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An Exploratory Study of the Effects of Aquatic Walking on Function and Muscle Activity in Knee Osteoarthritis: Part 2

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Abstract

This paper presents Part 2 of a study that investigated the effects of an 8-week (3x/week) underwater treadmill (UT) walking intervention on knee osteoarthritis (KOA) outcomes in 6 adults with KOA (62.7 ± 14.2 years). The Knee Outcome Survey (KOS) for activities of daily living and muscle activity during a 10-m walk and a 20 cm step down were measured before and after the intervention. The following KOS measures improved after the UT walking program ($p < 0.05$; $g > 0.8$): stiffness, swelling, weakness, walking, going up stairs, going downstairs, kneeling on the front of the knee, squatting, and sitting with the knee bent. Knee flexion excursion during stance of walking increased after the UT walking intervention ($p = .01$). Co-activation between the tibialis anterior and medial gastrocnemius decreased during the 20 cm step down ($p = .04$). The findings of this study support using the WWE as a model for UT walking interventions in KOA.

Keywords: aquatic exercise, underwater treadmill walking, knee osteoarthritis, EMG, Knee Outcome Survey

Introduction

Osteoarthritis (OA) is a progressive joint disease affecting over 32.5 million adults in the United States (Centers for Disease Control, 2021). While several joints in the body may be impacted by OA, a large number of OA cases (i,e,, 83%) affect the knee (Vina & Kwoh, 2018). In 2020, worldwide estimates of knee osteoarthritis in person 40 years and older were around 654.1 million people, with a pooled global incidence of knee OA to be 203 per 10,000 person-years in those 20 years and older (Cui et al., 2020). Age is major factor of this disease since 88% of the current population diagnosed with OA are 45 years or older (Park et al., 2018).

Persons with knee OA frequently experience pain, inflammation, stiffness, and a variety of functional limitations (Centers for Disease Control, 2020, Neogi, 2013). A plethora of studies have demonstrated mobility impairment in persons with OA (Al Amer et al., 2018; Mills et al., 2013; Guccione et al., 1994), particularly during walking, stair ascent, and stair descent (Childs et al., 2004; Hortobgyi et al., et al., 2005; Mills et al., 2013). Increased hamstring activity and higher co-activation above and below the knee have been observed during these movements (Childs et al., 2004; Hortobgy et al., 2005). Consequences of progressive worsening of symptoms, such as pain, stiffness, inflammation, and diminished physical function may contribute to a cumulative cycle that leads to diminished ability to perform activities of daily living (Onder et al., 2006). Standard approaches to treating knee osteoarthritis (KOA) often focus on improving functional activities most affected by the disease.

Exercise and physical therapy are essential to the comprehensive medical treatment of OA (Bartels et al., 2016; Deyle et al., 2020). A common exercise that is recommended to persons with OA is walking. Due to these benefits, walking programs, such as the Arthritis Foundation's Walk with Ease (WWE) program, have been developed because it is inexpensive, safe, and has been shown to reduce pain (Bruno et al., 2006; Wyatt et al., 2014), stiffness (Wyatt et al., 2014) and disability (Callahan, 2009) in persons with OA. While walking programs, such as the WWE program, have shown promising results, traditional land-based walking has been shown to increase knee joint loading in persons with KOA (Baliunas et al., 2002), a factor believed to be related to degenerative changes in cartilage (Frost, 1994; Radin et al., 1991).

An alternative to land-based exercise that is commonly used is aquatic exercise. Aquatic exercise has been shown to be superior to land-based exercise at improving pain, muscle strength, balance, coordination, and joint stability in persons with OA (Bartels et al., 2016, Barker et al., 2014; Denning et al., 2010; Silva et al., 2008; Fransen et al., 2015; Hinman et al., 2007). The effectiveness of aquatic exercise when compared to land-based exercise has been attributed to the "unloading" effect water provides through buoyancy (Denning et al., 2010). One mode of aquatic exercise that controls water depth, temperature, and walking speed and has been effectively utilized in persons with OA is underwater treadmill (UT) walking (Byrne et al., 1996; Denning et al., 2010).

An exploratory study that combines an established walking program, such as WWE, with the UT may yield positive changes on pain, stiffness, swelling, and functional limitations in persons with KOA. Additionally, such an intervention may show benefits to the detrimental muscle activity patterns that have been observed in persons with KOA. Therefore, the purpose of this exploratory study was to investigate the effects of an aquatic walking program that was based on an established land-based walking program (Arthritis Foundation's WWE). It was hypothesized there would be significant improvements in symptoms and functional limitations as measured by the knee outcome survey (KOS) after an UT walking intervention based upon the WWE program. It was also hypothesized that there would be significant improvement in kinematic measures during the stance phase of walking and while descending from a 20 cm step after participating in the aquatic walking program. Lastly, it was hypothesized that coactivation of musculature above and below the knee would decrease during the stance phase of walking and decrease while descending a 20 cm step after participating in the aquatic walking intervention.

Method

Participants

The inclusion criteria for the exploratory study were that participants had a physician diagnosis of KOA and physician clearance to participate in the aquatic WWE program. The participants (mean ± SD, age = 62.7 ±14.2) of the exploratory study included men (*n* = 3) and women (*n* = 3) who were recruited from the local community. Mean height and body mass were 172.8 ±10.9 cm and 105.4 ±28.9 kg, respectively. All participants were screened for health risks and each participant read and signed an informed consent prior to beginning the study. This study was approved by the University Institutional Review Board before data collection.

Procedures

Each participant had their height (cm) and body mass (kg) measured, completed the Knee Outcome Survey (KOS) for activities of daily living (ADLs), identified the limb that was most consistently painful, and measured muscle activity during a 10m walk and while perform a 20cm step down. Each of these outcomes were measured before (PRI) and after (PST) an 8-week UT walking intervention.

The KOS is self-report measure that that is indicated for variety of knee disorders including osteoarthritis. The KOS is divided into two main categories of activities of daily living (ADLs) and sports activities. The current study exclusively used the ADL portion of the KOS, which has two subscales of symptoms (6 items) and functional limitations (8 items) with an additional global rating item that assesses level of functioning during usual activities on a scale from 0 to 100 (100 being the level of function prior to OA). Each of the subcategories of the ADL portion of the KOS are scored successively on a scale of 5 to 0, with 5 rating being the least problematic and 0 being the most problematic.

Muscle activity was assessed during a 10m walk and while descending a step 20cm in height. A 20cm step was chosen because it is a common rise used in the United States. A wireless surface electromyography (sEMG) system (Trigno EMG, Delsys Inc., Boton, MA, USA) was used to measure muscle activity of the vastus lateralis (VL), semitendinosus (ST), tibialis anterior (TA), and medial gastrocnemius (MG). Prior to placement, skin at the electrode sites was prepared by shaving (standard disposable safety razor), debriding (Redux), and cleansing (isopropyl alcohol). All electrodes were positioned according to the procedures and locations suggested by the SENIAM project (SENIAM, 2021). Once signal verification was achieved, muscle activity during a 3s maximal isometric contraction was performed and recorded across three trials. The highest of the MVIC trials were used to normalize muscle activity in the previously indicated muscles during the descending phase of the step-down and during the stance phase of the 10m walk trials. Electronic goniometers (Biometric, Ltd., Ladysnith, VA) were integrated, aligned to the greater trochanter and lateral malleolus, and positioned on the lateral side of the painful leg. The electronic goniometers assessed degree of knee flexion excursion during the stance phase of walking and during the descent of a 20cm step. Foot switch relays (FSR) were positioned on the inferior portion of the calcaneus, distal head of the 5^{th} metatarsal, distal head of the 1^{st} metatarsal, and the inferior portion of the hallux on the foot with the most painful knee. The FSR is an integrated sensor allowed for differentiation between stance and swing phases of gait.

The participants completed an aquatic-based walking program that was performed 3x/week for 8-weeks using a self-contained UT (Hydrotrack, Ferno, Wilmington, OH). The aquatic-based walking program was modeled after the land-based Arthritis Foundation's WWE program, which is usually 6-weeks in duration. An 8-week duration was chosen to represent existing UT walking studies for other conditions (Conners et al., 2014; Stevens et al., 2014). The intensity was self-paced throughout the entire intervention. The duration during the first week was 10 minutes and was increased by 5 minutes per week accumulating to a final duration of 45 minutes of walking in week 8. Water temperature was set between 32°-36° Celsius and water height was to the xiphoid process (Bartels et al., 2016; Denning et al., 2010). Knee pain (most painful knee) was recorded just prior each session and speed was recorded half-way through each session. The NRS was used to measure pain in the most painful knee and speed of the treadmill (m·sec) was measured by timing belt revolutions. Participants were only allowed to miss 2 sessions across the entire 8-week program and the missed sessions were not allowed to be within the same week.

Statistical Analyses

Alternative statistical procedures were used to fit the exploratory nature of the study. In accordance with Tabachnick and Fidell (2013) suggestions to compensate for the small pilot sample size and improve generalizability, *t*-tests were conducted to prevent issues related to power and overfitting of multiple variables in a model with a small sample size. Hedge's *g* calculations for paired-samples *t*-tests were used to determine effect size. An alpha level of $p = .05$ was used for all statistical analyses.

Results

The UT walking program had a 98.6% compliance rate during the intervention with 2 participants missing one session for non-health related issues. No exercise-related injuries were reported during the intervention. Table 1 shows the pre-intervention and post-intervention scores and statistics from the ADL portion of the KOS. Within the symptoms portion of the KOS there were significant improvements in stiffness ($p = .004$), swelling ($p = .006$), and weakness ($p = .02$) after the aquatic-based walking intervention. The functional limitations portion of the KOS revealed significant improvements in walking (p = .03), going up stairs (p = .01), going downstairs (p = .02), kneeling on the front of the knee (p = .02), squatting (p = .005), and sitting with knee bent (p = .009) after the aquatic walking program. All statistically significant outcomes in both the symptoms and functional limitations subscales demonstrated large effect size (see Table 1). There was also a significant improvement on both the total ADL score (p = .008) and the global rating score (p = .002) after the study intervention.

No change in time in stance phase occurred during the 10m walk after the aquatic walking intervention. Significant increases in knee excursion (p = .01) with large effect size (g = 1.20) were observed during walking after the aquatic intervention. Normalized mean muscle activity and co-activation above and below the knee did not change during walking after the aquatic-based walking program (see Table 2). Time descending a 20cm step and knee excursions did not significantly change after participating in the aquatic walking program. The normalized mean muscle activity and co-activation between the VL and ST did not significantly change after the intervention. Muscle co-activation between the TA and MG significantly decreased during 20 cm step down task after the aquatic-based WWE intervention (p = .04). A large effect size was observed with decreased coactivation (g = .88). Table 3 illustrates the mean muscle activity and co-activation patterns during descent of a 20cm step.

Discussion

The purpose of this initial study was to examine the effects of an aquatic adaptation of the Arthritis Foundation's WWE program on symptoms, functional limitations, and muscle activity in persons with KOA. While the effects of aquatic interventions on symptoms and functional outcomes have been established (Bartels et al., 2016, Barker et al., 2014; Denning et al.; Silva et al., 2008; Fransen et al., 2015; Hinman et al., 2007), investigations of muscle activity in KOA have been limited to acute situations (Childs et al., 2004; Hortobgyi et al., 2004; Lyytinen et al., 2010). Furthermore, a dearth of studies examining the effects of well-established programs (Bruno et al., 2006; Callahan, 2009; Wyatt et al., 2014) that have been adapted to an aquatic environment have been published. It was hypothesized that the aquatic-based walking program used in this study would significantly improve symptoms, functional limitations, and muscle activity outcomes.

Table 1.
Pre-intervention and post-intervention scores on the knee outcome survey on the activities of daily living (N = 6)

	PRI *M* (±*SD*)	PST *M* (±*SD*)	*t*(5)	*p*	*g*
Symptoms					
Pain	2.7 (.52)	3.5 (.84)	1.75	.07	.67
Stiffness	**2.3 (.52)**	**3.8 (.75)**	**4.39**	**.004**	**1.65**
Swelling	**3.5 (.84)**	**4.7 (.52)**	**3.80**	**.006**	**1.43**
Giving way, buckling, or shifting	3.3 (1.21)	4.2 (1.17)	1.75	.07	.67
Weakness	**2.8 (.41)**	**3.7 (.82)**	**2.71**	**.02**	**.82**
Limping	2.8 (1.17)	3.8 (1.17)	1.73	.07	.65
Functional limitations					
Walking	**3.2 (1.17)**	**4.3 (.52)**	**2.45**	**.03**	**.92**
Going up stairs	**2.7 (.82)**	**4.0 (.00)**	**3.16**	**.01**	**1.19**
Going down stairs	**2.7 (.82)**	**3.8 (.98)**	**2.91**	**.02**	**1.09**
Standing	3.7 (1.03)	4.3 (.52)	1.35	.12	.51
Kneeling on the front of the knee	**2.2 (1.17)**	**3.5 (1.05)**	**2.70**	**.02**	**1.02**
Squatting	**2.0 (.00)**	**3.3 (.82)**	**4.00**	**.005**	**1.51**
Sitting with knee bent	**3.0 (1.27)**	**4.5 (.55)**	**3.50**	**.009**	**1.32**
Rise from a chair	3.3 (1.03)	4.2 (.41)	1.75	.07	1.47
Total ADLS (%)	**57.4 (11.0)**	**79.5 (7.4)**	**3.56**	**.008**	**1.34**
Global rating score (%)	**63.3 (10.8)**	**88.3 (6.9)**	**5.34**	**.002**	**2.01**

Note. PRI = pre-intervention; PST = post-intervention; Hedge's *g* strength interpretation was large effect = 0.8, medium effect = 0.5, small effect = 0.2.

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Table 2.

Kinematic and muscle activity patterns during walking (N = 6)

	PRI	PST			
	M (±*SD*)	*M* (±*SD*)	*t*(5)	*p*	*g*
Time in stance (s)	.74 (.07)	.75 (.06)	0.63	.28	.26
Knee flexion excursion (ºROM)	**51.4 (8.0)**	**55.1 (8.4)**	**3.19**	**.01**	**1.20**
Normalized muscle activity (%)					
Vastus lateralis	19.7 (7.4)	20.6 (11.8)	0.35	.37	.13
Semitendinosus	21.0 (18.3)	19.3 (14.4)	0.27	.43	.07
Tibialis anterior	38.2 (13.7)	32.9 (14.5)	0.72	.25	.27
Gastrocnemius	36.7 (29.5)	42.4 (29.5)	0.73	.25	.28
Muscle co-activation					
Vastus lateralis-semitendinosus	.620 (.893)	.592 (.822)	0.06	.48	.02
Tibialis anterior-gastrocnemius	.976 (.669)	.663 (.317)	0.95	.19	.36

Note. PRI = pre-intervention; PST = post-intervention; Muscle co-activation = (EMG_S/EMG_L) *$(EMG_S + EMG_L)$, EMG_S is the level of activity in the less active muscle and EMG_L is the level of activity in the more active muscle. Hedge's *g* strength interpretation was large effect = 0.8, medium effect = 0.5, small effect = 0.2.

Table 3

Kinematic and muscle activity patterns during descent of 20 cm step (N = 6)

	PRI *M* (±*SD*)	PST *M* (±*SD*)	*t*(5)	*p*	*g*
Time in stepdown (s)	1.25 (.24)	1.07 (.25)	1.27	.13	.48
Knee flexion excursion (ºROM)	82.7 (13.2)	80.4 (10.9)	0.65	.27	.25
Normalized muscle activity (%)					
Vastus lateralis	26.7 (8.2)	21.6 (10.1)	1.17	.15	.43
Semitendinosus	21.0 (24.7)	14.5 (7.6)	0.66	.27	.25
Tibialis anterior	43.3 (26.6)	31.1 (9.9)	1.53	.09	.58
Gastrocnemius	30.2 (19.2)	22.3 (21.2)	0.94	.19	.35
Co-activation					
Vastus lateralis-semitendinosus	.495 (.824)	.298 (.252)	0.59	.29	.22
Tibialis anterior-gastrocnemius	**1.27 (.857)**	**.941 (.546)**	**2.17**	**.04**	**.88**

Note. PRI = pre-intervention; PST = post-intervention; Muscle co-activation = (EMG_S/EMG_L) *(EMG_S + EMG_L), EMG_S is the level of activity in the less active muscle and EMG_L is the level of activity in the more active muscle. Hedge's *g* strength interpretation was large effect = 0.8, medium effect = 0.5, small effect = 0.2.

The results of our study indicated that there were significant improvements in perceived stiffness, swelling, weakness, walking, ascending stairs, descending stairs, kneeling on the front of the knee, squatting, and sitting with knee bent, all of which had corresponding large effect sizes. It is possible that the exploratory nature of this study with a small sample size contributed to the lack of significant statistical findings in the remaining measures within the symptoms and functional limitations subscales, as each of them exhibited improvements that trended towards statistical significance but did not meet the 0.05 threshold. The improvement in the KOS scores from pre-intervention to post-intervention in our study reflected the findings from previous aquatic interventions (Bartels et al., 2016, Barker et al., 2014; Denning et al.; Silva et al., 2008; Fransen et al., 2015; Hinman et al., 2007) and demonstrated that aquatic walking may improve the perception of symptoms and functional limitations from KOA.

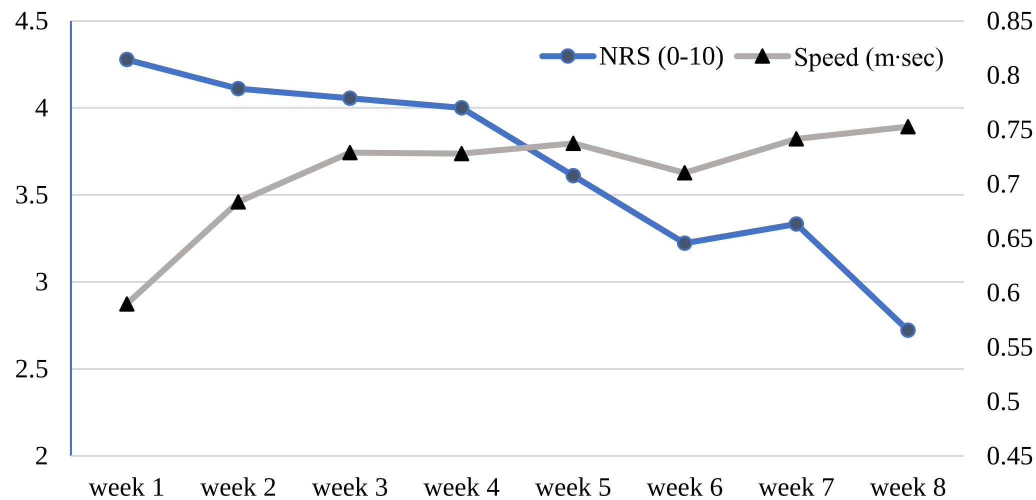
Previous studies have presented evidence that those with KOA have increased muscle co-activation above and below the knee while walking, ascending stairs, and descending stairs (Childs et al., 2004; Hortobagyi et al., 2005). A combination of reduced knee flexion excursion and increased muscle co-activation during the stance phase of walking and while descending a step has also been observed (Childs et al., 2004). These authors suggested that the combination of decreased movement and increased co-activation during these tasks may represent a stiffening of the knee joint. Our study demonstrated a significant increase in knee flexion excursion during the stance phase of walking and a significant decrease in muscle co-activation below the knee during step descent denotes the efficacy of the UT walking intervention at addressing factors exemplifying joint stiffening.

Childs et al. (2004) suggested that decreased knee flexion excursion and increased muscle activation together were representative of knee joint stiffening. We found it interesting that there was a significant increase in knee flexion excursion during the loading phase of walking without significant decrease in co-activation above and below the knee after the aquatic walking intervention. Also, after the intervention there was significant decrease in co-activation below the knee without a significant increase in knee flexion excursion during the step-down maneuver. The lack of combined findings in each task may be due to the preliminary nature of this study. Another possibility is the differences in the participant inclusion criteria used in our study compared to the previous studies. Earlier study criteria only included persons with KOA that had a Kellgren-Lawrence (K-L) radiographic evidence of grade 2 or more (Childs et al., 2004; Hortobagyi et al., 2005), whereas the current exploratory study had less strict criteria. Future studies, should explore the effects of similar aquatic interventions on persons with radiographic evidence of grade 2 or more, as indicated by the K-L classifications.

The WWE walking program is a self-paced walking program that progressively increases duration week to week. We found that this land-based walking program was easily adapted to the aquatic environment. While the self-contained UTs used in our study are not cost effective or easily accessible to the public, they do provide the appropriate level of control needed to investigate changes that occur during and after an intervention. Although not an outcome of this study, pain (NRS) and self-selected speed (m·sec) were monitored for each training session. Figure 1 shows the mean pain and self-selected speed across the 8-week intervention. Notably, pain progressively decreased while self-selective speed in the UT progressively increased. These positive changes in pain and self-selected pace attest to the effectiveness of adapting the land-based WWE to an aquatic environment.

Figure 1.

Mean pain (NRS) and self-selected speed (m·sec) by week during training sessions



Conclusion

In conclusion, the results from this initial study demonstrated improvements in symptoms, functional limitations, kinematic, and muscle activity after an 8-week UT walking intervention. While muscle activation above the knee and kinematic parameters while descending a 20cm step were not statistically improved, it is possible that more stringent inclusion criteria and higher sample size would yield different results due to increased statistical power. The Arthritis Foundation's WWE is a land-based program that is designed to for mass utilization by the public. The excessive joint loading of land-based activities may be detrimental to persons moderate-severe KOA (K-L grades >2). In such cases the joint unloading effects of aquatic interventions are often utilized. Comparisons between land-based and aquatic-based walking programs should be a focus of future studies. The findings of this study support using the Arthritis Foundation's WWE as a model for UT walking programs.

References

Al Amer, H.S., Sabbahi, M.A., Alrowayeh, H.N., Bryan, W.J., & Olson, S.L. (2018). Electromyographic activity of quadriceps muscle during sit-to-stand in patients with unilateral knee osteoarthritis. *BMC Research Notes, 11*(1), 1-6. https://doi.org/10.1186/s13104-018-3464-9

Baliunas, A.J., Hurwitz, D.E., Ryals, A.B., Karrar, A., Case, J.P., Block, J.A., & Andriacchi, T.P. (2002). Increased knee joint loads during walking are present in subjects with knee osteoarthritis. *Osteoarthritis and Cartilage*, *10*(7), 573-579. https://doi.org/10.1053/joca.2002.0797

Barker, A.L., Talevski, J., Morello, R.T., Brand, C.A., Rahmann, A.E., & Urquhart, D.M. (2014). Effectiveness of Aquatic Exercise for Musculoskeletal Conditions: A Meta-Analysis, *Archives of Physical Medicine and Rehabilitation*, *95*(9): 1776-1786. https://doi.org/10.1016/j.apmr.2014.04.005.

Bartels, E.M., Juhl, C.B., Christensen, R., Hagen, K.B., Danneskiold-Samsoe, B., Dagfinrud, H., & Lund, H. (2016). Aquatic exercise for the treatment of knee and hip osteoarthritis (Review). *Cochrane Database of Systematic Reviews*, *3*(CD005523), 1-56. https://doi.org/10.1002/14651858.cd005523.pub3

Bruno, M., Cummins, S., Gaudiano, L., Stoos, J., & Blanpied, P. (2006). Effectiveness of two Arthritis Foundation programs: Walk With Ease, and YOU Can Break the Pain Cycle. *Clinical Interventions in Aging*, *1*(3), 295-306. https://doi.org/10.2147/ciia.2006.1.3.295

Byrne, H.K., Craig, J.N., & Wilmore, J.H. (1996). A comparison of the effects of underwater treadmill walking to dry land treadmill walking on oxygen consumption, heart rate, and cardiac output. *Journal of Aquatic Physical Therapy*, *4*(1), 4-11.

Callahan, L.F. (2009). Physical activity programs for chronic arthritis. *Current Opinions in Rheumatology*, *21*(2), 177-182. https://doi.org/10.1097/bor.0b013e328324f8a8

Centers for Disease Control. (2021, August 30). *Arthritis.* https://www.cdc.gov/arthritis/basics/osteoarthritis.htm

Childs, J.D., Sparto, P.J., Fitzgerald, K., Bizzini, M., & Irrgang, J.J. (2004). Alterations in lower extremity movement and muscle activation patterns in individuals with knee osteoarthritis. *Clinical Biomechanics*, *19*(1), 44-49. https://doi.org/10.1016/j.clinbiomech.2003.08.007

Conners, R.T., Morgan, D.W., Fuller, D.K., & Caputo, J.L., (2014). Underwater treadmill training, glycemic control, and health-related fitness in adults with type 2 diabetes. *International Journal of Aquatic Research and Education, 8(4)*, Article 8. https://doi.org/10.25035/ijare.08.04.08

Cui, A., Li, H., Wang, D., Zhong, J., Chen, Y., & Lu, H. (2020). Global, regional prevalence, incidence and risk factors of knee osteoarthritis in population-based studies. *EClinicalMedicine*, *29*(100587): 1-13. https://doi.org/10.1016/j.eclinm.2020.100587

Denning, W.E., Bressel, E. & Dolny, D.G. (2010). Underwater Treadmill Exercise as a potential treatment for adults with osteoarthritis, *International Journal of Aquatic Research and Education, 4*(1): Art. 9. https://doi.org/10.25035/ijare.04.01.09

Deyle, G.D., Allen, C.S., Allison, S.C., Gill, N.W., Hando, B.R., Petersen, E.J. et al. (2020). Physical therapy versus glucocorticoid injection for osteoarthritis of the knee. *The New England Journal of Medicine, 382*(15), 1420-1429. https://doi.org/10.1056/nejmoa1905877

Fransen, M., McConnell, S., Harmer, A.R., Van der Esch, M., Simic, M., & Bennell K.L. (2015). Exercise for osteoarthritis of the knee. *Cochrane Database Systematic Reviews, 1*, 1465-1858. https://doi.org//10.1002/14651858.CD004376.pub3

Frost, HM. (1994). Perspectives: a biomechanical model of the pathogenesis of arthroses. *The Anatomical Record, 240*(1): 19-31. https://doi.org/10.1002/ar.1092400103

Guccione, A.A., Felson, D.T., Anderson, J.J., Anthony, J.M., Zhang, Y., Wilson, P.W., et al. (1994). The effects of specific medical conditions on the functional limitations of elders in the Framingham Study. *American Journal of Public Health, 84*(3), 351-358. https://doi.org/10.2105/ajph.84.3.351

Hale, L.A., Waters, D., & Herbison, P. (2012). A randomized controlled trial to investigate the effects of water-based exercise to improve falls risk and physical function in older adults with lower-extremity osteoarthritis. *Archives of Physical Medicine & Rehabilitation, 93*, 27-34. https://doi.org/10.1016/j.apmr.2011.08.004

Hinman, R.S., Heywood, A.E., & Day, A.R. (2007). Aquatic physical therapy for hip and knee osteoarthritis: results of a single-blind randomized controlled trial. *Physical Therapy, 87*(1), 32-43. https://doi.org/10.2522/ptj.20060006

Hortobágyi, T., Westerkamp, L., Beam, S., Moody, J., Garry, J., Holbert, D., & DeVita, P. (2005). Altered hamstring-quadriceps muscle balance in patients with knee osteoarthritis, *Clinical Biomechanics, 20*(1): 97-104. https://doi.org/10.1016/j.clinbiomech.2004.08.004

Mills, K., Hunt, M., & Ferber, R. (2019). Biomechanical deviations during level walking associated with knee osteoarthritis: a systematic review and meta-analysis. *Arthritis Care & Research, 65*(10), 1643-1665. https://doi.org/10.1002/acr.22015

Neogi T. (2013). The epidemiology and impact of pain in osteoarthritis. *Osteoarthritis Cartilage, 21(*9): 1145-53. https://doi.org/10.1016/j.joca.2013.03.018

Onder, G., Cesari, M., Russo, A., Zamboni, V., Bernabei, R., & Landi, F. (2006). Association between daily pain and physical function among old-old adults living in the community: Results from the ilSIRENTE study. *Pain, 121*(1–2): 53–59. https://doi.org/10.1016/j.pain.2005.12.003

Park, J., Mendy, A., & Vieira, E.R. (2018). Various types of arthritis in the United States: Prevalence and age-related trends from 1999 to 2014. *American Journal of Public Health, 108*: 256-258. https://doi.org/10.2105/AJPH.2017.304179

Radin, EL, Burr, DB, Caterson, B, Fyhrie, D, Brown, TD, Boyd, RD (1991). Mechanical determinants of osteoarthrosis. *Seminars in Arthritis and Rheumatism*, *21*(3 Suppl 2): 12-21. https://doi.org/10.1016/0049-0172(91)90036-Y

SENIAM. (2021, August 15). *Recommendations.* Retrieved from SENIAM website: http://seniam.org/

Silva, L.E., Valeria, V., Pessanha, A.P., Oliveira, L.M., Myamoto, S., Jones, A., & Natour, J.(2008). Hydrotherapy versus conventional land-based exercise for the management of patients with osteoarthritis of the knee: a randomized clinical trial. *Physical Therapy, 88*(1), 12-21. https://doi.org/10.2522/ptj.20060040

Stevens, S.L., Caputo, J.L., Fuller, D.K., & Morgan, D.W. (2014). The effects of underwater treadmill training on leg strength, balance, and walking performance in adults with incomplete spinal cord injury. *The Journal of Spinal Cord Medicine; 38*(1), 91-101. https://doi.org/10.1179/2045772314y.0000000217

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Pearson/Allyn & Bacon.

Vina, E.R. & Kwoh, C.K. (2018). Epidemiology of osteoarthritis. Current *Opinions in Rheumatology, 30*(2): 160-167. https://doi.org/10.1097/bor.0000000000000479

Wyatt, B., Mingo, C.A., Waterman, M.B., White, P., Cleveland, R.J., & Callahan, L.F. (2014). Impact of the Arthritis Foundation's Walk With Ease program on arthritis symptoms in African Americans. *Preventing Chronic Disease*, *11*:E199. https://doi.org/10.5888/pcd11.140147