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Video game–based coordinative training improves ataxia in children with degenerative ataxia

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ABSTRACT

Objective: Degenerative ataxias in children present a rare condition where effective treatments are lacking. Intensive coordinative training based on physiotherapeutic exercises improves degenerative ataxia in adults, but such exercises have drawbacks for children, often including a lack of motivation for high-frequent physiotherapy. Recently developed whole-body controlled video game technology might present a novel treatment strategy for highly interactive and motivational coordinative training for children with degenerative ataxias.

Methods: We examined the effectiveness of an 8-week coordinative training for 10 children with progressive spinocerebellar ataxia. Training was based on 3 Microsoft Xbox Kinect video games particularly suitable to exercise whole-body coordination and dynamic balance. Training was started with a laboratory-based 2-week training phase and followed by 6 weeks training in children's home environment. Rater-blinded assessments were performed 2 weeks before laboratory-based training, immediately prior to and after the laboratory-based training period, as well as after home training. These assessments allowed for an intraindividual control design, where performance changes with and without training were compared.

Results: Ataxia symptoms were significantly reduced (decrease in Scale for the Assessment and Rating of Ataxia score, $p = 0.0078$) and balance capacities improved (dynamic gait index, $p = 0.04$) after intervention. Quantitative movement analysis revealed improvements in gait (lateral sway: $p = 0.01$; step length variability: $p = 0.01$) and in goal-directed leg placement ($p = 0.03$).

Conclusions: Despite progressive cerebellar degeneration, children are able to improve motor performance by intensive coordination training. Directed training of whole-body controlled video games might present a highly motivational, cost-efficient, and home-based rehabilitation strategy to train dynamic balance and interaction with dynamic environments in a large variety of young-onset neurologic conditions.

Classification of evidence: This study provides Class III evidence that directed training with Xbox Kinect video games can improve several signs of ataxia in adolescents with progressive ataxia as measured by SARA score, Dynamic Gait Index, and Activity-specific Balance Confidence Scale at 8 weeks of training. *Neurology*® 2012;79:1–5

GLOSSARY

ABC = Activity-specific Balance Confidence Scale; **DGI** = dynamic gait index; **INAS** = Inventory of Non-Ataxia Symptoms; **SARA** = Scale for the Assessment and Rating of Ataxia.

Effective treatments for patients with degenerative ataxia are scarce. It has been recently shown that intensive coordinative training based on physiotherapeutic exercises improves degenerative ataxia in adult patients,[1-3] but its effectiveness is still disputed.[4] This situation is even more complicated in children with degenerative ataxia as neurodegeneration in this rare condition often includes several additional extracerebellar systems and as physiotherapeutic exercises in children have drawbacks, including often low motivation for high-frequent physiotherapy.

Supplemental data at www.neurology.org

Supplemental Data

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Here we present a prospective cohort study assessing the benefits of video game–based coordinative training in children with degenerative spinocerebellar disease. The goal of this pilot study was to provide evidence that these patients can improve whole-body coordination and dynamic balance by an 8-week phase of intensive but at the same time highly motivational and playful coordination training.

METHODS

Patients. From June 2011 until October 2011, 10 consecutive patients (age 15.4 ± 3.5 years) were recruited from the ataxia clinic of the Neurology Clinic and the Children's Hospital, University of Tübingen, Germany, based on following inclusion criteria: 1) progressive degenerative ataxia in the absence of any signs of inflammatory, vascular, malformation, or tumor CNS disease; 2) age between 8 and 20 years; 3) Scale for the Assessment and Rating of Ataxia (SARA) total score >3, but SARA gait score of <4 at baseline (walking without support possible), thus ensuring sufficient capacity to benefit, but also to complete the training sessions; 4) absence of visual loss, hearing disturbances, mental retardation, and predominant nonataxia movement disorders. Patients yielded a mean ataxia severity of 10.9 ± 2.3 on the SARA[5] with a variable load of additional extracerebellar involvement measured by the Inventory of Non-Ataxia Symptoms (INAS) score.[6] For clinical details, see the table and appendix e-1 on the *Neurology*® Web site at www.neurology.org.

Standard protocol approvals, registration, and patient consents. All children and their respective legal guardians gave informed consent prior to participation. The study had been approved by the local institutional ethical review board.

Study design. We assessed the effectiveness of an 8-week video game–based training, consisting of a 2-week laboratory training individually supervised and directed by a physiotherapist, followed by 6 weeks during which the patients were asked to continue exercises at home. Patients were examined 4 times: 2 weeks before intervention (E1), immediately before the first training session (E2), after the 2-week laboratory-training period (E3), and after the 6-week home-training phase (E4).

To control for variability of performance not caused by the intervention, patients were taken as their own controls in an intra-individual control design (level of evidence Class III). Three different comparisons were performed: 1) by comparing E1 with E2, we determined the variability of test performance caused by daily condition, or practice effects. We assessed the effects of the training intervention; 2) by comparing E2 with E3, revealing the short-term training effects; and 3) by comparing E2 with E4, indicating the long-term training effects.

Video game–based coordinative training. The strategy of the video game–based training aimed to train motor capacities known to be dysfunctional in ataxia, namely goal-directed limb movements, dynamic balance, and whole-body coordination. Moreover, children were to train a cognitively demanding interaction in a virtual environment, forcing them to rapidly react to novel situations and to constantly recalibrate predictions about upcoming events. Three commercially available Microsoft Xbox Kinect games were deemed to meet these criteria: "Table Tennis," "Light Race," and "20000 Leaks" (for details, see appendix e-2). Training was started with a supervised laboratory-based 2-week training phase, consisting of 4 1-hour training sessions per week. After laboratory training, children were instructed to train 6 weeks in their home environment. Patients and parents were asked to document the intensity and performance of playing in a daily training protocol.

Table Clinical data of the participants of the study[a]

								DGI				ABC		
Patient	Age, y	Age at onset, y	Gender	Diagnosis	CE/AF	INAS E1	SARA E1	E1	E2	E3	E4	E2	E3	E4
C1	12	1	F	arCA	CE	5	13.5	13	14	19	18	21.6	36.6	31.6
C2	15	13	M	arCA	CE	1	12	13	15	16	19	36.6	33.3	55.0
C3	13	7	M	FA	AF	4	9.5	20	20	18	21	61.6	56.6	73.3
C4	14	6	M	FA	AF	2	12	20	19	18	18	50.0	53.3	47.5
C5	18	14	F	FA	AF	4	12.5	16	15	13	16	55.0	68.3	65.0
C6	20	16	F	AOA2	CE	7	12	15	13	18	16	38.3	28.3	18.3
C7	20	12	M	FA	AF	2	13.5	10	7	14	13	27.5	55.0	35.0
C8	13	2	M	ADCA	CE	0	7	22	23	24	24	20.0	35.0	43.3
C9	11	2	F	ADCA	CE	2	7.5	21	21	22	22	30.0	33.3	50.0
C10	19	2	F	arCA	CE	5	9.5	14	13	17	14	5.0	5.0	5.0
Ø	15.4					3.2	10.9	16.4	16	17.9	18.1	34.5	40.7	42.4

Abbreviations: ABC = Activity-specific Balance Confidence Scale (range from 0% to 100% confidence for the individual items); ADCA = autosomal dominant cerebellar ataxia (all tested negative for spinocerebellar ataxia 1, 2, 3, 6, 7, 12, 14, 15, 17); AF = predominantly afferent ataxia; AOA2 = ataxia with oculomotor ataxia type 2; arCA = autosomal-recessive ataxia (all tested negative for FA, POLG, PEO1, AOA1, AOA2, ataxia with vitamin E deficiency [AVED], lysosomal storage diseases); CE = predominantly cerebellar ataxia; DGI = dynamic gait index (covers a range from 0 to 24, with 24 being the highest possible score); FA = Friedreich ataxia; INAS = Inventory of Non-Ataxia Symptoms (range from 0 to 16, 16 means most severe nonataxia symptoms).

[a] Ataxia was clinically assessed at the 4 examinations E1–E4 using the Scale for the Assessment and Rating of Ataxia (SARA) as primary outcome measure (see figure 1). SARA covers a range from 0 (no ataxia) to 40 (most severe ataxia). The SARA score includes 8 items: 3 items rating gait and posture, 1 item for speech disturbances, and 4 items for limb-kinetic functions.

Clinical outcome measures. Primary outcome measure was the SARA score (table). SARA testing was performed by a movement disorders specialist (M.S.) and was video recorded. After all subjects had completed all examinations, videos of single examinations of individual subjects were presented in a random fashion to an ataxia specialist (J.S.) who was blinded to the number of the specific examination (E1–E4). The SARA scores of the blinded rater were taken for analysis.

In parallel, a physiotherapist (C.S.) who was blinded for these SARA scores independently rated patients' balance capacities using the dynamic gait index (DGI).[7] Moreover, to reflect the impact on subjective confidence in activities of daily living, patients were asked to self-report their balance confidence in these activities using the Activity-specific Balance Confidence Scale (ABC).[8] Finally, they had to indicate their pleasure and motivation for training on a motivation scale (appendix e-3).

Quantitative movement analysis. Motor performance was evaluated by quantitative movement analysis using a VICON MX motion capture system (for details, see appendix e-4).

For gait analysis, patients were instructed to walk normally at a self-determined pace. From each patient we recorded 15–20 gait cycles within 5 walking trials. Gait was measured as established previously.[1,9] Variability measures were calculated using the coefficient of variation CV = σ/μ, normalizing the standard deviation with the mean value.

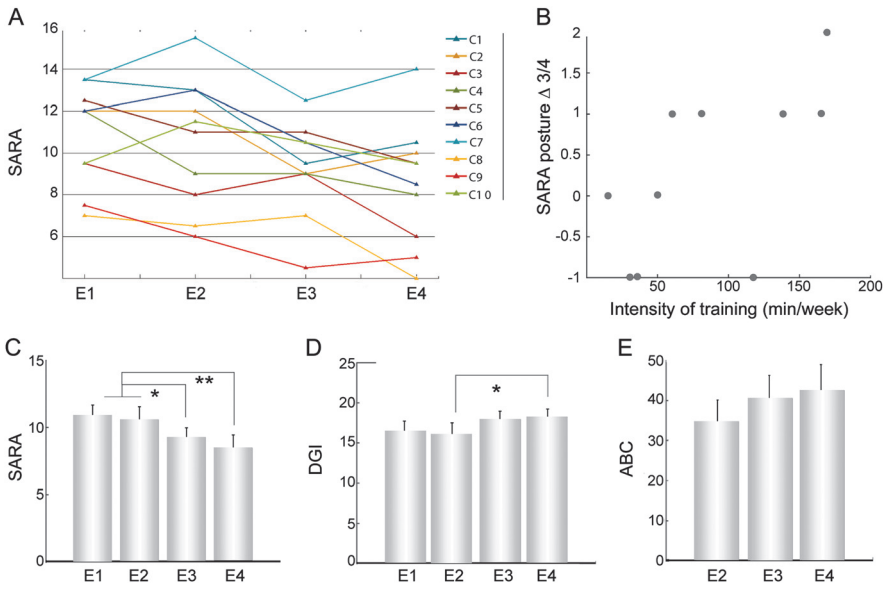
In addition, a goal-directed leg placement task tested for movement accuracy and dynamic balance capacities (for details, see appendix e-5).

Statistical analysis. Repeated-measurements analyses were performed using the nonparametric Friedman test (χ^2, p values) to determine within-group differences between examinations E1 and E4. When the Friedman test yielded a significant effect ($p < 0.05$), post hoc analysis was performed using a Wilcoxon signed-rank test for pairwise comparisons between assessments. For the latter we report 2 significance levels: uncorrected ($p < 0.05$*) and Bonferroni-corrected for multiple comparisons ($p < 0.05/6$**). Spearman rho was used to examine the correlation between SARA scores and movement parameters. Statistical analysis was performed using the software packages MATLAB and SPSS.

RESULTS Children were able to improve their game-specific behavior and scores substantially for all games (Friedman test, $\chi^2 > 15.4$, $p < 0.0004$). Training was experienced as highly enjoyable and motivational both during the laboratory training phase and during home training (see appendices e-3 and e-6).

Clinical scores. Differences in ataxia symptoms (measured by SARA) across the 4 assessments were confirmed using a Friedman test ($\chi^2 = 15.5$, $p = 0.0013$). Comparisons between specific examinations of the SARA score revealed reduction (−2 points on average) comparing pre/postintervention (Wilcoxon signed-rank test: E2/E3: $p < 0.02$*, E2/E4: $p < 0.001$**) (figure 1, A and B). In contrast, there is no improvement comparing preintervention examinations (E1/E2, $p = 0.62$), indicating that there is no relevant influence of factors beyond intervention. The decrease of ataxia symptoms is reflected predominantly by a reduced SARA posture subscore ($\chi^2 = 18.4$, $p = 0.0003$). The decrease in this subscore correlated with the training intensity ($r = -0.62$, $p = 0.05$, figure 1B). In correspondence to

Figure 1 Group data from clinical measures



(A) Scale for the Assessment and Rating of Ataxia (SARA) scores at examinations E1–E4 of individual patients. (B) Relationship between intensity of home training (x-axes) and the difference of the SARA posture score between examinations E3 and E4 (y-axes). Positive Δ values denote improvements. Further diagrams show group comparisons of the examinations E1–E4 for (C) SARA score, (D) dynamic gait index (DGI), and (E) Activity-specific Balance Confidence Scale (ABC scores were not determined at E1). Asterisks indicate significant differences between examinations (*$p < 0.05$).

the SARA findings, scores in the DGI increased, indicating an improvement in dynamic balance ($\chi^2 = 8.2$, $p = 0.04$*; E2/E4: $p = 0.01$*; figure 1D). There was a tendency toward improvement also in the ABC score (figure 1E), with 7 of 10 patients showing increases between E2 and E4, yet these improvements failed to reach statistical significance on the group level (table).

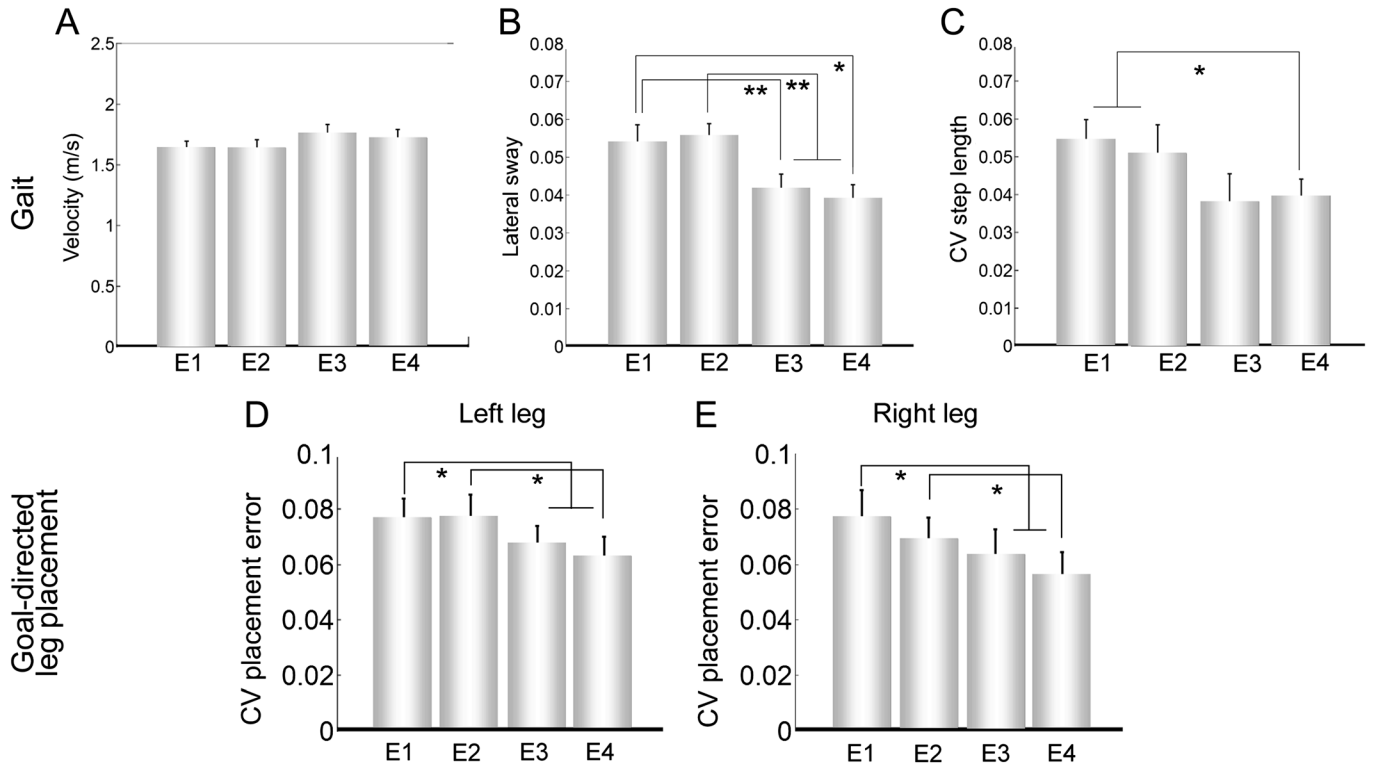
Quantitative movement analysis. Gait analysis revealed a decrease in step variability ($\chi^2 = 9.84$, $p = 0.019$) (E2/E3: $p = 0.08$; E2/E4: $p = 0.04$) and decrease in lateral sway ($\chi^2 = 10.92$, $p = 0.012$) (E2/E3: $p = 0.005$**; E2/E4: $p = 0.003$**) (figure 2, A–C), both indicating an improvement of dynamic balance and a decreased risk of falling. Both parameters correlated with the SARA posture subscore ($r > 0.36$; $p < 0.024$).

The goal-directed leg placement task (appendix e-5) revealed a decreased target error for both legs (right: $\chi^2 = 11.93$, $p = 0.007$**; left: $\chi^2 = 8.3$, $p = 0.03$*) in the comparison of pre/postintervention (left: E2/E3: $p = 0.12$; E2/E4: $p = 0.02$; right: E2/E3: $p = 0.07$; E2/E4: $p = 0.01$) (figure 2, D and E). Leg placement errors correlated positively with lateral body sway ($r = 0.35$, $p = 0.037$), indicating a strong influence of dynamic balance capacities for this task. Leg placement performance correlated with SARA posture subscore ($r > 0.69$, $p < 0.001$) and with the SARA kinetic subscore for the corresponding leg (left: $r = 0.37$, $p = 0.027$; right: $r = 0.47$, $p = 0.004$).

DISCUSSION We aimed to provide evidence that children with degenerative ataxia can improve several measures of whole-body coordination and dynamic balance by highly motivational intensive coordination training. Early-onset degenerative ataxia might be one of the most difficult groups of ataxias to treat due to its onset during motor development, its progressive nature, and the significant damage also to extracerebellar systems.[10]

Our results demonstrate a significant reduction of various ataxia symptoms already after 2 weeks laboratory training, more pronounced after the full training period of 8 weeks. This finding not only indicates that children with degenerative ataxia are able to benefit from intensive coordinative training—despite progressive underlying degeneration—but that they also profit from training in the home environment. Training benefit thereby seems to depend on training intensity, as indicated by the correlation between training intensity and decrease in the SARA posture subscore ($r = 0.67$, $p = 0.05$). The highly significant correlations between clinical ataxia items and computerized movement measures reflecting multi-joint

Figure 2 Group measures from quantitative movement analysis for gait (A-C) and the goal-directed leg placement task (D+E)



The 4 bars indicate the examinations E1–E4. Asterisks indicate significant differences between examinations (Wilcoxon signed-rank test, *$p < 0.05$, **$p < 0.05/6$). Variability measures were calculated using the coefficient of variation $CV = \sigma/\mu$, normalizing the standard deviation with the mean value. For the goal-directed leg placement, placement error is normalized with the mean of step length.

coordination and dynamic balance control demonstrate that these improvements do not predominantly reflect unspecific changes (e.g., increased cardiovascular endurance) but improvements in ataxia-specific dysfunction.

Importantly, children were highly motivated throughout the whole demanding training period, and they experienced feelings of success about their own movements.

Thus, this training strategy helps to maximize the function of each child in his or her particular disease state, and might—at least in some cases—slow down a possible downward spiral of ataxia-related immobility and further deterioration of coordinative functions.

Limitations of this pilot study consist of the phenotypic and etiologic heterogeneity of early-onset degenerative ataxia patients, including genetically undiagnosed patients. Moreover, the number of patients is small due to the orphan state of this disease. Thus, we were unable to perform subgroup analyses in order to examine 1) whether patients with cerebellar vs afferent ataxia profit to a different extent or 2) to identify further predictors for individual training benefit. However, our findings already indicate a highly motivational, cost-efficient and home-based rehabilitation strategy to train dynamic balance and interaction with dynamic environments that might be useful for a large variety of young-onset movement disorders.

AUTHOR CONTRIBUTIONS

W. Ilg: design and conceptualization of the study, analysis and interpretation of the data, drafting the manuscript. C. Schatton: analysis and interpretation of the data. J. Schicks: analysis and interpretation of the data. M. Giese: interpretation of the data, revising the manuscript. L. Schöls: conceptualization of the study, revising the manuscript. M. Synofzik: design and conceptualization of the study, analysis and interpretation of the data, drafting the manuscript.

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DISCLOSURE

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