A Dynamic Difficulty Adjustment Model for Dysphonia Therapy Games

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Keywords: Voice Disorders, Sustained Vowel Exercise, Dynamic Difficulty Adjustment Model, Maximum Phonation Time.

Abstract: Studies on childhood dysphonia have revealed considerable rates for voice disorders in 4 – 12 year-old children. The sustained vowel exercise is widely used as a technique in the vocal (re)education process. However this exercise can become tedious after a short practice. Here, we propose a novel dynamic difficulty adjustment model to be used in a serious game with the sustained vowel exercise to motivate children on practicing this exercise often. The model automatically adapts the difficulty of the challenges in response to the child's performance. The model is not exclusive to this game and can be used in other games for dysphonia treatment. In order to measure the child's performance, the model uses parameters that are relevant to the therapy treatment. The proposed model is based on the flow model in order to balance the difficulty of the challenges with the child's skills.

1 INTRODUCTION

Many children have speech sound disorders (SSD) that may affect not only their health, but also their social interactions and development process (Furlong et al., 2017b). Different types of SSD exist. Some are related to language and speech disorders while others are related to voice disturbances (Guimarães, 2007). Deviations in the quality of an individual's voice are known as dysphonia, and can occur as a result of inappropriate vocal behavior or due to neurological, physiological or social factors, among others. Studies on vocal analysis with children between the ages of 2 to 12 years, report that voice disorders affect from approximately 4 to 38% of children, with hoarseness and breathy voice as the most frequent problems (Duff et al., 2004; Oliveira et al., 2011; Tavares et al., 2011). In some cases, voice pathologies can be naturally corrected while children grow up. In other cases the child may need to attend speech therapy for recovery and vocal (re)education.

An important aspect of therapy is the repetition of the exercises. Yet repeating the vocal exercises used to correct voice problems may be monotonous and tiring (Bowen, 2015; Eriksson et al., 2005). Thus, speech and language pathologists (SLPs) usually try to create more appealing sessions through the use of several techniques, such as board games. Some SLPs resort to PowerPoint animations or try to adapt computer games that can be manually controlled: when the child succeeds, the SLP uses the PowerPoint animations or makes the game progress to motivate the child on practicing the exercise.

In order to detect and treat dysphonia symptoms, SLPs commonly use the sustained vowel (SV) exercise in therapy sessions with children (American Speech-Language-Hearing Association (ASHA), 2018; El Sharkawi et al., 2002; Mota et al., 2012; Swart et al., 2003). The goal of this exercise is to say a vowel for as long as possible while maintaining the voice intensity level stable. The SV exercise is widely used in therapy sessions to evaluate the patient's voice quality, detect the existence of dysphonia, the severity of the pathology, as well as to complement the treatment for dysphonia. Additionally, this exercise is used with voice professionals like actors and journalists, who make a constant vocal effort and need to learn how to correctly put the voice. This exercise is also commonly used in therapy with patients with Parkinson's disease (El Sharkawi et al., 2002; Swart et al., 2003).

As a contribution to improve the motivation of children on doing the sustained vowel exercise, we have developed the *sustained vowel game*, a serious computer game for this exercise. A first simpler version of this game was previously proposed (Lopes et al., 2016). The new version includes several new important characteristics that are proposed here. The

Lopes, V., Magalhães, J. and Cavaco, S.
A Dynamic Difficulty Adjustment Model for Dysphonia Therapy Games.
DOI: 10.5220/0007402901370144
In *Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2019)*, pages 137-144
ISBN: 978-989-758-354-4

game's current version includes (1) a set of different scenarios and main characters that children can control with their voices. In this way, the game can be interesting to children with different tastes and interests.

In order to keep the child motivated on playing often, it is important that the difficulty of the game adapts to the child's performance. If the game is too easy for the child it may become tedious, on the other hand, if it is too difficult the child can get frustrated for not reaching the end of the game. In other words, if the challenge is too difficult it may cause a non-desired effect: the child may be unmotivated to repeat the exercise or can even reject doing it.

An important characteristic of the game, already included in its previously proposed version, is that it can be adjusted to each child's needs through a set of customizable parameters. In addition, we now propose (2) a dynamic difficulty adjustment (DDA) model that allows the game to meet the child's changing needs and progress as well as capabilities so that the child does not feel frustrated with the inability to solve the tasks nor looses the motivation on doing the exercise when the tasks are too easy for the child. For that, the game automatically adapts the difficulty of the challenge based on the child's performance during the previous trials. During each trial, the child's performance is measured based on a set of relevant parameters in order to manage the automatic adaptation of the difficulty.

In the remaining sections, we discuss related work (section 2), a simple DDA model that depends only on one of the parameters relevant to the SV exercise (section 3.1) and we discuss the final DDA model used in our game, which is a more complex model that uses two parameters to measure the child's performance and decides how to increase the game's difficulty based on this performance measure (section 3.2).

2 RELATED WORK

Taking advantage of the current technological advances, several computer and mobile games have been developed to complement traditional speech therapy techniques (Eriksson et al., 2005; Furlong et al., 2017a). Some of these games can assist SLPs on keeping the children motivated on doing the therapy exercises, such as the set of applications from the LittleBeeSpeech (Hanks et al., 2018), Falar a Brincar (Tavares et al., 2017) and sPeAK-MAN (Tan et al., 2013), which focus on articulation problems, or Flappy Voice (Lan et al., 2014) and Carvalho's interactive game for training the Portuguese vowels (Carvalho, 2008) which focus on problems like apraxia and vowels recognition, respectively.

As different children have different needs, present different kinds of sigmatism and with different levels of severity, the parameterization of the games is an important aspect of these systems. Another important aspect to avoid that the children loose interest in playing or even feel frustrated when the level of difficulty is to high for them, is to adapt the level of difficulty dynamically.

While a player-adaptable concept is used in some of these systems, such as Flappy Voice, the concept consists of a very simple approach (Hanks et al., 2018; Lan et al., 2014; Tavares et al., 2017). Alternatively, Yun et. al. proposed a methodology that automatically adjusts the game difficulty using a profile-based adaptive difficulty system (Yun et al., 2010). They want to improve the gaming experience by using player profiles to determine the best difficulty level to each player. They use the players' prior gaming experience and their preferences to create the players' profiles. Afterwards, they use these parameters to set the game difficulty adjustment thresholds, and they use a performance-based algorithm to adjust the difficulty settings. To do this, they transform the player's performance data into a point scale. If the output is greater than the positive threshold they increase the difficulty level. On the other hand, if the output is less than the negative threshold they decrease the difficulty level.

Demediuk and colleagues proposed another approach that changes the challenge level according to the players' performance (Demediuk et al., 2016). They developed an adaptive training framework to construct an opponent, whose strategies and behavior adapt in response to the progress of the player. Their goal is to alter the level of challenge of the opponent according to the changes in the player's proficiency.

There are several strategies that can be followed in order to implement a serious game adaptability model (Jonathan et al., 2012). These include the rubber banding technique, which controls the state of the game by varying global resources or specific exercise variables. This technique is generally used in racing games, as the Mario Karts game (Jonathan et al., 2012; Rietveld et al., 2015). The idea behind this technique is based on the manipulation of the available resources in the game, so that the performance of a player starts very limited, within a certain threshold. This technique challenges the players to overcome new tasks until they reach a maximum level, where the resources are fully available.

In addition to this approach, the flow model tends to be widely used (Schell, 2008). This model controls the resources and variables of the game according to the player's performance with the game platform. More specifically, this control is achieved by balancing the proposed challenge with the player's skills. The player is presented a repeating cycle of increasing challenges, until a threshold is reached and the player receives a reward or some new resources to motivate him/her to keep on playing. The flow model was defined as a generalized scheme and it is important to understand the game variables that affect the player's experience in order to define how to make the game progress.

Here we propose a dynamic difficulty adaptable scheme that follows the principles of the flow model. While some of the models described above may be appropriate for the specific game to which they were proposed, they may be inadequate for other applications. We use the proposed model in a serious game for speech therapy, but the model is suitable for other therapy games for voice pathologies. In this case, the player's experience should be maintained within the flow channel, through the influence of the variables relevant to therapy.

3 THE DYNAMIC DIFFICULTY ADJUSTMENT MODEL

The SV exercise consists of producing a vowel for as long as possible with a stable intensity level. The phonation time achieved during the SV exercise is an important measure of voice quality (Colton et al., 2011). It helps evaluating the child's ability to control the breathing while producing a sound at the requested intensity level. The analysis of this variable can be used both for assessing the individual's aerobic capacity and for vocal treatment, for example, for stabilizing the intensity of the sound produced (American Speech-Language-Hearing Association (ASHA), 2018). The repetition of the SV exercise helps children improve their maximum phonation time (MPT) and control their voice intensity and stability.

The proposed serious game implements the SV exercise and is controlled by the child's voice in real-time (Lopes et al., 2016). The game's goal is to make the main character reach a target. In order to make the main character move, the child has to produce a sustained vowel while achieving the expected values for the speech parameters of interest to the therapy exercise: the phonation time and the intensity level.

The current version offers several scenarios with child appropriate themes that aim to keep the children interested and comfortable, so that they see the therapy not as a hassle but as a fun and challenging experience. Some of the scenarios are illustrated in figure 1. As an example, in the top left scenario, the submarine should reach the crab with the gift, and in the bottom left scenario, the boat should reach the gift in the island.

The proposed game allows the SLP to parameterize the expected MPT, that is, the MPT that the child should reach, and which we call MPT_e. During the gameplay, MPT_e is the time that the main character needs to move (walk, fly, swim, etc.) to reach the game target. The game offers five different possible values for MPT_e: 2, 4, 6, 8 and 10 seconds as the MPT estimated for children is 10 seconds (Prater and Swift, 1995). We use the expression $MPT_e(r)$ to refer to MPT_e of trial run r. The MPT achieved by the child at trial run r is called $MPT_a(r)$. For simplicity, we sometimes refer to these functions simply as MPT_a and MPT_e.

Depending on the pathology, the child may need to train the SV exercise with a low, medium or high intensity. Children who usually speak very low, must train speaking at higher intensities, whereas children who tend to increase the volume and, as a consequence, strain their vocal cords, must practice speaking at softer intensities. In order to correct these behaviors, children can practice the SV exercise with a low, medium or high intensity, according to their needs.

The game allows the SLP to choose the intensity level to be practiced from three possible values (one value for low intensity, one for medium and another for high intensity) (Lopes et al., 2016). We call this the expected intensity level (or expected loudness), L_e.

The child may have difficulties in stabilizing at the requested intensity and obviously, it is not expected that the child achieves a perfectly constant intensity level. Thus small variations in intensity should be allowed and it is essential to establish the allowed variation interval. Our model uses a minimum and maximum threshold, L_m and L_M, around L_e to define this interval:

$$\Delta L = [L_m, L_M], \tag{1}$$

where $L_e \in [L_m, L_M]$. We use the expressions $\Delta L(r)$ and $L_e(r)$ to refer to the intensity level interval and expected intensity of trial run r, but we will often drop the variable r for simplicity.

While the game's first version used a fixed ΔL size (Lopes et al., 2016), we now defined three intensity level intervals for ΔL, such that different difficulty levels use different intensity interval sizes ($\Delta L^n = [L^n_m, L^n_M]$ with $n \in \{1,2,3\}$). The lowest difficulty level allows the widest ΔL, while the highest difficulty level allows the narrowest ΔL.

Figure 1: Some scenarios in the sustained vowel game.

Table 1: Allowed intensity levels and intensity interval sizes in dB (SPL).

intensity level	L_e	L_m^1	L_M^1	L_m^2	L_M^2	L_m^3	L_m^3
high	85	80	90	70	100	50	100
medium	60	50	70	47.5	75	45	80
low	40	35	45	30	50	30	55

The game's difficulty depends on MPT_e and ΔL. Combining the different possibilities for the values of MPT_e and ΔL sizes, the game offers 15 different difficulty levels (for each L_e, that is, for the low, medium and high intensity values). Table 1 shows the possible values for L_e and the allowed intensity intervals, which were chosen with the help of an SLP and related work (Fox and Boliek, 2012). Note that the expression $\Delta L(r) = \Delta L^n$ means that trial run r uses the n-th intensity level interval size.

The game's current version offers the option of adapting the game's difficulty manually or automatically. In the latter case, the SLP chooses the initial difficulty level (defined through an initial value for MPT_e and an initial ΔL), and afterwards the game runs an algorithm for adapting the difficulty level before each new trial, that is, the game adapts the values of MPT_e and ΔL dynamically. For this algorithm we propose a new dynamic difficulty adjustment model. The main goal of the automatic adaptation of the difficulty is to keep the child motivated on playing.

Difficulty adjustments should take into account the player's performance, and the player's performance should be a measure of the parameters to be improved in therapy: the maximum phonation time and the voice's intensity and stability. If the child achieves the expected values for these parameters, the child is ready to access a more demanding level, with more ambitious expected values. Otherwise, if the values achieved are lower than what is expected, it means that the child had a poor performance in the game and the challenge difficulty should be decreased.

Below we first discuss a simple adaptation model that measures the child's performance only in terms of the MPT achieved by the child (section 3.1), and then we discuss the proposed DDA model, which is a more complete model that measures performance both in terms of the achieved MPT and speech production intensity stability (section 3.2).

3.1 Maximum Phonation Time

It is intended that during the task the child obtains $MPT_a(r) = MPT_e(r)$. If the child is not be able to reach the expected MPT (because $MPT_a < MPT_e$), the main character will not reach the target. If this happens for several trials, the child can feel frustrated with the game. In these situations, the child's achieved performance is below the expected performance. Thus, it is important to define a lower value for MPT_e to avoid having a frustrated child.

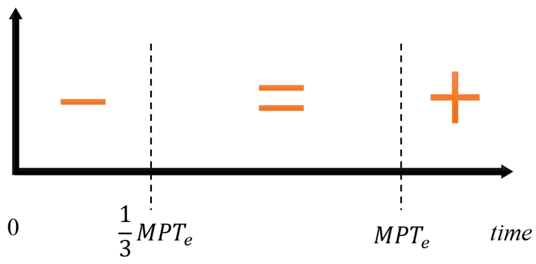

Figure 2: Scheme for updating MPT_e. The difficulty level should be decreased (− region), maintained (= region), or increased (+ region).

On the other hand, if the child is achieving a positive performance, that is, obtaining $MPT_a = MPT_e$ in successive trials, she may be ready for a higher difficulty level, since she has already stabilized the aerobic capacity requested for the respective degree of difficulty.

It is important to define when to decrease or increase MPT_e. There are situations in which the child achieves MPT_e and we should not increase the expected MPT immediately. A difficulty level enhancement should be difficult to achieve in order for the child to stabilize his performance with the current degree of difficulty. On the other hand, a lower level should be easier to achieve to avoid frustration when the level is not appropriate to the child's ability. Also, if the child fails once, it is not necessarily good to decrease MPT_e immediately. In some cases, we should give the child another chance and let him try again. For instance, if the child does not reach MPT_e but $MPT_e - MPT_a$ is small, we should let him try again. However, if $MPT_e - MPT_a$ is large, we should soon decrease the value of MPT_e. We use a threshold of $\frac{1}{3}MPT_e$. This scheme is represented in figure 2 and can be summarizes as follows:

1. If $MPT_e < MPT_a$ we will shortly increase MPT_e but first we let the child play a few more trials with this MPT_e so that the child stabilizes his performance with the current MPT_e.
2. If $\frac{1}{3}MPT_e < MPT_a \leq MPT_e$ we let the child try again a few more trial runs before changing MPT_e.
3. If $MPT_a \leq \frac{1}{3}MPT_e$ we will soon decrease MPT_e. The achieved MPT was much smaller than the expetect MPT, which means that the exercise is too difficult for the child with this MPT_e value.

In order to define when and how to change MPT_e, we use a cumulative value that measures the time-evolving maximum phonation time performance, $P_{MPT}(r)$, where r represents the trial run. The value of P_{MPT} increases (that is, $P_{MPT}(r) > P_{MPT}(r-1)$) when the child has a good performance, and decreases otherwise. We increase or decrease the value of MPT_e by 2 seconds depending on the value of P_{MPT}. P_{MPT} of the current trial r is updated as follows:

$$P_{MPT}(r) = \begin{cases} P_{MPT}(r-1) + MPT_a(r), & if\ MPT_e(r) \leq MPT_a(r) \\ P_{MPT}(r-1) - \frac{MPT_e(r)}{MPT_a(r)}, & if\ \frac{1}{3}MPT_e(r) < MPT_a(r) \\ & \leq MPT_e(r) \\ -\frac{1}{3}MPT_e(r), & if\ MPT_a(r) \leq \frac{1}{3}MPT_e(r) \end{cases} \tag{2}$$

with $P_{MPT}(0) = 0$ (the initial value of P_{MPT} before the start of the first trial).

In addition to defining the function's behavior, it is necessary to establish the limits between which the P_{MPT} may vary before there is an update of the value of MPT_e. The interval $]-\frac{1}{3}MPT_e(r), 2MPT_e(r)[$ determines the possible variation for $P_{MPT}(r)$. Thus,

$$MPT_e(r+1) = \begin{cases} MPT_e(r) - 2, & if\ P_{MPT}(r) \leq -\frac{1}{3}MPT_e(r) \\ & \wedge MPT_e(r) \geq 4 \\ MPT_e(r) + 2, & if\ P_{MPT}(r) \geq 2MPT_e(r) \\ & \wedge MPT_e(r) \leq 8 \\ MPT_e(r), & otherwise \end{cases} \tag{3}$$

Note that when the level change is reached, the current performance is reset, that is, it is reduced to 0. Thus, we add the following first line to equation 2:

$$P_{MPT}(r) = \begin{cases} 0, & MPT_e(r-1) \neq MPT_e(r) \\ & \vee r = 0 \\ P_{MPT}(r-1) + MPT_a(r), & if\ MPT_e(r) \leq MPT_a(r) \\ P_{MPT}(r-1) - \frac{MPT_e(r)}{MPT_a(r)}, & if\ \frac{1}{3}MPT_e(r) < MPT_a(r) \\ & \leq MPT_e(r) \\ -\frac{1}{3}MPT_e(r), & if\ MPT_a(r) \leq \frac{1}{3}MPT_e(r) \end{cases} \tag{4}$$

3.2 Speech Intensity Level

While it is important to consider the MPT_a by the child at trial run r to decide the value of MPT_e of the next trial, it is also important to consider how the speech production intensity varies during the trial. When the game starts, the SLP chooses an appropriate expected intensity level, L_e. While performing the SV exercise, one must keep the intensity level as stable as possible and as close to L_e as possible. Thus,

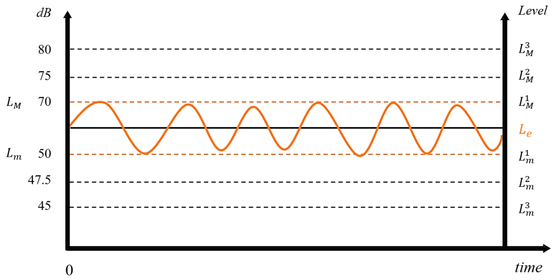

Figure 3: Allowed variation intensity level intervals, ΔL. The figure illustrates a case with $L_m = 50$ dB, $L_M = 70$ dB, and $L_e = 60$ dB. The orange line illustrates the time-varying speech intensity level achieved by the child, $L_a(t)$.

the sound intensity level achieved by the child, L_a, is one of the variables measured by our algorithm.

The intensity of the speech production, L_a, is allowed to fluctuate within the interval ΔL. The speech intensity level achieved by the child is a time-varying function, $L_a(t)$ (figure 3). During the game, the main character moves towards the target, exclusively, when the speech production intensities ($L_a(t_0)$, $L_a(t_1)$, $L_a(t_2)$, ...) are within the defined thresholds, that is, within ΔL.

As explained above, different difficulty levels use different intensity interval sizes ΔL. Figure 3 illustrates the three allowed interval sizes. The first trial run always starts with the widest intensity interval size, $\Delta L(1) = \Delta L^3$.

Now let us analyze how the difficulty of the game changes in reaction to L_a, that is, how MPT_e and ΔL of the next trial are updated. Like in the previous section, here we also measure the child's performance to determine when to change the game's difficulty. There are several situations that we must take into account. (1) If the child is able to keep L_a within the expected limits during the whole trial run r, that is, if $MPT_e(r) \leq MPT_a(r)$ and $L_a(t) \in \Delta L(r)$, for all t, then the difficulty of the next trial run can increase by reducing the size of ΔL or increasing MPT_e. (1.1) Let us suppose that $\Delta L(r)$ is too wide (for instance, $\Delta L(r) = \Delta L^3$). In this case, before increasing MPT_e for the next trial, we should reduce the size of the intensity level interval, that is, if $\Delta L(r) = \Delta L^n$ then $\Delta L(r+1) = \Delta L^{n-1}$. (1.2) However, if $\Delta L(r) = \Delta L^1$, the narrowest interval size, then since the intensity interval size cannot be reduced anymore, to increase the difficulty of the next trial run, we can increase the size of MPT_e. (1.3) Another possibility is when we have a wide $\Delta L(r) = \Delta L^n$ but the child achieves an intensity variation within ΔL^{n-i}, with $i > 1$. In this case, we can make a bigger reduction on the size of ΔL.

On the other hand, (2) if the child registers a variation that exceeds the limits ($L_a(t) \notin \Delta L$, for a few t), his intensity levels are not stable. Note that, if the intensity variation is too discrepant, there is no point in having the child trying to achieve a long MPT and maintain or increase ΔL. It is preferable to reduce the expected MPT and have the child learn how to stabilize his voice for a shorter time.

$$P_{MPT}(r) = \begin{cases} 0, & MPT_e(r-1) \neq MPT_e(r) \\ & \vee r = 0 \\ P_{MPT}(r-1) + MPT_a(r), & if\ MPT_e(r) \leq MPT_a(r) \\ & \wedge \forall_t\, L_a(t) \in \Delta L^1 \\ P_{MPT}(r-1) - \frac{MPT_e(r)}{MPT_a(r)}, & if\ \frac{1}{3} MPT_e(r) < MPT_a(r) \\ & \leq MPT_e(r) \\ -\frac{1}{3} MPT_e(r), & if\ MPT_a(r) \leq \frac{1}{3} MPT_e(r) \\ & \wedge \exists_t\, L_a(t) \notin \Delta L^{n+1}, n < 3 \end{cases} \tag{5}$$

$MPT_e(r)$ is still defined by equation 3 but $P_{MPT}(r)$ is now defined by equation 5. Note that there are slight differences between the old definition of $P_{MPT}(r)$ (equation 4) and its new definition (equation 5).

In order to decide when to update ΔL we use another measure of performance that takes into account both the achieved MPT and intensity variation. We call this measure $P_{\Delta L}$:

$$P_{\Delta L}(r) = \begin{cases} 0 & if\ \Delta L(r-1) \neq \Delta L(r) \\ & \vee r = 0 \vee MPT_e(r-1) \neq MPT_e(r) \\ P_{\Delta L}(r-1) + \frac{1}{|\Delta L_a(r)|} & if\ MPT_e(r) \leq MPT_a(r) \\ & \wedge \forall_t\, L_a(t) \in \Delta L(r) \\ P_{\Delta L}(r-1) - \frac{|\Delta L_a(r)|}{|\Delta L(r)|} & if\ |\Delta L_a(r)| > |\Delta L^n| \\ & where\ \Delta L(r) = \Delta L^n \\ P_{\Delta L}(r-1) & otherwise \end{cases} \tag{6}$$

where $|\Delta L_a|$ measures the achieved intensity variation. $|\Delta L_a| = L_{amax} - L_{amin}$, where $L_{amax} \geq L_a(t)$ and $L_{amin} \leq L_a(t)$ for every $L_a(t)$ in trial run r. Note that if the difficulty level changes (because there is a reduction on the size of the allowed intensity interval or in the value of MPT_e) the performance $P_{\Delta L}$ is reset to 0. The performance $P_{\Delta L}$ increases for situation (1) above. On the other hand, it should decrease for situation (2) when $\Delta L_a(r)$ exceeds ΔL^n. Considering a trial, where the MPT_e increased, the $\Delta L(r) = \Delta L^1$. If the child experienced a bad performance during consecutive trials, the game should give the chance to try with the next larger ΔL. However, if the child's performance remains low, the P_{MPT} decrements and the MPT_e will decrease.

As mentioned above, the game starts with the widest interval size. Once the child starts to achieve a good performance with this interval size, the interval size decrements. As mentioned above, it is possible to have big decrements on the size of ΔL when the intensity variation achieved by the child is much smaller than $|\Delta L|$. On the other hand, once the child has reached the narrowest interval size (ΔL^1), it is possible to increase the difficulty level by increasing MPT_e. If with this new value of MPT_e the child's intensity variation is wider than $|\Delta L^1|$, then we increase the interval size a bit, to give the child some more time to stabilize his voice for this longer MPT. In this case, we increase the interval to ΔL^2 but we will not increase it further than that, because the child has already achieved a smaller interval size for a shorter MPT. The following expression reflects how and when to change ΔL:

$$\Delta L(r+1) = \begin{cases} \Delta L^2, & if\ \Delta L(r) = \Delta L^1 \wedge P_{\Delta L}(r) \leq 0 \\ \Delta L^{n-i}, & if\ \Delta L(r) = \Delta L^n \wedge P_{\Delta L}(r) > \frac{2}{|\Delta L(r)|} \wedge n > 1 \\ \Delta L(r), & otherwise \end{cases} \tag{7}$$

where i determines the size of the decrement on ΔL and is defined as follows: $1 \leq i \leq n-1$ and $i = n - n'$ where $|\Delta L_a| \leq |\Delta L^{n'}|$ and ($n' = 1 \vee |\Delta L_a| > |\Delta L^{n'-1}|$), with $n' < n$. For instance, if $\Delta L(r) = \Delta L^3$ and the child is able to make a correct sound production with $|\Delta L_a| \leq |\Delta L^1|$, then $\Delta L(r+1)$ can be updated to ΔL^1.

The proposed model was developed taking into consideration the variables in the therapy process relevant for the SV exercise. In cases in which the child's performance is low for a specific variable, the correspondent performance is decremented. Otherwise, if the child performs the exercise correctly, the variables' performances are positively updated.

Additionally, when the performance of a variable reaches a lower or upper boundary, the game's parameters related to that variable become easier or harder, respectively. This was done to try avoiding that the children's experience moves them out of the flow channel nor triggers a feeling of anxiety or boredom with the gameplay experience.

4 CONCLUSION

Different children can have different levels of a specific pathology and children of different ages may achieve different performances during their in-game experience. Therefore, it is desirable that the therapy games can be adjusted to each child situation. In response to these needs, we have previously proposed a serious game for voice pathologies that uses the SV exercise. The previous version of this game provides the possibility of manually adapting the difficulty, by allowing the SLP to choose the desired maximum phonation time and intensity level. Therefore, the SLP can customize the variables thresholds, according to the child needs.

Here we propose an automatic difficulty adjustment model that evaluates the child's performance in real-time and adjusts the state of the game variables dynamically. This model is used in our SV game and is suitable for games for voice pathologies. The model relies on the basic principles of the flow model. It measures performance based on specific parameters of interest to speech therapy and allows the fluctuation between tense and release moments, keeping the child engaged to hold on playing, while increasing her skills. This technique will allow different children to practice therapy exercises, repetitive and monotonous, in a motivating way that challenges themselves. Thus, it has the potential to help the SLP on creating a fun and relaxing environment that motivates children to practice therapy exercises repeatedly.

The proposed model uses the maximum phonation time and vocal intensity to measure the player's performance. These are the most relevant variables to the treatment of many dysphonia types. However, there are other sound features that may be extracted, analyzed and carefully included in a future extension of the model. The right correlation between all variables must be ensured, as well as the evolution of an efficient and enthusiastic child's learning curve in all of them, independently. Finally, in order to validate if the proposed DDA model enhances the child gaming experience and motivates the child to continue playing, as future work, we will run a user test in which children interact with the game using the proposed model.

ACKNOWLEDGEMENTS

This work was supported by the Portuguese Foundation for Science and Technology under projects BioVisualSpeech (CMUP-ERI/TIC/0033/2014) and NOVA-LINCS (PEest/UID/CEC/04516/2013).

REFERENCES

American Speech-Language-Hearing Association (ASHA) (2018). Voice Disorders: Treatment. Retrieved from https://www.asha.org/ in Jun/2018.

Bowen, C. (2015). *Childhood apraxia of speech*, page 343–350. John Wiley and Sons, L.td., 2 edition.

Carvalho, M. (2008). Interactive game for the training of portuguese vowels. M.Sc. thesis.

Colton, R. H., Casper, J. K., and Leonard, R. (2011). *Understanding voice problem: A physiological perspective for diagnosis and treatment: Fourth edition*, pages 202–205.

Demediuk, S., Raffe, W. L., and Li, X. (2016). An adaptive training framework for increasing player proficiency in games and simulations. *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts - CHI PLAY Companion '16*.

Duff, M. C., Proctor, A., and Yairi, E. (2004). Prevalence of voice disorders in African American and European American preschoolers. *Journal of Voice*, 18(3):348–353.

El Sharkawi, A., Ramig, L., Logemann, J. A., Pauloski, B. R., Rademaker, A. W., Smith, C. H., Pawlas, A., Baum, S., and Werner, C. (2002). Swallowing and voice effects of Lee Silverman Voice Treatment (LSVT®): A pilot study. *Journal of Neurology Neurosurgery and Psychiatry*, 72(1):31–36.

Eriksson, E., Balter, O., Engwall, O., Oster, A.-M., and Kjellstrom, H. (2005). Design recommendations for a computer-based speech training system based on end-user interviews. *2005 (SPECOM)*.

Fox, C. M. and Boliek, C. A. (2012). Intensive Voice Treatment (LSVT LOUD) for Children With Spastic Cerebral Palsy and Dysarthria. *Journal of Speech Language and Hearing Research*, 55(3):930.

Furlong, L., Erickson, S., and Morris, M. E. (2017a). Computer-based speech therapy for childhood speech sound disorders. *Journal of Communication Disorders*, 68:50–69.

Furlong, L., Erickson, S., and Morris, M. E. (2017b). Review: Computer-based speech therapy for childhood speech sound disorders. *Journal of Communication Disorders*, 68:50 – 69.

Guimarães, I. (2007). *A ciência e a arte da voz humana*. ESSA, 1 edition.

Hanks, H., Hanks, C., and Suman, M. (2018). Little Bee Speech. Retrieved from http://littlebeespeech.com/ in Dec/2018.

Jonathan, T., Bruno, B., and Abdenour, B. (2012). Understanding and implementing adaptive difficulty adjustment in video games. In *Algorithmic and Architectural Gaming Design: Implementation and Development*, chapter 5, pages 82–106.

Lan, T., Aryal, S., Ahmed, B., Ballard, K., Gutierrez-Osuna, R., Gutierez-osuna, R., and Texas, A. (2014). Flappy Voice: An Interactive Game for Childhood Apraxia of Speech Therapy. *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play*, 2(1):429–430.

Lopes, M., Magalhães, J., and Cavaco, S. (2016). A voice-controlled serious game for the sustained vowel exercise. In *Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology*, ACE '16, pages 32:1–32:6, New York, NY, USA. ACM.

Mota, L., Santos, C., Vasconcelos, J., Mota, B., and Mota, H. (2012). Applying the technique of sustained maximum phonation time in a female patient with adductor spasmodic dysphonia: a case report. *Revista da Sociedade Brasileira de Fonoaudiologia*, 17:351 – 356.

Oliveira, R., Teixeira, L., Gama, A. C., and de Medeiros, A. (2011). Análise perceptivo-auditiva, acústica e autopercepção vocal em crianças. *Jornal da Sociedade Brasileira de Fonoaudiologia*, 23(2):158–163.

Prater, R. J. and Swift, R. (1995). *Manual de Terapeutica de la voz*. Masson-Litle, Brown.

Rietveld, A., Bakkes, S., and Roijers, D. (2015). Circuit-adaptive challenge balancing in racing games. In *Conference Proceedings - 2014 IEEE Games, Media, Entertainment Conference, IEEE GEM 2014*.

Schell, J. (2008). *The Art of Game Design: A Book of Lenses*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.

Swart, B. J. D., Willemse, S. C., Maassen, B., and Horstink, M. W. (2003). Improvement of voicing in patients with parkinsons disease by speech therapy. *Neurology*, 60(3):498–500.

Tan, C. T., Johnston, A., Ballard, K., Ferguson, S., and Perera-Schulz, D. (2013). {sPeAK-MAN:} towards popular gameplay for speech therapy. In *Proceedings of The 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death*, page 28.

Tavares, E. L. M., Brasolotto, A., Santana, M. F., Padovan, C. A., and Martins, R. H. G. (2011). Epidemiological study of dysphonia in 4-12 year-old children. *Brazilian Journal of Otorhinolaryngology*, 77(6):736–746.

Tavares, J., Lopes, J., Cunha, M., and Saldanha, R. (2017). Falar a Brincar. Retrieved from https://falarabrincar.wordpress.com in Sep/2017.

Yun, C., Trevino, P., Holtkamp, W., and Deng, Z. (2010). PADS: Enhancing Gaming Experience Using Profile-Based Adaptive Difficulty System. In *Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games - Sandbox '10*, pages 31–36.