

Combined nano-particle drug delivery and physiotherapy in treatment of common injuries in dance-sport

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(Received April 29, 2022, Revised March 6, 2023, Accepted March 9, 2023)

Abstract. Combination of novel technologies with traditional physiotherapy in rehabilitation in injured athletes have shown to provide improved time of recovery. In specific, nanodrugs delivery systems are widely utilized as a counterpart to the physiotherapy in injuries in sports. In the present study, we focus on the common injuries in dance-sports, their recovery and the effect combination of nano-particle drug delivery with the physiotherapy practices. In this regard, a comprehensive review on the common injuries in dance sport is provided. Moreover, the researches on the effectiveness of the nano-particle drug delivery in therapy of such injuries and in similar cases are provided. The possibility of using combination of nano-particle drug delivery and physiotherapy is discussed in detail. Finally, using artificial intelligence methods, predictions on the recovery time and after-treatment side-effects is investigated. Artificial Neural Network (ANN) predictions suggested that using nano-particle drug delivery systems along with physiotherapy practices could provide shortened treatment time to recovery in comparison to conventional drugs. Moreover, the post-recover effects are less than the conventional methods.

Keywords: ANN; dance-sport; injury recovery; nano-drug; nano-particle drug delivery; physiotherapy

1. Introduction

Combination of novel technologies with traditional physiotherapy in rehabilitation in injured athletes have shown to provide improved time of recovery. In specific, nanodrugs delivery systems are widely utilized as a counterpart to the physiotherapy in injuries in sports (Habibi *et al.* 2016, 2018a, b, 2019b, d, e, Ebrahimi *et al.* 2019a, Esmailpoor Hajilak *et al.* 2019, Pourjabari *et al.* 2019, Safarpour *et al.* 2019a, Zhu *et al.* 2022, Dai *et al.* 2023, Zheng *et al.* 2023). Nano-particle drug delivery have proven to be more effective than the traditional drug consumption in the sense that they target directly a specific organ (Fazaeli *et al.* 2016, Habibi *et al.* 2017, 2019a, c, Safarpour *et al.* 2018, 2019b, Alipour *et al.* 2020, Ebrahimi *et al.* 2020a, Ghazanfari *et al.* 2020, Safarpour *et al.* 2020, Chen *et al.* 2022). Moreover, using magnetic nano-particles it is possible to physically displace and manipulate drug-delivery nano-particles to have more concentration in certain region of the body (Ebrahimi *et al.* 2019b, c, 2020b, Hashemi *et al.* 2019, Moayedi *et al.* 2019, 2020a, b, Mohammadgholiha *et al.* 2019, Mohammadi *et al.* 2019, Habibi *et al.* 2020, Oyarhossein *et al.* 2020, Shariati *et al.* 2020c, d, Shokrgozar *et al.* 2020). Conventional physiotherapy practices are sometimes jointed with medicine intervention to speed up the recovery process.

There numerous studies could be found in the literature

regarding effects of different parameters on the injury occurrence in dance-sports including age, training intensity, body load (Hashemi *et al.* 2019, Al-Furjan *et al.* 2020e, Al-o, q, s, Bai *et al.* 2020, Cheshmeh *et al.* 2020, Li *et al.* 2020a, Lori *et al.* 2020, Najaafi *et al.* 2020, Shariati *et al.* 2020e, Xiong *et al.* 2020, Guo *et al.* 2021b, Liu *et al.* 2021a). There also could be found studies on the injury toll during training and competitions with a sight on the number of injuries per hour and repetition of injuries (Riding McCabe *et al.* 2014, Premelč *et al.* 2019). Wanke *et al.* (2014) reported that over 70% out of 100 Latin Americans participants in the examinations have endured severe traumatic injuries in their dancesport activities. Among these injuries, near 20% were chronic injuries which effects lasted for a long time. The injuries were occurred during training time and their occurrence was higher in female dancers in comparison to male dancers. In another study, Premelč *et al.* (2019) examined dance sports athletes for type, site and number of incidents in 124 international dancers. It was revealed that the incident of injuries were higher in female dancers compared to male dancers. Moreover, on the type of injuries, traumatic injuries showed much less incidents in comparison to chronic damages or complaints. The sites of injuries were also different in male and female athletes with spine injuries were more common in males while foot damages were abundant in female injuries and damages. The number of injuries increased with increase in age of the dancesport athletes while in male athletes the intensity of exercises was also influential. Premelč *et al.* (2019) collected the injuries among 97 ballet and modern dancers to observe the site, severity and number of injuries in a period of 12 months. They reported that the injuries were meaningfully higher in female than

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male athletes. Their collected data shows age and gender differences in the injuries in all parameters they investigated. Huang (2022) investigated the effects of core muscles unbalance on the stability of the dancesport athletes. The results showed no meaningful differences between two groups of athletes one with core balance exercises and another with regular trainings. Dang *et al.* (2022) systematically reviewed the effects of fitness training on the dance injuries. They found that 80% of the athletes benefited from fitness training to reduce the risk of injuries in dance sports. Wyon *et al.* (2013) also reviewed the articles on the type of injuries commonly occurred in dancesport. They listed the common injuries as neck, shoulder, spine, knee, lower leg and foot in athletes. McCabe *et al.* (2014) examined 127 female dancer to discover the extension neck injury in them. They found that this injury was occurred among 25% of the athletes due to their specific pose during dancing. Moreover, this type of injury are more prevalent in younger dancers. Therefore, particular attention should be paid to this female-specific injury.

Utilization of nanotechnology in curing many traumatic injuries has become a widespread research subject among scientists (Nicol *et al.* 2015, Wang *et al.* 2020a, Cellot *et al.* 2021, Yang *et al.* 2021, Guido *et al.* 2022, Serov and Vinogradov 2022). Nicol *et al.* (2015) reviewed utilization of gold nanoparticles in the field of drug delivery for anticancer agents. The necessitate of modifying surface properties are the main subject in nanoparticle drug delivery systems. Wang *et al.* (2020a) provides a review on the gold nanoparticle-based drug delivery systems with focus on the tumor targeting nano-drug delivery. Sharma *et al.* (2020) explored articles on the application of nano-medicine in curing brain traumas. Niu and Yan (2022) studied the utilization of nanotechnology in repairing ligament injuries in dance sports. The randomly selected a group of 30 individuals with ligament injuries and divided them into 3 groups of test, control and blank groups. It was revealed from their studies that after 2, 4 and 8 weeks of comparison between test and control groups, significant achievements in terms of uniformity and strength of ligament were observed. Silveira *et al.* (2016) performed examinations on Wistar rats to observe the effects of different method therapies including combination of gold nanoparticles with other recognized methods. They found that in traumatic muscle injuries combination of gold nanoparticles and ultrasound plus dimethyl sulfoxide had advantages in terms of oxidative stress and inflammatory reaction (Adamian *et al.* 2020, Al-Furjan *et al.* 2020c, d, Li *et al.* 2020b, Liu *et al.* 2020a, b, Wang *et al.* 2020b, Zare *et al.* 2020, Zhou *et al.* 2020, Dai *et al.* 2021a, b, Guo *et al.* 2021a, Habibi *et al.* 2021, He *et al.* 2021, Huang *et al.* 2021a, Liu *et al.* 2021b, Shao *et al.* 2021, Wu and Habibi 2021, Zhang *et al.* 2021, Kong *et al.* 2022).

In curing traumatic injuries in dancesports, there are several parameters affecting the time and level of curing. As observed from the review above, the injuries in dancesports are dependent on age, gender, fitness training and other parameters. On the other hand, therapy of injuries include several methods which the newest one in using nano-drug

delivery system. Based on the severity and site of the injury the therapy method could differ considerably. Therefore, analyzing all of these data for tackling an injury is barely possible based on the theoretical analysis. Statistical analysis in such problems could be helpful. However, in statistical analysis the behavior and dependency of the outputs are not clear on the inputs. Artificial neural networks could deal with such problems with many inputs and several outputs in addition to construct a mathematical correlation between inputs and outputs. This method has been utilized in many fields including nanoparticle synthesis (Moradi *et al.* 2022a, Lingamdinne *et al.* 2023), structural mechanics (Derogar and Djavanroodi 2011, Truong *et al.* 2021, Xie *et al.* 2022) and health care systems (Catto *et al.* 2003) which have proven to be accurate and fast response.

In the present study, we focus on the common injuries in dance-sports, their recovery and the effect combination of nano-particle drug delivery with the physiotherapy practices. In this regard, a comprehensive review on the common injuries in dance sport is provided. Moreover, the researches on the effectiveness of the nano-particle drug delivery in therapy of such injuries and in similar cases are provided. The possibility of using combination of nano-particle drug delivery and physiotherapy is discussed in detail. Finally, using artificial intelligence methods, predictions on the recovery time and after-treatment side-effects is investigated.

2. Nonlocal elasticity theory

2.1 Common injuries in dancesports

As briefly mentioned in Introduction, the injuries in dancesports are highly dependent on the fitness training, age and gender and could vary from neck to foot and also could be categorized as traumatic and chronic. The locations of common injuries are marked in Fig. 1. The research by McCabe *et al.* (2014) shows that the most injured sites of dancers bodies are neck, shoulders, spine, knee, lower foot and foot. Therefore, injuries are very diverse in dance athletes.

One of the neck injuries in dance is the extension neck injury which very common in female dancers in which the female dancer's head inclined backward to the left or right side and she couldn't move her head to its upright position. This injury usually requires medical intervention to be cured. Another neck injury is the neck muscle strain resulting from numerous movements of head from side to side (Hou *et al.* 2021, Liu *et al.* 2021c, Dong *et al.* 2022, Fan *et al.* 2022a, b, Hu *et al.* 2022, Huang *et al.* 2022, Luo *et al.* 2022a, Luo *et al.* 2022b, Moradi *et al.* 2022c, Wang *et al.* 2022b, c, Yang *et al.* 2022a, b, Zhang *et al.* 2022, Zheng *et al.* 2022, Zhou *et al.* 2022a, Fang *et al.* 2023, Jin *et al.* 2023, Wang *et al.* 2023). In addition, excessive stretching the neck cause the spine curve deviation from its normal curve and causes pain and stiffness. Injuries in shoulders are mostly due to abrupt movement of the hand from side to side which results in severe rupture in upper arm and

impingement in shoulders. In addition, rotator cuff injury is one of the common injuries in shoulder site. Spine injuries categorized into six types. The first type of injury is the hyperlordosis in which the spine curve inward the body. This chronic injury occurs due to weak core muscles. The second type of injury, spondylolysis, is a fracture of pars interarticularis in the spine. Pars interarticularis are bones connecting two successive vertebrae. This damage happens in sports requiring high extension in the lumbar area like volleyball, football and dancing. Third is the spondylolisthesis in which one of the vertebra bones moves forward with respect to its relative original position. This injury are due to excessive extension in the lumbar area and are more prevalent in male athletes. Other types of injuries in the spine are relative to muscle injuries and includes lumbar facet sprain, discogenic back pain, and muscle spasm (Gottschlich and Young 2011). Injuries in knee site also common in dancers. Anterior knee pain occurs in almost 33% of dancers and it comes with repetitive stress. Changing dance style usually provokes the pain. Patellar Tendonitis is another knee injury afflicting the tendon connecting kneecap to the shinbone resulted from misalignment in leg. Iliotibial band touching the bones in the knee area is another injury caused by unbalanced hip muscle strength. Other type of injuries in lower foot and foot also exist. These injuries are commonly categorized as chronic injuries while traumatic injuries are due to harsh forces from falling and impacts resulting in the bone fracture and skin tear.

2.2 Nano-particle drug delivery systems

Conventional drug delivery systems are distributing the drug chemicals all over the body and a portion of the drug are received by the targeted organ (Huang *et al.* 2021b, Jiao *et al.* 2021, Ma *et al.* 2021, Moradi *et al.* 2021, Xu *et al.* 2021, Zhao *et al.* 2021, Fan *et al.* 2022a, Luo *et al.* 2022b, Michael *et al.* 2022, Wang *et al.* 2022a, Xia *et al.* 2022, Yu *et al.* 2022, Zhou *et al.* 2022b). This approach commonly requires a higher drug to be administered to the body of patients. Using nano-particles drug delivery the drugs would be released at the targeted organ more precisely and extremely lower drug is required to achieve the same goal in the therapy. This also means the minimizing of drugs' side effects and ensures the proper delivery of the drug to the targeted organ. Directing the nano-particles carrying the drugs in the body are performed in several ways. One of the main ways in utilizing magnetic nano-particles and using magnetic field to drive the nano-particles and drug to the targeted organ. Another way is to use temperature sensitive nano-particle drug carriers. Using this method it become possible to release the drug in certain temperature. Therefore, by slight change in temperature in the targeted organ, all the drug could be released. Another method is using pH of the environment to separate the drug from functionalized surface of the nano-particles. By administering a acidic solution at immediate neighborhood of the targeted organ, the drug will be released at that position and not other sites.

Several factors are important in nano-particle systems.

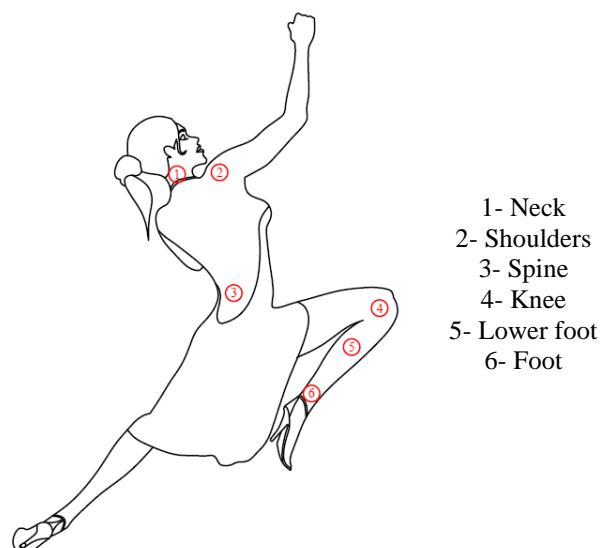


Fig. 1 Most injured sites of dancers (Riding McCabe *et al.* 2014)

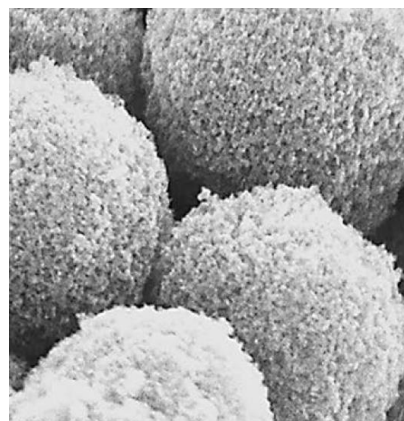


Fig. 2 Nano-particles for the purpose of drug delivery with high specific surface area (Al-Attafi *et al.* 2017)

The first one is the biodegradability of the nano-particles. Only biodegradable nano-particle are allowed to be utilized in therapy of injuries. The second factor is the specific surface area of the nano-particles which directly affects the drug carrying capacity of the nano-particle. Nano-particles with low specific surface areas are not favorable as drug carriers. One another significant factor of the nano-particles is their ability to construct chemical or physical bond with the drug and releasing it in certain conditions. Therefore, functionalized nano-particles are produced to make it possible for nano-particles to keep the drug on their surfaces. In Fig. 2, produced nanoparticles with high specific surface area is demonstrated adopted from Al-Attafi *et al.* (2017).

2.3 Using nano-particle drug delivery system in curing dancesport injuries

As discussed in the above sections the nano-particles are becoming a widespread drug carriers in the research area specifically in healing injuries. On the other hand, the types of injuries in the dancesports are among injuries that several

research articles discusses the advantages of nano-particle drug delivery system in dealing with them. Therefore, it is possible to use nano-carriers is rehabilitation of injuries in dancesport. Here, we will focus of traumatic muscle injuries in dancesport athletes (Al-Furjan *et al.* 2020a, b, g, f, h, i, j, k, l, m, n, p, r, t, u, v, 2021a, b).

2.4 Acquisition of results

The data utilized in the present study is collected from different sources (McCabe *et al.* 2014, Silveira *et al.* 2016). The effects of nanoparticle on the healing and rehabilitation of the injury in the dancesport athletes will be evaluate using artificial neural network (Zainah and Shahaboddin 1801, Khanouki *et al.* 2016, Shah *et al.* 2016a, b, Shariati *et al.* 2016, 2019, 2019b, c, 2020f, i, 2021c, d, e, f, Tahmasbi *et al.* 2016, Khorami *et al.* 2017, Milovančević *et al.* 2019, Suhatriil *et al.* 2019, Razavian *et al.* 2020, Yazdani *et al.* 2021, Jahandari *et al.* 2022, Tavakkoli *et al.* 2022a).

3. Artificial neural network (ANN) predictions

Using artificial neural networks could aid the researcher for predictions of results of an undone experiments using the results of previous experiments. The so-called intelligence in this systems tries to find correlation between independent factor and dependent factors. Therefore, using this system, we can generalize the results of several independent experiments and gather them in one network. For and account, the size of synthesized nanoparticles are dependent on many factors. Using artificial intelligence it could be predicted that using new set of experiments which size could be produced (Moradi *et al.* 2022a, b). Moreover, in the elimination of hazardous materials from waste water also several factor including temperature, pH and others are included (Davoodnabi *et al.* 2021, Hosseini and Toghroli 2021, Nouri *et al.* 2021, Shariati *et al.* 2021a, b, 2020a, b, Hosur Shivaramaiah *et al.* 2022, Naveen Kumar *et al.* 2022, Tavakkoli *et al.* 2022b). The artificial intelligence methods makes it possible to predict which material could be eliminated with which chemical in what condition (Lingamdinne *et al.* 2023). Here, we devised a ANN to predict the time and level of rehabilitation of injured muscles using age, gender, fitness training time and method of healing the injured muscle using combination of healing methods with nano-particle drug delivery. The structure of the network is shown in Fig. 3. The network compromises from four layers: 1 input and 1 output layers and 2×75 inner layers.

We used Scikit-Learn package in Python for constructing the ANN (Pedregosa *et al.* 2011). A supervised network with Adam optimization algorithm which utilized gradient decent technique (Arabnejad Khanouki *et al.* 2010, Shariati *et al.* 2012, 2019a, 2020a, b, g, h, j, k, 2021a, 2022a, b, Shah *et al.* 2015, Ismail *et al.* 2018, Wei *et al.* 2018, Sajedi and Shariati 2019, Naghipour *et al.* 2020a, Naghipour *et al.* 2020b, Shariat *et al.* 2020, Toghroli *et al.* 2020, Tavakkoli *et al.* 2022a). This method is efficient in minimizing convex loss functions. The loss function could be mean squared error (MSE):

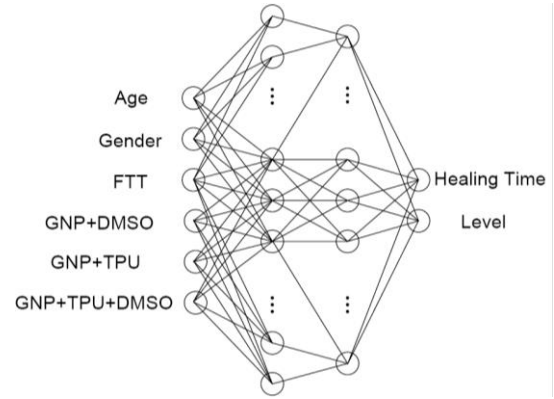
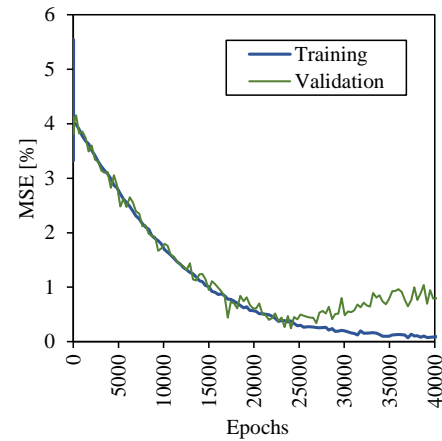
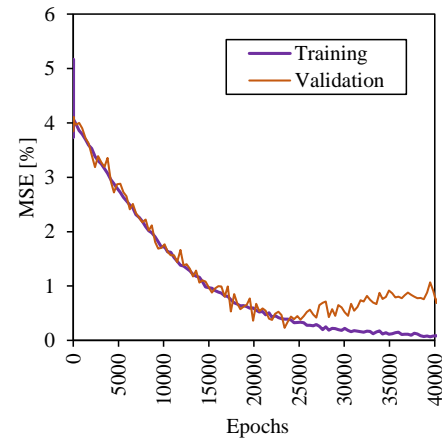


Fig. 3 Schematic of neural network with six inputs and two output. (therapeutic pulsed ultrasound (TPU), dimethyl sulfoxide (DMSO), gold nanoparticles (GNP), fitness training time (FTT))



(a) Rehabilitation time



(b) Rehabilitation level

Fig. 4 Training and validation MSE for ANN

$$MSE = \frac{1}{N} \sum_{i=1}^N (O_i - \hat{O}_i)^2 \quad (1)$$

The number N is the total number of dataset we extracted from the given references. The actual values of healing time and level is denoted by \hat{O}_i and the predicted values given by ANN are O_i .

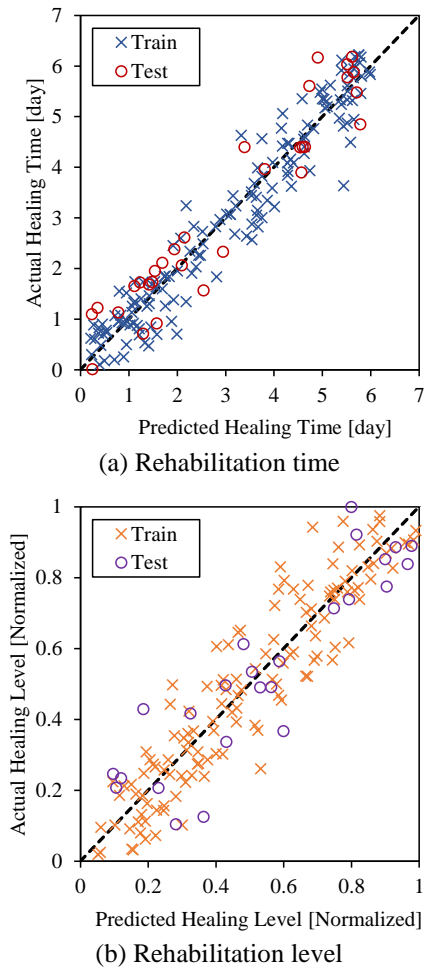


Fig. 5 Training and testing predicted value by ANN in comparison to measured value

4. Results

The results of the ANN prediction are provided in this section for combination of using nano-particle drug delivery and physiotherapy in rehabilitation of injuries in the dance sports. In this regard, at the first step, the ANN is trained and validated and second by comparing actual time and level of rehabilitation using the combined method.

4.1 ANN results

The ANN should be first trained to ensure that it provides satisfactory accurate results and also it is not over-fitted. For this purpose, two parallel computations are performed by ANN. In the first set of computation, training process, the network tries to minimize loss function of MSE. After each step or epochs of training process the difference between actual value and the predicted value are determined. In the second process, the trained network in each epoch is checked with a set of data to see if the predicted error is the same as the training or not. The iteration continues until the error of the second set of data deviates from the training error. This situation is a sign of overfitting the network. In this condition, ANN could not be

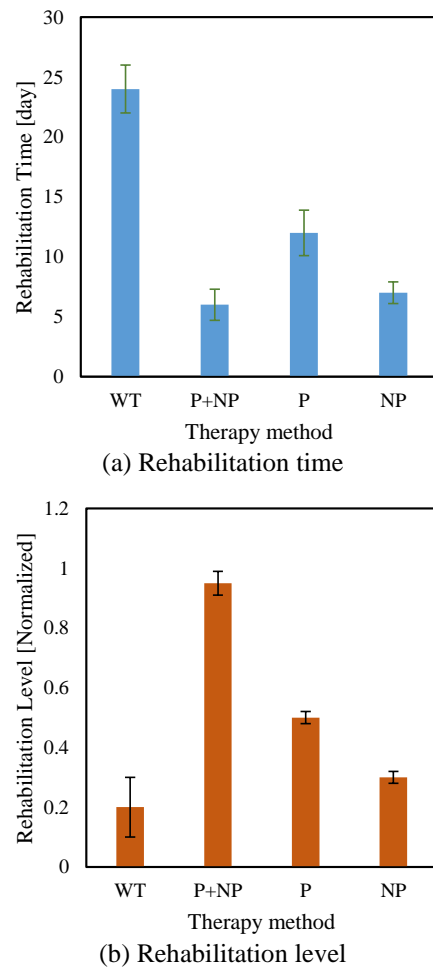


Fig. 6 Effect of different combinations of therapies in healing dancesport injuries. (WT: without any treatment, P: Physiotherapy, NP: Nano-particle)

approved to provide reliable prediction any more. As seen in Fig. 4, after 20000 epochs the error measure between validation dataset and the training dataset deviates. The validation dataset is chosen randomly from the original set with fraction of 15% of the total data. Moreover, another 15% is reserved for testing network. Since the ANN have similar error for both training and validation process.

In the testing process, 15% of the original data set is used to check if the ANN yet provide reliable data for a new set of unknown outputs or not. As seen in Fig. 5, the predicted value from ANN are in good correlation with the actual values of rehabilitation time and level. It is seen that for the case of rehabilitation time, the ANN provide $R^2 = 0.93$ and $R^2 = 0.86$ correlation factors for training and testing processes, respectively. On the other side, for the case of rehabilitation level, the ANN provide $R^2 = 0.89$ and $R^2 = 0.84$ correlation factors for training and testing processes, respectively. These values of the correlation factors are satisfactory since the data we used are collected from different sources.

As seen above, the combination of nano-particle drug delivery system with conventional physiotherapy could be effective in the injuries arose in sports specifically in

dancesports. The utilization of the ANN also provides additional tools in predicting the effects of different combination of therapies and could be utilized further with more parameters involved in the injury healing processes. Now, we have a trained network which could be utilized to compare two different conditions of including nanoparticles drug carriers and without this materials. In Fig. 6, Effects of different combinations of therapies on the rehabilitation time and level are depicted. It is seen that, without any therapy, it takes 24 days for a muscle injury to heal with a very low level of normalized healing level in comparison to healthy muscle. Combination of physiotherapy and nano-particle drug carriers shows the best healing time with 5 days and highest healing level with 0.8 of healing with respect to healthy muscle. On the other hand, using only nanoparticles or physiotherapy provides moderate time and level of rehabilitation as predicted by ANN.

5. Conclusions

Combination of novel technologies with traditional physiotherapy in rehabilitation in injured athletes have shown to provide improved time of recovery. In specific, nanodrugs delivery systems are widely utilized as a counterpart to the physiotherapy in injuries in sports. In the present study, we focus on the common injuries in dancesports, their recovery and the effect combination of nanoparticle drug delivery with the physiotherapy practices. In this regard, a comprehensive review on the common injuries in dance sport is provided. Moreover, the researches on the effectiveness of the nano-particle drug delivery in therapy of such injuries and in similar cases are provided. The possibility of using combination of nano-particle drug delivery and physiotherapy is discussed in detail. Finally, using artificial intelligence methods, predictions on the recovery time and after-treatment side-effects is investigated. Artificial Neural Network (ANN) predictions suggested that using nano-particle drug delivery systems along with physiotherapy practices could provide shortened treatment time to recovery in comparison to conventional drugs.

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