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Does Narrative Feedback Enhance Children’s Motor Learning in a Virtual Environment?

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Abstract

Augmented feedback has motivational and informational functions in motor learning, and is a key feature of practice in a virtual environment (VE). This study evaluated the impact of narrative (story-based) feedback as compared to standard feedback during practice of a novel task in a VE on typically developing children’s motor learning, motivation and engagement. Thirty-eight children practiced navigating through a virtual path, receiving narrative or non-narrative feedback following each trial. All participants improved their performance on retention but not transfer, with no significant differences between groups. Self-reported engagement was associated with acquisition, retention and transfer for both groups. A narrative approach to feedback delivery did not offer an additive benefit; additional affective advantages of augmented feedback for motor learning in VEs should be explored.

Keywords

augmented feedback; narratives; motor learning; motivation; engagement; children

Introduction

Augmented (or extrinsic) feedback about task performance and results has both motivational and informational functions for motor learning (Schmidt & Lee, 2013; Subramanian, Massie, Malcolm, & Levin, 2010; Wulf & Lewthwaite, 2016; Chiviacowsky, Wulf, Wally, & Borges, 2009). Providing augmented feedback during or after practice can enhance the rate and extent of motor learning in healthy individuals (Schmidt & Lee, 2013; Fujii, Lulic, & Chen, 2016; Sharma, Chevidikunann, Khan, & Gaowqzeh, 2016; Sullivan, Kantak, & Burtner, 2008) and those with neuromotor impairments (Subramanian et al., 2010; van Dijk,

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SUPPLEMENTAL DATA

Supplemental data for this article can be accessed on the publisher’s website.

Jannink, & Hermens, 2005; van Vliet & Wulf, 2006; Ezekiel, Lehto, Marley, Wishart, & Lee, 2001). In typically developing children and children with cerebral palsy for whom motor learning processes differ from adults, more research to determine optimal feedback delivery is required, as a recent review of modality (visual or auditory) and frequency (concurrent or terminal) of feedback to enhance upper limb motor learning could not make recommendations for most effective feedback parameters (Robert, Sambasivan, & Levin, 2017). In particular, the potential for feedback and other practice conditions to influence learner motivation and/or engagement in ways that directly or indirectly facilitate learning is an area of growing research focus (e.g., Wulf & Lewthwaite, 2016; Badami, Vaez Mousavi, Wulf, & Namazizadeh, 2011; Hoffman & Nadelson, 2010). In pediatric rehabilitation, understanding how to optimally structure feedback content to enhance children's motivation and engagement in the practice of repetitive motor tasks is one way to optimize both the effectiveness of and adherence to therapy.

Motivation is “a psychological property that encourages action toward a goal by eliciting and/or sustaining goal-directed behavior” (Lohse, Boyd, & Hodges, 2016, p.172). Both extrinsic (driven by an external outcome) and intrinsic (driven by inherent interest or enjoyment) motivation (Ryan & Deci, 2000) have motor learning benefits (Abe et al., 2011; Wulf, Lewthwaite, Cardozo, & Chiviawosky, 2018). Engagement, “an affective quality or experience of a participant in a task that emerges from focused attention, aesthetic pleasures, and perceptions of novelty” (Lohse et al., 2016, p.172), can have *indirect* effects on learning via enhanced motivation to increase practice duration (Lohse et al., 2016; Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013). There is also early evidence that engagement can *directly* enhance learning processes by supporting long-term information retention. Lohse et al. (2016) were the first to explore engagement-mediated learning effects in humans in an experiment demonstrating that playing a more aesthetically-enriched video game improved skill retention as compared to playing a sterile version of the game. A follow-up study using electroencephalography showed that engaged learners had increased information processing, as measured by reduced attentional reserve (Leiker et al., 2016).

Motivation and engagement underlie the appeal of electronic media for children in the US, where 81% of children live in households that own at least one gaming device (Robb, 2015). Parents, schools, and clinicians are interested in active video games (AVGs) that rely on movement player that is fairly similar to ‘real-life’ exercise participation (Bailey & McInnis, 2011), because they may increase physical activity in otherwise sedentary children and youth (Howcroft et al., 2012a, 2012b; Page, Barrington, Edwards, & Barnett, 2017). AVGs are used in rehabilitation because they can engage users in motivating meaningful task-specific activities in a feedback-rich and challenging environment (Deutsch & Westcott McCoy, 2017; Lohse et al., 2013; Levin, 2011; Levac, Rivard, & Missiuna, 2012; Levin, Weiss, & Keshner, 2015; Levac & Sveistrup, 2014). A key rationale for rehabilitation use is their potential to elicit repetitive practice, since practice dosage is a primary factor underlying neuroplastic changes in motor learning (Kleim & Jones, 2008). While evidence suggests that children with disabilities are more motivated to practice in virtual as compared to physical environments (Tatla et al., 2013; Tatla, Sauve, Jarus, Virji-Babul, & Holsti, 2014; Bryanton et al., 2006), children's motivation declines over lengthy gameplay periods (James,

Ziviani, King, & Boyd, 2016). This lack of motivation limits practice dosage and reduces the potential therapeutic benefits of AVG play.

Enhancing motivation, engagement, and adherence to interventions require a better understanding of the specific “active ingredients” of virtual environments (VEs) that children find motivating or engaging and the impact of these factors on motor learning outcomes. Augmented feedback – information that is externally presented, rather than intrinsically to the learner – may be one such active ingredient. Augmented feedback is integral to interaction with a VE. AVGs provide visual, auditory (and sometimes tactile) feedback, often simultaneously (e.g., numerical knowledge of results in the form of a score and auditory knowledge of performance in the form of sounds related to success or failure) (Lyons, 2015). Indeed, augmented feedback in VEs is embedded within the audiovisual aesthetics that differentiate practice in a virtual context from conventional therapy. While it is undoubtedly one of many factors that may support skill acquisition in VEs, preliminary evidence links feedback presentation in VEs to motor learning outcomes (Lyons, 2015; Subramanian, Massie, Malcolm, & Levin, 2010). However, there has been little exploration, particularly in pediatrics, of the specific relationship between VE feedback modality or frequency, the learner’s affective state, and motor learning outcomes.

Narratives, defined as “any two or more events arranged in a chronological or causal order” (Rimmon-Kenan, 2002), are a unique option to structure feedback content in VEs. Children’s identification with characters is a primary catalyst for their response to narratives (Heilman, 2003). Studies demonstrate that narratives can increase engagement in didactic instructional materials (Koenig, 2008; Parker & Lepper, 1992; Waraich, 2004). The potential for narratives in a motor-skill context stems from findings that narrative information is a more persuasive tool for changing health-related behavior than didactic information (Hinyard & Kreuter, 2007; Lu, Baranowski, Thompson, & Buday, 2012; Taylor & Thompson, 1982). For example, playing a story-based childhood obesity-combating game changed children’s realworld behaviors, as compared to playing a nonnarrative game (Lu et al., 2012). Lu et al. (2016) demonstrated that children who viewed a narrative related to the game prior to AVG gameplay increased their physical activity during AVG play as compared to those who played the same game without viewing the narrative. However, there has been limited exploration of narratives in AVGs thus far: less than 10% of available off the shelf games contain a narrative element (Lu, Kharrazi, Gharghabi, & Thompson, 2013).

Narratives may enhance intrinsic motivation and engagement in task practice via reduced cognitive load, increased attention to task, suspension of disbelief, personalization of the narrative, creation of deep affection for characters in the narrative, and increased *presence* in the VE (Gorini et al., 2011; Lu et al., 2016; Lu, 2015). Presence can be defined as the subjective experience of being in one place or environment even when physically situated in another (IJsselsteijn, Freeman, & de Ridder, 2001). Narratives may support presence in a VE by instilling vivid personal experiences and enhancing the learner’s identification with the task (Gorini et al., 2011; Isen, 2000; Lu et al., 2016; Zajonc, 1980). Gorini et al. (2011) found that a narrative-based VE enhanced self-reported presence as well as physiological indicators of arousal in healthy young adults as compared to a nonnarrative condition.

To our knowledge, this is the first study to explore the effect of narrative feedback on typically developing children's motivation, engagement, and motor learning in a VE. Our objectives were to:

1. Compare the effect of narrative versus nonnarrative feedback on self-reported motivation and engagement. We hypothesized that narrative feedback would enhance children's self-reported motivation and engagement.
2. Evaluate whether self-reported engagement and motivation during acquisition predicts retention and transfer performance. We hypothesized that higher motivation and/or engagement would be associated with better retention and transfer performance.
3. Compare the effect of narrative vs nonnarrative feedback on acquisition, retention, and transfer of a novel balance skill. We hypothesized that children receiving narrative feedback would more quickly acquire the skill and better retain and transfer skill performance.

Methods

Design

Repeated measures study in which motor learning was assessed via retention and transfer phases following an initial acquisition period.

Setting and Virtual Environment

The study took place in the Rehabilitation Games and Virtual Reality Lab at Northeastern University. The VE used in this study is the Stability and Balance Learning Environment (STABLE; Motekforce Link, The Netherlands), a 130-degree projection flat-screen VE incorporating a force plate (Motek ForceLink, using National Instruments Analog to Digital Converter with a sampling rate of 250 kS/s at 16-bit; Centre of Pressure error <10 mm), and 4 VICON motion capture cameras to collect 3D motion data (from 1 marker located on a wand held by the participant).

Participants

A convenience sample was recruited from the local community via postings on university and community listservs. No sample size calculations were undertaken for this study. Inclusion criterion was the ability to read at age-specific grade level in English. Exclusion criteria were visual, cognitive, attentive, or auditory disabilities that would interfere with gameplay: unstable cardiovascular, orthopedic, or neurological condition preventing participation in minimal/moderate exercise, or a diagnosis of a seizure disorder. Participants provided informed assent/consent via procedures approved by Northeastern University's Institutional Review Board.

Study Procedures

Children completed the pre-test questionnaires (see Outcomes) and were randomized to either the narrative or nonnarrative feedback group. They completed baseline postural

stability tests (quiet stance, quiet stance feet together, single leg stance, anteroposterior, and medio-lateral limits of stability) in the STABLE system to familiarize their interaction with the VE. Participants received game instructions according to their assigned group conditions and completed twenty, 90-second task trials. Following each trial, participants received short verbal feedback from the RA using standardized wording. The research assistant (RA) chose the specific feedback according to the predominant movement error made during the trial. Following the 20 trials, participants completed the User Engagement Scale (UES) and the Intrinsic Motivation Inventory (IMI). They returned 2–7 days later for one session which included retention (10 trials of the same task, with no feedback) and transfer (10 trials of a related but more challenging [requiring faster response times, avoidance of additional unpredictable obstacles] task) tests.

Task

The “*Forest of Magmire*” VE (see Figure 1) is a 90-second task requiring the player to move his/her body in anterior/posterior and medial/lateral directions on the force plate to control an avatar through a forest path while avoiding obstacles. The player must stay on the path to navigate to virtual objects representing bunnies frozen by an evil wizard. Once the player has reached these targets, he/she must reach and “free” the bunnies by touching the objects using a wand with a reflective marker held in his/her dominant hand. In order to successfully touch the objects, the game requires a specific amount of lateral weight-shift in the direction of reach. The amount of weight-shift required was calibrated to 95% of the participant’s LOS during game setup and visually indicated in the VE. The goal of the game was to free as many bunnies as possible and reach the end of the course as quickly as possible, without running into obstacles. Points were gained for freeing bunnies and lost when running into an obstacle. Players viewed their points on the screen throughout the game and received auditory knowledge of results’ feedback about success or failure throughout the gameplay.

Feedback Content

Investigators developed feedback content by observing a convenience sample of five typically developing children representing our target age range playing the task, using their observations to develop an error framework of 14 categories of movement errors typically made during the game. These categories are presented in Table 1. Investigators then worded three to five feedback statements in a child-friendly language related to each error category (see Table 2 for examples). Across both groups, other elements known to influence motor learning were held constant. For example, feedback directed participants’ attentional focus externally toward the goal, rather than internally toward their movements, and enhanced participants’ expectancies for success.

Investigators developed a narrative about the task with a beginning, middle, and end that provided information about characters and plot. The narrative was embedded in instructions about how to play the task given to the narrative group prior to testing. The nonnarrative group received the same gameplay instructions, but without the narrative context.

Outcome measures

1. Demographics: A study-specific demographic questionnaire provided information about age, grade level, and experience with AVGs.
2. Physical activity participation: The Physical Activity Questionnaire is a valid and reliable (Kowalski, Crocker, & Faulkner, 1997; Thomas & Upton, 2014) self-administered questionnaire using nine questions to assess frequency of physical activity participation in the past seven days. Higher scores represent more frequent physical activity participation.
3. Motor learning: 3a) *Task score*: based on points gained by staying on path and freeing bunnies minus points lost by hitting obstacles. The maximum possible score for a perfect trial was 80 (10 points for each bunny and a 20 point bonus for finishing the course in the allotted time). 3b) *Percentage time off-path*: reflects the time in which the player was on the designated path as opposed to off it during each trial.
4. Motivation: The IMI (McCauley, Duncan, & Tammen, 1989) is a multidimensional 27-item survey assessing dimensions of interest/enjoyment, perceived competence, effort/ importance, and tension/ pressure. We used a language-modified IMI scale for children with a six-point visual analog response scale with anchors on “Not true at all” and “Definitely true.”
5. Engagement: The UES (O’Brien & Toms, 2013) is a reliable and valid multidimensional scale comprised of six distinct factors: Focused Attention, Perceived Usability, Endurability, Novelty, Aesthetics, and Felt Involvement. We used a language modified UES with a six-point VAS with anchors on “Not true at all” and “Definitely true” and focused on four of the six factors (Focused Attention, Perceived Usability, Novelty, and Aesthetics).

Analyses

All analyses were undertaken with SPSS v.23. The effect of the independent variables Testing Period (Acquisition, Retention, or Transfer) and Group (Narrative or Nonnarrative) on Score and Percentage time off-path were evaluated using mixed effects models. The building of both models followed a progression that aimed at analyzing the effect of adding each variable of interest, one step at a time. In all models, a random intercept and a random effect for Session were estimated within Participant, as well as a random slope for Trial within each combination of Session and Participant. We started with a model with fixed effects for Session (Model 1), then added a fixed effect for Group (Model 2), and finally added interactions between Group, Session and Trial (Model 3). As the Interactions were not significant (p -value = 0.230 in the model for Score and p -value = 0.204 in the model for Percentage time off-path) and Model 2 had a better fit ($AIC_{\text{Model 2}} = 13,542.673$ vs $AIC_{\text{Model 3}} = 13,543.232$ in the model for Score and $AIC_{\text{Model 2}} = 12,920.690$ vs $AIC_{\text{Model 3}} = 12,921.072$ in the model for Percentage time off-path), we took Model 2 as our base model, to which we added the moderator variables IMI and UES, one at a time (Model 4 with IMI and Model 5 with UES) and then both at the same time (Model 6).

In the model for Score, despite Model 6 having the best fit ($AIC_{\text{Model 6}} = 12,225.896$), the addition of both IMI and UES in the model made UES insignificant, probably due to both scales being highly correlated. In fact, the analysis of Models 2, 4, 5, and 6 suggests that the Intercept, IMI, and UES are correlated and no more than one of them should be used in the model at the same time, thus leaving us with Models 2, 4, and 5 to choose from. Model 5 has the best fit and is thus the chosen option ($AIC_{\text{Model 5}} = 12,229.676$ vs $AIC_{\text{Model 4}} = 13,402.320$ $AIC_{\text{Model 2}} = 13,542.673$).

The results for % time off-path are analogous to those for Score, but the fit of Model 5 is actually better than that for Model 6 ($AIC_{\text{Model 5}} = 11,651.024$ vs $AIC_{\text{Model 6}} = 11,653.023$), making it even easier to choose Model 5 as the best model.

The Group and Session variables were contrast-coded, following a Helmert scheme and the Trial variable was mean-centered within each session, in order to produce more meaningful parameters and interactions, as well as increase the power of comparisons between effects.

Independent *t*-tests evaluated between-group differences in UES and IMI subscales. Differences in frequency counts between groups for each feedback category were evaluated using chi-square tests, with absolute values of 2.0 or higher for adjusted residuals indicating significance.

Results

This paper reports the results of all measures and conditions. There were no data exclusions.

1. Participant demographics

Twenty children between the ages of 7 and 13 years (16 males, mean age 9.2 years, SD 2.5 years) participated in the narrative condition and 18 participants in the same age range (15 males, mean age 9.8 years, SD 3.0 years) participated in the nonnarrative group. Fifteen participants in the narrative group were involved in recreational or competitive sports, and 15 had previous experience playing AVGs. In the nonnarrative group, 13 were involved in sports and 14 had previous experience playing AVGs. There were no significant differences in score on the PAQ or on any postural stability test between groups. There was no difference in mean time between acquisition and retention/transfer testing visits (Narrative 4.9 days, SD 1.7 days; Nonnarrative 4.9 days, SD 1.2 days).

2. Feedback content

Each participant received 20 instances of feedback during acquisition (i.e., one feedback delivery following each of the 20 acquisition trials). Table 3 provides feedback frequencies and indicates significant differences between groups.

3. Between-group differences in acquisition, retention and transfer

3.1. Trial Score

There was a significant difference in average score between acquisition, retention, and transfer ($t[\text{df } 57.685] = 5.611, p < 0.001$) and between retention and transfer ($t[\text{df } 83.471] =$

2.497, $p = 0.014$) regardless of group. Acquisition testing has an average score 12.57 lower than the retention and transfer, whereas the average for transfer is 6.19 higher than retention. There was no statistically significant group effect. Figure 2 illustrates between-group differences in score.

3.2. Percentage Time off-path

There is a significant difference between acquisition and retention (t [df 62.521] = 2.053, $p = 0.044$) regardless of group, but not between acquisition and transfer (t [df 72.226] = 2.407, $p = 0.056$) or between retention and transfer (t [df = 77.512] = -0.357, $p = 0.722$). Acquisition testing presents an average percentage time off-path of 4.96% higher than retention. There is no statistically significant group effect. Figure 3 illustrates between-group differences in percentage time off-path.

Motivation and Engagement

4.1. Effect on Score

Predictors based on total scores from the UES and the IMI surveys were added to the model. Although either score improves the model when added individually, the fit achieved by the insertion of UES is better ($AIC_{UES} = 12,229.676$ vs $AIC_{IMI} = 13,402.320$). The effect of UES is significant (t [df = 35.121] = 13.843, $p < 0.001$) across all time points. An average score increase of 8.92 points is observed for every unit increase in the UES scale.

4.2. Effect on Percentage Time Off-Path

Predictors based on total scores from the UES and the IMI surveys were added to the model. Although either score improves the model when added individually, the fit achieved by the insertion of UES is better ($AIC_{UES} = 11,651.024$ vs $AIC_{IMI} = 12,800.063$). The effect of UES is significant (t [df = 35.074] = 16.340, $p < 0.001$) across all time points. An average percentage time off-path decrease of 9.15 points is observed for every unit increase in the UES scale.

4.3. Between-group Differences

Figures 5 and 6 illustrate differences in group scores on subscales of the IMI and UES. These figures show that the two groups have a very similar profile in terms of motivation and engagement.

Discussion

Learner motivation and engagement can have direct and indirect motor learning benefits in healthy young adults, but there is currently no evidence linking these constructs to improved learning in children. Motivation and engagement are relevant constructs to practice in VEs, which are used in a variety of rehabilitation contexts (Levac, Glegg, Colquhoun, Miller, & Noubary, 2017). Researchers and therapists are interested in creating VE practice conditions that optimize and sustain children's natural motivation to engage with these environments. The provision of visual-augmented feedback that can be manipulated and standardized is one VE practice condition that differentiates learning in a virtual from a physical context.

Narratives are options to structure or supplement visual feedback content in VEs because of their universal appeal for children (Lu et al., 2012). This study evaluated the effect of feedback provided in the context of a narrative about a visual VE on children's motivation, engagement, and motor learning during practice of a novel task. Contrary to our hypothesis, we found no difference in motor learning metrics at acquisition, retention, or transfer according to the content of feedback presented. There were no significant differences in self-reported motivation or engagement between groups. However, IMI total score was a significant predictor of percentage time off-path across testing sessions and feedback groups.

Children in both groups improved their performance over the course of the 20 acquisition trials, receiving feedback after each trial about how to move their body to successfully interact with the game. Both groups received the most feedback about the shift in weight bearing required to unlock the bunny once it had been touched. Children in the narrative group received more frequent feedback about staying on path in order to touch the columns and unlock the bunnies, which corresponds to their (nonstatistically significant) worse performance in percentage time off-path. Children in the nonnarrative group received more frequent feedback about moving slowly, leaning, and general encouragement to continue improving once it was clear that they understood all the possible ways to improve their errors. These differences between groups suggest that center of pressure control was the primary challenge for children in the study in terms of being successful in the task. Differences between groups in how children interacted with the force plate to control their center of pressure suggest that children in the narrative group had more challenges with larger-scale control (i.e., navigating changing their center of pressure through a moving course) and children in the nonnarrative group had more difficulty with trunk control over a static base of support. There were no significant between-group differences in postural stability that might explain these differences.

Based on previous beneficial findings related to narrative use (Lu et al., 2016; Lu et al., 2012; Lu et al., 2013), we had hypothesized that narrative feedback would support children's motivation and engagement during task acquisition to a greater extent than regular feedback in ways that would, after a period of consolidation, improve retention and transfer performance. Instead, while the between-group difference was not statistically significant, the narrative group performed more poorly at each time point as compared to the nonnarrative feedback group. Rather than being beneficial, the narrative feedback may have instead placed an extra burden on children's information processing abilities and working memory. Reducing cognitive load has been proposed as a hypothesized mechanism behind the potential of narratives to generate motivation and engagement (Lu, 2015), but our study used a narrative in the context of learning a complex motor task, which involves an existing cognitive load. The narrative feedback may have further increased the cognitive load because it included story elements, and was therefore more verbose than the nonnarrative feedback. It also referred to characters and situations that had been introduced during task instructions, requiring children to use working memory to make connections with information that had been presented earlier. Leiker et al. (2016) linked learner engagement to greater information processing. Given that both groups reported high engagement in the task, and that the task was difficult (as evidenced by the fact that no participant achieved the maximum score), the

added narrative may have been an extra cognitive burden that was a detriment to performance.

Children in both groups improved their task performance between acquisition and retention sessions. The improved performance on a subsequent retention session, during which time feedback was not provided, reflects a time period typically indicative of an effect on memory consolidation. Motivation and engagement may improve consolidation of motor-skill learning through encoding of information during or after practice, influencing retention (Lohse et al., 2016). Both narrative and nonnarrative groups reported high motivation and engagement, as evidenced by scores over the median for all subscales of the IMI and UES. Both groups played the same challenging, visually pleasing AVG, where they never achieved a perfect score. These factors alone may have enhanced motivation and engagement and contributed to observed performance improvements at retention, regardless of feedback content. Lack of improvements from retention testing to transfer performance in both groups may reflect the fact that children did not have sufficient practice opportunities to master the task, limiting their ability to perform well on a more challenging version.

Previous work exploring learning a novel motor task in a VE in typically developing children did not find a predictive influence of motivation or engagement (Levac & Jovanovic, 2017). The finding that total UES score, which measures dimensions of focused Attention, perceived usability, endurance, novelty, aesthetics, and felt involvement, was associated with performance (in terms of score and percentage time off-path) at retention and transfer contributes to the literature by providing one of the first indications that engagement may relate to learning in VEs for typically developing children, which should be replicated in a larger sample.

Children experienced the narrative as passive (i.e., they listened to it being delivered verbally) rather than interactive. This may have reduced the potential impact of the narrative for engagement that could be achieved via the mediating construct of presence. Narratives have been found to enhance presence in VEs (Gorini et al., 2011). Some authors have shown that presence can enhance learning in immersive VEs (Persky et al., 2009; Selverian & Hwang, 2004), though other results have been less conclusive (Winn et al., 2002; Mikropoulos, 2006). Higher presence has been linked to more interactive, active content in VEs as opposed to passive didactic content (Persky et al., 2009). Subsequent work will use a more interactive narrative and endeavor to include a measure of presence, once a psychometrically valid instrument is created for children. Indeed, further exploration of the associations between motivation, engagement, and presence in VEs is required to understand the direction of these relationships and their potential impact on both adherence to practice and practice outcomes.

Study Limitations

A study limitation was the lack of a no-feedback control group, limiting the ability to distinguish impact of the feedback (either narrative or nonnarrative) as compared to another factor related to repeated practice on retention improvements. Ethical rationale prohibited including a no-feedback control group: beta testing with children suggested that the VE task

was sufficiently challenging that children would require some verbal support in learning the task.

We chose to focus on narrative provision through *verbal* instructions and feedback because this is most similar to regular therapy sessions in which therapists are providing additional verbal feedback when using off-the-shelf AVGs. As such, the similarity between groups in audiovisual aesthetics and challenge may have created a ceiling effect for motivation and engagement, reducing the additive effect of a narrative in a single group. In addition, children in the nonnarrative group may have also independently constructed their own personal narratives related to the engaging VE. Subsequent work could include the nonnarrative group practicing the task in a more “sterile” VE to account for this possibility.

Children in the narrative group relied on imagination or mental imagery to construct the narrative in their minds based on the introduction and feedback, which induced person-dependent effects that were not consistent or equal across participations. Character and plot are the main features in narrative (Lu, 2015); in our study children did not view the avatar in the form of a person or figure, but rather had to imagine their character, which may have represented an additional cognitive burden and reduced their engagement in the story. Further distinguishing between the two groups by including visual representation of the narrative may have reduced the cognitive burden of processing the verbal feedback in the narrative format. The narratives were created by the study team rather than professionals in children’s media and were not tested for clarity with children, potentially reducing their impact. The study utilized established measures of motivation and engagement, but the specific language-modified versions were not psychometrically evaluated. There was variation in retention time periods between children (from two to seven days) that was needed due to logistic constraints of family availability; this did not differ between groups.

The complicated nature of the task, which offered multiple possibilities for error in both gameplay (e.g., straying off path, hitting obstacles, missing targets) and body movements (e.g., insufficient weight-shifting, extraneous body movement), prompted the decision to offer 14 categories of feedback relevant to these errors. A shorter, less complex task with fewer error categorizations would have potentially allowed for more abundant practice repetitions and required participants to absorb a lesser amount of information, leading to different results. Finally, the study procedures did not specifically ask participants whether they felt the study feedback enhanced their motivation, engagement, or learning.

Next Steps for Research

We will build on our exploration of narrative influences in VEs by visually integrating the narrative into gameplay. In doing so, it will be important to further emphasize evidence-based game design principles known to enhance engagement, such as interactivity, choice, exploration, and reward (Lohse et al., 2013). To understand whether narratives could instead have an *indirect* effect on learning by increasing the amount of practice, we can allow participants in the narrative condition to choose additional practice repetitions, controlling for the amount of practice by yoking participants in other conditions to chosen practice amounts. In addition to further exploration of narrative inclusion in VEs, subsequent studies will further explore the motivational advantages of motor learning of other types of

augmented feedback in VEs. For example, this could include evaluating evidence-based feedback content suggestions from the Optimizing Performance through Intrinsic Motivation and Attention for Learning (OPTIMAL) theory of motor learning (Wulf & Lewthwaite, 2016) in a VE context and using objective neurophysiological measures that are known correlates of affective state, such as EEG, skin conductance, and/or heart rate variability rather than subjective self-report to quantify the impact of different VE feedback conditions on motivation, engagement, and learning. In addition, evaluating information processing using a neurophysiological method such as electroencephalography (EEG) or a self-report measure of cognitive workload such as the NASA Task Index (TLX; NASA 1986) will be useful to elicit the extra cognitive burden of narrative feedback in a subsequent study.

Conclusion

Much remains to be understood about the specific features of VE interaction that children find motivating and/or engaging and whether either of these affective states can directly influence motor learning. In this first exploration of the addition of a narrative context to feedback provided about performance during learning of a novel balance task in a VE, we found that for a fixed duration of practice, the added narrative did not increase self-reported motivation or engagement nor impact motor learning. However, initial findings of a relationship between engagement and acquisition, retention and transfer performance advance the field by showing that affective state may impact motor learning outcomes in typically developing children. Subsequent research should strive to replicate this finding and will better integrate narratives into established concepts known to enhance intrinsic motivation by integrating a more interactive visual narrative into the VE and measuring the effects using objective neurophysiological measures.

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FIGURE 1.
Forest of Magmire virtual environment displayed in the STABLE.

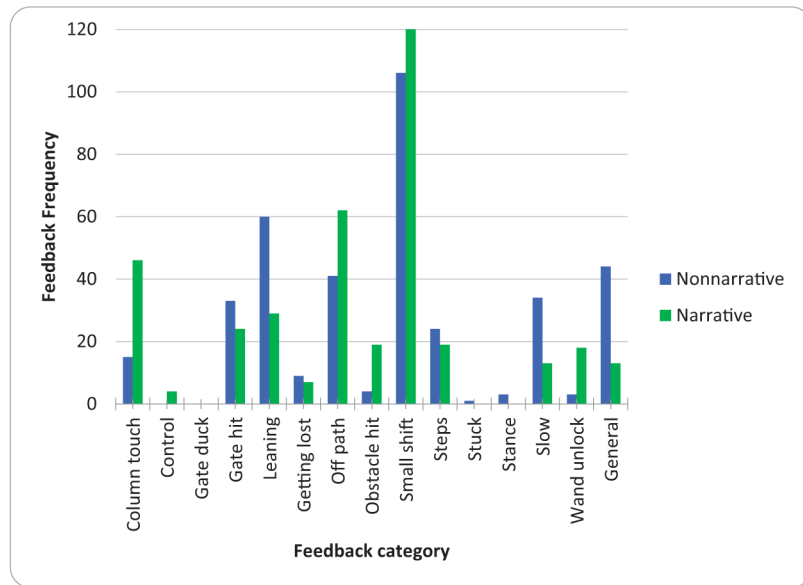


FIGURE 2.
Between-group differences in feedback frequencies.

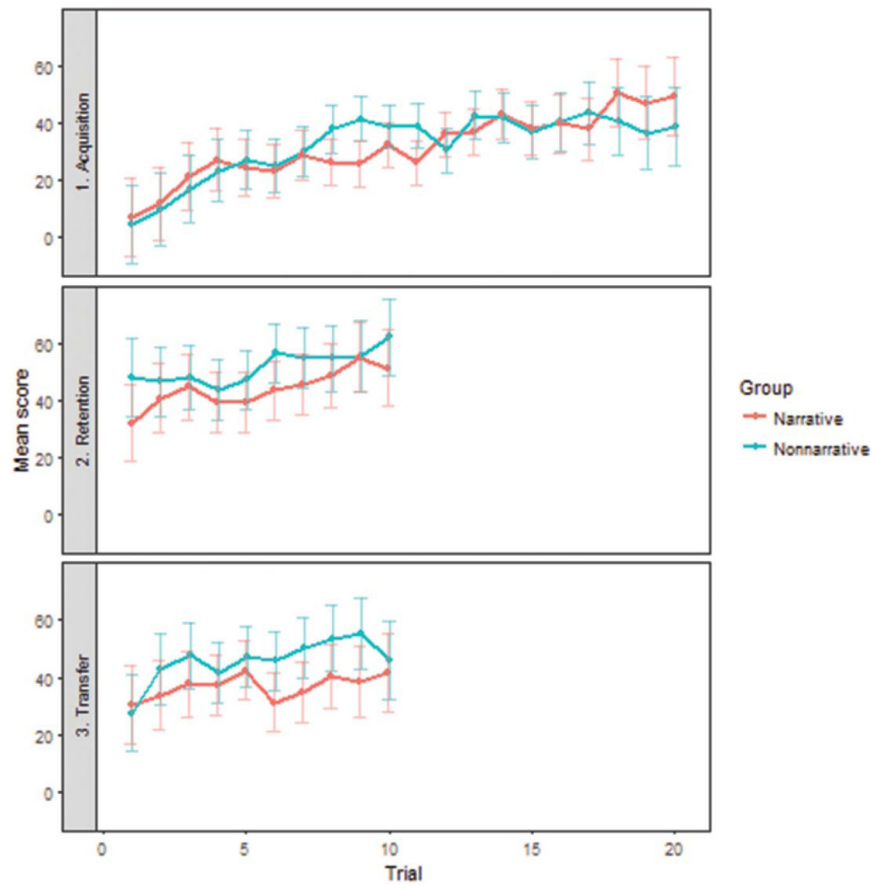


FIGURE 3.
Between-group differences in score.

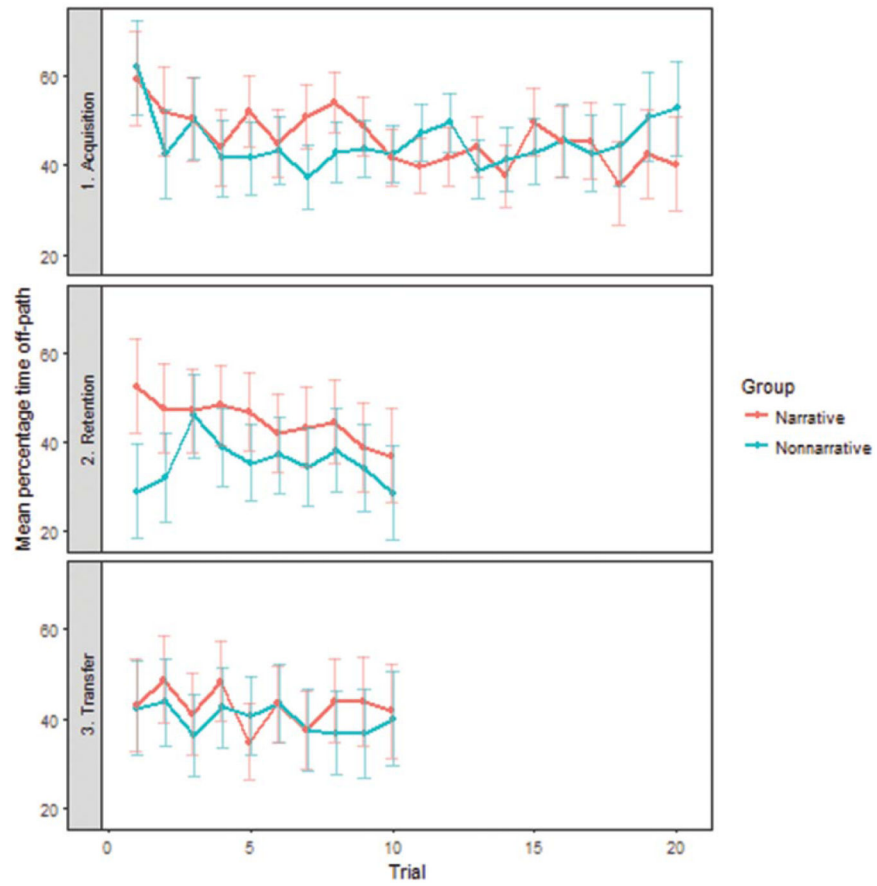


FIGURE 4. Between-group differences in percentage time off-path.

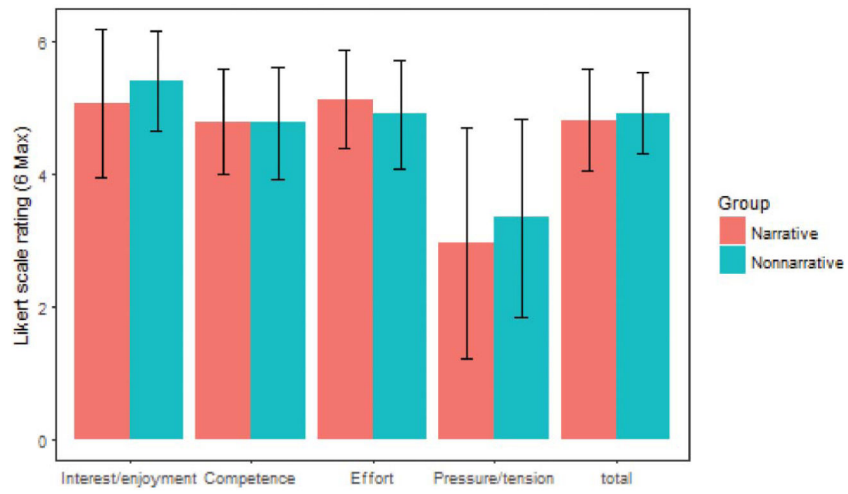


FIGURE 5. Between-group differences in Total score and subscales of the Intrinsic Motivation Inventory.

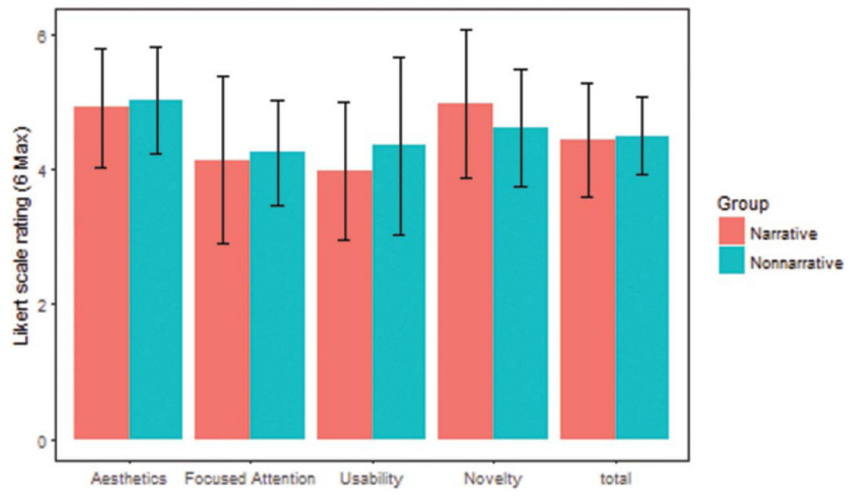


FIGURE 6. Between group differences in Total score and subscales of the User Engagement Scale.

TABLE 1.

Feedback categories and their description.

Column touch	Not touching the target columns
Control	General trouble controlling avatar
Gate duck	Trying to duck under gate
Gate hit	Hitting the electric gate because not stopping to wait, or getting stuck at electric gate
General	Encouragement to continue improving once understanding of game mechanics was achieved
Leaning	Leaning at trunk instead of shifting with whole body
Getting lost	Getting lost in the environment; didn't know they were supposed to stay on the path
Straying off path	Not getting lost, but still going off path too much accidentally and not touching enough fireflies
Obstacle hit	Hitting obstacles (fireflies)
Small shift	Not weight shifting enough to unlock the bunny
Steps	Taking steps on the force plate and not being able to control avatar because off centered
Stuck	Getting stuck behind an obstacle
Stance	Placing one foot too far back and not getting the results wanted
Slow movement	Moving too slowly
Wand unlock	Weight shift OK, but having trouble bringing wand to center of white dot to unlock bunny

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TABLE 2.

Examples of feedback provided in each condition

	Nomnarrative	Narrative
General trouble controlling avatar	<i>It looks like you ran out of time in the game this time around, but that's okay... because you're still learning how to control the ball of light. Next time, maybe you can try to experiment with it and see how it responds to your movements.</i>	<i>Alright, so you ran out of time to save the bunnies this time around, but you can try again. Learning magic in the land of Magmire takes a lot of time, but you've nearly mastered it. Controlling the Lightning Sphere is really hard, but you can definitely do it. Maybe if you experiment with how it responds to your movements, you be able to control it better.</i>
Going off path	<i>I think you'd come across a lot more rabbits if you follow the path more closely. There's an entire section with more bunnies in it. So slowing down may not be what you want to do, but if you find those bunnies you've been missing, you'll get a lot more points. It's okay to stop for a moment to get an idea of where the path is.</i>	<i>I think you could save a lot more of the bunnies if you follow the path more closely. You know, the rabbits have been telling scary stories about Furplepus for years. It's probably very tempting to take shortcuts through the forest to avoid him and get to the end of the trail faster. But you might miss some of the traps if you do that, and those bunnies wouldn't be very happy, so try to stick to the path.</i>
Hitting obstacles	<i>One thing to remember is to avoid the red lights. They're there for a reason: to see how good you are at seeing them and staying away from them... anyway, I think you'll be able to do it lot better next time.</i>	<i>One thing to remember is to avoid the red fireflies. Furplepus put them there for a reason: to sap magic from your Lightning Sphere. He's always thinking up new ways to steal magic from the rabbits of Magmire, and this certainly is a good one. Anyway, I think you'll be a lot better at staying away from his red firefly traps next time.</i>

TABLE 3.

Feedback frequencies between groups

Feedback category	Nonnarrative group frequency	Narrative group frequency	Adjusted residual
Column touch	15	46	3.8 *
Control	0	4	1.9
Gate duck	0	0	N/A
Gate hit	33	24	1.5
Getting lost	9	7	0.7
General	44	13	4.6 *
Leaning	60	29	3.9 *
Off path	41	62	1.8
Obstacle hit	4	19	3.0 *
Slow	34	13	3.4 *
Small shift	106	152	2.8 *
Steps	24	19	1.0
Stuck	1	0	1.0
Stance	3	0	1.8
Wand unlock	3	18	3.1 *

* significant at $p < 0.05$.

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