The use of auditory feedback and edible reinforcement to decrease toe walking among children with autism

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We replicated and extended previous research on the use of auditory feedback to decrease toe walking exhibited by 3 children with autism. After pretreatment screening analyses suggested that toe walking occurred independent of social consequences, we attached squeakers to the heels of each participants' shoes. The squeakers provided auditory feedback when participants walked appropriately (i.e., with a heel-to-toe gait). For all participants, the auditory feedback itself produced increases in appropriate walking. For 1 participant, this feedback was sufficient to reduce toe walking to clinically acceptable levels; however, for 2 other participants, delivery of edible items paired with the auditory feedback was necessary. Intervention effects maintained when the schedule for edible delivery was thinned for all participants. In addition, for 2 participants, effects maintained when the intervention was implemented in a different setting and with a different person with no edibles or a thin schedule of edibles.

Key words: auditory feedback, autism, toe walking

Toe walking, or walking with a bilateral toe-to-toe gait, is estimated to occur in as many as 20% of children with autism and related disabilities (Ming, Brimacombe, & Wagner, 2007). Although occasional toe walking presents little cause for concern, frequent toe walking can lead to a number of health problems, including a shortened Achilles tendon, extreme tightening of the calf and foot muscles, and poor posture. Thus, orthopedic specialists recommend addressing toe walking soon after it is noticed (Sobel, Caselli, & Velez, 1997).

Medical interventions for toe walking consist of surgery and serial casting. Surgery involves lengthening the heel cord which often tightens as a result of prolonged toe walking (Hall, Salter, & Bhalla, 1967). Serial casting involves placement of a patient’s lower legs and feet in a series of plaster or fiberglass casts to stretch the muscles surrounding the ankle (Pistilli, Rice, Pergami, & Mandich, 2014). Although effective, both interventions are invasive and may result in a long period of time during which the patient has limited mobility.

Behavioral interventions, which are less intrusive, are often explored before medical interventions are pursued. Several behavioral interventions have been examined, including differential reinforcement (Hobbs, Altman, & Halldin, 1980), punishment (Barrett & Linn, 1981), and the use of stimuli which signal reinforcement availability (Hodges, Wilder, & Ertel, 2018). Recently, behavioral interventions for toe walking have focused on providing auditory feedback contingent upon appropriate walking (Hodges, Betz, Wilder & Antia, 2019; Persicke, Jackson & Adams, 2014). Although auditory feedback may have functioned as reinforcement in some cases in...
Figure 1. Percentage of steps with toe walking across baseline (BL), Gaitspot™ Squeakers only (SQK), fixed ratio (FR4), FR4 + Blocking (block), FR4 + Blocking + Hand on Shoulder (HOS), FR6, FR8, FR10, and variable ratio (VR) 10 conditions. Open circles represent generalization probes with another experimenter (Exp.) or mom; open squares represent generalization probes in another location.
these studies, in other cases it had to be paired with primary reinforcement before it functioned as a reinforcer.

Persicke et al. (2014) adapted a procedure described by TAGteach™ (Teaching with Acoustical Guidance; TAGteach International, 2018) to address toe walking exhibited by a young child with autism. They first used stimulus–stimulus pairing (i.e., sound of click paired with delivery of a preferred edible) to establish the sound as a conditioned reinforcer. Next, they delivered a click contingent upon each appropriate step to increase appropriate walking. The experimenters also applied slight downward pressure to the participant’s shoulders contingent upon toe walking. This procedure was first evaluated by itself then when combined with the clicker. Although the pressure procedure by itself was ineffective, the pressure procedure plus the clicker increased appropriate walking and decreased toe walking to low levels. Finally, the experimenters successfully thinned the delivery of the clicking sound to a fixed ratio (FR) 4 schedule and maintained their results.

Hodges et al. (2019) replicated and extended Persicke et al. (2014) with a boy with autism. First, they used a stimulus–stimulus pairing procedure in which the clicking sound was paired with a high-preference toy during approximately thirty 15-trial sessions. Next, the authors evaluated the conditioned reinforcer in the absence of additional procedures. The conditioned reinforcer, by itself, was effective for increasing appropriate walking. Finally, Hodges et al. assessed intervention effects in a different setting and thinned the schedule of reinforcement delivery (i.e., the clicker was provided on an FR 1 schedule, but the delivery of the preferred toy was thinned).

Although the use of a clicker to provide auditory feedback to increase appropriate walking and decrease toe walking has been shown to be effective, it is labor intensive and potentially prone to error. That is, a therapist must closely observe the participant walking and provide a click contingent upon each appropriate step. Other methods of providing auditory feedback are needed to circumvent these problems associated with manually operated clickers.

Another method of providing auditory feedback involves the use of cloth “squeakers” (GaitSpot Squeakers™) that wrap around the back of the heel and provide an audible sound (i.e., high-pitched squeak) when the middle portion of the heel contacts the ground with force typically applied when walking. Marcus, Sinnott, Bradley, and Grey (2010) evaluated these squeakers to reduce toe walking exhibited by three children with autism in brief sessions. They first paired the sound of the squeakers (i.e., the researcher squeezed a squeaker) with the delivery of preferred edible items or tokens that could be exchanged for preferred activities. Next, they placed the squeakers on each participant’s feet and delivered an edible item or token contingent on three consecutive squeaks. They also employed some components of simplified habit reversal (SHR; Miltenberger, Fuqua, & Woods, 1998) as part of their intervention, although they did not specify the exact SHR components. Once toe walking decreased to low levels, the authors thinned the schedule of delivery of edible items to a variable ratio (VR) 10 schedule contingent upon squeaks.

Although this intervention appears promising, Marcus et al. (2010) may have included some unnecessary intervention components (e.g., SHR). In addition, they did not examine if the squeaker-produced auditory feedback itself (i.e., without pairing with edible items or tokens) could increase appropriate walking. Thus, the purpose of the current study was to replicate and extend Marcus et al. by evaluating the Gaitspot™ squeakers in the absence of other intervention components. In addition, we included a pretreatment screening analysis (Querim et al., 2013) to confirm that toe walking occurred independent of social consequences. We also evaluated whether the squeaker-produced auditory feedback itself (i.e., without...
pairing with preferred edible items or tokens) increased appropriate walking. We then paired the squeakers with edible items if necessary. Finally, for two participants, we thinned the schedule of reinforcement and assessed the squeakers with a different experimenter or a caregiver and in novel settings.

METHOD

Participants, Setting, and Materials

Three male children, each with a multiyear history of frequent toe walking, participated in the study. Joey (age 6), Carl (age 5), and Zion (age 4) each with a diagnosis of autism spectrum disorder. Joey and Zion spoke in multiple word sentences, and Carl communicated using one- to two-word phrases. None of the participants had previous exposure to any intervention for toe walking. Carl and Joey’s sessions took place in a hallway at a children’s hospital, at which they also received early intensive behavioral intervention services. Zion’s sessions took place in a hallway at his preschool. Sessions for the pretreatment screening analysis were conducted in a large room with a one-way observation window.

The materials used in this study included Gaitspot™ squeakers (one for each foot, for each participant) and edible items. The squeakers were circular, plastic pods with a small hole in them and were 3.5 cm in diameter. The squeakers produced a 1-s, high-pitched squeak when pressure was applied. The squeakers come with an adjustable strap and are placed on the underside of the heel of a participant’s shoe. Although it may be technically possible for a Gaitspot™ squeaker to produce a sound if a participant steps with the toe and then applies pressure on the heel, none of the participants in the current study exhibited this form of step (i.e., they simply stepped heel first).

Data Collection

Toe walking was defined as a step in which the heel did not touch the ground. Appropriate walking was defined as any step in which both the heel and the front portion of the foot touched the ground. During the pretreatment screening analysis, observers collected data on the percentage of intervals with toe walking. Each 5-min session was divided into 10-s intervals. Observers recorded the number of intervals in which toe walking occurred at least once (i.e., partial interval recording). This number was then divided by the total number of intervals in the session (i.e., 30) and converted to a percentage.

The dependent variable during the treatment evaluation was the percentage of steps in which the participants engaged in toe walking during each session. To obtain this number, we divided the total number of steps with toe walking by the total number of steps in the session. We then multiplied this number by 100 and converted it to a percentage. Observers video recorded each participants’ steps by attaching a camera to a selfie-stick and walking directly behind the participant, as he walked down a hallway. Observers then watched these videos and collected data on the number of steps with toe walking.

Interobserver Agreement and Treatment Integrity

During the pretreatment screening analysis, a second observer independently collected data during all sessions. To calculate interobserver agreement (IOA), we divided the number of intervals with agreement between the observers by the total number of intervals, then multiplied by 100 and converted this number to a percentage. IOA was 100% across participants. During the treatment evaluation, a second observer independently collected data on 66% of Joey’s sessions, 68% of Carl’s sessions, and 100% of Zion’s sessions. Data were compared on a session-by-session basis. To calculate IOA, we divided the smaller count by the larger count for each session, multiplied this number by 100, and converted it to a percentage. IOA for toe walking was 93% (range, 88% to 100%) for Joey, 93% (range, 90% to 100%) for Carl, and 98% (range, 96% to 100%) for Zion.
To assess treatment integrity during treatment evaluation sessions in which edibles were delivered (for Carl and Zion), observers scored the number of times the experimenter delivered the participant’s preferred edible item according to the programmed schedule of reinforcement. Treatment integrity was calculated by dividing the number of edible deliveries by the number of times an edible should have been delivered for each session, multiplying this number by 100, and converting it to a percentage. Treatment integrity data were collected on 68% of Carl’s sessions and 100% of Zion’s sessions and accuracy was 100% for each participant.

Procedure

Pretreatment screening analysis. We used a pretreatment screening analysis (Querim et al., 2013) to verify that all participants’ toe walking occurred independent of social consequences. This analysis consisted of observing participants walking alone in a room for 5 min while experimenters collected data through a one-way observation window. No items were present in the room and participants were simply told to walk around. Three analysis sessions were conducted for each participant.

Joey engaged in toe walking during a mean of 89% (range, 83% - 93%) of steps, Carl engaged in toe walking during a mean of 98% (range, 96% to 100%) of steps, and Zion engaged in toe walking during a mean of 98% (range, 96% to 100%) of steps. These data suggest that all participants’ toe walking persisted in the absence of social consequences.

Treatment evaluation. We used reversal designs to evaluate the effects of the Gaitspot™ squeakers and additional interventions on toe walking. The goal was to decrease toe walking to 10% of steps or fewer. This goal was established in consultation with a pediatric orthopedic specialist.

Baseline. During baseline, all participants were observed walking 100 steps in a hallway. No programmed consequences were delivered for toe walking or appropriate steps. Each session began when the experimenter said, “Let’s walk.” Data were collected on the next 100 or 1,000 steps taken (during extended baseline sessions). During the session, the experimenter walked next to the participant, but did not otherwise interact with him. To assess intervention effects during extended sessions in various settings, the experimenter conducted baseline probes of 1,000 steps for two participants (Joey and Zion) in a different setting (a grocery store for Joey, and outside of the school for Zion). Carl’s family relocated, so no probe data were collected, as we knew he would be unavailable for extended sessions. In addition, to evaluate intervention effects in the presence of someone other than the experimenter, Joey participated in a 100-step baseline probe with his mother. Zion’s primary caregiver was not available to participate in a probe, so a different experimenter conducted the additional 100-step probe.

Squeakers only. Prior to squeakers-only sessions, the experimenter attached the Gaitspot™ squeakers to the participant’s shoes. Sessions were similar to baseline, in which participants walked 100 steps in the hallway. However, in these sessions when the participant engaged in an appropriate heel-to-toe step, the squeakers produced a squeak.

Pairing plus edible reinforcement. After the squeakers-only phase, Carl and Zion were exposed to pairing sessions, during which the sound of the squeak was paired with edible items. We included this phase because although the squeakers-only phase was somewhat effective to reduce toe walking for these two participants, toe walking still occurred above clinically acceptable levels. Thus, the pairing plus edible reinforcement phase allowed an evaluation of whether additional decreases in toe walking were possible. Prior to pairing, a multiple stimulus without replacement (MSWO; DeLeon & Iwata, 1996) preference assessment was conducted with edibles to determine each participant’s most preferred snack item. The participant was seated at a table across from
the experimenter. The experimenter placed the squeaker in her hand in front of the participant, delivered the sound of the squeak, and then immediately presented one piece of the participant’s most highly preferred edible. The squeak and edible were paired every 30 s for 20 three-trial pairing sessions. The participant did not have access to any preferred items or activities other than the edible item that was presented after each squeak. Following pairing, toe-walking sessions resumed. These sessions were identical to the squeakers-only sessions described above, except this time, each participant’s most highly preferred edible was delivered on an FR 4 schedule (i.e., contingent on four heel-to-toe steps as counted by the experimenter).

Additional intervention components. During reinforcer consumption, Zion would attempt to take one or two toe-walking steps. To further reduce toe walking and to prevent it during consumption, the experimenter stepped in front of or blocked Zion, preventing him from walking. The FR 4 schedule of reinforcement remained in effect during this condition and all other aspects of this condition were identical to the squeakers-only condition.

To reduce Zion’s toe walking even further, we added a procedure that involved placing a hand on Zion’s shoulder for 3 s contingent on each instance of toe walking. The purpose of this added procedure was to prevent Zion from taking any additional steps so that the delivery of preferred edible items was postponed (i.e., it served as a “time out” from the opportunity to earn preferred edible items). After the 3 s, the experimenter removed his hand from Zion’s shoulder and allowed Zion to continue walking. The blocking and FR 4 schedule of reinforcement remained in effect during this condition.

After a minimum of three consecutive sessions of toe walking at 10% of steps or fewer, the experimenter thinned the edible reinforcement schedule from an FR 4, to FR 6, to FR 8, to FR10, and then (for Zion) to VR10. If a participant’s toe walking increased to more than 10% of steps in a session, the schedule returned to the previous value.

Probes. Intervention probes, which were identical to baseline probes except that participants wore the squeakers, were also conducted at the conclusion of the study for Joey and Zion. The purpose of these probes was to assess intervention effects in a different location or with a different experimenter. During the intervention probes, no edible items were delivered to Joey, and Zion received an edible item on a VR 10 schedule. Due to an unrelated medical concern, we were unable to conduct probes with Carl.

RESULTS

The upper (Joey), middle (Carl), and lower (Zion) panels of Figure 1 depict the results of the treatment evaluation. Joey engaged in high levels of toe walking during all baseline conditions and during the 100-step probe with his mother (i.e., 81% of steps), and his 1,000-step probe in the store (i.e., 75% of steps). During both squeakers-only conditions, Joey engaged in lower levels of toe walking (M = less than 10%). Data from his postintervention 100 step probe with his mother revealed he engaged in toe walking during 15% of steps. During his 1,000-step probe in the store, he engaged in toe walking for 67 out of the 1,000 steps (6.7%).

During all baseline conditions, Carl engaged in high levels of toe walking. During both squeakers-only conditions, Carl’s mean toe walking decreased to moderately low levels, but did not meet the 10% criterion. After the pairing sessions, Carl’s mean steps with toe walking decreased to 5% during the first FR 4 condition (range, 3% to 9%) and 6% during the second FR 4 condition (range, 4% to 11%). During the FR 6 condition, Carl’s mean toe walking was 3% (range, 2% to 7%) followed by 2% (range, 0% to 5%) during the FR 8 schedule. Upon thinning to the FR 10 schedule, Carl’s mean percentage of toe walking increased to 9% (range, 1% to 25%). Although low, Carl’s toe walking still did not meet
the criterion of three consecutive sessions at 10% or less in order to thin the schedule further. The return to the previous schedule of reinforcement (i.e., FR 8) decreased toe walking to a mean of 7% of steps (range, 5% to 9%). Subsequently, the FR 10 schedule decreased toe walking to a mean of 5% (range, 2% to 10%). Immediately following this condition, Carl had an unrelated medical issue; thus, we were unable to conduct the final VR10 phase or the 100 and 1,000 step final probes with him.

Zion engaged in high levels of toe walking during all baseline conditions. During the 1,000-step probe outside he engaged in toe walking for 74% of steps. Zion's caregiver was not available for a 100-step probe, but we did conduct a 100-step probe with a different experimenter; Zion engaged in toe walking during 91% of steps. During the squeakers-only conditions, Zion engaged in lower levels of toe walking, but he did not meet the 10% criterion.

With the implementation of pairing + edible reinforcement, Zion's mean toe walking was 12% (range, 5% to 19%) during the first FR 4 reinforcement schedule. During the next FR 4 condition, his mean toe walking was 23% (range, 7% to 41%). The data from these conditions did not meet the criteria to thin the schedule to FR 6; the blocking condition (FR 4 + Block) was then introduced. During the FR 4 + block condition, Zion's mean toe walking decreased to 12% of total steps (range, 1% to 22%). Even though toe walking decreased, the data from this phase still did not meet the criteria to thin the schedule further. The addition of a hand on shoulder (HOS) procedure to the FR 4 + blocking condition reduced toe walking to a mean of 14% (range, 9% to 22%). During the second FR4 + block + HOS condition, mean toe walking was 13% (range, 3% to 35%). Although mean toe walking was not below 10% during this condition, the last three data points were below 10%, so we implemented the FR 6 schedule. During the FR 6 schedule, mean toe walking was 9% (range, 4% to 12%). During the FR 8, FR 10, and VR10 schedules, mean toe walking was below 6% (range, 1% to 11%). During Zion's 100-step probe with another experimenter, he engaged in toe walking for 1 out of the 100 steps (1%) and during his 1,000-step probe outside, he engaged in toe walking for 24 steps (2.4%).

DISCUSSION

After a pretreatment screening analysis suggested that toe walking by three young children with autism occurred independent of social consequences, we used Gaitspot™ squeakers to decrease toe walking. The squeakers produced reductions in toe walking for all three participants. For one participant (Joey), the auditory feedback produced by the squeakers reduced toe walking to less than 10% of steps. For two other participants, the addition of preferred edible items was necessary to decrease toe walking to 10% of steps. Zion also required blocking and a hand on shoulder procedure, although these were eventually faded. We also conducted probes in a novel location and with a novel experimenter or caregiver; toe walking was elevated during baseline probes and occurred infrequently during treatment probes. All probes were conducted with squeakers but with either no food delivery or lean schedules of food delivery.

These data replicate the findings of Marcus et al. (2010), who used Gaitspot™ squeakers, along with other intervention components (i.e., simplified habit reversal) to increase appropriate walking among three children with autism. These data extend Marcus et al. by verifying that toe walking occurred independent of social consequences, by demonstrating that the squeakers themselves (without other intervention components, such as SHR) can be effective, and by demonstrating that the auditory feedback produced by the squeakers (before pairing with preferred items) can be effective for some children.

The use of squeakers has some advantages over other manual methods of delivering auditory feedback to decrease toe walking. For example, because the use of clickers (Hodges et al., 2019;
Persicke et al., 2014) requires the therapist to observe appropriate steps, it can be labor-intensive. Squeakers provide auditory feedback without a therapist having to observe each step. Of course, in the current study, this advantage applies to only one of the three participants because Carl and Zion required delivery of preferred edible items (which necessitates monitoring) to achieve and maintain appropriate walking. Nevertheless, although squeakers may require monitoring in some cases, they don’t require direct observation of each step (i.e., the experimenter can hear the squeak without having to watch the participant’s steps), as do clickers. Another advantage of squeakers is that they may be more socially valid than clickers, at least in some settings. Clickers are often associated with training nonhuman animals; for this reason, parents and other caregivers may be reluctant to use clickers in schools or other community settings. Squeakers, on the other hand, or types of shoes that produce sounds or lights, are worn by many young children. Of course, the squeakers can be loud, and may make it difficult to hear instructions or interact with others. Future research should formally evaluate the social validity of the squeakers and the effects produced by squeakers. Parent ratings of child walking could be used both pre- and post-intervention to evaluate the outcome.

One limitation of this study is that we did not assess the extent to which the intervention effects generalized in the absence of the squeakers. That is, even at the FR10 and VR 10 schedules, participants still wore the squeakers, which continued to produce auditory feedback. We attempted to reduce the volume of the squeakers with the eventual goal of fading them altogether, but were unable to do so because the plastic pod on the squeaker is not adjustable. Future research should devise a method of fading the auditory feedback produced by the squeakers or fade the presence of the squeakers themselves. Valentino, LeBlanc and Raetz (2018) wrapped a pager with a cloth to reduce vibratory feedback; perhaps something similar would be effective for auditory feedback.

Another limitation is that, for Carl and Zion, we did not assess the extent to which the pairing by itself (with no additional delivery of edible items during sessions) was sufficient for maintaining appropriate walking. That is, immediately after pairing, we also delivered edible items on a FR 4 schedule for appropriate walking. Thus, it is unknown whether the pairing procedure would have influenced the effects of the squeakers alone. However, our goal was to establish control over toe walking without having to frequently deliver edibles; this goal was accomplished, as we ended with a FR 10 (Carl) or VR 10 (Zion) schedule of delivery for each participant. These schedules can be reasonably implemented by caregivers in many settings.

Relatedly, we combined both stimulus–stimulus pairing and response-contingent edible reinforcement for Carl and Zion. Thus, it is unclear whether one or both of these components was necessary to produce behavior change. Future research could address this limitation by isolating the component(s) responsible for decreasing toe walking. To accomplish this, researchers could conduct squeaker-only sessions after pairing or conduct response-contingent pairing sessions only, followed by squeaker-only sessions.

Future research should examine the prevalence of automatic reinforcement in the maintenance of toe walking. Although toe walking by all three participants in the current study occurred independent of social consequences, this may not be true in all cases. Future research should also attempt to identify the specific source of stimulation produced by toe walking. It is possible that toe walking enables avoidance of contact between the heels of the foot and the ground (automatic negative reinforcement). On the other hand, it is also possible that toe walking is strengthened by the additional pressure it produces on the top portion of the foot (automatic positive reinforcement). Interventions that differentially target each of these possibilities might be developed and evaluated.
It should be noted that we did not assess the extent to which toe walking was sensitive to social consequences in this study. That is, although the pretreatment screening analysis showed that toe walking occurred independent of social consequences, it could have also been sensitive to social consequences. Toe walking that is sensitive to social consequences may warrant a different intervention. For example, toe walking maintained by social positive reinforcement in the form of attention might be treated using noncontingent attention, attention extinction, or the delivery of attention contingent upon appropriate steps. Future research should examine these interventions.

To summarize, we demonstrated that toe walking maintained by automatic reinforcement can be successfully reduced using auditory feedback produced by GaitSpot™ squeakers. For all participants, the auditory feedback itself produced increases in appropriate walking. For one participant, this feedback was sufficient to reduce toe walking to clinically acceptable levels; however, for two other participants, delivery of edible items paired with the auditory feedback was necessary to achieve clinically acceptable levels. Clinicians should consider the use of this or a similar intervention when addressing this relatively common behavior exhibited by individuals with autism and related disorders.

REFERENCES

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