Spring 5-12-2022

Adaption, Retention, and Readaptation Strategies for Unfamiliar LEKA (Lower-Extremity Knee Angles)

Leea M. Perry
Northern Illinois University

NORTHERN ILLINOIS UNIVERSITY

Adaption, Retention, and Readaptation Strategies for Unfamiliar LEKA (Lower-Extremity Knee Angles)

A Capstone Submitted to the

University Honors Program

In Partial Fulfillment of the

Requirements of the Baccalaureate Degree

With Honors

Department Of

Kinesiology and Physical Education

By

Leea Perry

DeKalb, Illinois

May 2022

ABSTRACT

Purpose

This capstone aimed to look into individuals' abilities to adapt, retain, and readapt a newly-provided, typically over-exaggerated, goal knee angle for their right leg based upon feedback received and accuracy of examined gait pattern.

Methods

Research was carried out using individuals aged 18-25, looking at the potential of "learning" per say, a new pattern for their rather instinctual previously formed habits for walking. Knee angle, both baseline and individuals' attempts at goal angle, were measured with a knee brace worn throughout data collection. Participants for this study were blind in terms of what their goal LEKA (lower-extremity knee angle) was. The only information presented to participants while taking part in the study was 1 of 2 types of feedback. Types of feedback included positive, or reward feedback, and negative, or punishment feedback. Throughout the study, individuals strived to "perform" to the best of their ability in terms of meeting their goal knee angle.

Results

Collected data was analyzed to show not only if individuals were capable of adapting their typical walking pattern to match an over-exaggerated angle, but also to show which feedback type produced the best results in terms of adaptation, retention, and readaptation. Major findings indicated that all individuals were fully capable of changing their knee angle from their "baseline" or typical knee angle they have grown accustomed to while walking, as well as indications that the positive feedback strategy produced the most concise, consistent results. This

assumption was based on overall consistency trends within the data, as well as learning curve, retention value, and memory of previously adapted walking patterns.

Conclusions

Overall, programs similar to the study conducted can be beneficial additions to pre-existing care plans. Examples of settings where this type of therapy may be utilized include outpatient physical therapy facilities, as well as any inpatient, acute care setting. Implementations of a program such as this could be supplemented to any locomotor based therapy, which is oftentimes used for individuals suffering from strokes or spinal cord injuries (Mayo Clinic, 2020). For a more consistent outcome, our results display that positive reinforcement is the more reasonable type of feedback in terms of input given to an individual in therapy. Providing individuals with a reward feedback system can aid in producing the most beneficial results.

Significance

This work is extremely significant when it comes to rehabilitation healthcare fields, such as physical therapy. As previously mentioned, individuals such as stroke patients, those recovering from major lower-extremity surgeries, or anyone who may have lost the ability to walk, may need help in the process of reconstructing walking habits. Providing a systematic program in which beneficial, continuous feedback is provided to individuals to help them obtain a goal knee angle when walking can significantly speed up the rehabilitation process.

Keywords:

Lower-Extremity Knee Angle (LEKA), Adaptation, Retention, Readaptation, Feedback

INTRODUCTION

The human body is thought to be an extremely methodical, instinctive-based system. Actions coming as almost second-nature, such as walking, seem nearly impossible to alter. However, in individuals such as stroke patients, those recovering from major surgery, or even typical, healthy people, habits learned when it comes to walking can shockingly be changed rather quickly through setting a goal and providing feedback. In a similar study looking at stroke patients and walking rehabilitation on a split treadmill (two belts traveling at different speeds for each leg), researchers observed that after a 15 minute adaptation period, improvements in symmetrical walking patterns were already observed in those previously struggling with asymmetrical walking patterns (Reisman et al., 2007). Treadmill rehabilitation strategies including adaptation periods for new walking or gait movements have proven to show improvements to the baseline measurements/patterns rather quickly. When followed by additional treatment sessions, the results may become long lasting.

Additionally, a study conducted regarding the adaptation to weight being added to one lower limb while walking discusses participants' abilities to adjust their walking style in order to compensate for the newly added mass. It also looks into the lasting effects of the weight on walking patterns after the weight is removed. Nobel and Prentice (2006) explain that participants experienced an adaptation phase of about 45-50 strides after the weight was added. After the completion of the adaptation, individuals in the study experienced an increase in knee extensor and flexor movements to compensate for the imbalance due to the added weight. Not only were participants generally able to adapt their typical walking style to fit their new environment, but these patterns seemed to carry on after the weight was removed. In the post-weight portion of the study, participants demonstrated increased ankle, knee, and hip extension when compared to levels taken in their baseline period. The individuals in this study were healthy, young adults, meaning that most of them returned to their typical walking style fairly soon after this, however, this data is extremely significant in someone who may not have an ideal walking or gait pattern. There is great significance in seeing that as individuals, we have the capability to not only adapt to a new style of walking, but carry on with that style of walking after our bodies have adjusted.

Our examination of the adaptation of a newly-introduced knee angle consists of the adaptation period, much like the previously mentioned study, followed by a retention, washout, and readaptation period, all of which will give us information on how the participant’s walking pattern has changed in comparison to their baseline. In our investigation of changing or instating new walking habits, we took a closer look at an individual's ability to change their instinctive knee angle to match their goal LEKA, as well as how well individuals are able to hold onto this information during the washout, retention, and readaptation phases. Participants in our study were also provided with feedback during the adaptation, retention, and readaptation phases. The different styles of feedback provided to individuals were deemed reward or punishment input. Feedback style was also considered when determining how well an individual was able to adapt and retain. The combination of adaptation strategy as well as most-beneficial feedback style can help to formulate an advantageous therapy plan for individuals struggling to regain proper walking habits.

SIGNIFICANCE

In many cases, individuals who are deemed as post-stroke, surgery, or injury can potentially have difficulties regaining their walking abilities in terms of both gait and extension/flexion of the hip, ankle, and knee, all significant joints in the action of walking. A study conducted with spinal cord injury (SCI) victims and uphill walking is very telling in terms of the typical walking styles of individuals after a traumatic event. This particular study looks at the variations in walking style when a treadmill is shifted from normal to an uphill angle in both SCI patients and a control group of individuals (Leroux et al., 1999). When the angle of the treadmill was increased, immediately the control group demonstrated change in their hip, knee, and ankle movements. More specifically, the control group displayed an increase in “hip flexion and ankle dorsiflexion” in combination with a “gradual decrease in knee extension” (Leroux et al., 1999). However, when looking specifically at SCI patients, they did in fact demonstrate similar changes in hip flexion, but had almost no change in knee angle and “large variations” in terms of ankle dorsiflexion when the treadmill shifted upwards. Individuals with SCIs were able to adjust to the uphill inclination of a treadmill, but not in the same way that the control, non-injured group was. In order to maximize usage of the full leg in the adaptation of new walking movements, therapy treatments looking to increase knee angle could potentially benefit these individuals. Taking full advantage of all joints involved in the movements of walking can optimize an individual's capabilities with regards to everyday walking habits and the adaptation of walking habits depending on environmental factors.

Furthermore, individuals suffering from knee pain due to arthritis or general wear and tear may have issues with fully bending or extending their knee. Interventions such as physical therapy can assist individuals in regaining full movement of their knee, improving their overall walking abilities. In a research study comparing the effects of manual PT in participants with knee osteoarthritis (OA) compared to a healthy control group, manual therapy has shown to have immediate effects on those struggling with knee pain and stiffness (Taylor et al., 2014). After only a one-time 30-minute manual physical therapy session, individuals with OA experienced greater range of motion when measurements were compared with their baseline, while the healthy control group who had a typical, full range of motion baseline saw no change after manual therapy. Taylor et al. (2014) explains that the loss of full range of motion of the knee can have an effect on someone's ability to walk and/or stand properly. This assists in explaining that optimal walking and standing abilities can be significantly improved by the increase in the overall range of motion/extension of the knee. With research backing that manual PT, as well as an abundance of other interventions have large effects on overall knee pain and stiffness, we hope to explore the effects of the implementation of an adaptive knee angle treatment into an already existing therapy plan.

METHODS

Participants consisted of a group of college-aged students (roughly 20-25), all of which are healthy and have not recently experienced a traumatic accident or injury. Upon arrival, participants were offered a thorough explanation of the study, as well as the possible risks, benefits, and goals of the research. The informed consent form offered at the end of the detailed packet needed to be signed in order for the participant to continue. Once data collection could begin, the dominant hand of the participant needed to be verified. In order to keep data collection consistent, all participants were required to be right-handed. This was determined using the Edinburgh Handedness Inventory (Oldfield, 1971). Following the determination of right-hand dominance in all participants, a competency questionnaire was administered to all individuals. The Mini-Mental State Examination was utilized to determine any potential cognitive impairment (Folstein, 1975). This examination took between 5 and 10 minutes, and involved a series of general questions and tasks. A score of 24-30 on this examination was ideal in order to again keep data collection as consistent as possible.

Additional informational aspects such as age and sex were then gathered to be added to the overall data. Basic measurements such as height and weight were taken for each individual. Leg length measurements, which were based on the participants' greater trochanter to the lateral malleolus of each leg, were then taken in order to determine the proper walking speed. Leg length was taken for both the right and left leg, and these measurements were then averaged. Walking speed was calculated by taking ⅔ of the averaged leg length, and multiplying that number by 1.33. The calculated speed would be inputted into the program to set the treadmill at an individualized value for each participant, ensuring both their safety and comfortability while walking. This equation is displayed below.

$$Walking\ Speed = (average\ leg\ length)(1.33)$$

The desired knee angle was again individualized to each individual. However, this calculation could not be completed until the individual began walking. The desired knee angle was calculated based on the average value of their knee angle measurements taken during the baseline period. Upon the start of data collection, before the adaptation period began, 30 degrees was added to the average baseline knee angle of the participant. This angle would be the newly-introduced "goal" angle the participant is trying to meet while walking (participant was kept blind from their goal angle). This equation is shown below.

$$Goal\ LEKA = Average\ Baseline\ LEKA + 30°$$

Before collection of data began, the participant was randomly and blindly assigned a feedback style. Feedback style could be punishment or reward, and was based on a point-like system. A reward feedback style gave higher "points" when the LEKA was closer to the desired, calculated knee angle assigned to each participant prior in the data collection process. The closer their knee angle to their goal LEKA, the higher number of points they received. This feedback was displayed to individuals on a monitor placed in front of the treadmill. Higher point values displayed as "+4", showing participants within this feedback category they were meeting (or very close to meeting) their desired LEKA. Points given decreased as LEKA grew farther from the participants goal knee angle. This meant that as their knee angle continued to decrease or increase farther away from the target, the lower the points given to the participant (ie +3, +2, +1, +0). The punishment feedback style worked very similarly, with an opposite point system. The participants within this feedback style would be deducted points the farther they got from their desired LEKA. Therefore, when a participant was very close to meeting or meeting their goal knee angle, the feedback presented on the screen would appear as "-0", showing them that no points were being deducted and they were in a good place. The farther away an individual went from their desired LEKA, the more points were deducted, displaying -1, -2, -3, or -4 respectively.

Data collection consisted of gathering information, both quantitative and qualitative, based on perception of behavior and numerical values taken while the individual was participating in the study. Statistics on LEKA were collected and separated into phases. The first phase is referred to as the baseline phase, in which individuals are instructed to "walk normally". This helped to monitor their typical knee angle, and gave us a good idea of where they started before feedback was given, however individuals could see their real-time knee angle displayed on the screen. The baseline stage lasted 125 right-leg steps, or 250 total steps. Following this, they switched into the adaptation, or “learning” phase. This phase is where feedback began, whether it be punishment or reward. The adaptation phase consisted of 250 right leg steps, or 500 total steps. After adaptation, participants moved into the retention phase, where feedback was no longer given, and participants were blind to their knee angle. The goal of the retention phase was to see how accurately they were able to perform the task of meeting their desired knee angle based on what they learned in the adaptation phase. The retention stage lasted 250 right-leg steps, or 500 total steps. The washout stage followed, in which feedback was no longer offered, but participants were able to see what their current knee angle was, similar to the baseline phase. Walking pattern was observed and compared to the baseline walking pattern to see how the newly introduced knee angle affected it. This phase lasted a total of 250 steps, or 125 right leg steps. The final phase of data collection was the readaptation phase. Here, feedback resumed, and individuals were tested on their ability to retain and remember the walking pattern they had adapted originally. This phase consisted of 125 right-leg steps, or 250 total steps. The stages of data collection are further explained in Figure 1.

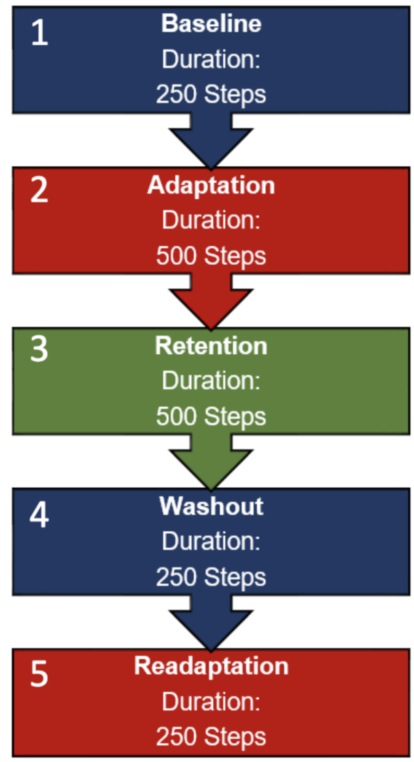


Figure 1: Data collection process broken up into stages depending on type of feedback given to participants. Baseline stage: no feedback, participant could see current knee angle while walking (blue) → adaptation stage: feedback begins (either punishment or reward) (red) → retention stage: no feedback given, participant is completely blind to knee angle (green) → washout stage: no feedback, participant could see current knee angle while walking (blue) → readaptation phase: feedback resumes (red).

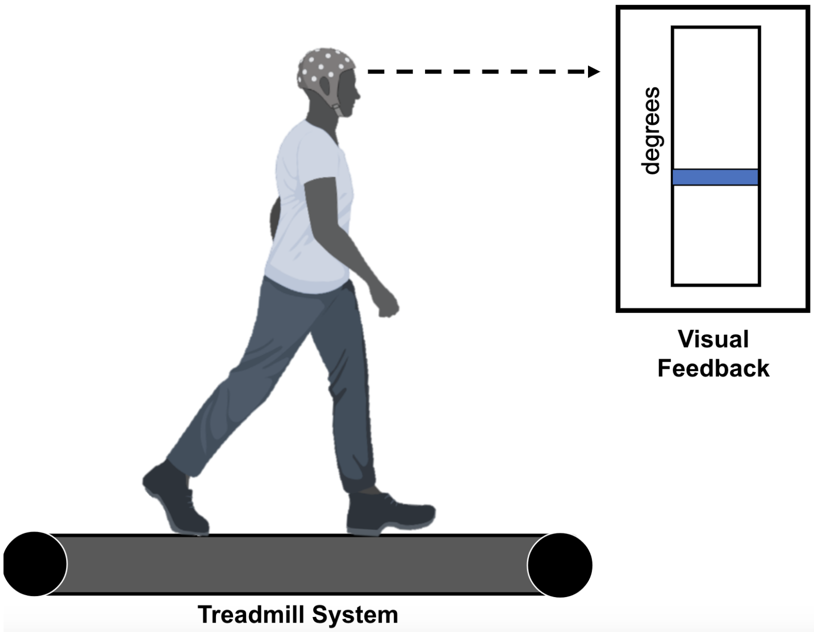


Figure 2: Data Collection Setup.

A more descriptive image showing location of treadmill, display screen, and what participants were able to see during various stages of data collection is shown in Figures 2 and 3.

Steps taken by the individual were tracked using a monitoring device placed on the right leg of the participant. This device measured maximum knee angle each time the participant took a step with their right leg. For each phase in the data collection, statistics for maximum knee angle were compiled into either 5 or 10 groups of data points or blocks, depending on the length of the stage. The baseline, washout, and readaptation stages consisted of 5 blocks of data, while adaptation and retention were made up of 10. These data sets helped to categorize the data in a more organized fashion, rather than looking at the overall raw data and attempting to analyze trends. Within each of these data blocks, an average value for maximum knee angle was given. The average maximum values taken from the 2 most successful participants (1 from each of the 2 feedback styles) for each data

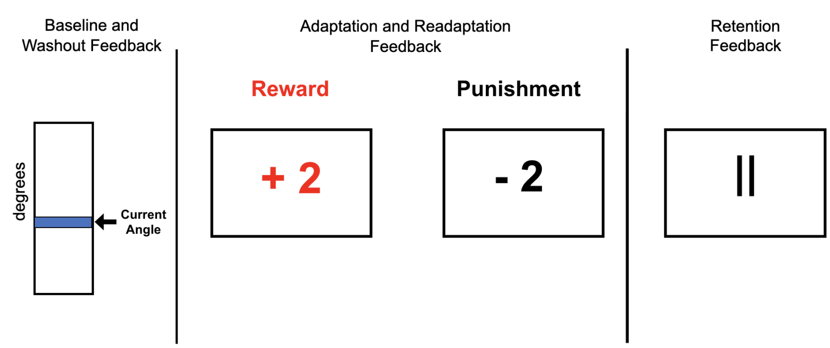


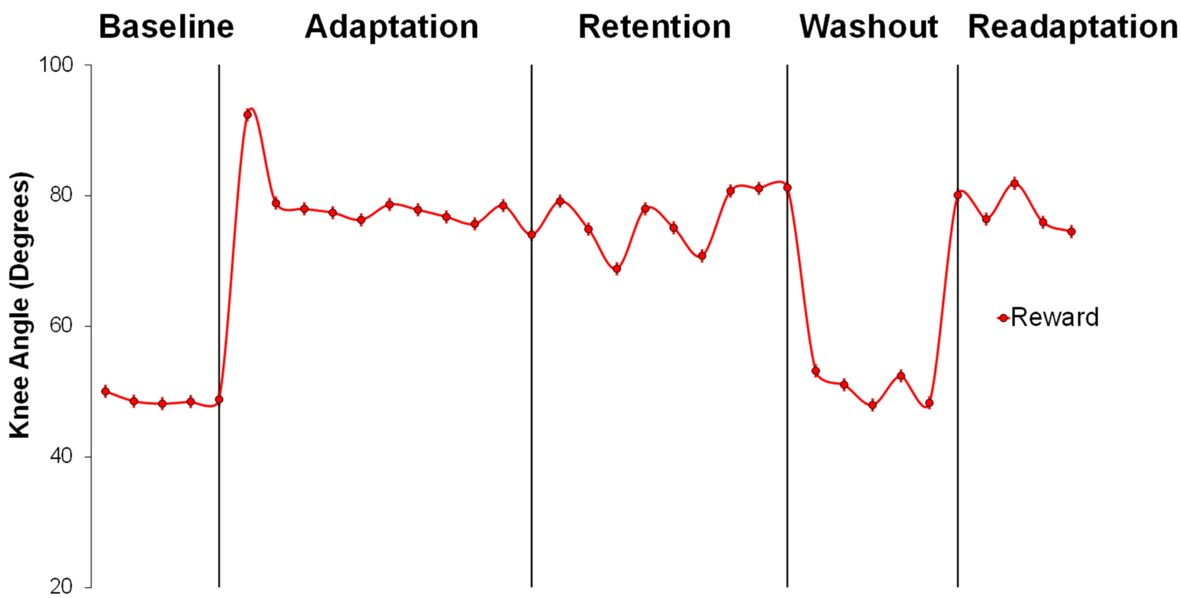
Figure 3: Display on screen as seen by participants at various stages of data collection.

block coming from all 5 stages of data collection are what we used for further data analysis. The final values for the 2 most successful participants are shown in Table 1.

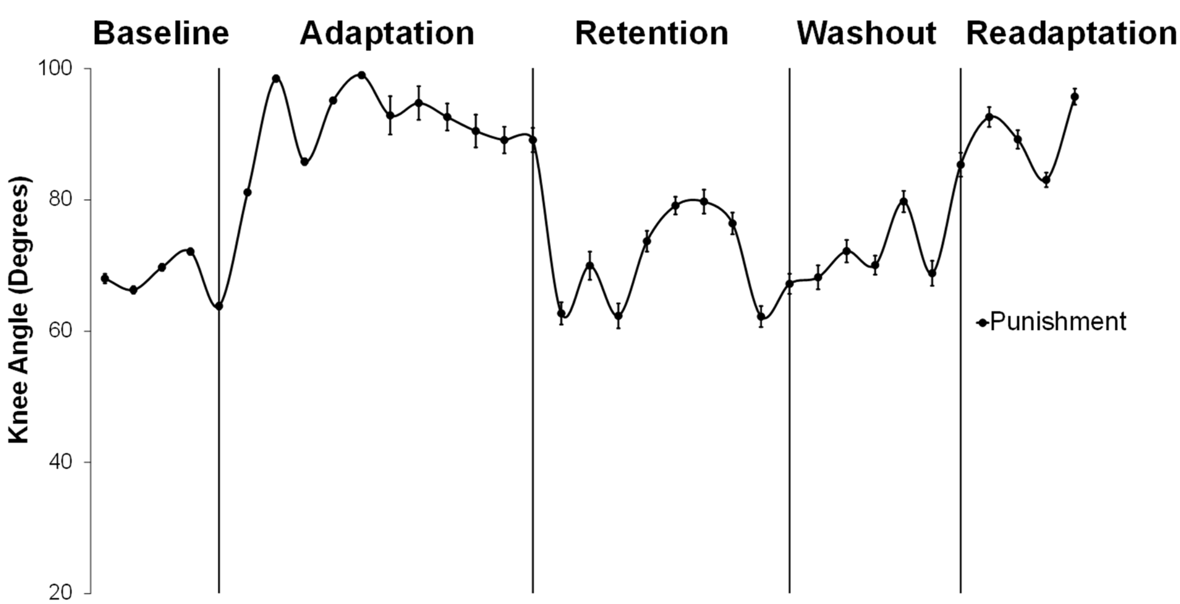
These average maximum values were used to determine patterns in the data, and helped visualize how well a participant adapted the newly-introduced knee angle, as well as how they were able to retain this walking pattern. These values were compiled into graphs, separated by the various phases of data collection. The best data was selected from each feedback style, giving us 2 final graphs. These plots are displayed as Graphs 1 and 2.

	Reward Subject	Punishment Subject
Data Block	Baseline Values	
1	50.06	68.0075
2	48.55	66.29
3	48.17	69.725
4	48.495	72.11
5	48.825	63.82
	Adaptation Values	
1	92.385	81.1475
2	78.855	98.475
3	77.99	85.815
4	77.4	95.145
5	76.3	99
6	78.65	92.875
7	77.83	94.76
8	76.755	92.625
9	75.68	90.49
10	78.47	89.115
	Readaptation Values	
1	74.045	89.115
2	79.16	62.71
3	74.88	69.97
4	68.82	62.335
5	78.005	73.705
6	75.08	79.13
7	70.8	79.74
8	80.72	76.415
9	81.115	62.225
10	81.23	67.21
	Washout Values	
1	53.205	68.205
2	51.07	72.185
3	47.975	70.06
4	52.425	79.745
5	48.31	68.82
	Readaptation Values	
1	80.087	85.355
2	76.425	92.62
3	81.88	89.21
4	75.94	83.045
5	74.495	95.725

Table 1: Average maximum knee angles presented from organized data of baseline, adaptation, retention, washout, and readaptation for most successful reward and punishment feedback participant (color coating indicates if/when feedback was given and matches color coordination in Figure 1).

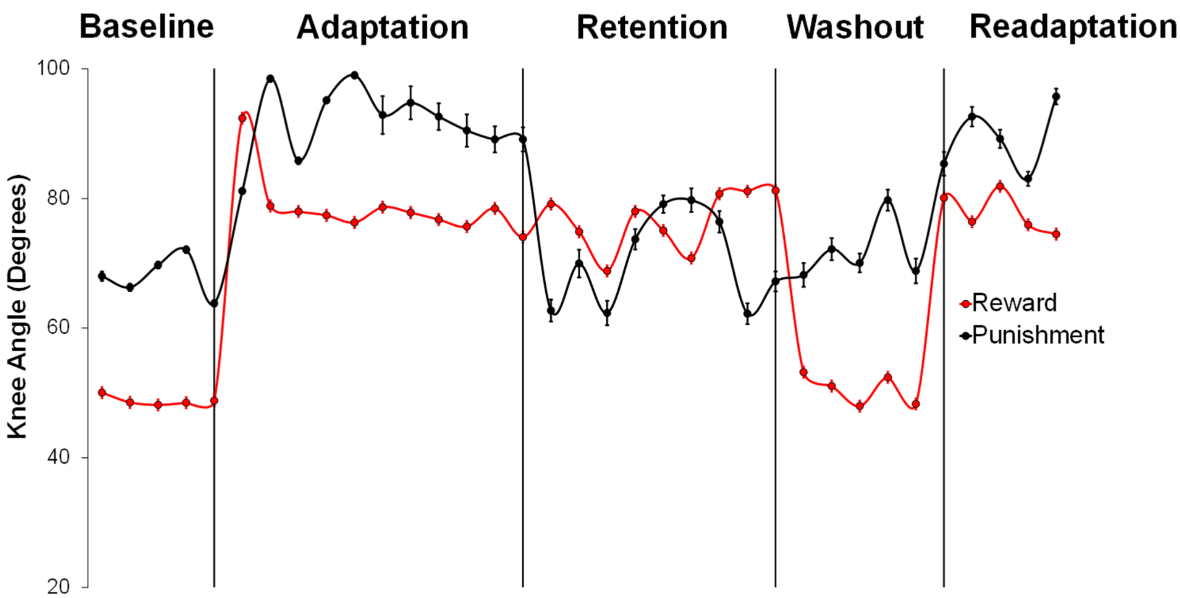


Graph 1: Plot of maximum knee angle vs time for most successful reward feedback participant.



Graph 2: Plot of maximum knee angle vs time for most successful punishment feedback participant.

In order to compare the effectiveness of the two types of feedback styles, we added both data collection patterns to the same graph. This helps to display both the learning curve of each participant and the consistency of their newly-adapted walking patterns. This graph is shown below.



Graph 3: Plot displaying punishment and reward feedback participant data, showing average maximum knee angle data taken over each period of data collection.

RESULTS

To further examine data and determine both sustainability and productivity of the different feedback styles we examined the learning curve, progress loss, and overall consistency of each participant's data. To determine learning curve of both subjects, the last 2 average maximum values of the baseline data collection period were averaged together, giving us a singular ending average value for the baseline knee angle of a participant. Following this, the maximum average values of blocks 8 and 9 from the adaptation period were averaged. This is considered to be the "plateau of learning". This again gave us 1 value indicating where each individual stood in terms of what they had learned during the adaptation period, or, when they learned to alter their knee angle. When the ending baseline value was subtracted from the adaptation plateau of learning value obtained for each participant, the resulting value showed the average increase in knee angle from the end of the baseline phase to the prime learning period of the adaptation phase. This number represents the learning curve of the participant based on the feedback they were given, and the point in which it began. This procedure was repeated for both the punishment and reward feedback participants so their learning curves could be compared. The numerical values used to calculate the learning curve, as well as the quantitative value of the learning curve itself are displayed in Table 2.

Adaptation (Blocks 8 and 9)			Retention (Blocks 1 and 2)	
Reward	Punishment		Reward	Punishment
78.47	89.115		79.16	62.71
74.045	89.115		74.88	69.97
Mean			Mean	
76.2575	89.115		77.02	66.34
Difference (Adaptation Avg-Retention Avg)				
	Reward		Punishment	
	-0.7625		**22.775**	

Table 2: Data used to determine learning curve for reward and punishment participants. Yellow highlighted boxes indicate average values used for calculation of learning curve. Quantitative value for learning curve displayed at bottom of table.

To compare the two learning curves, we added them to a bar graph in order to show the difference in amount of adaptation made between the two participants. This data is shown in Graph 4.

Graph 4: Learning curve or "growth" comparison between baseline and adaptation periods for punishment and reward feedback participants.

Another aspect we wanted to look into was how well each participant retained their newly-developed walking habits. For this determination, we wanted to again use blocks 8 and 9 of data collection (the plateau of learning), where the participant was receiving feedback, and blocks 1 and 2 at the beginning of the retention period, where the participant was no longer receiving feedback. To obtain these values, we followed a similar procedure to obtaining the learning curve value, where we averaged the two data blocks (8 and 9 from adaptation, 1 and 2 from retention) and subtracted the average value from the adaptation period from the average values from the retention period. This ending value showed us how much progress made during the adaptation period was lost, and how much of the new habit the participant was able to retain with no visual feedback. The data blocks used to calculate the retention value, as well as the numerical value itself is shown in Table 3.

Because our goal was to compare feedback styles, we again wanted to place these 2 quantitative values into a chart to show the difference in amount of progress lost between the two feedback styles. This chart is displayed in Graph 5.

Adaptation (Blocks 8 and 9)			Retention (Blocks 1 and 2)	
Reward	Punishment		Reward	Punishment
78.47	89.115		79.16	62.71
74.045	89.115		74.88	69.97
Mean			Mean	
76.2575	89.115		77.02	66.34
Difference (Adaptation Avg-Retention Avg)				
	Reward		Punishment	
	-0.7625		**22.775**	

Table 3: Data used to determine retention for reward and punishment participants. Yellow highlighted boxes indicate average values used for calculation of learning curve. Quantitative value for retention displayed at bottom of table.

Graph 5: Retention difference or "loss" of adaptation between adaptation and retention periods for reward and punishment subjects.

The final comparison we wanted to make was the overall ability of the individual to readapt to the desired LEKA after feedback resumed again. This means comparing the adaptation period to the readaptation period. We again used blocks 8 and 9 of the adaptation period, averaged the two, and subtracted this value from the average of blocks 1 and 2 of the readaptation period (where feedback resumed). This value represents the amount of difference or "loss" we saw for each participant from the first time they learned the new walking pattern, to the second time they were asked to perform based on feedback. The calculation gave us a numerical comparison between the ability of each participant to readapt the previously-learned walking pattern after feedback had stopped for a period of time. This quantity for each participant was deemed their "savings", as this is how much the participant was able to remember between where feedback was first given and when feedback had resumed after being paused. The values used to obtain "savings" for the reward and punishment participants, as well as the savings value themselves are shown in Table 4.

Adaptation (Blocks 8 and 9)			Readaptation (Blocks 1 and 2)	
Reward	Punishment		Reward	Punishment
78.47	89.115		80.087	85.355
74.045	89.115		76.425	92.62
Mean			Mean	
76.2575	89.115		78.256	88.9875
Difference (Readaptation Avg-Adaptation Avg)				
	Reward		Punishment	
	1.9985		**-0.1275**	

Table 4: Data used to determine "savings" for reward and punishment participants. Yellow highlighted boxes indicate average values used for calculation of learning curve. Quantitative value for "savings" displayed at bottom of table.

The chart displaying the savings of the reward and punishment participants as well as the comparison between the two is displayed below.

Graph 6: Difference or "savings" between first feedback period of adaptation and second feedback period of readaptation for each feedback style.

DISCUSSION

After data collection, we analyzed plots of average maximum LEKA to determine trends in how well an individual was able to adapt to and retain a new walking pattern, all while correlating this with feedback style. While examining the plot of the reward feedback style for maximum average LEKAs over the multiple phases of data collection, we can note very clear, distinct separation between the phases, indicating where feedback started and stopped. The baseline phase displays an initial average maximum LEKA of about 50 degrees. Immediately after, we see a spike in average maximum knee angle, insinuating that feedback has started, and the participant was aiming to have their knee angle match the goal knee angle. In the first stages of the adaptation phase, average maximum knee angle is very high, though soon after the maximum knee angle of the participant becomes extremely consistent. This consistency remains throughout the adaptation and retention phases while feedback is still being given. Once feedback is halted during the washout phase, the participants average maximum knee angle begins to shift back towards the baseline levels. However, it is important to note that while very similar to baseline average maximum knee angle of around 50 degrees or so, we can see a very slight increase at the washout phase, where the average seems to be at about 52 or 53 degrees. After the conclusion of the washout phase, feedback is again implemented for the readaptation phase, and we notice the individual's average maximum knee angle return to the level it was previously seen at during adaptation and retention.

The punishment feedback subject showed some similarities to the reward feedback style. For the most part, there were distinguishable differences between stages where one could tell exactly when feedback started, stopped, and resumed again, although these distinctions were not as clear as what could be seen on the reward feedback plot. The baseline average maximum knee angle for the punishment feedback participant sat between 60 and 70 degrees, and again spiked right as feedback began, as we saw with the reward participant. We saw the knee angle slightly even out and become more consistent throughout the adaptation period, however it slightly fell off during the retention period. During retention and washout, the average maximum knee angle returned to similar levels seen in the baseline stage. This differed from the plot of the reward feedback as throughout the entirety of the adaptation and retention periods, maximum average LEKA remained fairly consistent. When feedback resumed in the readaptation phase, maximum average knee angle of the participant began to increase again but never became steady or consistent.

The goal for the learning curve was to be as close to 30 degrees as possible, as this was the amount added to the initial baseline knee angle to create the goal LEKA. Meaning, the higher the value for the learning curve, the closer the participant was to their goal LEKA. However, in the case of the values for retention and savings, the lower the values were, the better. This is due to the fact that when looking at retention, we were examining the amount of change the participant displayed in their knee angle between the adaptation period and the retention period, or in other words, how much progress they lost when feedback had been paused. When the value is lower for retention, that means the participant had lost a smaller amount of progress, and was able to consistently remain at the level of knee angle they had become accustomed to during the adaptation period. As for the savings value, again, we were looking at progress lost between the initial adaptation period and the readaptation period. After feedback had been resumed in the readaptation period, the goal was to see how close participants could get their LEKA to the LEKA they had adapted previously. Meaning, the lower the number for savings, the better, as their readapted LEKA would be closer to their previously-adapted LEKA.

The reward participant was most successful in terms of the learning curve value, and showed that they almost fully reached their 30 degree increase by the end of the adaptation period. With a value of 27.925 compared to the punishment participant's learning curve of 18.1975, the individual receiving reward feedback was more effectively able to reach their goal LEKA. When looking into retention values, again, the reward feedback participant seemed to most effectively retain what they had learned during adaptation once feedback had stopped. With a retention value of -0.7625 compared to the punishment participant's retention value of 22.775, we can see the reward participant clearly "lost" less progress in terms of staying consistent with their goal LEKA. In regards to the savings value, or how much had been carried over from the initial adaptation period, where feedback began, to the readaptation period where feedback resumed, the punishment participant displayed less loss, however, the difference in this case was much less drastic. The punishment participant showed a difference between adaptation and readaptation of only -0.1275, while the reward participant showed a difference of 1.9985. As previously stated, the difference between the two participants concerning the savings value was far smaller, however it is important to note that the punishment participant showed greater long-term retention when looking at the discrepancy between adaptation and readaptation periods.

Additionally, there are a few important factors to note when it comes to possible errors in data collection. Qualitative observations were collected by researchers to help indicate and probable sources for errors. An important aspect to take into consideration was potential malfunctions with data collection equipment. During the punishment trial selected as the most successful participant, there were times where the leg ankle monitor would slip down the participant's leg, or fall down to their angle completely, hindering its ability to properly monitor knee angle. This could have been a possible source for error, and may have affected the accuracy data for the punishment participant. However, it remains important to acknowledge the fact that even with these potential sources for error within data collection of the punishment participant, the overall data from the reward participant selected remains more telling and displays a more distinct trend between phases.

To further expand, another potential fault within our data could have fallen within the initial calculation of determining goal LEKA. The goal LEKA was based solely on the average baseline angle displayed by the participant at the start of data collection. As previously mentioned, this mean value was supplemented with an additional 30 degrees, giving us the goal

LEKA. This process may be somewhat flawed however. Taking the average of the baseline LEKA measurements in a participant is not completely fool-proof, especially when the baseline values are not showing to be very consistent. For example, in the punishment feedback participant, we see the baseline values for average maximum LEKA to be pretty inconsistent throughout the 5 data blocks, whereas in the reward feedback participant, the values tend to be more even. This could have negatively impacted the punishment subject's ability to reach their desired, or goal LEKA as it may have been determined as too high or too low, depending on what their true baseline value should have been. Inconsistent baseline knee angles seen within the punishment participant can most likely be drawn back to the fact that walking with the device strapped to one leg can be difficult, and something that takes some time to get used to. In further research, a way to avoid this error could be to allow the participant more time in the baseline phase in order to give them more time to become used to the device, and overall give a more accurate reading of what their typical knee angle would be. Otherwise, collecting data for more participants can help to lower the effects of this possible error.

An important aspect to also take note of is the fact that the length of time that the participant is walking in the study could potentially cause inconsistent data. The total time of walking varied based on the speed of the treadmill/how quickly the individual was walking. Typically, the data collection process that included active walking lasted anywhere from 1 to 1.5 hours. While the set speed of the treadmill was meant to be comfortable, this can still take a toll on someone's body, especially if they are not used to walking for that length of time. This was a factor that I believe should also be taken into consideration in terms of validity of our results as well as if this study were to be continued with further participants. However, the individuals participating in this particular study did not make comment about how long the walking time was, and did not appear to be fatigued, indicating that this may have not been a substantial issue present in our data collection process.

CONCLUSIONS

Altogether, we have concluded that the results of our data collection using various feedback styles to track and monitor knee angle adaption, retention, and readaptation over a period of time, the reward feedback style is most beneficial for participants. Not only did the graphs and tables display clear distinctions between data collection periods based on when feedback began, paused, and resumed, but we also acknowledge the fact that positive reinforcement may improve the overall morale of an individual receiving locomotive based treatment. Treadmill-based training for individuals looking to improve ambulatory function such as individuals suffering from a spinal cord injury, who are post-stroke, post-surgery, etc. is extremely difficult and can at times be frustrating. For this reason, positive feedback may help to keep an individual motivated and encouraged when tackling this extremely difficult task. Individuals taking part in positively-reinforced treadmill training displayed more overall confidence as well. The reward style feedback graph displayed that the participant was extremely successful at reaching their goal LEKA, as well as keeping their knee angle consistent across periods in which feedback was given. Meaning that not only was the individual able to obtain their goal LEKA, but remain there as well. When considering the best approach to formulating a treatment plan using this type of treadmill-based training, it is important to take into account what will achieve the best results in both physical and mental rehabilitation of the individual.

Consistency is a key aspect to consider when determining effectiveness of feedback style. Simply viewing the graphs can be extremely telling in terms of consistency. Specifically, looking at the ability of the participant to not only reach their LEKA, but remain there throughout the adaptation, retention, and readaptation phases. When analyzing the graphs in this sense, it is apparent that the reward participant had a far easier time initially reaching their goal LEKA, but also was more successful in terms of retaining this walking pattern when feedback had paused during retention. Additionally, the reward feedback participant was clearly able to again, reach their desired LEKA, and remain consistent once it had been reached during the readaptation phase, or, when feedback resumed. With the punishment participant's data, we see a lot more inconsistiveness, where they were able to reach and remain consistent at their LEKA level during adaptation, but lost a lot of that progress and consistency during the retention phase. This pattern can again be seen at the readaptation phase, where the participant reached the LEKA but could never fully obtain and meet the angle at a constant rate. This is shown by the unevenness of the plot compared to the more even and smooth transitions that can be seen in the reward participant's plot.

Other components of data taken into consideration when formulating conclusions included the learning curve, retention, and savings values. In all cases but 1, the reward feedback participant displayed a value we have determined as more "effective" in terms of what would be looked for when exploring treatment options. As previously mentioned, reward feedback proved to be more successful in terms of learning curve and retention, while only falling behind the punishment feedback participant in the savings category. These results elucidate that the reward feedback had a more substantial effect on the participant's ability to reach their goal LEKA.

The learning curve value of the reward participant was not only much higher than the learning curve of the punishment feedback participant, but was also extremely close to the desired level of 30 degrees above their average baseline LEKA. Additionally, the retention, or the ability of the participant to remain consistent with their adaptation knee angle once feedback is paused, was also much smaller in the reward feedback compared to the punishment feedback. This is very telling, and shows that when feedback stopped, the reward participant had a much easier time staying at the desired LEKA, and showed a smaller difference between the adaptation and retention periods. When it comes to the savings value, or how much is lost between the initial adaptation and readaptation periods, we do see a larger amount of loss in the reward participant. The difference is very small in both cases however, with neither the reward or punishment participant seeing more than a 2 degree loss between initially adapting their new walking pattern and the reevaluation of it. Based on the face that the numerical values for savings and the small amount of discrepancy between the values for reward and punishment participants, it is fair to say this does not make as large of an impact in terms of determining overall effectiveness of a feedback style based on the large differences seen in learning curve and retention values between the two styles.

The repetition of movement seen individuals participating in this study also reflects the effectiveness it could have in real-world treatment scenarios. In terms of the study we conducted using healthy, young individuals who have not foregone either an injury or surgery, we did not expect to see changes between the baseline and washout periods. The individuals participating in our research were not attempting to rehabilitate their knee, and therefore do not have "progress" to be made so to speak. However, if this type of therapy were to be used in a care plan for someone who has either gone through a substantial injury or surgery affecting the knee, the goal would be to see overall changes in the range of motion in their knee, or improvements in the knee angle. In order to see improvements in knee angle, therapists would want to look at changes between baseline levels and washout levels over multiple treatment sessions. The repetitiveness of walking with an altered knee angle in an individual with limited range of motion would eventually lead to an increased ability to bend the knee while walking, improving ambulatory function. Reiner et al. (2005) explains “Task-oriented repetitive movements can improve motor performance in patients with neurological or orthopaedic lesions”. This supports the expectation that if this therapy were to be used in, for example, a stroke victim, therapists would see improvements or “changes” in baseline and washout levels over time as this treatment would be used as an attempt to improve range of motion.

Additionally, the implication of treadmill training such as ours in a rehabilitation plan can offer a multitude of other benefits as well. According to Macko et al. (2001), treadmill training used in patients who had suffered a stroke not only improved gait, but also overall physical conditions and capabilities. “Peak exercise performance” improved in all patients who had participated in the treadmill training program for 3 months, as well as lowered their oxygen demand (Macko et al., 2001). This is extremely telling, and helps to reinforce the fact that the addition of a treadmill-based locomotor rehabilitation program while being difficult, can help to improve an individual’s health in a multitude of ways, offering numerous benefits to those who chose to take part. Another study conducted by Nooijen et al. (2009) indicates when researching 4 different treadmill therapy approaches, improvements in gait could be seen in all individuals who participated in the study, no matter the approach. This is another reassurance that a treadmill rehabilitation program can benefit individuals across the board and help them to improve multiple aspects of ambulatory function. Giving this type therapy more significance and substantialness when considering implementing into a pre-existing, or new patient care plan.

Supplementary studies should be conducted to strengthen the claim that this type of rehabilitation would benefit those regaining or strengthening their abilities to walk. It is important to consider the fact that this study was conducted using a young adult population, all of which were healthy and did not previously suffer from a stroke, spinal cord injury, or like condition. For this reason, additional research is vital in order to substantiate claims that this type of therapy would benefit these specific populations. Furthermore, collecting data from a number of additional participants is ancillary to the process of reinforcing our results. Time constraints hindered us from collecting further data from more participants, meaning statistics should continue to be collected. Supporting data will help to vindicate what we have previously discussed, and provide validity to our claims.

Further research should also be conducted in terms of the most advantageous approach to a rehabilitation strategy such as the one we looked into. Rehabilitation processes involve a variety of aspects, all of which must be considered through the perspective of wanting to best-assist the individual at hand. Outside studies conducted resembling ours included one that looked at treadmill training in stroke patients, comparing programs in which the treadmill increased speed while the patient was performing therapy, compared to interventions where treadmill speed remained consistent (Pohl et al., 2002). The results of this study determined that individuals taking part in treadmill training where the speed of the treadmill was adjusted improved walking abilities significantly more in stroke patients compared to programs where treadmill speed did not change (Pohl et al., 2002). This speed change or consistency would be an example of an additional aspect to consider before implementing our treadmill rehabilitation program into a care plan, to assess if it is something we believe would further benefit the individual taking part.

Overall, while a difficult and trying task, treadmill-based rehabilitation and manipulating the knee angle of individuals who have previously faced a stroke, spinal cord injury, major surgery, etc., there are also extreme benefits that come with it. Through our research, we were able to conclude that by giving participants a goal knee angle based on their leg length, and setting them at a personalized treadmill speed produced results displaying that the individuals were capable of obtaining these goal LEKA, and could carry out this newly-introduced walking habit for an extended period of time. When taking into consideration feedback style, reward feedback proved to be most beneficial in terms of success of the individual at both achieving and remaining at their desired LEKA. Studies such as these continue to be extremely vital to the rehabilitation community, and provide new methods of rehabilitation that may help individuals regain ambulatory function to improve their condition even further than they would have been able to before. Walking is sometimes thought of to be an everyday, habitual aspect of life, but it impacts us more than we'll ever know. Improving someone's ability to walk through therapy not only improves physical condition, but improves their overall quality of life.

REFERENCES:

Folstein MF, Folstein SE, McHugh PR "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975 Nov; 12(3):189-98. **Example of examination: https://www.ncbi.nlm.nih.gov/projects/gap/cgi-bin/GetPdf.cgi?id=phd001525.1**

Leroux, A., Fung, J., & Barbeau, H. (1999). Adaptation of the walking pattern to uphill walking in normal and spinal-cord injured subjects. *Experimental brain research*, *126*(3), 359-368. Retrieved from: https://link.springer.com/article/10.1007/s002210050743

Macko, R. F., Smith, G. V., Dobrovolny, C. L., Sorkin, J. D., Goldberg, A. P., & Silver, K. H. (2001). Treadmill training improves fitness reserve in chronic stroke patients. *Archives of physical medicine and rehabilitation*, *82*(7), 879-884. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0003999301134052

Mayo Clinic Staff. (2020, April 1). Locomotor training for spinal cord injury. *Mayo Clinic.* Retrieved from: https://www.mayoclinic.org/tests-procedures/locomotor-training-for-spinal-cord-injury/about/pac-20394608

Noble, J. W., & Prentice, S. D. (2006). Adaptation to unilateral change in lower limb mechanical properties during human walking. *Experimental brain research*, *169*(4), 482-495. Retrieved from:

https://link.springer.com/article/10.1007/s00221-005-0162-3

Nooijen, C. F., Ter Hoeve, N., & Field-Fote, E. C. (2009). Gait quality is improved by locomotor training in individuals with SCI regardless of training approach. *Journal of neuroengineering and rehabilitation*, *6*(1), 1-11. Retrieved from: https://link.springer.com/article/10.1186/1743-0003-6-36

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113. Retrieved from: https://doi.org/10.1016/0028-3932(71)90067-4

Pohl, M., Mehrholz, J., Ritschel, C., & Rückriem, S. (2002). Speed-dependent treadmill training in ambulatory hemiparetic stroke patients: a randomized controlled trial. *Stroke*, *33*(2), 553-558. Retrieved from: https://www.ahajournals.org/doi/full/10.1161/hs0202.102365

Reisman, D. S., Wityk, R., Silver, K., & Bastian, A. J. (2007). Locomotor adaptation on a split-belt treadmill can improve walking symmetry post-stroke. *Brain*, *130*(7), 1861-1872. Retrieved from: https://academic.oup.com/brain/article/130/7/1861/323790?login=true

Riener, R., Lunenburger, L., Jezernik, S., Anderschitz, M., Colombo, G., & Dietz, V. (2005).

Patient-cooperative strategies for robot-aided treadmill training: first experimental results. *IEEE transactions on neural systems and rehabilitation engineering*, *13*(3), 380-394. Retrieved from: https://ieeexplore.ieee.org/abstract/document/1506824

Taylor, A. L., Wilken, J. M., Deyle, G. D., & Gill, N. W. (2014). Knee extension and stiffness in osteoarthritic and normal knees: a videofluoroscopic analysis of the effect of a single session of manual therapy. *Journal of orthopedic & sports physical therapy*, *44*(4), 273-282. Retrieved from: https://www.jospt.org/doi/10.2519/jospt.2014.4710