

An Online Chess Game Designed for People with Dyslexia

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ABSTRACT

Teaching chess to students with learning disabilities has been shown to benefit their school performance in unrelated domains. At the same time, chess involves skills that are highly correlated with dyslexia, such as visuospatial and calculation abilities. In this paper, we created an online chess game designed for people with dyslexia and seek to understand whether people with dyslexia learn and play chess online in ways that differ from other students and whether such differences may be leveraged to improve classroom performance. To test how people with dyslexia learn to play chess we carried out a within-subject experiment with 62 participants, 31 of them with diagnosed dyslexia. Participants used an instrumented web-based chess learning platform that we developed to (i) complete lessons on how to play chess and about chess theory, (ii) work through exercises designed to test and reaffirm their skills, and (iii) play chess against a computer opponent. We could not find significant differences on four dependent measures out of the twelve measures we collected. Therefore, dyslexia might have an impact on how people learn and play chess using a computer, suggesting that chess may be useful as a fun way to help people with dyslexia improve their abilities.

Keywords

Dyslexia; Serious Games; Chess

Categories and Subject Descriptors

K.4.2 [Computers and Society]: Social Issues—*Assistive technologies for persons with disabilities*; K.3 [Computers in Education]: Computer Uses in Education—*Computer-assisted instruction*.

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1. INTRODUCTION

Dyslexia is a specific learning disorder that is related to school failure and obstructs many daily activities, most notably reading [16, 26]. Lyon *et al.* made a comparison of the definitions of dyslexia and reached to the following definition of dyslexia: “Dyslexia is defined as a specific learning disability with neurological origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. [...] Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge [31].” Overcoming dyslexia means a great effort for children and requires undertaking regular training [23]. Dyslexia is frequent. From 10 to 17.5% of the population in the U.S.A. [25] and from 8.6% to 11.8% of the Spanish speaking population [37] have this disability.

Why Chess? Chess instruction can impact learning in domains beyond chess itself. For example, chess instruction helped 92 French speaking students to measurably improve their verbal ability [13]. The mechanism for this transfer is not well understood but chess may be particularly well matched to dyslexia because learning chess involves skills that are neurologically related with dyslexia, such as visual and spatial abilities [14, 15, 47], calculation ability [2, 7, 41] and executive functions [11, 21, 35], *e.g.* attention, planning and problem-solving.

Why a Computer Game? This presents a computer based chess game for people with dyslexia and how people with dyslexia learn to play chess online in comparison with a control group. Games have the potential to provide engaging exercises that improve the reading performance of children with dyslexia [29, 32]. Even computer games that do not specifically address reading skills can benefit children with dyslexia. For instance, playing action computer games increased the spatial and temporal attention of 20 children with dyslexia resulting in significantly improved reading skills [12]. Chess is particularly interesting for investigation because it is both a game and requires many of the same skills addressed in dyslexic training.

If people with dyslexia learn and play on-line chess differently, it would suggest that computer-based chess could be targeted for dyslexia. With this goal in mind, we designed a game to learn chess on-line and carried out a within subject experiment with 62 people, 31 with diagnosed dyslexia, to explore, for the first time, how people with dyslexia learn and play chess. For some of the dependent measures we gathered, results show differences between groups on chess

training exercises as well as in chess playing. This suggests that dyslexia has an impact in on-line chess training, and that chess skills might be related to dyslexia and potentially used in education as it has been already done with other cognitive disabilities [2, 41, 44].

Next, we describe related work, then the design of the chess game in relationship with dyslexia related skills. Then we explain the methodological design of the study. Later, we present and discuss the results followed by the conclusions.

2. RELATED WORK

There are an extensive number of studies that explore in different ways the following research question: “Can a set of skills acquired in a specific domain (in our case, chess) generalize to other domains (e.g., mathematics, reading) or to general abilities (e.g., reasoning, memory)?” [19]. On one hand there are studies that support that transfer is a function limited to tasks that share cognitive elements [1, 42]. On the other hand, it was suggested that transfer abilities depend on intelligence [43]. With these considerations in mind we divide related work on studies about chess and education, learning disabilities, and dyslexia.

2.1 Chess and Education

Gobet and Campitelli [19] and later Bart [3] made a review of the studies that explore the possible transfers of chess in education suggesting that chess instruction provides educational benefits.

Frank [13] conducted a study in Zaire with 92 teenagers (16 to 18 years old) that were randomly allocated either to a compulsory chess group or to a control group. The chess group met for an hour twice a week over one year. Instruction included lectures, tests, simultaneous games, and practice. The study explored whether efficacy and the influence of learning chess in several cognitive aptitudes, including spatial ability, perceptual ability, reasoning, creativity, and general intelligence. The participants were administered 18 post tests¹ The experimental group performed better than the control group on “numerical aptitude” and “verbal ability.” However, the results regarding “numerical aptitude” shall be taken with care because “numerical aptitude” predicts chess skills itself and second the differences were not due to an improvement of the experimental group but by a descend on the numerical aptitude of the control group. So only “verbal ability” was convincingly influenced by chess instruction.

Christiaen and Verhofstadt-Denève [9] carried out a study with 20 fifth-grade Belgian students plus a matched control group. During 42 weeks the chess group received one hour a week of chess instruction. The students were administered three tests.² No effects were found on the performance in the tests. The only effect was found with school scores (higher for the experimental group); however, the authors warns of a possible unwanted contamination from the teachers.

Fried and Ginsburg [15] explored the effects of chess instruction on the development of perceptual ability, visuospatial ability, and attitude towards school. The authors carried out a study with 34 and 35 children with mild learning

¹The *Primary Mental Abilities Test*, the *General Aptitude Tests Battery*, the *Differential Aptitude Test*, the *D2 test* and the *Rorschach test* [14].

²The *Piaget’s Balance and Liquid tests* and the *PMS (aptitude tests for orientation purposes)* [9].

and behavior problems (fourth and fifth grade) from Brooklyn, New York. Each participant was randomly assigned to one of three groups: chess, counseling (which was used as a placebo group), and no-contact. Chess instruction consisted of lectures, demonstrations and games. After 18 weeks, the participants were administered three tests to measure perceptual and visuospatial abilities³ and a survey of school attitudes. No difference was found between the three groups.

In summary, results weakly support transfer from chess instruction in population without cognitive or learning disabilities.

2.2 Chess and Learning Disorders

Similar to the studies with general population, results of the studies that explore the impact of chess and learning disorders are more promising [3].

Hong and Bart [22] studied the impact of chess instruction in the cognitive abilities on 38 students at risk of academic failure. The analysis found no significant differences between the cognitive changes registered by the treatment group and the control group. However, the authors found that the chess ratings of the group who played chess correlated with the *Test of Nonverbal Intelligence* [6], indicating that high chess ratings contributes to the improvement of cognitive skills.

Scholz *et al.* [41] measured the impact of chess training on the concentration and calculation abilities with 31 German children with learning disabilities based on lower intelligence (IQ 70-85). The experimental group was randomly assigned to receive one hour of chess lessons instead of one hour of regular mathematics lessons per week for the duration of one school-year. While the author could not find any effects on the concentration abilities between groups, calculation abilities for simple addition tasks and counting improved significantly for the group that took chess classes.

Barrett and Fish [2] investigated the cognitive effects of a 30-week chess-training program within mathematics classes with 31 students in special education in a middle school in southwestern United States (sixth, seventh and eighth grades). The participants were randomly placed into two groups: one receiving the chess instruction along a portion regular mathematics instruction; and one that received all of the regular mathematics instruction and none chess instruction. The students undertook a standardized test of mathematics competencies⁴ and mathematics course grades were also recorded. The authors found a significant relationship between chess instruction and end-of-year grades. Second, there was a statistically significant relationship between chess instruction and mathematics test scores.

In conclusion, studies on chess training and students with learning disabilities present positive results, supporting the idea of using chess training to promote higher-order thinking skills among disabled students [44].

2.3 Chess and Dyslexia

To the best of our knowledge the only study that relates chess and dyslexia is a recent one by Estaki *et al.*[11]. The

³The “figure completion” subtest of the revised version of the *Wechsler Intelligence Scale for Children* for measuring perceptual ability, and the “block design” subtest of the same test for measuring visuospatial ability [15].

⁴A version of the *Texas Assessment of Knowledge and Skills* modified for special education students [2].

authors analyse the behaviour of 12 students with dyslexia (second grade) from elementary schools in Iran. The children played chess for 3 months (24 sessions, one hour a day, 2 days a week). The authors used pre and post tests⁵ to measure the following executive functions: attention, planning and problem-solving. There was not found any significant relation between chess training and planning and problem-solving. There was found a significant relation between training of chess and attention. However, this study lacks of a comparison with control group nor a control condition, the experimental group is small, and it is not stated how the authors controlled that the participants had dyslexia.

2.4 Our Approach

We have created a game designed for people with dyslexia taking into account both the content and the interface design of the chess game. Given that it is not clear whether skills acquired by chess lessons are transferable to other domains related to dyslexia, this study addresses a fundamental research question before addressing potential skill transference: Do people with dyslexia learn to play on-line chess differently?

To the best of our knowledge it is the first time that both populations are compared regarding on-line chess training, including playing against a computer opponent.⁶

3. CHESS GAME DESIGN

This section explains the different criteria we followed to create the content and the interface design of the chess game. We relate the skills needed for each lesson part with previous studies on dyslexia.

3.1 Content Design

Given chess complexity, the content design of the lesson aimed an efficient and direct approach to chess. Hence, we followed two criteria: (1) the classic method to teach chess by Kulaç [27, 28] from the Fédération Internationale Des Échecs (World Chess Federation); along with (2) the expertise of a professional chess player (top 5% in the world)⁷

The full instruction game is composed of 9 lessons. The goal of each lesson is to learn how each piece moves gradually as well as chess strategies.

- Lesson 1: Board & pawns
- Lesson 2: Coordinates & bishop
- Lesson 3: Rooks
- Lesson 4: Queen
- Lesson 5: King & typical queen-rock-bishop mates
- Lesson 6: Knights

⁵The tests used were the *Executive Functions Evaluation Scale (Wisconsin (WCS))* and *Executive Functions Evaluation Scale (Tower of London Test)* [11].

⁶Previous studies have focused on the impact of face-to-face chess lessons on students [19, 3, 11].

⁷Sergi Subirats, second author of this paper. The following URL shows the world position of Subirats according to Fédération Internationale Des Échecs (World Chess Federation). <http://ratings.fide.com/card.phtml?event=2292475>

- Lesson 7: Practice exercises
- Lesson 8: Test your knowledge! (Review of all the previous lessons)
- Lesson 9: Pieces value activity (basic strategic movements)

Each of the lessons was designed for a 30-45 minutes session. At the end of the lesson the players can play against the machine to practice what they have learnt. Each of the lessons are structured as follows.

Lesson Structure.

1. **Theory:** The first part explains the theoretical background of the lesson. Similarly to instructional chess books [27, 28] this part combines text and figures. For instance in Figure 1 it is shown how the squares are identified on the chessboard according to the official system of coordinates defined by the (World Chess Federation). During this part the user has to answer questions about the content of the lesson to check that it is understood.

Since this part of the lesson requires reading and comprehension, it is related to the difficulties of dyslexia. On one hand dyslexia has been defined by a reading disability [46]. On the other hand, poor comprehension is not directly related with dyslexia. Dyslexia is related to decoding and not to problems in oral or listening comprehension [10], that is, poor comprehension is caused by decoding mistakes, such as word recognition.

2. **Exercises:** The design of the exercises are based on classic methodology to learn how to play chess. The exercises target different skills needed to play chess. There are four types of exercises. For each exercise the player has five tries before the next one.

- (a) *Square Exercises:* in this task the player has to click on a certain square of the chess board. The square is either directly named by its coordinates on the board or indirectly by specifying it as the result of moving a given piece.
- (b) *Color Exercises:* the player is asked to identify the color of the square (black or white) where a certain piece is located or a move takes place.
- (c) *Piece Exercises:* the player is asked to identify whether there is -or will be after a move- a piece in a certain square of the board.
- (d) *Moving Pieces Exercises:* in this task the player has to move pieces on the board. Different exercises are defined depending on the piece. For instance, in Figure 1 we show the Pawn Race designed for this lesson. Depending on the lesson the move included famous chess openings and moves [28, 27].

These exercises require other skills that have been found to be related with dyslexia. These are visuospatial attention [45, 47] and numerical ability [17, 7].

3. **Playing:** We implemented an algorithm that plays elementary chess so the user can play a game against



Figure 1: Screenshots of the *Theory* part of the lesson (left) and of the *Move* exercises (right).

the machine practicing the piece movements of the lesson. For instance, in Figure 1 we show a chess game of lesson 1 where the player plays only using the pawns.

This part of the lesson is related to executive function because it required planning and predicting two piece movements ahead. Executive function is widely studied in correlation with dyslexia [5, 21, 35], such as ability of attention, planning and problem-solving.

3.2 Interface Design

Text presentation has a significant effect on the readability of people with dyslexia [20, 36]. To ensure the readability for this target group, we took into consideration previous studies in accessibility research. The column width was not wider than 60 characters per line, the text was presented in black on creme background using *Arial* typeface with a minimum font size of 14 points [4, 38].

To ensure usability, we made two design iterations of the interface based on the feedback of two pilot tests using the think-aloud protocol [30], with 3 adults and 4 children during their regular chess classes.

4. METHODOLOGY

To study the effect of dyslexia on learning and playing chess with a computer we conducted a study with 62 participants, 31 of them with diagnosed dyslexia. The participants first completed a chess lesson on-line. Using a within-subjects design, we compared the evolution of the groups taking mouse tracking measures as objective data as well as their subjective perceptions via questionnaires.

4.1 Design

In our study design, *dyslexia* served as an *independent variable* with two levels: having diagnosed dyslexia or not. The participants completed the first lesson of a computer-based chess instruction game that we designed for this purpose. See designed details in Section 3.

4.2 Participants

We recruited 64 participants, 32 of them with diagnosed dyslexia. The participants were asked to prove that they were diagnosed by a hospital or specialised center. Since attention-deficit disorder (ADD) and attention-deficit hyperactivity disorder (ADHD) are comorbid [18]⁸ with dyslexia and attention play an important role in chess, we controlled that none of the participants had ADD nor ADHD.

The average age of the participants with dyslexia was 20.44 with a standard deviation of 1.44, and their age ranged from 10 to 44 years old. The age of the participants without dyslexia ranged from 9 to 52 ($M = 22.66, SD = 14.50$). There were 17 male and 15 female participants with dyslexia and 15 male and 17 female participants without dyslexia.

They all had experience playing computer games; 15 did not know how to play chess (8 with dyslexia, 7 without dyslexia), 23 participants knew the movements of the pieces but had hardly ever played chess (10 with dyslexia, 13 without), 21 of them sometimes played chess (11 with dyslexia and 10 without) and 5 played chess very frequently (3 with dyslexia and 2 without). Regarding education, 9 participants finished primary education (5 with dyslexia and 4 without), 31 finished high school (16 with dyslexia and 15 without), 6 finished college (5 with dyslexia and 4 without), 6 finished university (2 with dyslexia and 4 without) and 9 had professional education (4 with dyslexia and 5 without).

⁸Comorbidity indicates a medical condition (in this case ADD and ADHD) existing simultaneously but independently with another condition (dyslexia).

4.3 Dependent Measures

For quantifying the performance and the perceptions of the participants we defined twelve *dependent measures* extracted either via mouse tracking data or questionnaires.

Objective Measures

We measured the interaction time of the participants using milliseconds. For gathering the mouse tracking data we recorded the mouse clicks and whether the mouse was over the defined elements in the lesson, *i.e.* the chessboard or specific chessboard squares.

For measuring the performance of **Theory** we used:

- *Theory Time*: This measure records the time in seconds that the participant spends reading the text and understanding the lesson. The text is on the screen until the participant clicks the *Next* button.
- *Answer Accuracy*: A Boolean value to indicate whether the correctness or incorrectness of the answers given to questions about the chess theory.

For measuring the performance of the **Exercises** we defined the following dependent measures:

- *Exercise Time*: Time in seconds that the participant spends to complete the exercise. The time starts counting when the user moves the mouse over the chess board only. In this way we discard the time that the participant spends solving the exercise itself, such as reading the instructions.
- *Number of Squares*: Number of squares that the mouse of the participant goes through the chessboard during the exercise.
- *Number of Tries*: Number of tries that the participant uses until finding the correct answer or running out of chances (five tries per exercise).
- *Time to First Try*: Time that the participant spends before submitting the first try of the exercise.
- *First Try Correct*: A Boolean value to indicate whether the first attempt to solve the exercise was correct.

For measuring the performance of **Playing** we used:

- *Game Time*: Time in seconds that the participant spends to complete the chess game.
- *Number of Movements*: Number of movements that the participant makes during the chess game.
- *Time to First Move*: Time that the participant spends before making the first move on the game.
- *Game Score*: A Boolean value to indicate whether the participant wins the game.

Subjective Measures

Subjective measures were gathered by self-report questionnaires using 5-point Likert scales.

- *Subjective Performance*: The participants rated how well they think they did the chess tasks. The scores range from 1 = *Very bad* to 5 = *Very good*.

- *Subjective Impact of Dyslexia*: The participants with dyslexia were asked to rate whether they believe if dyslexia had an impact on playing chess. On a 5-point Likert scale, participants rated to which extent dyslexia interfered with their chess skills. The scores range from 1 = *Dyslexia interferes negatively* to 5 = *It does not interfere at all*.

4.4 Materials

All participants completed (1) a demographic questionnaire, (2) a questionnaire that collected the subjective ratings; and (3) an on-line chess lesson (Section (3)). The lesson was implemented on a web page and consisted of 28 slides: 4 of theory, 2 with one question each, 21 exercises, and 1 interface in which the participant played chess against the computer.

4.5 Procedure

The participants took the lessons at their homes using their own computers that they already use and are comfortable with. The session took around 30 minutes and the first author was on-line to help them understand the tasks so the participants did not experience more learning stress than minimal. Each participant performed the following three steps. After submitting the on-line consent form, they began with a questionnaire that was designed to collect demographic information. Second, the participants were given specific instructions and completed each of the steps of the lesson: theory, exercises and practice (chess game). While they answered the questions and the exercises they could not go back to previous content. They were asked to complete the lesson without any interruptions with the exception of a break that was placed in the middle of the experiment. Finally, they were asked to complete a questionnaire with their subjective ratings.

5. RESULTS

In the first step we cleaned up the data. One person turned out to be gifted (with dyslexia, 15 years) and clearly outperformed the rest of the participants (for instance, she finished the chess game 6.03 times faster than the average). We omitted her data in order to not bias the results. Thus, our quantitative results reflect the data of the remaining 63 participants. To test for significant differences between groups, we used matched-paired t-tests for parametric data and dependent 2-group Wilcoxon Signed Rank test for non-parametric data.⁹ We used Shapiro-Wilk tests to determine whether each variable was normally distributed or not. For the Likert scales we used non-parametric tests [8]. We used the R Statistical Software 2.14.1 [34] for our analysis, using the standard value of $p < 0.05$ as threshold for significant results. Table 1 summarises the scores for all dependent variables.

5.1 Learning Chess Theory

We found a significant effect on the *Theory Time* between groups ($t(2.52) = 160.58$, $p = 0.013$). Participants with dyslexia presented higher mean times while reading the

⁹To handle missing values in the repeated measures statistical tests, we filled the gap with “NA” (not available) value. In R Statistical Software 2.14.1, NA is a placeholder specially defined for this purpose.

Dependent Variable	Participants with Dyslexia			Participants without Dyslexia			Significance
	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>M</i>	<i>SD</i>	<i>Mdn</i>	
Theory / <i>Theory Time</i>	25.53	33.73	14.63	17.33	13.68	13.68	$p = 0.013$
Theory / <i>Answer Accuracy</i>	95.16%	19.81	100%	93.94%	24.23	100%	$p = 0.987$
Exercise / <i>Exercise Time</i>	15.31	15.55	11.06	12.72	14.37	9.03	$p < 0.001$
Exercise / <i>Number of Squares</i>	25.34	26.24	17	19.85	18.48	14	$p = 0.003$
Exercise / <i>Number of Tries</i>	1.29	0.81	1	1.22	0.68	1	$p = 0.271$
Exercise / <i>Time to First Try</i>	12.89	11.51	10.03	11.198	11.45	8.75	$p < 0.001$
Exercise / <i>First Try Correct</i>	84%	37.0	100%	86%	35.0	100%	$p = 0.256$
Playing / <i>Game Time</i>	89.89	63.17	71.13	63.70	27.39	59.40	$p = 0.051$
Playing / <i>Number of Movements</i>	9.86	4.07	9	10.30	3.57	11	$p = 0.644$
Playing / <i>Time to First Move</i>	34.46	28.94	27.90	24.83	14.02	20.68	$p = 0.255$
Playing / <i>Game Score</i>	66%	48.0	100%	79%	42.0	100%	$p = 0.250$
<i>Subjective Performance</i>	3.66	0.90	3.5	3.72	0.73	4.0	$p = 0.672$
<i>Subjective Impact of Dyslexia</i>	2.43	1.45	2	na	na	na	na

Table 1: Means, medians and standard deviations for the comparisons between groups on the objective measures. Times are presented in seconds; “na” refers to not applicable.

theory about chess than participants without dyslexia (Table 1). We did not find a significant difference between the groups regarding their *Answer Accuracy* ($W = 510.50$, $p = 0.987$). Participants with and without dyslexia answered correctly 95.16% and 93.93% of the questions, respectively. Hence, we are not able to tell whether having dyslexia affected the answer accuracy.

5.2 Doing Chess Exercises

All Exercises. Between groups we found a significant effect on the total time to complete the exercises *Exercise Time* ($W = 232764.5$, $p < 0.001$); the *Number of Squares* tracked over the board ($W = 58924.5$, $p = 0.003$), and *Time to First Try* ($W = 218847$, $p < 0.001$). Participants with dyslexia spent more time on the board, went over a greater number board squares with the mouse, spent more timing until they performed the first try and spent more time on the exercises that participants without dyslexia.

We could not find effects for the *Number of Tries* ($W = 205536.5$, $p = 0.271$) nor for *First Try Correct* ($W = 196440.5$, $p = 0.256$). This means that belonging to a certain group –with or without dyslexia– did not have a significant effect on the number of tries and the number of correct answers at first try in the exercises.

Square Exercises. Between groups we found a significant effect on the time spent on the board (*Exercise Time*, $W = 56139.5$, $p = 0.010$), the *Number of Squares* tracked over the board ($W = 58924.5$, $p < 0.001$), the *Number of Tries* ($t(2.12) = 585.87$, $p = 0.035$), and the *Time to First Try* ($W = 54106.5$, $p = 0.022$).

Color Exercises. Between groups we only found a significant effect for the *Time to First Try* ($t(2.12) = 200.68$, $p = 0.035$).

Piece Exercises. Between groups we found a significant effect on the *Time to First Try* ($W = 20730.5$, $p = 0.001$), and the time to complete the exercise *Exercise Time* ($W = 22092.5$, $p < 0.001$).

Moving Pieces Exercises. Between groups, we could not find effects for the *Number of Squares* tracked over the

board ($W = 525.5$, $p = 0.855$), respectively. Similarly, we could not find effects on time spent to perform the first movement (*Time to First Move*, $W = 601$, $p = 0.085$). However if we take into consideration the *Exercise Time* there was an effect between groups ($W = 684$, $p = 0.020$). Participants with dyslexia, spent more time on solving the exercises ($M = 17.56$, $Mdn = 13.91$, $SD = 12.35$) than participants without dyslexia ($M = 13.33$, $Mdn = 9.26$, $SD = 10.49$).

5.3 Playing Chess

Between groups, we found a significant effect on the time spent on the board playing chess against the computer, *Game Time* ($W = 597$, $p = 0.051$).

However, we could not find effects on the *Number of Movements* tracked over the game ($W = 445.5$, $p = 0.644$). Similarly, we could not find differences between groups regarding the *Time to First Move* ($W = 523$, $p = 0.255$), nor for the *First Try Correct* ($W = 415$, $p = 0.250$). This means that having dyslexia only had a significant effect on the time playing against the computer.

5.4 Subjective Ratings

Subjective Performance. We could not find significant effects on the *Subjective Performance* between groups ($W = 482$, $p = 0.672$). Participants with and without dyslexia rated their performance similarly, ($M = 3.66$, $Mdn = 3.5$, $SD = 0.90$) with dyslexia and ($M = 3.72$, $Mdn = 4.0$, $SD = 0.73$) without dyslexia.

Subjective Impact of Dyslexia. Most of the 32 participants with dyslexia believed that dyslexia did not interfere on their chess skills, 40% chose option 5 and 13.33% of them chose option 4 on the Likert scale. Almost a quarter of the participants were ambivalent (23.33%); 10.00% (option 1) and 13.33% (option 2), which means that they believed that dyslexia negatively interferes on their chess skills.

6. DISCUSSION

When learning chess **Theory** participants with dyslexia spent significantly more time. This can be explained be-

cause this theoretical part of the lesson is composed by text and figures; people with dyslexia read significantly slower than people without dyslexia [16]. In fact, reading speed is one of the strongest indicators to detect dyslexia [46]. However participants from both groups answered most of the questions correctly without finding any differences. This can be explained by the fact that dyslexia affects decoding, but not necessarily comprehension; it affects comprehension only when the text decoding fails [33]. We designed the text content using frequent words and short sentences to make it more accessible for people with dyslexia [24], however, the text still had an impact on their reading speed.

Participants with dyslexia expended significantly more time moving the mouse over the chess board for resolving the **Exercises**. Also, they moved the mouse over a significantly greater number of squares. These differences among groups could indicate that dyslexia has an impact on the skills needed to solve these exercises, such as visuospatial attention and numerical ability [7, 17]. In fact, some studies have shown that people with dyslexia present visuospatial attentional disorder [45, 47] and it is estimated that 40% of the people with dyslexia have dyscalculia¹⁰ [7]. Hence, chess training could target such skills on participants with dyslexia. We also found significant differences on the *Time to First Try* however this could be explain by the fact that people with dyslexia read slower, since that time partly records the time that the participant spend reading the instructions.

Participants with dyslexia had significantly longer games when **Playing** chess against the machine. However, we could not find differences in other chess performance indicators, such as the number of movements or the score of the game. Hence, we cannot assert that dyslexia might have an impact on playing chess. However, the observed longer playing times could indicate that they require more time to make a chess move. This seems likely since participants with dyslexia spent an average of 9.12 seconds per move compared to the 6.18 seconds of the participants without dyslexia. Another possible explanation is that they might get lost more easily when they are drawing up the playing plan as a consequence of the visuospatial attentional disorder. This also depends on the game strategies of the participants: if they are thinking on the next movement only, or if they are trying to predict the machine following movements.

Limitations. One limitation of this study is that the performance on chess learning and playing was only measured for an elementary level of chess. However the data collected from mouse tracking and computer interactions was enough to make statistical tests and find differences between groups. Also, most of the participants were not familiar with chess: only 7.81% participants played chess frequently, while 23.44% did not know how to play chess and 35.94% only knew the pieces movements before taking the lesson.

7. CONCLUSIONS

This paper has presented game designed for people with dyslexia and a study that compares how people with and without dyslexia learn and play chess with a computer. The results show that people with dyslexia spend more time

¹⁰ A specific learning disability involving innate difficulty in learning or comprehending arithmetic. It is akin to dyslexia and includes difficulty in understanding numbers, learning how to manipulate numbers, learning mathematical facts, and a number of other related symptoms [7].

learning chess theory, doing training chess exercises and playing chess than people without dyslexia. However for other performance measures we could not find any effects (except from the number of squares tracked over the board). To our knowledge, this is the first time that people with and without dyslexia are compared in these terms.

The results suggest that dyslexia might have some impact on chess performance. This could indicate that some skills needed for chess share cognitive elements with dyslexia related conditions such as visuospatial attention disorder [45, 47] or dyscalculia [7, 17]. If this is true, this could suggest that chess training could have a subsequent transfer on dyslexia manifestations. It would also be consistent with previous studies that have found positive results teaching chess to students with learning disabilities [41, 44], or students that required special training [2, 22].

Now that we know that people with dyslexia present some differences in learning and playing computer-based chess, future work will focus on the development of a tool to learn how to play chess for people with dyslexia and its evaluation in an educational environment. We also plan to use chess games to predict dyslexia in addition to linguistic-based games who have been proven to be useful for dyslexia prediction tasks [39, 40].

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8. REFERENCES

- [1] J. R. Anderson. *Cognitive psychology and its implications*. WH Freeman/Times Books/Henry Holt & Co, 1990.
- [2] D. C. Barrett and W. W. Fish. Our move: Using chess to improve math achievement for students who receive special education services. *International Journal of Special Education*, 26(3):181–193, 2011.
- [3] W. M. Bart. On the effect of chess training on scholastic achievement. *Frontiers in psychology*, 5, 2014.
- [4] British Dyslexia Association. Dyslexia style guide, January 2012. <http://www.bdadyslexia.org.uk/>.
- [5] M. Brosnan, J. Demetre, S. Hamill, K. Robson, H. Shepherd, and G. Cody. Executive functioning in adults and children with developmental dyslexia. *Neuropsychologia*, 40(12):2144–2155, 2002.
- [6] L. Brown, R. J. Sherbenou, and S. K. Johnsen. *Test of Nonverbal Intelligence: A language-free measure of cognitive ability*. Pro-ed, 1990.
- [7] B. Butterworth. Foundational numerical capacities and the origins of dyscalculia. *Trends in Cognitive Sciences*, 14(12):534–541, 2010.
- [8] J. Carifio and R. Perla. Resolving the 50-year debate around using and misusing Likert scales. *Medical education*, 42(12):1150–1152, 2008.
- [9] J. Christiaen and L. Verhofstadt-Denève. Schaken en cognitieve ontwikkeling. (chess and cognitive development). *Nederlands Tijdschrift voor de Psychologie en haar Grensgebieden*, 1981.
- [10] C. Cornoldi and J. V. Oakhill. *Reading comprehension difficulties: Processes and intervention*. Routledge, 2013.

- [11] M. Estaki, K. Poshaneh, M. Yadollahi, and K. Ebrahimi. Impact of training of chess on executive functions (functions of planning, problem-solving, attention and flexibility) of dyslexic elementary school second graders of city of tehran.
- [12] S. Franceschini, S. Gori, M. Ruffino, S. Viola, M. Molteni, and A. Facoetti. Action video games make dyslexic children read better. *Current Biology*, 2013.
- [13] A. Frank. *Chess and aptitudes English translation of Frank's unpublished PhD thesis in French*. Saugus, MA: American Chess Foundation.
- [14] A. Frank and W. D'hondt. Aptitudes et apprentissage du jeu d'échecs du zaire (aptitudes and learning of the game of chess in zaire). *Psychopathologie Africaine Dakar*, 15(1):81–98, 1979.
- [15] S. Fried and N. Ginsburg. The effect of learning to play chess on cognitive, perceptual, & emotional development in children, 2006.
- [16] J. D. Gabrieli. Dyslexia: a new synergy between education and cognitive neuroscience. *Science*, 325(5938):280–283, 2009.
- [17] D. C. Geary and M. K. Hoard. Numerical and arithmetical deficits in learning-disabled children: Relation to dyscalculia and dyslexia. *Aphasiology*, 15(7):635–647, 2001.
- [18] E. Germano, A. Gagliano, and P. Curatolo. Comorbidity of adhd and dyslexia. *Developmental neuropsychology*, 35(5):475–493, 2010.
- [19] F. Gobet and G. Campitelli. Educational benefits of chess instruction: A critical review. In *Chess and education: Selected essays from the Koltanowski conference*, pages 124–143. Chess Program at the University of Texas at Dallas Dallas, TX, 2006.
- [20] P. Gregor and A. F. Newell. An empirical investigation of ways in which some of the problems encountered by some dyslexics may be alleviated using computer techniques. In *Proc. ASSETS'00*, pages 85–91, New York, NY, USA, 2000. ACM Press.
- [21] T. Helland and A. Asbjørnsen. Executive functions in dyslexia. *Child Neuropsychology*, 6(1):37–48, 2000.
- [22] S. Hong and W. M. Bart. Cognitive effects of chess instruction on students at risk for academic failure. In *Proceedings of the 7th international conference on Learning sciences*, pages 938–939. International Society of the Learning Sciences, 2006.
- [23] B. Hornsby. *Overcoming dyslexia*. Martin Dunitz, London, 1986.
- [24] J. Hyönä and R. K. Olson. Eye fixation patterns among dyslexic and normal readers: Effects of word length and word frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21(6):1430, 1995.
- [25] Interagency Commission on Learning Disabilities. *Learning Disabilities: A Report to the U.S. Congress*. Government Printing Office, Washington DC, 1987.
- [26] International Dyslexia Association. Frequently Asked Questions About Dyslexia, 2011. <http://www.interdys.org/>.
- [27] O. Kulaç. *Elementary Level Chess Class Book*. Fédération Internationale Des Échecs (World Chess Federation).
- [28] O. Kulaç. *Kulaç Teacher Guide*. Fédération Internationale Des Échecs (World Chess Federation).
- [29] F. Kyle, J. Kujala, U. Richardson, H. Lyytinen, and U. Goswami. Assessing the effectiveness of two theoretically motivated computer-assisted reading interventions in the united kingdom: Gg rime and gg phoneme. *Reading Research Quarterly*, 48(1):61–76, 2013.
- [30] C. Lewis. *Using the "thinking-aloud" method in cognitive interface design*. IBM TJ Watson Research Center, 1982.
- [31] G. R. Lyon, S. E. Shaywitz, and B. A. Shaywitz. A definition of dyslexia. *Annals of Dyslexia*, 53(1):1–14, 2003.
- [32] H. Lyytinen, M. Ronimus, A. Alanko, A.-M. Poikkeus, and M. Taanila. Early identification of dyslexia and the use of computer game-based practice to support reading acquisition. *Nordic Psychology*, 59(2):109, 2007.
- [33] L. Mosberg and D. Johns. Reading and listening comprehension in college students with developmental dyslexia. *Learning Disabilities Research & Practice*, 1994.
- [34] R Development Core Team. A language and environment for statistical computing (computer software), 2011. <http://www.R-project.org>.
- [35] A. Reiter, O. Tucha, and K. W. Lange. Executive functions in children with dyslexia. *Dyslexia*, 11(2):116–131, 2005.
- [36] L. Rello. *DysWebxia. A Text Accessibility Model for People with Dyslexia*. PhD thesis, Universitat Pompeu Fabra, 2014.
- [37] L. Rello and R. Baeza-Yates. The presence of English and Spanish dyslexia in the Web. *New Review of Hypermedia and Multimedia*, 8:131–158, 2012.
- [38] L. Rello and R. Baeza-Yates. Good fonts for dyslexia. In *Proc. ASSETS'13*, Bellevue, Washington, USA, 2013. ACM Press.
- [39] L. Rello, M. Ballesteros, A. Ali, M. Serra, D. Alarcón, and J. P. Bigham. Dyetective: Diagnosing risk of dyslexia with a game. In *Proc. Pervasive Health'16*, Cancun, Mexico, 2016.
- [40] L. Rello, K. Williams, A. Ali, N. Cushen White, and J. P. Bigham. Dyetective: Towards detecting dyslexia across languages using an online game. In *Proc. W4A '16*, Montreal, Canada, 2016. ACM Press.
- [41] M. Scholz, H. Niesch, O. Steffen, B. Ernst, M. Loeffler, E. Witruk, and H. Schwarz. Impact of chess training on mathematics performance and concentration ability of children with learning disabilities. *International Journal of Special Education*, 23(3):138–148, 2008.
- [42] M. K. Singley. *The transfer of cognitive skill*. Number 9. Harvard University Press, 1989.
- [43] R. J. Sternberg. *Handbook of intelligence*. Cambridge University Press, 2000.
- [44] K. Storey. Teaching beginning chess skills to students with disabilities. *Preventing School Failure: Alternative Education for Children and Youth*, 44(2):45–49, 2000.
- [45] S. Valdois, M.-L. Bosse, and M.-J. Tainturier. The cognitive deficits responsible for developmental dyslexia: Review of evidence for a selective visual attentional disorder. *Dyslexia*, 10(4):339–363, 2004.
- [46] F. R. Vellutino, J. M. Fletcher, M. J. Snowling, and D. M. Scanlon. Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, 45(1):2–40, 2004.
- [47] T. R. Vidyasagar and K. Pammer. Dyslexia: a deficit in visuo-spatial attention, not in phonological processing. *Trends in cognitive sciences*, 14(2):57–63, 2010.