Effect of Knee Brace Use on Healthy Gait

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ABSTRACT
The aim of this study was to determine the effect of three different knee braces on the normal gait of the participants. The study was focused specifically on observation of the angle of the knee, hip, and ankle during a normal gait cycle. Both the dominant and non-dominant legs were observed; ideally, a brace should not change the non-braced leg’s kinematics but should selectively minimize the range of motion in the braced leg’s kinematics. A recent study has shown that knee braces are not effective for individuals with normally aligned knees [1]. Using the results obtained from the present study, it was found that the use of a prophylactic knee brace sustained normal gait with minimal effects on the contralateral knee compared to the other braces studied. The order from highest to lowest efficacy was found to be the prophylactic brace, the neoprene sleeve, and then the unloader brace.

INTRODUCTION
This project focuses on knee brace efficacy to determine if the knee brace appropriately sustains normal gait without altering any aspects of the gait. This will allow for a better understanding of the effects of a knee brace on a damaged knee by analyzing how it affects gait on healthy participants.

Knee pain can be acute or chronic depending on the cause and severity; it can be caused by genetics, injury, or normal wear and tear [2]. Some risk factors leading to knee pain are sports, osteoarthritis, excessive weight, flexibility, and strength. Participating in sports increases the risk of knee injury by introducing the body to movements that are unnatural, and it can also be harmful to the tendons and ligaments of the knee. Excessive weight can also increase risk of knee injury due to the increased force that the knee will experience. Last of all, poor flexibility, as well as poor strength, can increase the risk of knee injury because the tendons and ligaments can be stiff, which will cause failure when strong displacement loads are exerted on the knee [3]. The knee injuries that can result from these risk factors include ACL tears, meniscus tears, inflammation of the bursae, patellar tendinitis, and many forms of arthritis [3]. Two publications were found that disclose different kinds of knee braces and on what type of injuries they are best used [4, 5]. Since there are multiple types of knee braces, all suited for different injuries, the ones that were analyzed include a prophylactic brace, an unloader brace, and a neoprene sleeve brace. All can be seen in Figure 1.

Figure 1. The three types of knee braces used in this study: the prophylactic knee brace (left), the unloader knee brace (middle), and the neoprene sleeve knee brace (right).

The prophylactic brace is used to protect or decrease injury to the outside ligaments of the knee from impact and forces that could be applied. The prophylactic brace is composed of composite bars designed to limit hyperextension and hinges with non-elastic straps. The use of a prophylactic brace can be helpful in increasing the stability of the injured knee by reducing the amount of abduction and adduction in the joint while providing minimal impact to flexion and extension of the knee [6]. An assessment of this type of brace that focused on athletic performance showed that players who used the prophylactic knee brace had a lower chance of repeated knee injury [7]. It has been shown that prophylactic braces affect proximal and distal joints on the braced limb at the midstance phase.
in the gait cycle [8]. This effect is seen as a straighter lower extremity, which can elicit compensations by the other joints in the braced limb, but it has not been determined if other effects were seen in the non-braced limb during the gait cycle. This knowledge will be used to investigate if this brace type affects the other leg during gait.

Unloader braces are used to relieve forces and pain from osteoarthritis of the knee. The brace can be made of plastic, metal, or combined plastic and metal hinges. Unloader braces are primarily used for reducing pressure in a degenerative area by redirecting forces to other areas of the knee. The effectiveness of unloader knee braces for preventing the progression of diseases is disputed [9].

The most common brace is a knee sleeve; it is used to provide compression, retain heat, and enhance balance. Typically, they are made of a soft elastic material, such as neoprene, specifically shaped to help support the knee. Knee sleeves have been shown to be effective in treating patellofemoral joint conditions [10].

The effects of an unloader brace in normally aligned knees has been researched. In addition to the unloader knee brace, this study will be looking at the effects of neoprene sleeve and prophylactic knee braces in normally aligned knees [12]. The goal was to compare the normal gait of each participant using the three different knee braces by examining the hip angle, knee angle, ankle angle, and ground reaction forces (GRFs) while walking, which is similar to methods used in previous studies [14]. Unlike other studies, this study also compared the effects of the brace on the non-braced leg’s kinematics. The research questions of this study are as follows:

- If the leg is braced at the knee, then does the other leg experience a significant change in kinematics at the ankle, knee, and hip?
- If the leg is braced at the knee, then are there significant changes in knee flexion angle during gait?
- If the leg is braced at the knee, then does the brace significantly affect the kinematics of the ankle and hip of that same leg?
- If the leg is braced at the knee, then does the ground reaction force change significantly?

METHODS
Participant Preparation
The sample size was determined by using a sample size calculator for a two-sample one-tailed t-test, using means for the two samples from the literature review for knee flexion angles with and without brace during cadence. Normal knee flexion during a standard gait cycle ranges from 15 degrees to 60 degrees [11]. The mean reported for knee flexion without brace is 65 degrees and the mean flexion angle with brace is 50 degrees, both with a standard deviation of 10 degrees [13]. A sampling ratio of 1 was used with a Type 1 error rate of 5% and a power of 0.80. From this, a sample size of at least six participants was calculated.

All study procedures were reviewed and approved by the Florida Gulf Coast University Institutional Review Board, and all participants gave their informed consent prior to participating. Participants were required to be between the age of 18 and 65 years old, must not have had any knee procedures, injuries, or surgeries, and must not have been using any type of brace in their daily routine at the time of the study. Additionally, only participants who were able to fit into a medium brace were recruited for the study because of funding limitations.

Potential participants were instructed to meet at the Qualisys Track Manager (QTM) recording room for the measurements to be taken. The QTM system uses infrared (IR) cameras to track the position and movement of reflective markers placed on anatomical landmarks. Reflective markers were then placed bilaterally on the anterior and posterior iliac spine, greater trochanter, medial and lateral epicondyles of the femur, medial and lateral malleoli of the ankle, the second metatarsal head, and on the calcaneus at the same height as the toe markers.

Data Collection
Participants were then instructed to walk across two calibrated force plates three times to determine each participant’s joint angles and GRFs in gait without any bracing. After the participant had completed his/her walk, they were instructed to run across the force plates three times to determine the same parameters assessed in the walking trial. Three trials for walking and three trials for running were taken for each condition in order to take the average joint angles during gait.

The participant was then assisted in putting on the first brace, selected at random (using an excel sheet) out of the brace groups that were being tested. The braces tested were the patellar tracking orthosis (PTO) by Breg Bracing (the prophylactic knee brace), the Irom Donjoy (unloader knee brace), and the McDavid sleeve (knee sleeve brace). The braces were to be tested only on the participant’s right leg. For each brace, some markers had to be removed and replaced externally on the brace over the appropriate anatomical landmarks. The braces were all adjusted according to manufacturer recommendations and to maximize the participants’ comfort. Participants were asked to walk around the testing room for up to five minutes until they felt comfortable wearing the brace. The participant then repeated the three walking and running trials. The brace was then removed and the participants were allowed to rest prior to fitting the next brace. The braces were sanitized after each trial with a 70% Ethanol spray and allowed to dry. This was repeated until each participant completed the trials with all three knee braces.

Angle Calculations
Angles used for statistical analysis were calculated through the use of the Matlab software and the QTM system. The angles used to describe kinematics of the braced and non-braced legs were flexion of the hip, knee, and ankle for
both legs. Each running and walking trial was processed to output the middle step for gait comparison to allow for the most normal gait cycle. If a trial did not include at least three steps, it was not used to calculate the average gait cycle; this disqualified the gait cycle for some of the running trials' data because of limitations of the size of the room used for data collection in the study. Therefore, that is why some of the running trials have smaller sample sizes.

**Hip Angle**
To calculate the angle of the hip, markers were placed on each leg on the greater trochanter (GT), posterior superior iliac spine (PSIS), anterior superior iliac spine (ASIS), and the lateral knee (KNE). From the QTM system, the positions of the markers were transferred to a .mat file for data processing. In MatLab, the back vector was defined as the cross product of the vector from the LASIS to the RASIS and the vector from LASIS to the LPSIS; the thigh vector was defined as the vector from the GT to the KNE. Using the law of cosines, the angle between the two vectors was then obtained, as shown below in equation (1). These angles were then compared to a percent of gait cycle from heel strike to heel strike to obtain an average and standard deviation of the trial conditions.

\[
\text{Hip Angle} = \cos^{-1}\left(\frac{\text{Thigh} \cdot \text{Back}}{|\text{Thigh}| \cdot |\text{Back}|}\right)
\]

The method used to calculate the hip angle was the same used by a study in sports medicine [14]. With the brace having an effect on the hip angle, the reflex with the hip flexed is shown to be inhibited, which is the cause of the change in the actions of the leg muscles [15]. However, it is unclear if this has any adverse effects if the hip angle is changed for long periods of time, as that was not shown in the study. The basis of this outcome was shown previously, where hip angle changes were observed in the contralateral hip joint of the braced limb [16].

**Knee Angle**
To obtain the knee angle, the law of cosines was used with the thigh vector, as defined above, and a shank vector defined by the vector from the KNE to the later malleolus (ANK) markers, as shown in equation (2).

\[
\text{Knee Angle} = \cos^{-1}\left(\frac{\text{Shank} \cdot \text{Thigh}}{|\text{Shank}| \cdot |\text{Thigh}|}\right)
\]

In the field of sports medicine, knee brace efficacy has long been disputed. Studies have shown that certain braces are less effective or even non-effective [2, 10]. From previous literature it is known that normal knee flexion during a standard gait cycle ranges from 15 degrees to 60 degrees [12].

**Ankle Angle**
The ankle angle was calculated using the shank vector, as defined above, and a foot vector defined by the vector from the calcaneus (HEE) to the second metatarsal head (TOE) markers as shown below in equation (3).

\[
\text{Ankle Angle} = \cos^{-1}\left(\frac{\text{Shank} \cdot \text{Foot}}{|\text{Shank}| \cdot |\text{Foot}|}\right)
\]

This angle was measured because it has not been researched extensively to assess the effects knee braces have on neighboring joint stability.

**RESULTS AND DISCUSSION**
Ten participants were recruited and completed the study. The youngest participant was 18, the oldest participant was 34, and the average participant age was 25.

**Hip Angle**

![Walking Hip Flexion Angle (Degrees)](image)

![Percent Gait (%)](image)

Figure 2a (upper) & 2b (lower): Average hip flexion angles of the left (contralateral) and right (braced) legs during the walking trials respectively. Sample sizes are as follows: Unbraced n=27, Prophylactic Brace n=25, Neoprene Sleeve Brace n=25, and Unloader Brace n=26. Grey area represents 95% Confidence Interval of the unbraced leg trials.

Figure 2 (upper) shows the left leg hip flexion angles, which was the limb contralateral to the braced limb. The figure
shows that there were no significant differences in the braced conditions when compared to the unbraced walking trials. Also shown in Figure 2 (lower): the right leg hip flexion angles were similar to when the participants were not wearing a brace.

![Knee Angle](image)

**Figure 4a (upper) & 4b (lower).** Average knee flexion angles of the left (contralateral) & right (braced) leg during walking. Sample sizes are as follows: Unbraced n=27, Prophylactic Brace n=25, Neoprene Sleeve Brace n=25, and Unloader Brace n=26. Grey area represents 95% Confidence Interval of the unbraced leg trials.

The knee flexion angles for the left leg during the walking trials are shown above in Figure 4a. Since the knee flexion angle for the unloader brace fell out of the grey zone around 45-60% of the gait cycle during the end of midstance and the beginning of midswing, there is a significant difference in the left leg’s knee flexion angle during that phase of gait for the unloader brace. The data also shows that the neoprene sleeve and the unloader knee flexion angles fell out of the grey area from about 75-90% during midswing; this indicates that there is a significant difference in the left leg’s knee flexion angle during that phase of gait for the neoprene sleeve and the unloader knee brace. The RoM of the left leg’s knee can also be seen increasing for all three of the braces analyzed in this study; a shift to the right can also be seen in the RoM for the neoprene sleeve, as well as the unloader brace.

For the running trials, there was a decreased hip flexion angle relative to the walking trials. As shown in Figure 3, there were no statistically significant differences in hip flexion between the braced and unbraced conditions during the running trials; however, for the right leg, there was a decreased hip flexion angle of about 5 degrees throughout the gait cycle for the braced conditions. Additionally, no significant differences were found for the range of motion of the hip for running or walking.

![Knee Angle](image)

**Figure 3a (upper) & 3b (lower).** Average hip flexion angles of the left (contralateral) & right (braced) leg during running trials. Sample sizes are as follows: Unbraced n=20, Prophylactic Brace n=15, Neoprene Sleeve Brace n=17, and Unloader Brace n=17. Grey area represents 95% Confidence Interval of the unbraced leg trials.
Also shown above in Figure 4b, the knee flexion angle for the unloader brace fell out of the grey zone around 45-70% of the gait cycle during the end of midstance and the beginning of midswing; there is a significant difference in the right leg’s knee flexion angle during that phase of gait for the unloader brace. The data also shows that the neoprene sleeve knee flexion angle fell out of the grey area from about 73-90% during midswing; this indicates that there is a significant difference in the right leg’s knee flexion angle during that phase of gait for the neoprene sleeve. The RoM of the right leg’s knee can also be seen decreasing for the unloader and prophylactic brace, while increasing, as well as shifting right, for the neoprene sleeve. There is a significant difference in the left leg’s knee flexion angle during that phase of gait for the unloader and the prophylactic brace. The trends seen for the RoM of the neoprene sleeve and the unloader brace include an increase in the RoM; the RoM of the right leg’s knee also has a shift to the right for the unloader brace, as well as a smaller shift to the right for the prophylactic brace.

Also shown above in Figure 5b for the right leg: the knee flexion angle for the unloader brace fell out of the grey zone around 1-10%, 45-60%, and 95-100% of the gait cycle during heel strike as well as midstance, and there is a significant difference in the right leg’s knee flexion angle during that phase of gait for the unloader brace. The RoM of the right leg’s knee has a shift to the right for the unloader brace.

There were no significant differences in RoM of the knee for either walking or running. Although no significant differences were found, some trends were observed. For walking, the RoM for the right leg’s knee was reduced by all brace types analyzed by this study. The unloader brace caused the greatest reduction in RoM, followed by the prophylactic brace, and finally the neoprene sleeve. The left leg’s knee had a greater range of motion for both the prophylactic brace and the neoprene sleeve, while the unloader brace was relatively unaffected. For running, the neoprene sleeve caused a decrease in RoM for the right leg, while the prophylactic brace caused a slight increase. As for the left leg’s knee, the RoM was decreased by the neoprene sleeve, while the prophylactic brace showed an increasing trend (although a larger sample would be needed to confirm this). For both legs, the unloader brace had the smallest effect on RoM.

**Ankle Angle**

The ankle flexion angles for the left leg during the walking trials are shown in Figure 6a. Since none of the braced conditions for the ankle flexion angle during the walking trials are outside of the grey area, there is not a significant difference in the left leg’s ankle flexion angle during gait for the three braces analyzed by this study. A trend can be seen around 50-90% of the gait cycle, starting before the midswing phase and ending just before heel strike, in which the neoprene sleeve and the unloader brace have a shift to the right in the position of gait phases. The prophylactic brace only experiences this shift from 70-90% of the gait cycle around midswing.

The ankle flexion angles for the right leg during the walking trials are also shown above in Figure 6b. Since none of the braced conditions for the ankle flexion angle during the walking trials are outside of the grey area, there is not a significant difference in the right leg’s ankle flexion angle during gait for the three braces analyzed by this study. A trend can be seen around 70% of the gait cycle during the midswing phase in which the neoprene sleeve and the unloader brace deviate with decreases in the RoM, but the prophylactic brace does not.

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**Figure 5a (upper) & 5b (lower). Average knee flexion angles of the left (contralateral) & right (braced) leg during running. Sample sizes are as follows: Unbraced n=20, Prophylactic Brace n=15, Neoprene Sleeve Brace n=17, and Unloader Brace n=17. Grey area represents 95% Confidence Interval of the unbraced leg trials.**

The knee flexion angles for the left leg during the running trials are shown above in Figure 5a. Since the knee flexion angle for the unloader and the prophylactic brace fell out of the grey zone around 1-10% and 70-90% of the gait cycle during heel strike as well as midswing,
The ankle flexion angles for the left leg during the running trials are shown in Figure 7a. Since none of the braced conditions for the ankle flexion angle during the running trials are outside of the grey area, there is not a significant difference in the left leg’s ankle flexion angle during gait for the three braces analyzed by this study. A trend can be seen throughout the whole gait in which the neoprene sleeve, the unloader brace, and the prophylactic brace shift right in the position of the gait phases; it can also be seen that the neoprene sleeve experiences a decrease in the RoM.

The ankle flexion angles for the right leg during the running trials are also shown in Figure 7b. Since none of the braced conditions for the ankle flexion angle during the running trials are outside of the grey area, there is not a significant difference in the right leg’s ankle flexion angle during gait for the three braces analyzed by this study. A trend can be seen throughout the whole gait in which the neoprene sleeve, the unloader brace, and the prophylactic brace shift down in the RoM; it can be seen that the unloader brace experiences the least downward shift in the RoM. However, there were no significant differences in either of the legs’ ankle RoM during gait for the three braces analyzed by this study.

CONCLUSION
As shown by the results, this study found that the contralateral leg did experience a significant change in angle of flexion as well as RoM at the knee, but the hip and ankle failed to show a significant change in angle of flexion or RoM. The unloader brace had a significant difference in the left (contralateral) leg’s knee for the walking and running trials, the neoprene sleeve had a significant difference for just the walking trials, and the prophylactic brace had a significant difference for the running trials only. This suggests that the knee is likely to have a difference in range of motion if the applied brace is more restrictive while
running. The data also showed that the knee flexion angle for the right or braced leg was significantly different for the unloader brace during the walking and running trials, and the neoprene sleeve was significantly different for the walking trial. The prophylactic brace did not show a significant difference for the walking or running trial on the right leg. It was also concluded that the flexion angles of the hip and ankle of the right leg were not significantly affected by any of the braces analyzed. The results of the study suggest that the knee brace with the most efficacy is the prophylactic knee brace, which can provide benefit to the gait while altering the participant’s normal gait the least. The neoprene sleeve showed to be the next in order of efficacy; this type of brace, however, should not be used by people with knee injuries, but as a preventative measure to reduce the risk of knee injury. Last, while the unloader knee brace proved to be the knee brace with the least efficacy, it plays an important role in the rehabilitation of people who have undergone knee surgeries because of its ability to lower the RoM significantly.

REFERENCES