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Illusory Effects on Stepping Over Obstacles After Lower Extremity Muscle Fatigue

by

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Undergraduate honors thesis under the direction of

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Abstract

The application of illusions on raised surfaces of objects can increase toe clearance height when people step over these obstacles. It is unclear how muscle fatigue of the lower limb would influence this performance, yet it could be of interest for populations that fatigue easily. In this study, we wondered whether fatiguing young healthy adults would decrease toe clearance when stepping over obstacles or whether they would inherently overcompensate for force reductions that accompany fatigue. Seventeen participants (age = 20.3 +/- .77 years, height = 164.4 +/- 10.73 cm, and mass = 64.7 +/- 4.22 kg) walked at a comfortable pace along a straight path requiring steps over two obstacles with their dominant leg in fatigued and non-fatigued states. Shoe boxes were used as obstacles and included a plain or illusory (vertical lines) surface on the rise of the box. Participants produced full range of motion bilateral calf raises until they could not continue to induce lower limb muscle fatigue. We recorded passive markers placed on each participant's halluces, ankles, knees, thighs, and shoulders during performance using a Qualisys motion capture system (Qualisys Medical AB, SE). Maximal toe clearance height (maxToe) during each step represented the primary variable of interest. A repeated measures ANOVA was used to determine whether maxToe was influenced by fatigue state (non-fatigued-NF; fatigued-F), box type (plain-P; illusory-ILL), and box position (first, second). Results revealed main effects of fatigue state and box type on maxToe such that maxToe in NF and ILL exceeded F and P, respectively. A significant interaction between box type and position revealed illusory influences such that maxToe for ILL exceeded P for the first box and this difference dissipated for the second box. These results indicate that lower limb muscle fatigue in young adults can reduced the toe clearance when stepping over obstacles, and that use of illusory surfaces on obstacles can help compensate for the reduced toe clearance that accompanies reductions in force

production for people in a fatigue state. The fact that use of illusory vertical lines on the first obstacle helped increase toe clearance over the second plain obstacle also provides evidence that the greatest attentional demands remain primarily on the first obstacle and do not decay for at least two steps.

Introduction

The efficient execution of motor skills involved with toe clearance during obstacle avoidance is an important aspect of daily life that influences the probability of tripping (Byju et al., 2016) and its resulting conditions like physical injury or functional decline (Stel et al., 2003). Activities such as stepping over a curb, climbing stairs, and hiking require individuals to maintain a significant level of toe clearance to ensure their desired self-sustainability by limiting falls resulting from variability in gait patterns (Barrett et al., 2010) or variability in gait surface elevations (Mills et al., 2008). Greater toe clearance abilities associate with an increase in the degree of flexion of the knee and ankle joints with a subsequent decrease in hip extension (Lin et al., 2015). Assessing the body kinematics of toe clearance improves our understanding of the impact of environmental and individual constraints on the probability of tripping during obstacle avoidance.

To maintain equilibrium of the body and uniform acceleration of the center of mass during obstacle avoidance tasks (Lin et al., 2015) antagonistic muscular interactions across the hip, knee, and ankle joints distribute power throughout the rest of the body segments (Harper et al., 2017). Toe clearance requires an increase in the muscle activity generated by the gastrocnemius and soleus muscles of the supporting limb involved with forward and upward propulsion of the body (Lin et al., 2015) especially during the second half of the gait cycle during normal walking (Pandy et al., 2010). A similar mechanism can be observed during stair ambulation and obstacle avoidance tasks. Weakness or inefficiencies in the joint and/or muscles involved in obstacle avoidance can greatly inhibit successful execution of this motor skill, leading to decreased stability and loss of balance (Lee & Chou, 2007). Instability proves increasingly relevant for age-related physiological changes such as independent control and coordination of muscles which decline in complexity with age (Chiu et al., 2015). Synaptic signals required for proprioception and coordinated movement of the lower limb joints fail to communicate with the necessary receptors in the proper manner causing a lack of control in the movement (Sainburg et al., 1993). This often results in increased variability in gait patterns and diminished independence in older adults (Oh-Park et al., 2012), explaining the age-related difficulties in maintaining body equilibrium during obstacle avoidance tasks (Kovacs, 2005).

Another major source of inefficiency during toe clearance is weakness in the muscle groups attributed a multitude of factors including neuromuscular declines from muscular dystrophy, muscular atrophy from a sedentary lifestyle, peripheral neuropathy, pain reflex, arthrogenic muscle inhibition, diabetes, as well as aging (Anderson et al., 2011). Muscle weakness and deterioration (sarcopenia) can occur gradually in elderly adults, making it difficult to regulate motor skills without assistance to avoid accidents and injuries. The understanding of the biochemical and physiological mechanisms involved with the interactions between sarcopenia and toe clearance can provide important information on how to better adjust to the effects of sarcopenia on tripping (Lee & Chou, 2007). The decrease in balance resulting from muscle weakness magnifies the effect of the speed-accuracy trade-off when performing avoidance tasks thus placing individuals in risky situations as they gravitate toward one extreme or another (Hreljac, 1993). For instance, to accommodate for possible impairments in their mobility, elders can accelerate various phases of gait (Berg et al., 1997) thereby increasing their likelihood of losing balance and falling (Quach et al., 2011). Slowing down during single leg stance in the gait cycle can also contribute to loss of balance (Kovacs, 2005), which links to greater risk of falling (Quach et al., 2011). The influences of sarcopenia and associated muscle weakness on toe clearance are unknown yet could provide insight into the fall risk associated with obstacle avoidance. In this study, we chose to concentrate on the fatiguing effects associated with muscle weakness on toe clearance during stepping over obstacles.

How does one revert or negate the impact of age-related physiological changes on motor skill performances? Visual illusions, which encourage length overestimations, provide a potential option to improve performance outcomes. When assessed with changes in gaze direction, the application of the vertical-horizontal (V-H) illusion increased length estimations and subsequent movements in the upper limb (Yan & Hondzinski, 2020). The V-H illusion, shown in Fig. 1, involves a horizontal line segment length that is bisected by an equal vertical line segment length, causing the vertical line to be commonly perceived as longer and its relative length overestimated (Mamassian & de Montalembert, 2010). When applying evenly spaced vertical lines to the front surface of an obstacle, similar to the V-H illusion, for lower body application, people produced similar differences in motor skills associated with the expected perceptual influences, thus a greater toe clearance than with a plain surface (Foster et al., 2015a). In addition, when applying evenly spaced vertical lines to the rise surface of stairs, healthy older adults produced a significant increase in toe clearance during stair ascent that was attributed to the length overestimation derived from illusion's effect on visual perception (Foster et al., 2015b). However, the literature is limited in applying illusory influences specifically to individuals with constraints such as lower limb weakness during obstacle avoiding motor skills.

The main goal of this study was to assess the interaction between illusions and muscle weakness and their effect on toe clearance during obstacle avoidance tasks. We wondered whether fatiguing young healthy adults would decrease toe clearance when stepping over obstacles or whether they would inherently overcompensate for force (Kirsch & Rymer, 1987) and/or proprioceptive (Sainburg et al., 1993) reductions that accompany fatigue. We also introduced an illusionary element to assess the presence of the illusion on toe clearance in a fatigue state. We questioned whether the fatigue state would cause a decrease in maximum to clearance and the introduction of the illusionary elements would counteract the effects of the fatigue states.

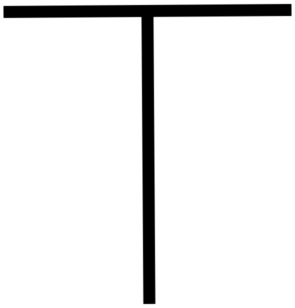

Figure. 1 Vertical-Horizontal Illusion

Methods

Participants

Seventeen college-aged students (15 females; mean age = 20.3 +/- 0.77 years) recruited from Louisiana State University participated in the study. Participants mean height and mass was 164.4 +/- 10.73 cm and 64.7 +/- 4.22 kg, respectively. Leg dominance was determined by asking participants which leg they would use to kick a ball as fast and as hard as possible. Fifteen participants answered right leg and two participants answered left leg. Participants were asked to wear short sleeve shirts, shorts, and prescribed corrective lenses, if applicable and required to limit physical activity for 24 hours before participating in the study. Those taking pharmaceuticals that interfered with movement control, or had any diagnosed neurological, neuromuscular, or musculoskeletal conditions were excluded from the study. A consent form was signed by each participant before the study began and each participant was informed that they could choose to withdraw from the study at any time. Study procedures were approved by the University’s Institutional Review Board.

Experimental Procedures

Participants were asked to walk barefoot at a comfortable pace along a straight path measuring 6.72 m and requiring steps over two obstacles with their dominant leg in fatigued (F) and non-fatigued (NF) states within a ten-second interval. Two shoe boxes (34.2 cm x 12 cm x 23.6 cm) were used as obstacles and included a plain (P) or illusory (ILL) surface on the rise of each box similar to elsewhere (Foster et al., 2015b). Seven vertical lines on the illusory box were placed 5.3 cm apart. Participants followed this path a total of sixteen times in the same direction for each trial and the boxes were switched every two trials so that P was first in half the trials and ILL was first in half the trials (Fig. 2). Eight of the trials occurred in the NF state and always were completed prior to the remaining eight trials which occurred in the F state.

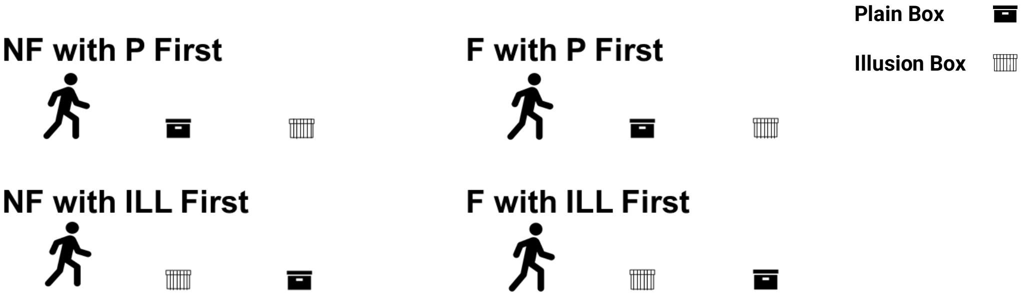

Figure 2. Participant Trial Conditions involving Fatigue State (Non-Fatigued-NF and Fatigued-F), Box Type (Plain-P and Illusory-ILL), and Box Position (First or Second).

The fatiguing procedure occurred immediately before the first two F trials and every two trials afterward. Participants were allowed to rest after two trials and before the next fatiguing procedure. Trials in which the non-dominant leg was used, or the dominant leg did not go directly over either obstacle were excluded and repeated.

Pre-trials were conducted with a third box to aid in the placement of the experimental obstacles to fit the stride pattern of each participant and ensure the dominant leg was used to step over them. Placement of the P and ILL boxes allowed participants to take two or more steps before reaching the first box and three or more steps after clearing the second box. Instructions were repeated before each trial for consistency. The initial order of the boxes was alternated between participants.

Fatiguing Protocol

Participants produced full range of motion (ROM) bilateral calf raises on a raised surface until they could not continue to induce lower limb muscle fatigue, mimicking that used previously (Yeomans et al., 2018). Full ROM was determined by identifying the angle between the highest point of plantar flexion and the lowest point of dorsiflexion. Adequate fatiguing was determined when the participant indicated they could no longer continue or when their excursion dropped under 75% of their full ROM for two consecutive calf raises. Participants were provided a support railing for safety purposes. The number of calf raises in each of four fatiguing rounds was recorded.

Data collection and analyses

We recorded passive markers during performance using a 4 camera Qualisys motion capture system (Qualisys Medical AB, SE) at 100 Hz. Reflective markers were placed on the distal aspect of the hallux of both feet, the lateral malleoli associated with the ankles, the lateral epicondyles of both knees, the lateral aspect of both thighs, and the greater tubercles of the humerus associated with the shoulders. Reflective markers were also placed on the sides of the top front corners of the ILL and P boxes and represented their positions in the 3D calibrated space. Marker trajectories were labeled using Qualisys system software, checked for accuracy, exported to text files, and subsequently uploaded to NI LabVIEW 2021 (32-bit) for further analysis using a customized program. Position data of each marker were lowpass filtered using a Butterworth 2nd order filter with 6 Hz cutoff frequency and differentiated with respect to time to obtain velocity profiles. Start and end of movement were determined when velocity was maintained below 5% of peak velocity for >100 ms before and after movement, respectively, similar to others (Hondzinski et al., 2016). Mean values for the primary variable of interest, maximal toe height, and secondary variables of interest, movement time, peak velocity, step length, ankle angle, and toe to box distance were collected for the first and second box of each trail (see definitions in Table 1). Averages were then calculated across the trials within each of four conditions (NF with P first, NF with ILL first, F with P first, and F with ILL first).

Table 1. Definition of Variables.

Definition of Variables	
Maximal Toe Height (maxToe)	Maximal height of the dominant leg's hallux toe marker in cm when stepping over the box of interest
Movement Time	Amount of time in seconds from when the dominant leg's hallux toe marker leaves the ground before the box of interest to when it lands back on the ground
Peak Velocity	Fastest tangential velocity/speed of the dominant leg's hallux toe marker over the box of interest in cm/s
Step Length	Distance in cm from non-dominant toe marker to the dominant toe marker immediately before stepping over the box of interest
Ankle Angle	Ankle angle at maxToe in degrees
Toe to Box Distance	Distance from the non-dominant toe marker in cm to the box of interest

Statistical Analysis

A repeated measure ANOVA on each variable of interest was used to analyze the results. Within subject factors included box position (First or Second), fatiguing state (F or NF), and box type (P or ILL). Tukey's HSD test were used when appropriate. Level of significance was determined at $p<0.05$. The effect size (ES), partial eta squared, was used to identify significant outcomes, and understand the strength of the relationships under three categories: small < 0.25, medium 0.25 – 0.40 and large > 0.40 (Cohen, 1969).

Results

Primary Variable: Toe Clearance

Maximal toe height (maxToe) was affected by the fatigue state ($F_{(1,16)} = 5.54$, $p = 0.03$, ES = 0.26) and the box type ($F_{(1,16)} = 13.14$, $p = 0.002$, ES = 0.45). For trials in NF, maxToe produced by participants was greater than in F (Fig. 3). Additionally, maxToe for the illusory box (ILL) was greater than for P (Fig. 4). We also found a significant box position x box type interaction on maxToe values ($F_{(1,16)} = 25.30$, $p = 0.0001$, ES = 0.61; Fig. 5). Trials where ILL was placed first in the sequence resulted in greater maxToe values than those where P was first in the sequence ($p = 0.001$). Instances where P was placed first, showed lower maxToe values than those where it was placed second ($p = 0.02$). However, placing ILL second showed lower maxToe values than when it was placed first ($p = 0.009$). Other comparisons did not reach the significant threshold ($p > 0.05$).

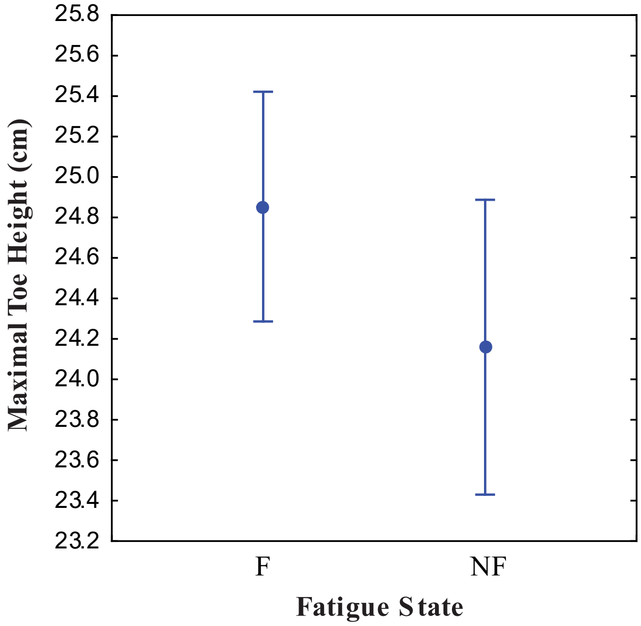

Figure 3. Mean Maximal Toe Height is presented for each Fatigue State (Non-Fatigued-NF and Fatigued-F). Error bars represent ±1 standard error.

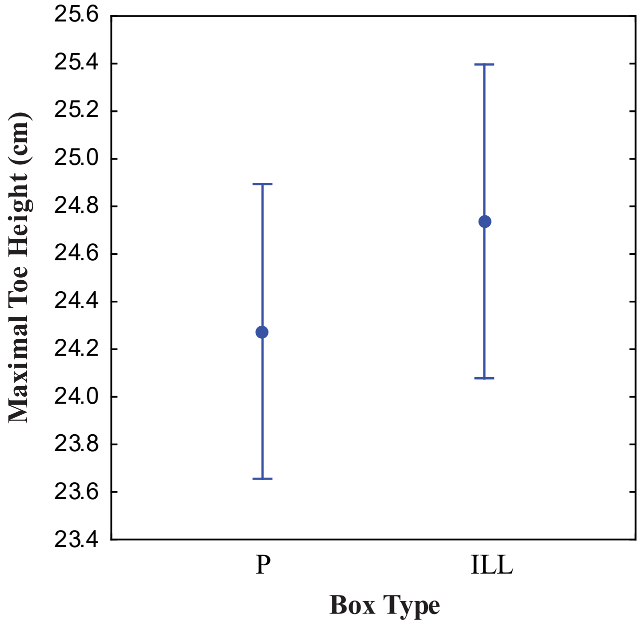

Figure 4. Mean Maximal Toe Height is presented for each Box Type (Plain-P and Illusory-ILL). Error bars represent ±1 standard error.

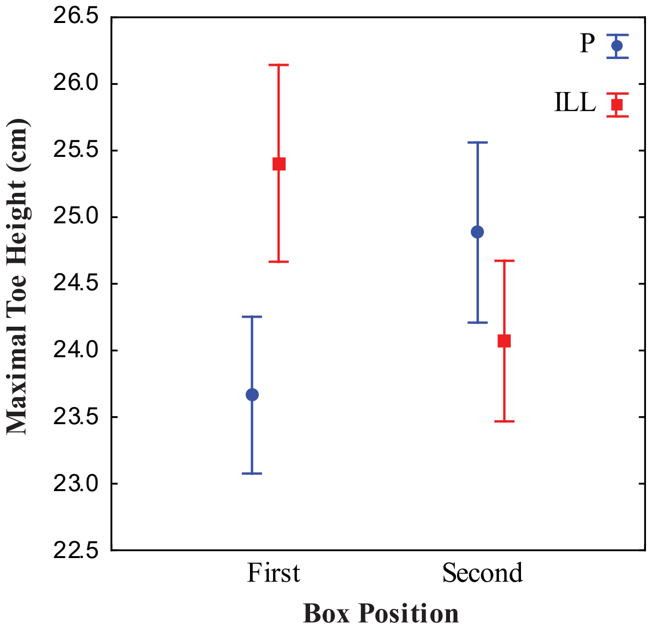

Figure 5. Mean Maximal Toe Height is presented for each Box Position (First and Second) and Box Type (Plain-P and Illusory-ILL). Error bars represent ±1 standard error.

Secondary Variables

Movement time was significantly affected by the box position ($F_{(1,16)} = 7.12$, $p = 0.02$, ES = 0.31) such that participants spent more time stepping over the first box in the sequence than stepping over the second box (Fig. 6). The interaction of fatigue state x box type had a significant effect on peak velocity ($F_{(1,16)} = 6.99$, $p = 0.02$, ES = 0.30) such that as participants stepped over ILL in F, they produced a greater peak velocity than stepping over ILL in NF (Fig. 7). Fatigue state, box position, or box type did not have a significant effect on step length, ankle angle, or toe to box distance.

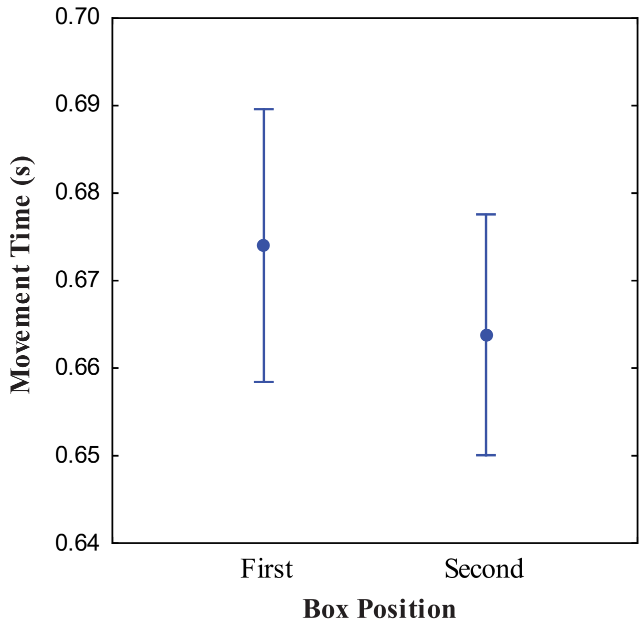

Figure 6. Mean Movement Time is presented for each Box Position (First and Second). Error bars represent ±1 standard error.

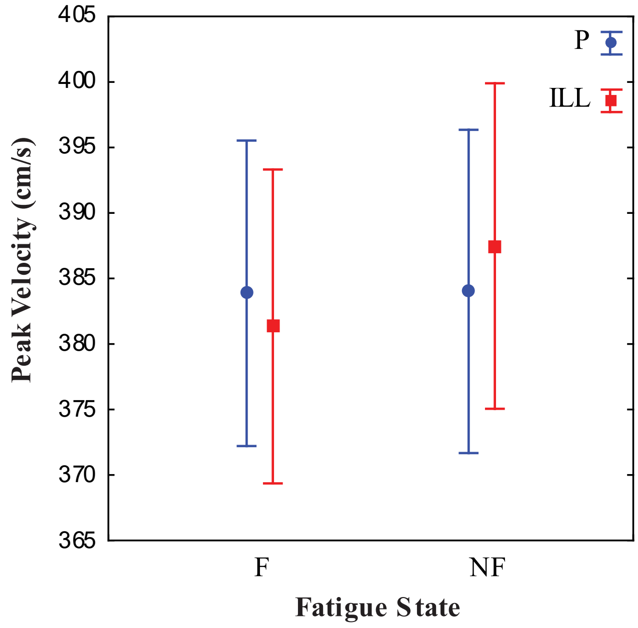

Figure 7. Mean Peak Velocity is presented for each Fatigue State (Non-Fatigued-NF and Fatigued-F) and Box Type (Plain-P and Illusory-ILL). Error bars represent ±1 standard error.

Discussion

The primary aim of this study was to investigate the effects of a vertical horizontal illusion-like configuration on toe clearance during obstacle avoidance and assess any accommodations made due to force reductions associated with lower limb muscular fatigue. We evaluated the effects of fatigue, illusion, and illusion position on the primary variable of maximal toe clearance height and secondary kinematic variables of interest and determined how results compared to outcomes provided in previous studies. Analysis of the primary and secondary variables offered insight into illusory and fatigue effects on performance control.

Spatial Aspects of Toe Clearance

The decrease in toe clearance in response to the fatiguing protocol supports previous studies that focus on the influence of physical fatigue on motor control performances in the lower limb during balance control tasks (Johnston et al., 1998). In this case people struggled to maintain balance during unilateral and bilateral static stance after a fatigue induced reduced force production to below 50% of non-fatigued strength. Similarly, overexertion, thus fatiguing, of the upper limb muscles during voluntary isometric contractions caused greater variability in force regulation in the bicep brachii muscle than when not fatigued (Cheng & Rice, 2010). The inability to regulate force would also explain how the fatiguing protocol in the present study induced an average decrease in toe clearance of 0.7 cm between trials in NF and those in F. Although the young adults used in the present study produced an average maximal toe height of 12.1 cm above box height in the fatigue state, this may not be the case for their older counterparts. The lack of a precautionary increase in toe clearance in response to internal factors as seen in populations like elderly adults, can lead to a greater risk of falls and subsequent injury (Hamel et al., 2005) and possible functional decline (Stel et al., 2003). The dangers of falling for older adults increased when toe clearance for stair ambulation dropped below 0.5 cm (Foster et al., 2015b). Thus, a decrease of 0.7 cm in toe clearance poses a significant amount concern for individuals who have difficulty completing obstacle avoidance and stair ascent efficiently.

The application of a vertical-horizontal illusion-like protocol revealed an increase in toe clearance to support length overestimations, as a result of illusionary influences, in the upper (Yan & Hondzinski, 2020) and lower (Foster et al., 2015a; Foster et al., 2015b) limbs. The results from this study showed an increase of almost 0.5 cm in maxToe as participants stepped over ILL as opposed to P on average and a maxToe difference between ILL and P of 1.7 cm when boxes were placed in the first position (compare mean First ILL and P, Fig. 5). For populations with diminished toe clearance capabilities, this response can help to increase the chance of successful execution of the motor skill and limit the probability of tripping (Byju et al., 2016). While the 0.5 cm increase in toe clearance with illusory stimuli does not completely compensate for the slightly greater decrease in toe clearance that accompanies fatigue (0.7 cm), it does offer some provisions that could limit the probability of tripping. The current results also indicated that toe clearance with illusory stimuli presented first during an approach to obstacle would compensate for the decrease in toe clearance that accompanies fatigue. Further studies are warranted to determine if similar outcomes exist for populations with neuromuscular declines.

The interaction between box position and box types presented another perspective to understand the mechanisms affecting toe clearance. Remember that in trials where P was placed first in the sequence, participants produced a lower maxToe than when P was second in the sequence following ILL. They did not perform the skill with a significantly higher maxToe for ILL when it was placed second in the sequence. On the other hand, in trials where ILL was placed first in the sequence, participants performed the skill with an overall higher maxToe for

ILL, as expected, and for the second box (P) in the sequence which did not contain the illusion (compare First ILL with Second P, Fig. 5). Length overestimation resulting from the illusion encouraged a higher maxToe (Foster et al., 2015a; Foster et al., 2015b) for ILL when placed first; however, it does not account for the increased toe clearance for P which was second in the sequence and lacked the illusion. These differences in maxToe, as a result of the positioning of both boxes, raise questions to the effect of illusions on the planning of motor skills as opposed to its online control (Glover, 2002).

Movement planning involves different processes that work together to prepare and organize motor commands to accomplish a desired goal (Orban de Xivry et al., 2017), while online control can be defined as the production of coordinated movements for purposeful interactions with the environment or other parts of the body (Latash et al., 2010). In this study, as participants approached the first box in trials where P was placed first, the generalized motor program constructed by the nervous system included motor commands for sufficient toe clearance to get over P. As they approached the second box in the sequence, ILL, inputs from the illusion which normally result in participants producing higher toe clearance in response to the length overestimations (Foster et al, 2015a) did not occur; no significant change in maxToe was observed (compare First P with Second ILL, Fig. 5). Apparently, people in this study did not make modifications of the generalized motor program to fit the new parameters in response to new illusory stimuli to allow for the full effect of the illusion. In fact, the maxToe values of ILL in the second position were lower than when in the first position and not significantly different than that of P in either position (Fig. 5). Clearly, application of the illusory element in the second position was minimal at best. A similar interaction can be seen in trials where ILL was placed first. The present data indicated that the generalized motor program constructed as participants approached the first box (ILL) included movement commands for greater toe clearance associated with the illusion. As they approached the second box in the sequence, P, removal of inputs from the illusion would normally associate with lower toe clearance yet did not. The maxToe values of P in the second position were higher than when it was in the first position and not significantly different than that of ILL in either position (see comparisons in Fig. 5). Such alterations by box position could occur if attention was limited to the first box in a trial which had a lasting influence that limits the effectiveness of the second box in that trial. Put simply, attention on the first box influences performance outcomes for clearing both boxes. Moreover, the influence of the illusion and its initial alteration of space-related outcome measures does not last very long during normal walking due a shift to proprioceptive control which diminishes the effect of the visual illusion (Prokop et al., 1997). It is evident that the planning effect did not decay in the time it took for subjects to clear the second box. Now we can begin to investigate the exact position and timing for the introduction of an illusion to ensure its consistent and efficient application to obstacle avoidance tasks.

Temporal Aspects of Toe Clearance

When engaging in repetitive tasks individuals tend to move faster with each repetition as indicated by shorter movement times (Swegan et al., 1958). In this study we saw a shorter movement time as participants stepped over the second box as opposed to the first box. Taking less time to step occurred regardless of the box type or fatigue state to suggest a possible influence of step repetition even for as little as two steps for the stepping task in the present study. This can be attributed to the increase in neural plasticity that occurs due to repetitive tasks (Wolf et al, 2002) allowing the nervous system to increase its proficiency in producing the necessary motor outcomes (Mateos-Aparicio & Rodríguez-Moreno, 2019). As participants approached the first box in each trial the necessary motor program was compiled, and the necessary muscles were also primed for the repetitive stepping movement.

The interaction of the box type and fatigue state resulted in a significant increase in the peak velocity as participants stepped over obstacles. Peak velocity for ILL was greater in F than NF and might be explained by faster dorsiflexion of the foot when fatigued due to the lower toe clearance. This possibility seems unlikely without the same performance for the plain box. A more feasible explanation could be the desire for greater stability while fatigued. The higher peak velocity in fatigued participants could occur if they sped up the movement of foot during the swing phase to complete the step quickly. A faster heel touch down would help people rapidly return to a double support phase, known for greater stability (Kovacs, 2005). Since movement time was based on toe velocity and not that of the heel, people could shift their weight to the dominant foot/heel more quickly when fatigued but movement would continue with plantarflexion to the surface without changing movement time across these trials. Further evaluation of the movement kinematics is warranted to explore this possibility.

Future Directions

The interaction of box position and box type on toe clearance poses questions that require further insight into the development of motor programs. Further investigation can help to better assess the influence that attention has on the effectiveness of illusions on toe clearance. We can better understand the timing to introduce the illusion and of illusory decay for consistent and efficient execution of obstacle avoidance tasks. Results from the current and further studies can then be applied to older adults. Additionally, visual illusions are also being used in the treatment of patients with vertigo and postural instability (van Kerckhoven et al., 2014) and warrant further study in their application for people who also struggle with postural instability. While the initial factors stem from different sources such as age-related and pain related weakness, the performance outcomes of both populations are limited and could be treated in a similar fashion.

Conclusion

We determined that the influences of length overestimations caused by illusions on toe clearance during obstacle avoidance tasks directly oppose the decline in toe clearance brought about by muscular fatigue of lower limb in young adults. Although the decay of adaptation effects to visual stimuli are inevitable (Kloth & Schweinberger, 2008), those as seen on toe clearance can last for at least two steps beyond the initial presentation.

References

Andersson, D. C., Betzenhauser, M. J., Reiken, S., Meli, A. C., Umanskaya, A., Xie, W., Shiomi, T., Zalk, R., Lacampagne, A., & Marks, A. R. (2011). Ryanodine receptor oxidation causes intracellular calcium leak and muscle weakness in aging. *Cell metabolism, 14(2), 196–207*. https://doi.org/10.1016/j.cmet.2011.05.014

Barrett, R. S., Mills, P. M., & Begg, R. K. (2010). A systematic review of the effect of ageing and falls history on minimum foot clearance characteristics during level walking. *Gait & Posture*, *32*(4), 429–435. https://doi.org/10.1016/j.gaitpost.2010.07.010

Berg, W. P., Alessio, H. M., Mills, E. M., & Tong, C. (1997). Circumstances and consequences of falls in independent community-dwelling older adults. *Age and Ageing, 26(4), 261–268.* https://doi.org/10.1093/ageing/26.4.261

Bhatt, T., Wening, J. D., & Pai, Y.-C. (2005). Influence of gait speed on stability: Recovery from anterior slips and compensatory stepping. *Gait & Posture, 21(2), 146–156.* https://doi.org/10.1016/j.gaitpost.2004.01.008

Byju, A. G., Nussbaum, M. A., & Madigan, M. L. (2016). Alternative measures of toe trajectory more accurately predict the probability of tripping than minimum toe clearance. *Journal of Biomechanics, 49*(16), 4016–4021. https://doi.org/10.1016/j.jbiomech.2016.10.045

Cheng, A. J., & Rice, C. L. (2010). Fatigue-induced reductions of torque and shortening velocity are muscle dependent. *Medicine & Science in Sports & Exercise, 42(9), 1651–1659.* https://doi.org/10.1249/mss.0b013e3181d6c5b5

Chiu, S.-L., Chang, C.-C., Dennerlein, J. T., & Xu, X. (2015). Age-related differences in inter-joint coordination during stair walking transitions. *Gait & Posture, 42(2), 152–157.* https://doi.org/10.1016/j.gaitpost.2015.05.003

Cohen, J. (1969). Statistical power analysis for the behavioural sciences. *New York: Academic Press.*

Foster, R. J., Buckley, J. G., Whitaker, D., & Elliott, D. B. (2015a). The addition of stripes (a version of the 'horizontal-vertical illusion') increases foot clearance when crossing low-height obstacles. *Ergonomics, 1–6*. https://doi.org/10.1080/00140139.2015.1105304

Foster, R. J., Whitaker, D., Scally, A. J., Buckley, J. G., & Elliott, D. B. (2015b). What you see is what you step: The horizontal–vertical illusion increases toe clearance in older adults during stair ascent. *Investigative Opthalmology & Visual Science*, *56*(5), 2950. https://doi.org/10.1167/iovs.14-16018

Glover, S. (2002). Visual illusions affect planning but not control. *Trends in Cognitive Sciences, 6(7), 288–292*. https://doi.org/10.1016/s1364-6613(02)01920-4

Hamel, K. A., Okita, N., Higginson, J. S., & Cavanagh, P. R. (2005). Foot clearance during stair descent: Effects of age and illumination. *Gait & Posture, 21(2), 135–140*. https://doi.org/10.1016/j.gaitpost.2004.01.006

Harper, N. G., Wilken, J. M., & Neptune, R. R. (October 19, 2017). "Muscle Function and Coordination of Stair Ascent." ASME. *J Biomech Eng. January 2018; 140(1): 011001*. https://doi.org/10.1115/1.4037791

Hondzinski, J. M., Soebbing, C. M., French, A. E., & Winges, S. A. (2016). Different damping responses explain vertical endpoint error differences between visual conditions. *Experimental Brain Research, 234(6), 1575–1587*. doi:10. 1007/s00221-015-4546-8

Hreljac, A. (1993). The relationship between smoothness and performance during the practice of a lower limb obstacle avoidance task. *Biological Cybernetics*, *68*(4), 375–379. https://doi.org/10.1007/bf00201862

Johnston, R. B., Howard, M. E., Cawley, P. W., & Loose, G. M. (1998). Effect of lower extremity muscular fatigue on motor control performance. *Medicine & Science in Sports & Exercise, 30(12), 1703–1707*. https://doi.org/10.1097/00005768-199812000-00008

Kirsch, R. F. & Rymer, W. Z. (1987). *Neural compensation for muscular fatigue: evidence for significant force regulation in man. Journal of Neurophysiology, 57(6), 1893-1910.* https://doi.org/10.1152/jn.1987.57.6.1893

Kloth, N., & Schweinberger, S. R. (2008). The temporal decay of eye gaze adaptation effects. *Journal of Vision* 2008;8(11):4. doi: https://doi.org/10.1167/8.11.4.

Kovacs, C. R. (2005). Age-related changes in gait and obstacle avoidance capabilities in older adults: A Review. *Journal of Applied Gerontology, 24(1), 21–34*. https://doi.org/10.1177/0733464804271279

Latash, M., Levin, M., Scholz, J., & Schöner, G. (2010). *Motor control theories and their applications. Medicina, 46(6), 382*. https://doi.org/10.3390/medicina46060054

Lin, Y., Fok, L. A., Schache, A. G., & Pandy, M. G. (2015). Muscle coordination of support, progression and balance during stair ambulation. *Journal of Biomechanics, 48(2), 340-347*. https://doi.org/10.1016/j.jbiomech.2014.11.019

Lee, H.-J., & Chou, L.-S. (2007). Balance control during stair negotiation in older adults. *Journal of Biomechanics*, *40*(11), 2530–2536. https://doi.org/10.1016/j.jbiomech.2006.11.001

Mateos-Aparicio, P., & Rodríguez-Moreno, A. (2019). The impact of studying brain plasticity. *Frontiers in Cellular Neuroscience*, *13*. https://doi.org/10.3389/fncel.2019.00066

Mills, P. M., Barrett, R. S., & Morrison, S. (2008). Toe clearance variability during walking in young and elderly men. *Gait & Posture*, *28*(1), 101–107. https://doi.org/10.1016/j.gaitpost.2007.10.006

Oh-Park, M., Perera, S., & Verghese, J. (2012). Clinically meaningful change in stair negotiation performance in older adults. *Gait & Posture, 36(3), 532–536.* https://doi.org/10.1016/j.gaitpost.2012.05.015

Orban de Xivry, J.-J., Legrain, V., & Lefèvre, P. (2017). Overlap of movement planning and movement execution reduces reaction time. *Journal of Neurophysiology, 117(1), 117–122.* https://doi.org/10.1152/jn.00728.2016

Pandy, M. G., Lin, Y.-C., & Kim, H. J. (2010). Muscle coordination of mediolateral balance in normal walking. *Journal of Biomechanics, 43(11), 2055–2064*. https://doi.org/10.1016/j.jbiomech.2010.04.010

Prokop, T., Schubert, M., & Berger, W. (1997). Visual influence on human locomotion modulation to changes in optic flow. *Experimental Brain Research, 114(1), 63–70*. https://doi.org/10.1007/pl00005624

Quach, L., Galica, A. M., Jones, R. N., Procter-Gray, E., Manor, B., Hannan, M. T., & Lipsitz, L. A. (2011). The nonlinear relationship between Gait Speed and falls: The maintenance of balance, independent living, intellect, and zest in the elderly of Boston study. *Journal of the American Geriatrics Society, 59(6), 1069–1073*. https://doi.org/10.1111/j.1532-5415.2011.03408.x

Sainburg, R. L., Poizner, H., & Ghez, C. (1993). Loss of proprioception produces deficits in interjoint coordination. *Journal of Neurophysiology, 70(5), 2136–2147*. https://doi.org/10.1152/jn.1993.70.5.2136

Stel, V. S., Smit, J. H., Pluijm, S. M., & Lips, P. (2003). Consequences of falling in older men and women and risk factors for Health Service use and functional decline. *Age and Ageing, 33(1), 58–65*. https://doi.org/10.1093/ageing/afh028

Swegan, D. B., Yankosky, G. T., & Williams, J. A. (1958). Effect of repetition upon speed of preferred-arm extension. Research Quarterly. *American Association for Health, Physical Education and Recreation, 29(1), 74–82*. https://doi.org/10.1080/10671188.1958.10612965

van Kerckhoven, G., Mert, A., & De Ru, J. A. (2014). Treatment of vertigo and postural instability using visual illusions. *The Journal of Laryngology & Otology, 128(11), 1005–1007*. https://doi.org/10.1017/s0022215114002254

Wolf, S. L., Blanton, S., Baer, H., Breshears, J., & Butler, A. J. (2002). Repetitive task practice: a critical review of constraint-induced movement therapy in stroke. *The neurologist*, *8*(6), 325–338. https://doi.org/10.1097/01.nrl.0000031014.85777.76

Yan, S., & Hondzinski, J. M. (2020). Gaze direction changes the vertical-horizontal illusory effects on manual length estimations. *Journal of Motor Behavior, 53(1), 92–104*. https://doi.org/10.1080/00222895.2020.1732286

Yeomans, M. A., Nelson, A. G., MacLellan, M. J., & Hondzinski, J. M. (2018). Visually-guided saccades attenuate postural sway under non-fatigued, fatigued, and stretched states. *Experimental Brain Research, 236(12), 3351–3361*. https://doi.org/10.1007/s00221-018-5384-2