 kg; BMI, 26.47 ± 4.72 kg/m²; and disease duration, 9.27 ± 9.25 years.

The physical therapy group (n = 18) consisted of women receiving a physical therapy program for lumbar disc herniation at the Physical Therapy and Rehabilitation Outpatient Clinic of Balcalı Hospital, Çukurova University, Adana. The mean demographic characteristics of this group were as follows: age, 57.05 ± 12.00 years; height, 161.77 ± 3.43 cm; body weight, 78.55 ± 12.31 kg; BMI, 30.00 ± 4.50 kg/m²; and disease duration, 8.38 ± 5.85 years.

The inactive group (n = 18) consisted of physically inactive women living in the Seyhan district of Adana who had been diagnosed with lumbar disc herniation and did not engage in regular exercise. The mean characteristics of this group were as follows: age, 53.11 ± 14.80 years; height, 161.72 ± 5.46 cm; body weight, 77.05 ± 14.21 kg; BMI, 29.52 ± 5.58 kg/m²; and disease duration, 9.27 ± 8.47 years.

Data Collection Instruments

Demographic and Clinical Information Form

The Personal Information Form developed by the researcher was used to assess the participants' demographic and clinical characteristics, including age, height, body weight, BMI, disease duration, occupational status, number of children, income level, smoking status, existing health problems, regularly used medications, and whether they exercised upon a physician's recommendation. The form was designed to systematically record the medical history of women with lumbar disc herniation.

Pain Level: Visual Analogue Scale (VAS)

The Visual Analogue Scale (VAS) was used to assess the patients' pain intensity. The VAS consisted of a 10-cm horizontal line, with 0 indicating "no pain" and 10 indicating "the worst pain ever experienced." Participants were asked to mark the point on the scale that best represented the intensity of their current low back pain. The marked point was then measured using a millimetric ruler and recorded as the pain score in centimetres. The VAS is a valid and reliable measurement tool that is widely used for the subjective assessment of acute and chronic pain. The method used in this study was based on the pain assessment studies conducted by Price et al. [18] and Huskisson et al.[19].

Quality of Life: SF-12 Health Survey

The Short Form-12 Health Survey (SF-12, Version 2.1) was used to assess the participants' quality of life. The SF-12 is a 12-item self-report instrument developed within the SF-12 framework to measure physical and mental health components over the previous four weeks [20]. Scores obtained for each subscale range from 0 to 100, with higher scores indicating better health status. The scale also provides two summary scores: the Physical Component Summary (PCS) and the Mental Component Summary (MCS). The Turkish validity and reliability study of the SF-12 was conducted by Koçyiğit et al., and the findings indicated that the instrument could be used to assess physical and mental health status in the Turkish population[20].

Kinesiophobia: Tampa Scale for Kinesiophobia (TSK)

The Tampa Scale for Kinesiophobia (TSK) was used to assess kinesiophobia, which refers to the expectation of movement-related pain and fear of movement. The TSK is a 17-item questionnaire developed to evaluate kinesiophobia in individuals with chronic low back pain, fibromyalgia, musculoskeletal injuries, and whiplash-associated disorders[21]. The scale uses a four-point Likert-type scoring system ranging from 1, "strongly disagree," to 4, "strongly agree." After reverse-scoring items 4, 8, 12, and 16, the item scores are summed to obtain a total score ranging from 17 to 68, with higher scores indicating greater levels of kinesiophobia. The Turkish adaptation and validity and reliability study of the TSK was conducted by Yılmaz et al. The results showed that the TSK is a valid and reliable instrument for assessing kinesiophobia in Turkish-speaking patients with chronic low back pain [22].

Data Collection Procedure

The data were collected by the researcher through face-to-face interviews. After providing informed consent, the patients were assessed at the swimming pool, the physical therapy outpatient clinic, or their homes in the case of the inactive group. Demographic and clinical information was first recorded using the relevant form, followed by administration of the VAS, TSK, and SF-12, respectively. The scales were explained in accordance with their standard instructions using clear and simple language that the participants could understand.

Ethical approval and informed consent

The study protocol was approved by the Osmaniye Korkut Ata University Health Sciences Ethics Committee at its meeting no. 7 held on 6 July 2026 (approval/document no. E.312451). All procedures involving human participants were performed in accordance with the relevant institutional and national guidelines and regulations and with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their inclusion in the study.

Data Analysis

Statistical analyses were performed using SPSS version 20.0. The normality of the data distribution was assessed using the Shapiro–Wilk test, and the results indicated that the data were normally distributed ($p > 0.05$). Descriptive statistics were used to evaluate the participants' age, height, body weight, educational status, occupational characteristics, and medication use. Differences in the study variables among the groups were examined using multivariate analysis of variance (MANOVA). The results were evaluated at a 95% confidence level, and p values below 0.05 were considered statistically significant.

Artificial Neural Network Modeling

Artificial Neural Networks (ANNs) were used to identify the nonlinear relationships between kinesiophobia and pain levels and the physical dimension of quality of life under different interventions applied to women with lumbar disc herniation. A separate ANN model was developed for each intervention group to independently evaluate group-specific data patterns. In the developed models, the total score of the Kinesiophobia Scale and the Pain Scale score were used as input variables. The physical health score obtained from the quality-of-life scale was defined as the output variable (Figure 1).

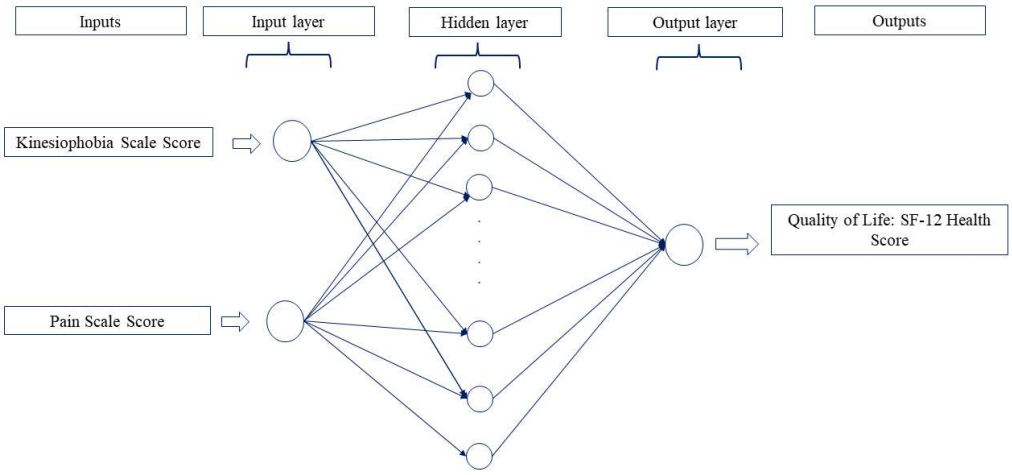


Figure 1. Layer structure of the artificial neural network model

Thus, the effects of kinesiophobia and pain levels on the physical dimension of quality of life were modeled separately for each intervention group.

The data obtained from each intervention group were divided into three subsets—training, validation, and testing—to evaluate the learning and generalization performance of the

models and to reduce the risk of overfitting. Of the total data, 80% were used for training, 10% for validation, and 10% for testing. The training dataset was used to determine the connection weights and bias values of the network. The validation dataset was used to monitor the training process and control overfitting. The test dataset was used to evaluate the predictive performance of the developed models on previously unseen data.

The Levenberg–Marquardt algorithm was selected for training the ANN models because of its rapid convergence and high predictive performance in nonlinear regression problems. During the determination of the network architecture developed for each intervention group, the number of neurons in the hidden layer was systematically varied from 1 to 20, and different network structures were compared. To limit the influence of initial weights on model performance, each network architecture was subjected to 1,000 independent training runs. The network structure that produced the lowest error values and the highest level of agreement across the training, validation, and test datasets was accepted as the optimal model for the corresponding intervention group.

The main parameters used in the modeling process were defined as follows:

Learning rate: 0.5

Momentum coefficient: 0.5

Maximum number of iterations: 500

Maximum validation checks: 50

Error tolerance: 1×10^{-5}

Number of independent training runs: 1,000

The predictive performance of the developed models was evaluated using Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE), and the correlation coefficient (R). MSE was used to determine the magnitude of the squared deviations between the observed physical health scores of quality of life and the scores predicted by the ANN. MAPE was used to calculate the average percentage error of the model predictions. The R coefficient was used to assess the strength of the relationship between the observed and predicted physical health scores of quality of life. For each intervention group, the network architecture with the lowest MSE and MAPE values and an R coefficient closest to 1 was identified as the best-performing model.

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(e_i - p_i)^2 \qquad (1)$$

$$\mathrm{MAPE} = \frac{1}{n}\sum \left|\frac{e_i - p_i}{e_i}\right| * 100 \qquad (2)$$

In the relevant equations, e represented the observed quality-of-life physical health scores, p represented the scores predicted by the ANN, and n represented the total number of observations.

Using the ANN models developed separately for each intervention group, the ability of the total Kinesiophobia Scale score and the Pain Scale score to explain and predict the quality-of-life physical health score was evaluated. The observed quality-of-life physical health scores were compared with the values predicted by the models. This comparison enabled the determination of the extent to which the model learned the data patterns specific to each intervention group and the level of accuracy with which the physical dimension of quality of life was predicted.

This approach extended the evaluation of the relationships between kinesiophobia, pain levels, and the physical dimension of quality of life beyond linear models and group means. By developing a separate ANN model for each intervention group, group-specific nonlinear relationships and latent data patterns were identified. Accordingly, a computational modeling framework was established to predict the quality-of-life physical health score with high accuracy based on the total Kinesiophobia Scale score and the Pain Scale score.

Results and Discussion

In this study, kinesiophobia, Visual Analogue Scale (VAS) scores, and quality-of-life levels were compared among women diagnosed with lumbar disc herniation who participated in swimming exercise, received physical therapy, or were physically inactive (inactive). The absence of significant differences among the groups in terms of age, height, body weight, BMI, and duration of lumbar disc herniation provided an appropriate basis for comparing the clinical variables (Table 1). This finding suggests that the differences observed in pain and other outcome variables may be largely associated with lifestyle and the interventions applied.

The aim of this study was to investigate kinesiophobia, Visual Analogue Scale (VAS) scores, and quality-of-life levels in women diagnosed with lumbar disc herniation who participated in swimming exercise, received physical therapy, or lived a physically inactive lifestyle.

Table 1. Demographic Characteristics of the Swimming Exercise, Physical Therapy, and Inactive Groups

Variables	Group	N	X	SD	F	Asymp. Sig
Age (years)	Swimming	18	48.33	12.17	.276	.760
	Physical therapy	18	57.05	12.00		
	Inactive	18	53.11	14.80		
	Total	54	52.83	13.30		
Body weight (kg)	Swimming	18	163.05	4.35	.677	.513
	Physical therapy	18	161.77	3.43		
	Inactive	18	161.72	5.46		
	Total	54	162.18	4.45		
Height (cm)	Swimming	18	70.50	13.37	.767	.470
	Physical therapy	18	78.55	12.31		
	Inactive	18	77.05	14.21		
	Total	54	75.37	13.53		
Body mass index (BMI)	Swimming	18	26.47	4.72	1.998	.146
	Physical therapy	18	30.00	4.50		
	Inactive	18	29.52	5.58		
	Total	54	28.67	5.11		
Duration of lumbar disc herniation (years)	Swimming	18	9.27	9.25	1.317	.277
	Physical therapy	18	8.38	5.85		
	Inactive	18	9.27	8.47		
	Total	54	8.98	7.85		

Table 2. Comparison of Kinesiophobia, Pain, and Quality-of-Life Scores Across the Study Groups (Kruskal–Wallis Test)

Variable	Swimming Mean Rank	Physical Therapy Mean Rank	Inactive Mean Rank	H	df	p
Total Kinesiophobia Scale Score	20.64	29.08	32.78	5.65	2	0.059
Pain Scale Score	17.75	29.14	35.61	12.12	2	0.002 *
Quality-of-Life Physical Health Score	33.28	22.89	26.33	4.07	2	0.130

Note. H = Kruskal–Wallis H test statistic; df = degrees of freedom. Statistical significance was set at $p < .05$. Indicates a statistically significant difference at the .05 level.

The Kruskal–Wallis test results showed that the study groups differed significantly only in terms of Pain Scale scores, $H(2) = 12.12$, $p = .002$. Examination of the mean ranks indicated that the inactive group had the highest pain scores (mean rank = 35.61), whereas the swimming group had the lowest pain scores (mean rank = 17.75). No statistically significant differences were found among the groups in total kinesiophobia scores, $H(2) = 5.65$, $p = .059$, or quality-of-life physical health scores, $H(2) = 4.07$, $p = .130$.

Table 3. Results of the Dunn–Bonferroni Multiple Comparison Test for Pain Scale Scores

Group Comparison	Test Statistic	SE	Z	p	P (Bonferroni-adjusted
Swimming–Physical Therapy	-11.39	5.20	-2.19	.028	.085
Swimming–Inactive	-17.86	5.20	-3.44	.001	.002*
Physical Therapy–Inactive	-6.47	5.20	-1.25	.213	.638

SE = Standard Error. The Bonferroni correction was applied. Statistical significance was set at $p < .05$.

The Kruskal–Wallis test revealed a statistically significant difference among the groups in terms of pain scores, $H(2) = 12.12$, $p = .002$. A Dunn–Bonferroni multiple comparison test

was performed to determine which groups accounted for this difference. The results showed a statistically significant difference in pain scores between the swimming and inactive groups (adjusted p = .002). In contrast, the differences between the swimming and physical therapy groups (adjusted p = .085) and between the physical therapy and inactive groups (adjusted p = .638) were not statistically significant. Examination of the mean ranks indicated that the inactive group had the highest pain level (mean rank = 35.61), whereas the swimming group had the lowest pain level (mean rank = 17.75).

This finding is consistent with the literature reporting the pain-reducing effects of aquatic exercise and swimming in patients with chronic low back pain and lumbar disc herniation. For example, a randomized clinical trial comparing therapeutic aquatic exercise with physical therapy modalities in patients with chronic low back pain reported greater and clinically more pronounced improvements in pain intensity, functional status, quality of life, sleep quality, and kinesiophobia in the aquatic exercise group [23]. The same study showed that aquatic exercise had positive effects not only on pain control but also on kinesiophobia and fear-avoidance behaviors [23]. Although no statistically significant difference in kinesiophobia was found among the groups in the present study (p = .059), the lower mean rank observed in the swimming group compared with the other groups suggests that this difference might reach statistical significance in a larger sample.

Studies examining the relationship between kinesiophobia, pain, and quality of life in patients with low back pain have shown that kinesiophobia is positively associated with pain intensity and negatively associated with the physical and mental components of quality of life [10]. From this perspective, the lower pain levels observed in the swimming group, together with its lower tendency toward kinesiophobia, as reflected by lower mean ranks than those of the other groups, are consistent with expectations. However, the absence of statistically significant differences among the groups in either the physical components of quality of life (p > .05) may be explained by several factors.

The similar duration of lumbar disc herniation across the groups suggests that the patients may have adapted to chronic pain, resulting in more homogeneous quality-of-life scores. In individuals living with chronic pain, quality of life is influenced not only by physical pain but also by psychosocial adjustment, coping strategies, and socioeconomic factors [10].

The finding that the physical therapy group had lower pain levels than the inactive group but higher pain levels than the swimming group is consistent with current evidence on the effectiveness of physical therapy in the treatment of lumbar disc herniation. Many sources describe physical therapy and rehabilitation as effective alternatives to surgery that reduce

pain and improve quality of life in patients with lumbar disc herniation [24]. It has also been reported that both exercise and physical therapy reduce pain and functional limitation in patients with chronic low back pain, while the reduction in pain may be more pronounced when physical therapy is combined with exercise [25]. Studies focusing specifically on aquatic exercise and swimming indicate that aquatic exercise may produce better outcomes than conventional physical therapy modalities for some variables [23]. In the present study, the absence of a statistically significant difference in pain between the swimming and physical therapy groups ($p = .085$) suggests that the clinical effects of these two approaches may be comparable, whereas swimming appears to provide a clear advantage over a inactive lifestyle.

The absence of significant differences among the groups in kinesiophobia and quality-of-life scores also indicates the need for multidisciplinary treatment approaches. A reduction in pain does not necessarily lead to a parallel reduction in fear-avoidance behaviors and psychosocial burden. Kinesiophobia is closely associated with learned behaviors, previous pain experiences, health beliefs, and psychological status and may therefore not be fully alleviated through physical interventions alone, such as exercise and physical therapy [10]. Accordingly, educational, counseling, and cognitive-behavioral approaches should be integrated into treatment programs alongside physical interventions such as swimming and physical therapy in the management of lumbar disc herniation.

ANN architectures with different numbers of hidden neurons were evaluated for each group comparison, and the models yielding the lowest error levels and the highest correlation coefficients were selected. The optimal numbers of hidden neurons and the corresponding MSE, MAPE, and R values of the selected models are presented in the table (Table 4).

Table 4. Performance Metrics of the Selected Models

Group	Hidden neuron	MSE	MAPE	R
Swimming–Physical Therapy	8	0.675	3.242	0.991
Swimming–Inactive	7	1.429	5.363	0.973
Physical Therapy–Inactive	11	0.705	3.41	0.991

When the optimal Artificial Neural Network models for the group comparisons were evaluated, network architectures with different numbers of hidden neurons were found to provide the highest predictive performance for each comparison. For the Swimming–Physical

Therapy comparison, the model with eight hidden neurons was identified as the optimal network architecture, with an MSE of 0.675, a MAPE of 3.242%, and an R coefficient of 0.991 (Figure 2).

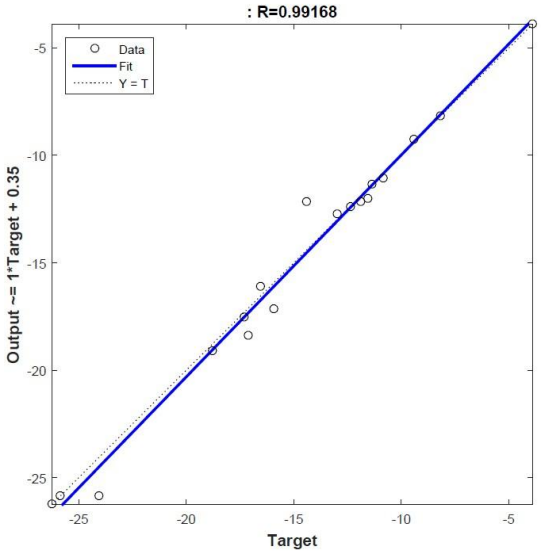


Figure 2. Regression Plot of the ANN Model for the Swimming–Physical Therapy Group

The low error values and the R coefficient close to 1 indicated that the physical health score of quality of life was predicted with high accuracy using the total kinesiophobia score and the Pain Scale score. The observed physical health scores of quality of life for the Swimming–Physical Therapy group largely overlapped with the values predicted by the ANN (Figure 3). The limited magnitude of the errors across the observations indicated that the model with eight hidden neurons successfully learned the underlying data pattern.

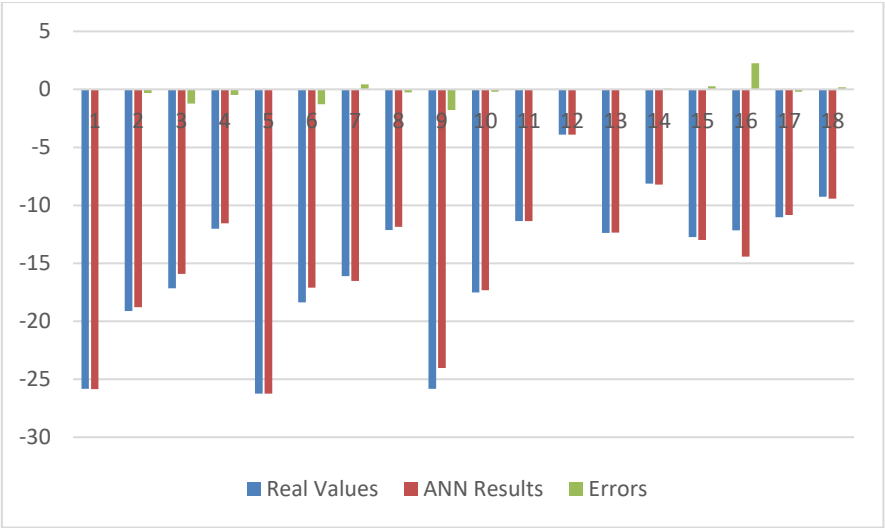


Figure 3. Comparison of the Observed and ANN-Predicted Quality-of-Life Physical Health Scores in the Swimming–Physical Therapy Group

For the Physical Therapy–Inactive comparison, the optimal model was obtained with 11 hidden neurons. For this model, the MSE was calculated as 0.705, the MAPE as 3.410%, and the R coefficient as 0.991 (Figure 3).

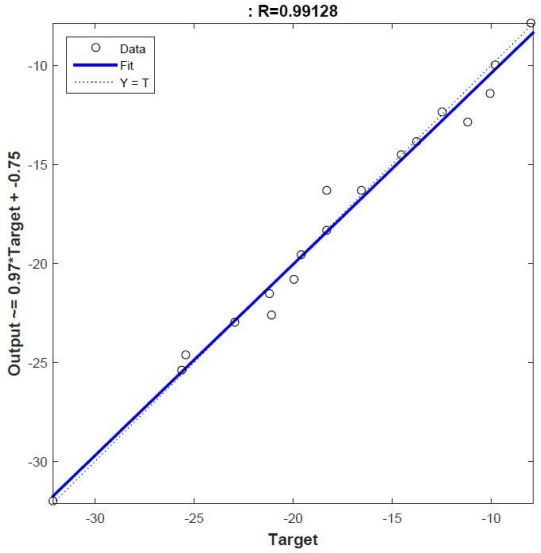


Figure 4. Regression Plot of the ANN Model for the Swimming–Inactive Group

These results demonstrated a very strong agreement between the predicted and observed quality-of-life physical health scores. However, because the MSE and MAPE values were slightly higher than those of the Swimming–Physical Therapy model, the predictive performance of the Physical Therapy–Inactive model ranked second. In the Physical Therapy–Inactive group, the quality-of-life physical health scores predicted by the ANN model with 11 hidden neurons were close to the observed values (Figure 5). The limited error values for most observations and the parallel distribution of the predictions and observed data indicated that the model had high predictive performance.

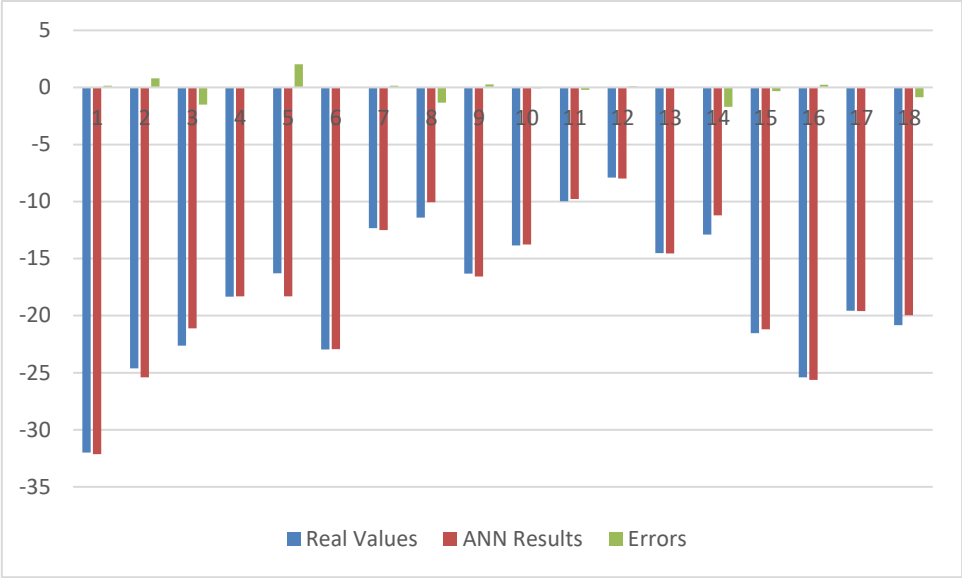


Figure 5. Comparison of the Observed and ANN-Predicted Quality-of-Life Physical Health Scores in the Physical Therapy–Inactive Group

For the Swimming–Inactive comparison, the optimal network architecture consisted of seven hidden neurons. In this model, the MSE was 1.429, the MAPE was 5.363%, and the R coefficient was 0.973 (Figure 6).

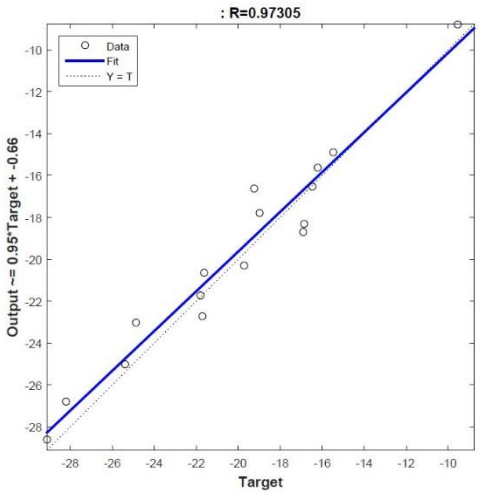


Figure 6. Regression Plot of the ANN Model for the Swimming–Inactive Group

The high R coefficient indicated a strong relationship between the observed and predicted values. However, the higher MSE and MAPE values compared with the other two models showed that prediction errors increased in this comparison and that the model had relatively lower predictive performance. In the Swimming–Inactive group, the observed values and the

predictions generated by the ANN model with seven hidden neurons generally exhibited a similar distribution (Figure 7). However, larger differences between the observed and predicted values were identified for some observations. This finding was consistent with the higher MSE and MAPE values obtained for this model compared with those of the other group comparisons.



Figure 7. Comparison of the Observed and ANN-Predicted Quality-of-Life Physical Health Scores in the Swimming–Inactive Group

When the models were evaluated collectively, the model with eight hidden neurons developed for the Swimming–Physical Therapy comparison produced the lowest MSE and MAPE values and the highest R coefficient. The model developed for the Physical Therapy–Inactive comparison showed a very similar level of performance, whereas the model for the Swimming–Inactive comparison had lower predictive performance than the other models. Differences in the number of hidden neurons indicated that the data pattern associated with each group comparison required a different level of network complexity. Based on these findings, the ANN model with eight hidden neurons developed for the Swimming–Physical Therapy comparison was identified as the best-performing structure for predicting the quality-of-life physical health score from kinesiophobia and pain variables.

CONCLUSION

In this study, swimming exercise, physical therapy, and a inactive lifestyle were compared in terms of pain, kinesiophobia, and quality of life in women diagnosed with lumbar disc herniation. No statistically significant differences were found among the groups in total

kinesiophobia scores or SF-12 physical scores. However, pain levels differed among the groups, and women who regularly participated in swimming exercise had lower pain scores than those receiving physical therapy and those leading a inactive lifestyle. This finding suggests that swimming exercise may be considered a physical activity option that supports pain management in women with lumbar disc herniation.

The ANN models developed to predict the SF-12 physical health score using total kinesiophobia and pain scores produced high correlation coefficients and low error values. The highest predictive performance was obtained from the model with eight hidden neurons developed for the Swimming–Physical Therapy comparison, while the Physical Therapy–Inactive model showed a similar level of performance. Although the model developed for the Swimming–Inactive comparison produced higher error values, a strong relationship was still observed between the predicted and observed scores. These results showed that the nonlinear patterns linking pain and kinesiophobia with the physical dimension of quality of life could be modeled using an ANN approach. However, because of the limited sample size, the models should be validated in larger and more diverse participant groups.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethical statement

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Author contribution

S.Ö. and D.S. designed the study and developed the experimental methodology. S.Ö. conducted the experimental work and data collection. A.G. performed the statistical analyses and contributed to data interpretation. All authors reviewed, revised, and approved the final version of the manuscript.

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